EnergyEfficiency4SMEs Follow-up Study

4 July 2025

Prepared for: Malta Business Bureau (MBB)

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Scope of Work

As per the MBB's Call for Quotation document titled "Economic Study on Energy Efficiency in Hotels& Manufacturing" with reference: EE4SMEs Grant Agreement No. 101076459 LIFE21-CET-AUDITS. Deloitte aims to assist the MBB and partner institutions/organisations in the other participating countries in:

- Carrying out a review of the data gathered to date by the project team.
- Conducting research to gather further insights and data pertinent to the study objectives.
- Formulating a complete state of play report addressing all the research objectives stipulated in the request for quotation.

More specifically, Deloitte Malta aims to fulfil the 4 research objectives mentioned in the Call for Quotation, namely:

- **Objective 1:** Examine Energy Efficiency Measures

  Evaluating energy efficiency measures collected through energy audits and performance surveys, assessing financing mechanisms used during implementation, and identifying barriers encountered.

- **Objective 2:** Conduct a Contextual Analysis

  Exploring the broader socio-economic benefits of energy savings, studying energy production trends in partner countries, estimating environmental externalities, and assessing current and future energy costs.

- **Objective 3:** Generate and Shortlist Recommendations

  Conducting short-listing exercises to refine the recommendations/measures.

- **Objective 4:** Evaluate and Prioritize Socio-Economic Impact

  Assessing the cost-benefit ratio and overall socio-economic impact of energy measures under various uptake and implementation scenarios, prioritizing actions with stakeholders.

Limitations of Study

The analysis and conclusions presented in Objective 1 (Examine Energy Efficiency Measures) are based solely on the data supplied by the client. As such, the accuracy, completeness, and reliability of the findings are contingent upon the integrity of the original data. The author assumes no liability for any errors, omissions, or misinterpretations resulting from inaccurate or incomplete data submissions. Readers are encouraged to interpret the results in Objective 1 with this context in mind and to consult the original data providers for clarification where needed.

Identifying and assessing the non-energy benefits (NEBs) and non-energy efforts (NEEs) of energy efficiency measures – whether they are quantified or not – is highly context-dependent. Therefore, producing reliable, non–company-specific estimates of these impacts would require extensive primary data collection, such as large-scale surveys and structured stakeholder workshops across all nine countries. The scale and resource demands of such effort lie beyond the scope of this study.

Given this constrain, the study adopted a pragmatic approach to achieve Objective 4. First, it applied Tool 1 from the KNOWnNEBs project, which is developed from over 130,000 data points, to assign relevant NEBs to each targeted energy efficiency measure. Second, it compiled related NEEs through desktop research of peer-reviewed literature, policy documents, and expert sources. Finally, it outlined clear, replicable methodologies for quantifying these impacts and converting them into monetary terms, providing a foundation that future analysis can built upon as more data becomes available.

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Background

EE4SMEs

EE4SMEs (EnergyEfficiency4SMEs) is an EU-supported initiative designed to significantly enhance energy efficiency, reduce energy consumption, and promote sustainable energy practices among small and medium-sized enterprises (SMEs). The project focuses on specific NACE sectors, namely:

- Accommodation and food service activities (NACE Code: I55 to I56.3.0)
- Manufacturing – Agri-food (NACE Code: C10 to C11.0.7)
- Manufacturing – Metalwork (NACE Code: C24 to C25.9.9)

EE4SMEs is implemented by a consortium of 23 partners across 9 European countries. These include Austria, Bulgaria, Cyprus, Estonia, France, Germany, Italy, Malta, and Spain.

Over a 36-month period, the project aims to directly support 1,000 companies in conducting energy audits, with a specific target of completing 141 audits within this timeframe. In addition, EE4SMEs focuses on strengthening the skills and expertise of 1,000 company personnel and 200 energy auditors and stakeholders (1).

The key objectives of EE4SMEs include (2):

1. **Best Practices and Recommendations:** Identify best practices from larger companies and adapt these into cost-effective, tailored recommendations for SMEs in the targeted sectors.

2. **Tool Development**: Create practical tools and resources that facilitate the energy transition process for SMEs.

3. **Action and Analysis:** Identify concrete energy-saving measures and, when needed, carry out additional studies-such as energy diagnoses and feasibility assessments-to ensure the viability of the proposed actions.

4. **Awareness and Commitment:** Raise awareness and encourage SMEs to adopt sustainable energy management practices that can lead to the implementation of energy management systems.

5. **Capacity Building:** Strengthen the capacity of SMEs through targeted training and support for the implementation of energy efficiency measures.

6. **Financing Options:** Explore innovative financing options and funding mechanisms to help SMEs implement energy efficiency initiatives successfully.

MBB’s Role and Background for EE4SMEs Follow-Up Study

The Malta Business Bureau (MBB), in partnership with the Energy and Water Agency (EWA), serves as the local implementing partner for the EE4SMEs project in Malta. In this capacity, MBB operates an information contact point offering free advisory services to SMEs. These services include guidance on financial grants and financing opportunities to support the implementation of sustainable projects aimed at reducing emissions. Additionally, MBB assists businesses in applying for energy audits, with the EWA fully or partially covering the costs of selected audits.

