ENOUGH

EUROPEAN FOOD CHAIN SUPPLY TO REDUCE GHG EMISSIONS BY 2050

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EXECUTIVE SUMMARY

This report gives an overview of the work of WP11 (Cooperation with the European Commission) regarding practice abstracts of the ENOUGH project. The objective of this task is to share the main project results of ongoing experiments to EU. To ensure this, resulting knowledge from the project will be fed into the EIP-AGRI (The Agricultural European Innovation Partnership) for dissemination to practitioners in several rounds.

This report provides the outcome of all practice abstracts published in the ENOUGH project, including the final practice abstract submitted to the EU Common Agricultural Policy (CAP) Network using the EIP-AGRI common format. The aim of the final practice abstract of ENOUGH was to include a short summary describing the main information/recommendation/practice that can serve the end-users in their daily practice, based on the activities and results of the project. Due to a broad range of results with different target groups, it was decided to create 8 practice abstracts in the final round, one per each work package 1-7 in the project and one summary of the whole ENOUGH project.

Deliverable 11.3

1 INTRODUCTION

This document provides the practice abstracts published in the ENOUGH project, including the Final Practice Abstract, published through the EIP-AGRI common format. The report is a deliverable (D11.2, Practice abstract on synergy exploitation with other projects) in Work Package 11 (Cooperation with the European Commission), task 11.2 (Practice abstracts).

2 PRACTICE ABSTRACTS

2.1 EIP-AGRI and EU CAP Network

The European Innovation Partnership for Agricultural productivity and Sustainability (EIP-AGRI) was a partnership launched by the European Commission to promote innovative projects in the agricultural sector and provide a closer relationship between research and practice. The EIP-AGRI Network became a part of the EU Common Agricultural Policy (CAP) Network in 2023. The EU CAP Network is about optimising the flow of information about agriculture and rural policy within the EU.

The EIP-AGRI common format was one of the actions of the EIP-AGRI, enabling sharing knowledge, solutions and research results in a standarised way to make it available and more easily to be put into practice ("practice abstracts"). Earlier this was done through the EIP-AGRI website, but this action is now moved to the EU CAP network website. It still follows the EIP-AGRI common format consisting of:

1) Obligatory elements
   - Project information (title, period, budget, etc.)
   - Objective of the project: what problems/opportunities does the project address that are relevant for the practitioner/end-user, and how will they be solved? (300-600 characters, word count – no spaces)
   - **Practice abstract (short summary for practitioners)**. The core of the submission. Summary on the (final or expected) outcomes (1000-1500 characters, word count – no spaces). The summary should contain information about (1) the main results/outcomes of the activity (expected or final), and (2) the main practical recommendation(s) (how to make use of the results, and what is the main added value to the end-user if making use of them). The text should be interesting, using a clear and easy language, underlining elements of particular relevance for the practitioners.
2) Recommended elements
   - **Description of project activities** (max. 600 characters, word count – no spaces)
   - Audiovisual material (e.g. videos)
   - Project website
   - Link to other informative websites

3) Optional elements
   - Additional field for the practice abstract: short summary according to the guidance in the text box above (max. 1500 characters, word count – no spaces)
   - Description of the context of the project
   - Additional information (if required by specific guidance at national/regional level
   - Additional comments

The website of EIP-AGRI is no longer updated after 1st of April 2023, but remains available in a static form as a reference of all previous EIP-AGRI activities. All the new and up-to-date information is now found on the EU CAP Network website.

2.2 Administrating the practice abstracts

Practice abstracts are submittet through an Excel file. Gidelines for the submission are available through the websites of EIP-AGRI. The submitted texts are provided below. One of the obligatory elements to fill out in the Excel sheet is the list of partners with including contact person and email address/phone. After dialogue with the Project Officer, it was decided to keep the personal data of the partner contacts out of the submission for the first round of abstracts.

The Excel file was sent to AGRI-EIP-PRACTICE-ABSTRACT@ec.europa.eu with Project officer and Policy officer on copy. The same Excel file will be updated and used for future submissions.

2.3 Project details

2.3.1 Objective of the project

The following text was sent in as the ENOUGH objectives in the first rounds of abstracts:

The ENOUGH project will provide technologies, tools and methods to contribute to the EU Farm to Fork strategy to achieve climate neutral food businesses. The ENOUGH objectives are: 1) Reducing greenhouse gas (GHG) emissions by at least 50% by 2050; 2) Reducing energy use and increasing energy efficiency; 3) Increasing the overall sustainability of food systems; 4) Providing selected innovative technological solutions and their potential for uptake at EU.