An initial high-level economic study, titled *“D5.3 EE4SMEs - Final High-Level Economic Report,”* was completed in October 2023. Its primary objective was to assess the current business needs for energy efficiency projects and the financing options available at both national and regional levels across participating countries. The study also includes sector-specific economic data and insights from self-assessment questionnaires, and it outlines key challenges, investment barriers, and high-level policy recommendations to support and advance energy efficiency initiatives among SMEs.

Building on this foundation, MBB is commissioning a follow-up study to revisit key areas covered in the initial report while expanding its scope to include: an analysis of the number and types of initiatives financed under the EE4SMEs project, a review of the financing mechanisms used for these initiatives, identification of barriers to financing, emerging trends and opportunities in the financing landscape, and recommendations for both the public and private sectors to develop or enhance financial mechanisms supporting energy efficiency initiatives.

Objective 1:

Examine Energy Efficiency Measures

Source: Templafy library, Deloitte Internal

Examine Energy Efficiency Measures

Evaluating energy efficiency measures collected through energy audits and performance surveys, assessing financing mechanisms used during implementation, and identifying barriers encountered.

Energy Audits

Directive (EU) 2023/1791 of 13 September 2023 on energy efficiency – read in tandem with the earlier Directive 2012/27/EU and Commission Recommendation (EU) 2024/2002, outlines the definition and objectives of energy audits.

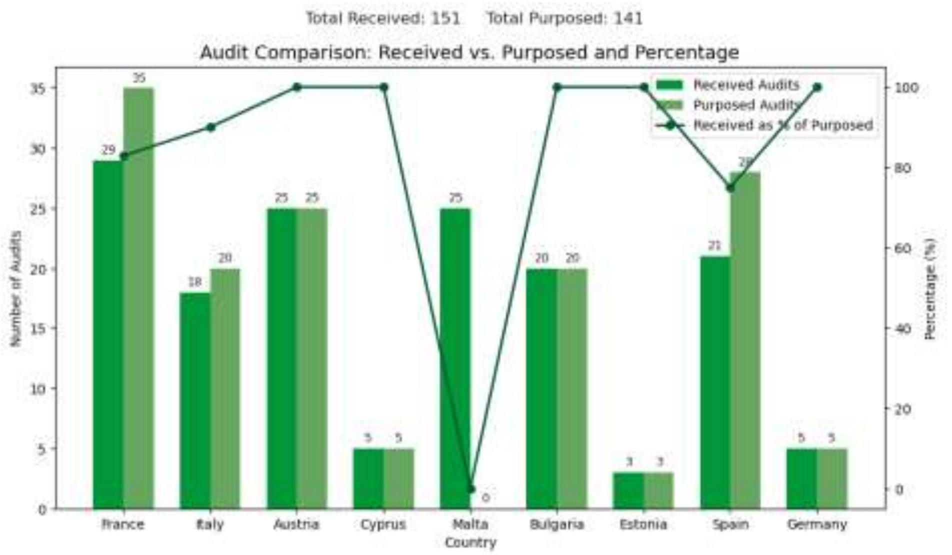
Under these directives, an energy audit is defined as a systematic process that starts with a detailed analysis of the energy consumption profile of a building, group of buildings, industrial or commercial operation, or public service. Based on this analysis, energy conservation measures (ECMs) are proposed, accompanied by economic analysis to guide investment decisions (3).

Enterprises with an average annual final energy consumption exceeding 85 TJ over the previous three years are required to implement a certified energy management system, typically aligned with ISO 50001 standards. Those with consumption between 10 TJ and 85 TJ, and without a management system, must conduct an energy audit and repeat it every four years. Although SMEs generally do not exceed these thresholds, the directive encourages them to undertake audits voluntarily and implement recommended measures. EU-funded initiatives, such as the EE4SMEs project, provide technical assistance and financial incentives to make energy audits more accessible for smaller enterprises.

Audits Received

As part of the EE4SMEs project's key performance indicators (KPIs), a total of 141 energy audits were initially planned ("purposed audits"), with specific targets allocated to each participating country under the grant agreements. "Received audits" refers to the number of completed audits submitted to the WP3 project team at the time of this report.