After updated objectives in Amendment, the following text was added in the abstracts for 2025:

The ENOUGH project will provide technologies, tools and methods to contribute to the EU Farm to Fork strategy to achieve climate neutral food businesses. The project will identify how the food industry can 1) Reduce GHG-emissions by at least 55% by 2030 compared with 1990 levels. 2) Achieve climate neutrality for food businesses by reducing energy use and increasing energy efficiency by 2050. 3) Improve the overall integrated sustainability of food systems whilst at the same time meeting societal goals. 4) Increase awareness among stakeholders and citizens of selected innovative systemic solutions and their potential for uptake at EU scale.

2.3.2 Project activities

Project activities are not obligatory, but recommended. Due to the wide variety of activities in the ENOUGH project, it was chosen to fill out a short text about project activities:

For the first time emissions from food production, processing and packaging, transportation, storage, retail display, catering and home consumption will be assessed as separate groups to identify where the greatest potential for emissions reduction and mitigation action can be applied. Strategic maps, digital tools and smart data will be developed and used to explore possible solutions. At the core of the ENOUGH project is the demonstration of technologies to reduce emissions. Their potential will be qualified and quantified in real life situations, and the most promising technologies will be widely communicated to the food industry.

2.4 First practice abstract: ENOUGH - European food chain supply to reduce GHG emissions by 2050

The first practice abstract was decided to be about the project in general and its expected outcomes. The following text was submitted:

Food systems are globally responsible for around a third of total greenhouse gas (GHG) emissions. These numbers are poorly quantified and lack detail for specific sectors and food groups. The food industry has made significant efforts to reduce emissions already with simple optimisation procedures and changes, so further reduction will require advanced technology.

The ENOUGH project (enough-emissions.eu) brings research, universities and industry together to tackle these challenges. We will generate new information on emissions from the food chain, develop strategic road maps (technical, political and financial), develop digital tools and smart data analysis methods to quantify and benchmark energy use and emissions in the food chain.

Promising decarbonisation technologies in real food industry environment will be demonstrated to provide European food companies tools and quantified information on the benefits and financial paybacks of low emission technologies. The technologies will be tested with regards to identified key products (meat, fish, dairy and fruit and vegetables) and opportunities for cross sector applicability. The focus will be thermal processes as the key products are perishable and require thermal processes throughout their life. Some key technologies are high temperature heat pumps (HTHPs) working with natural refrigerants and processes related to energy efficiency of cooling, freezing, heating and storage of food. Several demonstrations are also planned to generate hot water and steam in real life situations. Another important sector identified is transport, including for example home delivery. The outputs will be widely communicated to relevant food companies, policy makers and interested groups.

2.5 Second practice abstract: Mapping the GHG emissions of the European food supply chain

According to the latest study from the FAO[1], the total global GHG emissions from agrifood systems have increased by 9% from 2000 to 2020. This represent about one third of the global GHG emissions and is estimated to currently be 16 Gtonnes CO2eq.

Information related to GHG emissions is already contained in a number of trusted inventories (e.g. FAO, EDGAR-FOOD). However, these inventories have limitations as they often use different approaches and apply different boundaries and terminologies. They often do not have the level of

[1] FAOSTAT Analytical Brief 50: GHG emissions from agrifood systems: Global, regional and country trends.

granularity required to identify the key areas of the food chain where GHG emissions can be reduced or provide information on predicted future emissions.

In ENOUGH we are working to overcome these limitations by developing several tools to calculate GHG emission from the European food chains in 2019 (reference year), 2030 and 2050. The models can identify the food chain sectors and technologies which are responsible for the majority of the GHG emissions. They will also be able to assess the impact of future emissions scenarios and their impact on emissions from individual countries. Through this work a complete and precise emissions database with reliable predictions of GHG emissions will be established. The work will ultimately provide information on the impact of technical, climate and socio-economic changes to the food system and which interventions are likely to have the greatest overall impact to reduce GHG emissions. It will also help the European policy makers to set appropriate legislation to mitigate emissions from the food sector in the future.

2.6 Third practice abstract: Synergy exploitation with other projects

Collaboration with other project is essential to foster synergies, increase outreach and access expertise and results. In the ENOUGH project, synergy exploitation with other project has been reached in several ways.