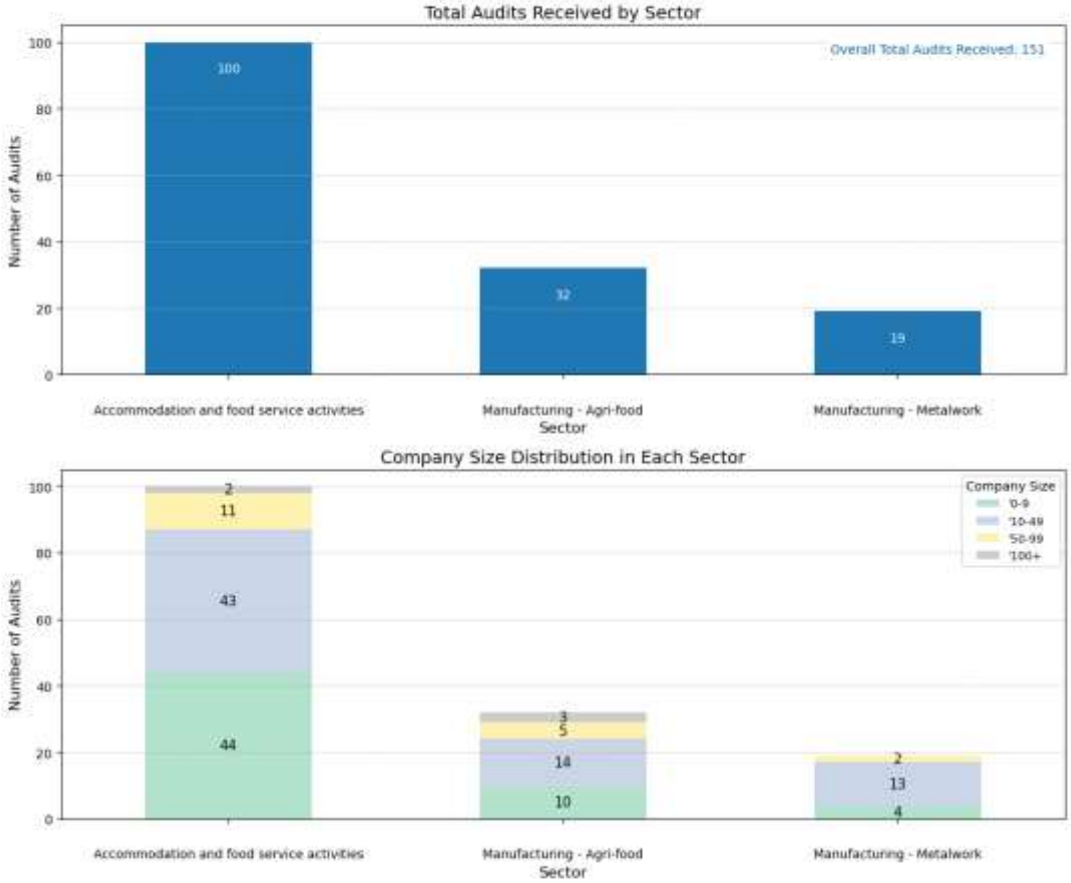
To date, 151 audits have been received, exceeding the original target by 7.1%. This overachievement is primarily due to several countries meeting or surpassing their assigned targets. Austria, Cyprus, Bulgaria, Estonia, and Germany each achieved 100% of their planned audits. **Malta, despite not having an assigned target, contributed an additional 25 audits.** In contrast, France, Italy, and Spain fell short of their targets, achieving approximately 83%, 90%, and 75% respectively.



Source: EE4SMEs WP3 Energy Audit Data

The methodology, progress, and results of these audits are documented under Work Package 3 (WP3), specifically in Deliverable 3.2, *"Energy Audit Reports and Basic Findings for the Participating SMEs,"* and Deliverable 3.3, *"Summary Report of the Basic Recommendations for Energy Upgrading Per Type of SME (Buildings and Processes)."* Selected findings from these deliverables are discussed in the following sections of this report, alongside additional insights derived from the raw energy audit data provided by the WP3 lead.

Across all participating countries, most audits (66%) were conducted within the Accommodation and Food Service Activities sector, followed by Manufacturing – Agri-food (21%) and Manufacturing – Metalwork (13%). In terms of company size, the audits predominantly focused on smaller enterprises, particularly those with fewer than 50 employees. Micro enterprises (0–9 employees) and small enterprises (10–49 employees) accounted for the majority of audit activities, while lower-medium (50–99 employees) and upper-medium enterprises (100+ employees) represented a smaller proportion. This distribution reflects the project's emphasis on engaging the foundational layers of the business ecosystem when conducting energy audits.



Source: EE4SMEs WP3 Energy Audit Data

The contracted energy auditors were tasked with recommending energy efficiency measures based on their site inspections. For each recommended measure, they provided key economic indicators, including capital cost, net present value (NPV), internal rate of return (IRR), payback period, and break-even period. They also estimated both primary and final energy savings - broken down by electricity and fuel - as well as the projected reduction in greenhouse gas (GHG) emissions.

Energy Performance Survey

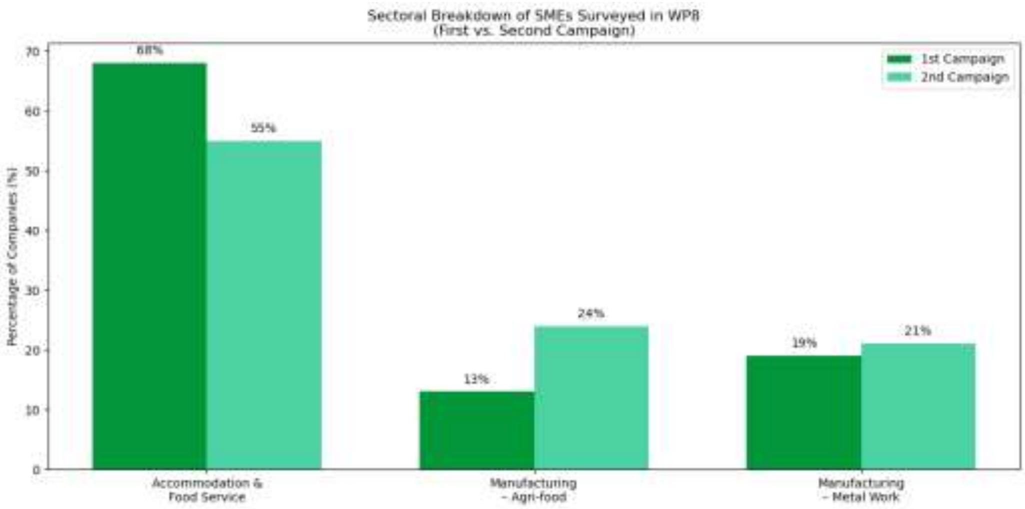
Following the launch of the EE4SMEs project, Work Package 8 (WP8) was established to monitor its effectiveness and impact. WP8 focuses on three key objectives:

- Measuring improvements in the energy performance of beneficiary SMEs.
- Evaluating other changes that enhance energy efficiency and reduce CO_2 emissions in participating SMEs.
- Capitalising on results within the participating countries.

Two progress reports summarising WP8's findings to date - Deliverable 8.1, *"Intermediate Report 1 – Life-CET-Business – EE4SMEs,"* and Deliverable 8.2, *"Intermediate Report 2 – Life-CET-Business – EE4SMEs"* - have been provided, along with the underlying survey data for Deliverable 8.2.

Surveys Received

Across both data collection campaigns, a total of 268 companies were surveyed. In the first WP8 survey, which included 123 firms, the majority of participating SMEs (68%) were from the accommodation and food services sector, with metalworking and agri-food manufacturing companies comprising 19% and 13% of the sample, respectively. In the second campaign, which surveyed 145 firms, participation expanded to include a wider range of manufacturing sub-sectors, particularly agri-food, while the share of companies from the hospitality sector decreased but remained represented.



Source: EE4SMEs WP8 Progress Reports

The dataset captures information on companies' energy efficiency measures, consumption patterns, investments, perceived barriers, and future plans for improving energy efficiency and adopting renewable energy.

Funding Mechanism – EU or Public Funding Programs:

Among the companies that reported implementing energy efficiency measures, an average of 30% (across both surveys) received support from EU or public funding programs. The most frequently cited funding mechanisms are listed below:

Source: EE4SMEs WP8 Progress Reports

Förderung des Klima- und Energiefonds (Austria) - This Climate and Energy Fund supports projects that advance Austria's energy transition and climate protection goals, focusing on innovations in renewable energy, sustainable mobility, and energy efficiency for municipalities, businesses, and research institutions (14).

Operational Programme "Innovations and Competitiveness" (Bulgaria) - Co-funded by the EU, this programme aims to enhance innovation and energy efficiency among Bulgarian SMEs by offering grants for green investments such as energy audits, building upgrades, and renewable energy installations (15).

CEE – Certificat d'Économies d'Énergie (France) - The Energy Savings Certificate (CEE) scheme requires energy suppliers to finance energy efficiency projects in exchange for certificates representing the energy saved, making it a key funding mechanism for industrial and building improvements in France (16).

PERF' – Programme CCI BFC (France) - Led by the Chamber of Commerce and Industry of Bourgogne-Franche-Comté (CCI BFC), this regional initiative offers guidance and co-funding for SMEs to conduct energy audits and implement recommended measures, particularly within industrial operations (17).

Other Funding Sources:

- KfW Energieeffizienzprogramm (Germany)
- BAFA Energy Consulting (Germany)
- Conto Termico (Italy)
- KredEx Energy Efficiency Loans (Estonia)
- Energy Efficiency & Renewable Sources Fund (EERSF) (Bulgaria)
- National Energy Efficiency Fund (FNEE) (Spain)
- ADEME SME Financing (France)
- SME Guarantee Scheme (MDB)

GUEST Projects – Energy Audit (Malta) - Led by Malta's EWA with MBB as a project partner, this initiative provides SMEs (boutique hotels and guesthouses) with free or subsidised energy audits to increase awareness of energy-saving opportunities and facilitate implementation by reducing upfront costs (18).

Energy Audits for SMEs (Malta) - Offered by Malta's EWA, the Energy Audits for SMEs scheme provides certified energy audits to SMEs across all sectors. Depending on eligibility, it covers between €2,500 and €6,000, reimbursing either the full or partial cost of the audit (96).

EENergy (EU-wide) – Funded through the Enterprise Europe Network, the EENergy initiative provides SMEs with direct, non-repayable grants of up to €10,000 to support energy efficiency improvements – covering advisory services, investments, or training designed to achieve at least a 5% reduction in energy consumption and GHG emissions (97).

Andalusian Regional Energy Agency (Spain) - The Agencia Andaluza de la Energía offers grants to SMEs for energy audits, equipment upgrades, and renewable energy installations (19).

NextGenerationEU (EU-wide, Spanish Allocation) -As part of the broader NextGenerationEU recovery programme, funding in Spain is directed towards green and digital transitions, with significant allocations for energy-efficient building renovations, SME support, and clean energy projects (20).