The **green deal support office (GDSO)** was established to assist projects funded within the green deal (GD) with collaboration and links to other relevant programmes. They have divided the projects into groups for the different sectors, and ENOUGH belongs to the **food working group (WG)** together with 8 other projects; Ago2Circular, EcoeFISHent, NeoGiANT, SchoolFood4Change, ClieNFarms, PestNu, ZeroW, SISTERS. Together we cover the whole food value chain.

The food working group is organised with an action plan, and the main areas of collaboration are 1) policy, 2) dissemination of results, 3) events, and 4) technical, operational and research cooperation. The working group has published Joint policy recommendations, created a common plan for dissemination and communication, done stakeholder mapping and mapping of events to look for possibilities to organise joint events. ENOUGH has also used the GDSO platform to publish two success stories from the project.

In addition to GDSO initiatives, ENOUGH have identified key topics within the project that overlap with other initiatives (including controlling storage conditions for fruits, vegetables, and other food products; climate-neutral packaging; fresh and sustainable food transport; thermal energy storage; and reducing food loss and waste). Projects of the food working group and other relevant projects identified have been invited to ENOUGH events like demonstrator workshop (September 2024), retail workshop (May 2025), and a policy event (June 2025).

2.7 Final practice abstracts

The final practice abstract of ENOUGH should aim to include a short summary which describes the main information/recommendation/practice that can serve the end-users in their daily practice, based on the activities and results of the project. Due to a broad range of results with different target groups, it was decided to send 8 practice abstracts in the final round, one per each work package 1-7 in the project, and one summarising the entire ENOUGH project.

2.7.1 Final practice abstract WP1: Baseline (1990) current (2019) and future (2030 and 2050) carbon emissions

The ENOUGH project identified carbon emissions in Europe for 1990 and 2019 and developed predictive models for 2030 and 2050 emissions of the food supply chain. Two independent models which predicted carbon emissions on the food chain were developed.

Food accounts for between 10-24% of the total emissions in selected European countries today, and there is a need for the food sector to decarbonise.

Integrated System Dynamics and Linear Programming models were used to forecast meat consumption trends and design optimized diets that maintain nutritional adequacy while substituting meat with alternative proteins. Up to 32% GHG emission reductions were demonstrated through replacement of meat with alternative proteins. The study recommends that **policymakers and public health authorities** support a gradual transition from meat to nutritionally appropriate alternative proteins, accompanied by public awareness campaigns. **Industry stakeholders** are encouraged to innovate and diversify alternative protein offerings to better match nutritional profiles and consumer preferences.

A cross-national model incorporating behavioural, regulatory, and technological drivers to project food supply chain emissions was developed. Over 60% emission reduction potential was found under a Low Emissions scenario, with grid decarbonisation, oil/gas transition, and energy labelling as the most effective interventions. The findings highlight the need for coordinated efforts across sectors: **industries** should prioritise electrification and energy-efficient technologies, **policymakers** must strengthen climate-aligned regulations and incentives, and **society** should embrace low-emission consumption behaviours.

2.7.2 Final practice abstract WP2: Technology roadmaps to decarbonise the European food chain

ENOUGH developed tailored technological roadmaps to decarbonise the various stages of the food supply chain (processing, storage, transport, retail, food service (catering) and domestic food storage) across six European locations; Paris (France), London (UK), Kaunas (Lithuania), Warsaw (Poland), Oslo (Norway) and Rome (Italy). Practical and market-ready solutions were prioritised. Technologies/operational opportunities to save carbon emissions were reviewed to identify the most suitable options. Typical facilities were modelled to assess the decarbonisation potential of technologies/operational changes when applied in the different countries. Each roadmap explains different scenarios, possible GHG savings and some main recommendations for the sector.

Results show that there are many options available for carbon reduction. Examples are electrification (move from fossil fuels), purchasing efficient equipment, minimising heat gains (e.g. infiltration, better insulation, operational efficiency, alternative practices/technologies), use of renewable energy, moving to natural refrigerants, use of heat pumps (low, plus high temperature), heat reclaim/exchange, auditing and maintenance (+skills).

Achieving climate neutrality by 2050 is feasible if the best technologies are applied, but this is reliant on decarbonisation of grid electricity and reduction of high GWP refrigerants. The timeline will differ between countries, depending on how quickly they decarbonise their energy systems and adopt sustainable technologies. Location has an impact on selection of equipment and overall benefits. Options are available to retrofit or for new systems, and early application reduces overall carbon emitted.

2.7.3 Final practice abstract WP3: Energy, behaviour, finance

The ENOUGH project developed practical strategies to decarbonise the European food supply chain by analysing both technological and financial pathways.

An energy roadmap was developed to quantify energy use in the sector and identify opportunities to transition away from fossil fuels, showing that oil and gas consumption could be reduced by more than 80% by 2050, with electricity becoming the dominant energy source. Refrigeration and cold chain technologies are among the most energy-intensive operations in the sector. Upgrades such as CO_2-based refrigeration, high-efficiency fans, variable speed drives, vacuum insulation, and smart controls can reduce electricity use by 15-17%.

In addition, existing business models such as servitisation and performance-based approaches were examined, and financing mechanisms including concessional loans, blended finance, and public-private partnerships were explored. The analysis focused on removing barriers to technology adoption, especially for small and medium-sized enterprises.

The key recommendations emerging from the work are: to prioritise energy-efficient and low-emission technologies in critical sectors such as refrigeration, heating, and transport; to adopt servitisation and performance-based business models that lower upfront costs and enable broader access to clean technologies; and to implement supportive regulatory measures, including minimum energy performance standards, fiscal incentives, and simplified access for small and medium-sized enterprises. Achieving the EU's 2030 and 2050 climate goals will require coordinated action across technology deployment, financing, and governance.

2.7.4 Final practice abstract WP4: Integration of heating, cooling, AC, thermal symbiosis and energy storage within and between sectors

Simulation tools can be essential to provide suggestions for reductions in GHG emissions from the food supply chain. In particular, such tools can help in identifying critical points where efforts should be concentrated to reduce energy consumption and GHG emissions. To helps users (e.g., policymakers, businesses, students) test different strategies and technologies to reduce emissions in the food chain, the **ENOUGH web-based tool** was developed to simulate emissions across the entire food supply chain, calculate energy use, CO_2-emissions and product quality indicators. A thorough investigation into the potential energy integration and waste heat recovery potentials within food supply chains is also undertaken, primarily employing exergy analysis to identify thermodynamic inefficiencies and optimize energy utilization. The ENOUGH tool differentiates itself from traditional Life Cycle Assessment (LCA) tools by focusing specifically on dynamic modeling of cold chain logistics, providing real-time data on product quality decline, energy consumption, and emissions. Designed to be accessible and user-friendly, the tool enables non-expert users to model scenarios, encouraging broader adoption among various stakeholders.

The tool is freely available through any web browser, and available at the ENOUGH website enough-emissions.eu (including reports on how the tool is made).

2.7.5 Final practice abstract WP5: smart data systems

The complexity of food supply chains and food processes management can be more easily addressed with decision support tools that can integrate quality preservation, energy consumption, and environmental impact.

The ENOUGH project developed **smart data systems (SDS)**, introducing a new multi-sided and multipart business application and framework that can provide a continuous improvement force to a vast set of food supply chains. The SDS is a business process that comprehends a platform, specifications, a set of digital tools and applications. Taken altogether, the work demonstrated the possibility of a paradigm shift in the use and conception of information technologies. A space and a pathway have been created that facilitate the achievement of the objectives proposed by the context of Industry 5.0, both at the European and global level, so that the reality of practice and research for improved sustainability of food supply chains can be advanced through inclusiveness, openness, participation, and innovation.

The lessons learnt that can be transferred to industry are 1) Try to address the complexity of the food supply chain through enhanced collaboration along the supply chain, 2) Keep in mind that being into the Industry 5.0 framework means that the human is increasingly at the centre of everything, and that all the dimensions of sustainability must be enforced at once, 3) Consider adopting technologies coming from the continuously evolving framework of the Blockchain - a key component and opportunity for the digital transformation and for the sustainable introduction and control of digital technologies, 4) Think systemically and holistically, apply systems engineering and consider the whole and parts of a system as a connected entity.

2.7.6 Final practice abstract WP6: Demonstrations of best technologies in key products and cross sectors

Substantial emissions reductions—up to 50%—can be achieved using technologies that already exist.