Funding Mechanisms – Other Sources:

For companies that implemented energy efficiency measures without public or EU funding, the WP8 reports and survey data do not specify the alternative financing mechanisms used. Therefore, desktop research and insights from high-level economic studies (D5.3) were used and revisited to identify the following options:

Bank Loans and Green Loans:

Traditional bank loans remain a widely used financing option for SMEs undertaking clean energy projects. Increasingly, commercial banks offer "green loans" or sustainability-linked loans specifically tailored to support energy efficiency improvements and renewable energy installations. These loans provide upfront capital that SMEs repay over time with interest, typically secured against project assets or company revenues.

Banks often offer preferential terms for projects with clear environmental benefits, such as reduced interest rates or extended repayment periods. In Spain, for example, BBVA and other banks are expanding green loan portfolios to support such initiatives (21). These loans are frequently combined with risk-sharing instruments from institutions like the European Investment Bank, which help reduce financial risk and encourage greater private sector investment in clean energy.

Equipment Leasing and Green Leasing:

Instead of purchasing equipment outright, SMEs can lease energy-efficient technologies or renewable energy systems, such as solar panels or electric vehicles. Under a "green lease" arrangement, a leasing company or bank buys the equipment and the SME makes periodic payments for its use. This model is particularly beneficial for high-cost clean technologies, as it eliminates the need for significant upfront investment.

In Austria, for example, the Klima- und Energiefonds has partnered with banks to promote clean technology leasing by combining public incentives with private financing (14). Similarly, solar leasing models in Malta and Cyprus enable companies to install solar panels on SME premises at little to no upfront cost, with the SME paying a fixed monthly fee rather than owning the system outright, thereby reducing barriers to renewable energy adoption (22).

Green Bonds and Sustainable Bonds:
Green bonds are fixed-income debt instruments whose proceeds are dedicated exclusively to environmentally beneficial projects. While SMEs typically do not issue their own green bonds due to their smaller scale, they can benefit indirectly. Large corporations or banks issue green bonds to raise capital, which is then used to finance numerous smaller projects, including energy upgrades for SMEs.
For example, in France, corporate green bonds have funded solar farm developments and building retrofits, with SMEs often involved as contractors or beneficiaries of financing down the supply chain (23). In Italy, banks such as Intesa Sanpaolo have issued green bonds and used the proceeds to provide discounted loans to businesses for renewable energy installations (24).

Energy Performance Contracts (EPCs) with ESCOs:
An Energy Performance Contract (EPC) is an agreement in which an Energy Service Company (ESCO) implements energy efficiency or renewable energy measures for a client, such as an SME, while guaranteeing a specified level of energy savings. This market-based mechanism typically requires no upfront payment from the SME; instead, the project costs are repaid over time using the savings generated from reduced energy consumption. Funding can come directly from the ESCO's balance sheet or from a bank or investor that provides capital based on the guaranteed future savings.
EPCs are widely used in Italy, which has one of Europe's largest ESCO markets. Italian ESCOs often bundle multiple projects to generate white certificates (tradable energy efficiency certificates), creating an additional revenue stream through the sale of these certificates (25).

Energy Service Agreements & Power Purchase Agreements (PPAs):
A Power Purchase Agreement (PPA) is a contract commonly used in renewable energy projects, where a developer or investor builds and operates a renewable energy installation - such as a solar array or wind turbine - and the customer (off-taker) agrees to purchase the generated electricity at a fixed rate over a long-term period, typically 10–20 years. For SMEs, this often involves hosting a solar PV system on their rooftop, funded by a third party, allowing them to buy clean electricity at an agreed price without making any capital investment in the system (26).
Similarly, some ESCOs offer Energy Service Agreements, installing equipment such as high-efficiency cogeneration units or boilers at the SME's site and then selling the resulting heat or energy to the SME. In this arrangement, the SME avoids the upfront cost of purchasing equipment and instead pays for the delivered service-whether heat, cooling, or electricity-at a rate that is typically lower and more efficient than their previous supply (27).

Carbon Credit Trading:
SMEs undertaking decarbonisation projects can generate carbon credits, typically equivalent to one ton of CO_2 (or its equivalent) emissions reduced per credit. For example, installing energy-efficient machinery or biogas units that verifiably cut emissions beyond a set baseline can result in certified credits, which can then be sold to other companies-often larger emitters-seeking to offset their emissions to meet compliance requirements or voluntary climate goals.
Within the EU, large emitters such as power plants, heavy industry, and aviation operators participate in the EU Emissions Trading System (EU ETS), a mandatory cap-and-trade scheme covering around 40% of the EU's greenhouse gas emissions. SMEs, especially those outside the sectors regulated under the EU ETS, typically engage in voluntary carbon markets to offset their emissions or support external climate

projects. These voluntary markets enable SMEs to buy or sell carbon credits generated from projects that reduce or remove greenhouse gases, including initiatives outside the EU or in unregulated sectors (28).

Energy Efficiency Certificates (White certificates):
Some countries, notably Italy and France, operate Energy Efficiency Certificate schemes, commonly known as "white certificates." These tradable certificates are awarded for verified energy savings. Utilities and large energy distributors, which have mandated energy-saving targets, can purchase these certificates from organisations that exceed their savings, such as ESCOs or companies implementing efficiency projects.
For SMEs, this means that by undertaking qualifying energy efficiency projects, they-or an ESCO acting on their behalf-can earn certificates that can be sold for cash, creating an additional revenue stream. Under Italy's Titoli di Efficienza Energetica (TEE) system, for example, an SME upgrading all factory lighting to LED would generate certificates based on the kWh saved (29). These certificates can then be sold to obligated parties, such as electricity distributors, either directly if the SME is accredited or via an ESCO that manages the certification and sale process.

Crowdfunding and Peer-to-Peer Financing:
With growing sustainability awareness, crowdfunding platforms now enable private citizens to invest directly in renewable energy and energy efficiency projects, including those led by SMEs. Through dedicated platforms such as Lendosphere in France (30), SMEs can raise funds for initiatives like solar farms or building retrofits from public or private investors, often offering a small equity stake, interest payments, or a share of future revenues in return.

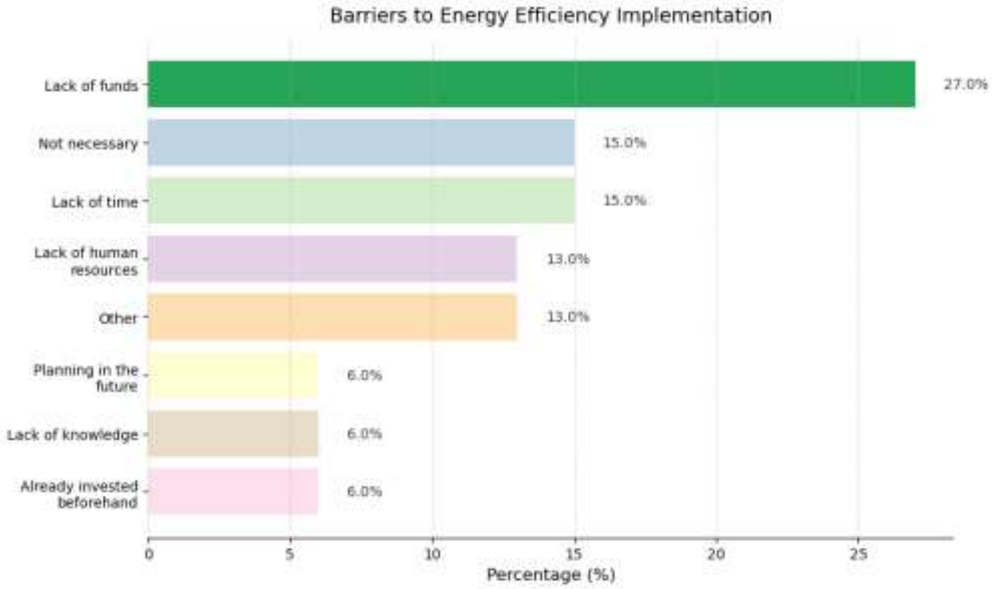
Hybrid Models (Blended Finance & Insurance):
In addition to purely private financing mechanisms, hybrid models combine private capital with guarantees or insurance products to reduce risks.

- **Energy Savings Insurance (ESI):** Developed by the Basel Agency for Sustainable Energy (BASE) and piloted in several EU countries, ESI involves an insurance company guaranteeing the expected energy savings from a project (31). For example, if an SME installs an energy-efficient compressor and the projected savings are not achieved, the insurance policy compensates the SME for the shortfall. This assurance increases bank confidence in lending and encourages SMEs to invest by reducing performance risk.

Overall, these mechanisms mobilise private capital and market incentives to support SME decarbonisation. In practice, SMEs often combine multiple tools-such as using a bank loan alongside an EPC with an ESCO, while also benefiting from white certificates and potentially selling carbon credits. Layering these financing sources makes projects more bankable and affordable.

Barriers to Financing:

Despite the availability of various public and private funding sources, SMEs often remain hesitant to invest in energy efficiency measures due to a combination of financial, organisational, and informational barriers. These challenges are documented in the WP8 D8.2 report and summarised below:



Source: EE4SMEs WP8 Progress Reports

Survey results identified lack of funds as the most common barrier, reported by 27% of respondents. Lack of time and the perception that energy efficiency measures are unnecessary were each cited by 15% of participants. Additionally, lack of human resources and other reasons were each mentioned by 13% of companies.

Beyond these primary categories, SMEs highlighted several qualitative barriers, including:

- **Concerns about profitability and return on investment (ROI)** - particularly when the ROI is perceived as too long-term or uncertain.
- **Administrative burdens and complexity** in accessing available support mechanisms.
- **Context-specific restrictions**, such as heritage protection rules, space constraints, the presence of asbestos, or building ownership issues.
- **Operational concerns**, including extended downtime during implementation, increased maintenance requirements, and compatibility challenges with existing systems.
- **Strategic or perceptual barriers,** such as other competing business priorities, pressure to increase turnover, or a general lack of interest or awareness regarding energy efficiency opportunities.

These findings underscore the importance of comprehensive support strategies that address not only financial limitations but also the operational, regulatory, and perceptual challenges SMEs face in pursuing energy efficiency.

Energy Efficiency Measures Analysis

The following sections compare energy efficiency measures identified through energy audits (WP3) and energy performance surveys (WP8) to provide insights into SME adoption patterns and underlying drivers. This analysis draws on selected findings from project deliverables, supplemented by raw datasets provided by project stakeholders.