In ENOUGH, the success of 21 real-world demonstrations across Europe proves that these solutions are feasible, scalable and adaptable to different products and sectors, offering a clear path to decarbonising the food supply chain. Demonstrators rely on natural refrigerants-based technologies, integrated thermal flows, application of energy storage, heat recovery, use of waste heat, and implementation of electrification for processing, heating and transport. Innovative storage and processing reduce food waste at industrial and domestic level. Finally, interaction with the grid and advanced control guarantee emission reduction and trustability of the chain. As examples, the two dairy sites in Austria and Norway demonstrated significant energy savings and CO_2 reductions using natural refrigerants, innovative heating and cooling systems, and thermal energy storage. The transport demonstrator in Italy proved the viability of natural refrigerant and electric-powered refrigerated transport, offering a scalable model for sustainable logistics. Other demonstrated technologies include advanced freezing technologies (brine, blast, CO_2 plate freezing), energy-efficient fruit storage using dynamic controlled atmosphere (DCA), sustainable packaging, optimised retail technologies (e.g. heat reclaim, thermal storage, demand-side response), and domestic innovations like freeze dryers and efficient refrigerators. The highest technology readiness level achieved is TRL 9, indicating full market readiness.

More details and final reports from each demonstrator are available at the ENOUGH webpage enough-emissions.eu.

2.7.7 Final practice abstract WP7: Policy, strategy, advice to achieve targets

Decarbonising the food system, particularly its cold chain components, requires a multi-level approach that integrates technological, policy, and behavioural strategies. There are significant policy gaps between current regulatory frameworks and the potential of technologies that could decarbonise the food chain. There is a lack of alignment between climate, energy, and food policies, which hinders coordinated action across the food chain.

Existing policies would profit from accounting for future food system needs, especially those related to the food cold chain. Forthcoming investments in research and innovation outlined by the European Commission's FOOD 2030 Research and Innovation Pathways for Action 2.0 show modest incentives for the food industry. This could lead to slow down innovation adoption and missing opportunities for emission reduction. Aligning policy tools with TRLs is important, particularly by supporting emerging technologies in the demonstration and market entry phases.

At the societal level, consumer behaviour remains a pivotal but underleveraged driver of food system transformation. Food choices are strongly influenced by socioeconomic factors and regional disparities, and sustainability awareness and willingness to pay for green products is uneven.

The transition to a sustainable low-carbon food system will also depend on engaging society. Behavioural change must be supported by clear information, affordable green choices, and systemic policy interventions that reflect the complexity of the food system. Without these coordinated efforts, the goals of the EU Farm to Fork Strategy risk being confined to niche markets and higher-income groups, leaving behind broader segments of the population.

2.7.8 Final practice abstract – main outcomes from the ENOUGH project

ENOUGH developed predictive models for 2030 and 2050 emissions of the food chain relative to 1990 and 2019 levels, showing that these emissions will remain high without intervention. In addition to the transition to renewable electricity generation, additional measures like improving efficiency of refrigeration systems, changing to natural working fluids, integrating heating and cooling, and reducing food waste are needed. ENOUGH developed technological roadmaps for various food chain stages (retail, catering, storage, transport, domestic, processing) across six countries, demonstrating how 40–50% emission reductions are achievable through technological and operational measures.

Substantial emission reductions can be achieved using technologies that already exist, and the 21 real-world ENOUGH demonstrators proved that these are not only feasible but scalable, offering a clear path to decarbonising the food chain.

To help users test different strategies to reduce emissions, the ENOUGH tool was developed to simulate the food chain to calculate energy use and emissions. Another web tool developed is the smart data systems (SDS), introducing a new multi-sided and multipart business application and framework that can provide a continuous improvement force to a vast set of food supply chains.

Reaching net-zero emissions will also require non-technological changes, like sufficient investments in clean technologies and solutions being allocated where needed. Current regulations are too general, and more targeted policies are needed for each stage of the food chain.

Urgent and coordinated action is needed now, involving all actors, to accelerate decarbonisation and secure a just and achievable path to climate neutrality.

3 CONCLUSIONS AND FURTHER STEPS

This document includes the final practice abstracts of the ENOUGH project ending in September 2025. In addition to the practice abstracts, several factsheets have been published on the ENOUGH webpage. All partners were invited to prepare factsheets with information about our project activities, results, and other relevant information. The practice abstracts will also be made into factsheets, so they can be found in the ENOUGH webpage in addition to the CAP Network platform.

enough-emissions.eu

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