However, these results should be interpreted with caution due to data limitations, including the small sample size and potential biases caused by the over-representation of certain countries, sectors, or company sizes.

Standardisation of Measures

Energy efficiency measures reported in both the energy audits (WP3) and energy performance surveys (WP8) were captured using broad, predefined categories. Rather than providing detailed descriptions, respondents typically selected general options such as "building heating," "compressed air," or "ventilation" to indicate the type of intervention implemented or recommended. Both sources also included an "Other" category to capture measures not covered by existing options.

WP8 uses a categorisation system outlined in Deliverables 8.1 (*D8.1 Intermediate Report 1 – Life-CET-Business – EE4SMEs*) and 8.2 (*D8.2 Intermediate Report 2 – Life-CET-Business – EE4SMEs*).

WP3 uses a classification system detailed in Appendix A of Deliverable 3.3 (*Aggregated Upgrade Measures Recommendations of the Energy Audit*).

However, the categorisation systems differed between WP3 and WP8 – each using different naming conventions and including measure types not present in the other. To enable comparison of measures across WP3 and WP8, standardisation was required. This process was challenged by the absence of clear definitions for many categories, necessitating the use of informed judgment to interpret each category's intended meaning and ensure consistent harmonisation.

The alignment of energy efficiency measures followed these steps:

- **Selection of Reference Framework**:
  The WP8 categorisation system was chosen as the primary reference due to its greater detail and broader coverage of measure types.
- **Reclassification of "Other" Measures:**
  Measures grouped under "Other" in WP8 were reviewed and reassigned to more suitable categories. Specifically:
  - Building renovation measures initially classified under "Other" were reassigned to existing WP8 categories. Where no suitable category existed, new categories were created to match WP3 classifications.
  - "*Industrial furnaces*", previously uncategorised under "Other," was assigned its own distinct category.
  - The category "Raising staff awareness" was created to specifically capture behavioural changes, distinguishing them from operational improvements, which are captured under the "Optimisation" category.
- **Mapping WP3 Measures to WP8 Categories:**
  Once the updated WP8 categorisation was finalised, all measures reported through WP3 were mapped to these standardised categories to ensure consistency.

Details of the alignment procedure and the full mapping of energy efficiency measures are provided in Appendix A.

Standardised Measure Categories

The following standardised categories were used in this analysis:

1. **Lighting**:
   Upgrading to energy-efficient lighting technologies (e.g. LEDs) to reduce electricity use and improve illumination quality.
2. **Building Heating**:
   Improving heating systems through high-efficiency equipment and better insulation to reduce energy consumption while maintaining comfort.
3. **Renewable Energies**:
   Integrating renewable sources such as solar panels or wind turbines to generate sustainable energy and reduce fossil fuel dependency.
4. **Heat Pumps and Heat Recovery**:
   Using heat pumps for efficient heating/cooling and implementing heat recovery systems to reuse waste heat from processes or ventilation.
5. **Compressed Air**:
   Optimising compressed air systems by fixing leaks, adjusting pressure settings, and upgrading equipment to increase efficiency in industrial operations.
6. **Ventilation**:
   Enhancing ventilation systems with energy recovery ventilators or demand-controlled ventilation to maintain air quality while reducing energy loss.
7. **Cooling**:
   Upgrading cooling systems to high-efficiency models and applying passive cooling strategies to lower energy consumption and improve indoor comfort.
8. **Energy Management**:
   Implementing automated systems and data analysis tools to monitor, control, and optimise energy use within facilities.
9. **Office Space (e.g., Equipment):**
   Using energy-efficient office equipment and power management practices to reduce electricity use in office environments.
10. **Facade Thermal Insulation, Roof Thermal Insulation, Openings Replacement, and Shading**:
    Enhancing facades, roofs, windows, and shading to reduce heat loss/gain through insulation, efficient openings, and shading devices.
11. **Industrial Furnaces**:
    Upgrading furnaces with advanced controls, efficient burners, and improved insulation to reduce energy use and enhance process efficiency.
12. **Distribution Networks and Insulation**:
    Improving efficiency in facility distribution systems by insulating pipes/ducts and optimising layouts to minimise energy losses.
13. **Pumps**:
    Installing energy-efficient pumps and controls, such as variable frequency drives, to align pump operation with system demand and reduce energy use.
14. **Optimisation**:
    Technical or procedural changes to existing systems or infrastructure that improve energy efficiency or reduce emissions without requiring significant behavioural change from users.
15. **Raising Staff Awareness**:
    Action focused on changing human behaviour to encourage more energy-conscious habits, without making major technical changes.
16. **Transportation**:

Actions that reduce the energy consumption or emissions of business-related transport activities – including fleets, logistics, commuting, and distribution.

Energy Efficiency Measures Attributes

Following the standardisation of energy efficiency measures from the energy audits and the energy performance survey, their key attributes were analysed to enable meaningful comparisons and insights. Three primary attributes were defined:

1. **technical feasibility,**
2. **economic viability, and**
3. **environmental impact.**

These attributes align with those reported in the WP3 and WP8 datasets and reflect the most commonly cited barriers to implementing or investing in energy efficiency measures, as identified in the WP8 survey and discussed earlier in this report.

The rationale for basing these attributes on reported barriers is intentional. When firms cite barriers such as high costs, technical challenges, or limited environmental benefits, they reveal the underlying criteria used to evaluate energy efficiency investments. For example, if a measure is rejected due to cost concerns, it indicates that economic viability is a critical consideration in decision-making. The same logic applies to technical feasibility and environmental impact.

Barriers related to strategic priorities, organisational perceptions, or context-specific factors were excluded from the attribute definitions, as these are often subjective and inconsistent across organisations.

The attributes are defined as follows:

- **Technical feasibility** assesses the level of difficulty involved in implementing a measure within the existing infrastructure.
- **Economic viability** considers the cost-effectiveness of a measure, including capital costs, operational savings, and payback periods.
- **Environmental impact** relates to the potential reduction in greenhouse gas (GHG) emissions and other associated environmental benefits.

Technical Feasibility

Due to insufficient data in the provided datasets to directly assess the technical feasibility of energy efficiency measures, a new evaluation methodology was developed. Informed by academic literature and technical guidelines, this approach assessed feasibility based on three key factors:

1. **installation complexity,**
2. **compatibility with existing infrastructure, and**
3. **maintenance requirements.**

Installation complexity refers to the scope and difficulty of implementing a measure. This includes the need for specialised engineering modifications, the extent of construction or retrofitting, potential downtime or operational disruptions, and whether installation can be phased or requires a single major intervention (7). Measures that can be installed quickly with minimal operational impact are considered more feasible than those requiring extensive construction or major system overhauls.

Compatibility with existing infrastructure assesses how well a measure integrates with current building systems, equipment, and structural constraints. This factor examines whether the new technology can be adopted without significant modifications to existing infrastructure (8). Measures offering straightforward integration (e.g. plug-and-play components) are rated as more feasible compared to those demanding extensive alterations.

Maintenance requirements and operability consider the ongoing operational implications of a measure. Ideally, feasible solutions should be reliable and not impose excessive maintenance demands beyond the capacity of facility staff or service providers (9). This includes the availability of spare parts and expertise, the frequency and complexity of maintenance tasks, and potential impacts on existing equipment lifespan. Measures requiring highly specialised maintenance or substantial changes to operational routines are deemed less practical, while those that reduce maintenance needs or can be managed using existing skills are favoured.

Each energy efficiency measure was assessed against the three feasibility factors using a simple scoring scale:

- 1 = **Low adherence** (high complexity, poor compatibility, heavy maintenance)
- 2 = **Moderate adherence** (some disruption, partial compatibility, moderate upkeep)
- 3 = **High adherence** (easy installation, seamless integration, low maintenance)

The individual factor scores were then summed to generate an overall feasibility score ranging from 3 (least feasible) to 9 (most feasible). This scoring system offers a consistent basis for comparing the technical practicality of different measures, as shown in the table below.

However, this approach has limitations. It does not account for site-specific conditions, operational constraints, or industry-specific factors that could influence the actual feasibility of implementation. Additionally, applying equal weighting across all criteria and using a simplified scoring method may overlook important technical nuances.

Therefore, **this methodology is intended solely for high-level comparative analysis within the scope of this study, particularly where pre-existing feasibility data is unavailable. It is not designed for detailed, site-specific decision-making. Enhancing the robustness of this assessment would require stakeholder input and the use of more advanced multi-criteria decision-making frameworks, which are beyond the current scope of this study**.

Measures	Installation Complexity	Compatibility	Maintenance Requirements	Technical Feasibility (Score)	Technical Feasibility
Optimisation	3	3	3	9	High
Office Equipment Efficiency	2	3	3	8	High
Raising Staff Awareness	3	3	3	9	High
Transportation	2	3	2	7	High
Heat Pumps and Heat Recovery	2	3	2	7	High
Lighting	3	3	3	9	High
Compressed Air	2	3	2	7	High
Pumps	2	3	2	7	High
Energy Management	2	2	2	6	Medium
Distribution Networks and Insulation	2	2	2	6	Medium
Building Heating	2	2	2	6	Medium
Industrial Furnace	2	2	2	6	Medium
Cooling	2	2	2	6	Medium
Ventilation	2	2	2	6	Medium
Renewable Energies	2	2	2	6	Medium
Roof Thermal Insulation	1	2	2	5	Low
Openings Replacement and Shading	1	2	2	5	Low
Façade Thermal Insulation	1	2	2	5	Low

Source: (10) – (13)

Economic Viability

To assess the economic viability of energy efficiency measures, this analysis evaluates both upfront investment requirements and long-term cost-effectiveness based on four key indicators:

1. **Capital Cost,**
2. **Net Present Value (NPV),**
3. **Energy Savings, and**
4. **Payback Period.**

Capital cost represents the initial expenditure required to implement an energy efficiency measure. Although it does not capture future savings or financial returns, it remains a critical consideration in investment decisions. In this analysis, most capital cost data was drawn from the WP8 energy performance survey rather than from energy audit estimates, as WP8 reflects actual implementation costs and therefore provides a more reliable basis for analysis. The only exception is the "Raising staff awareness" measure, whose capital cost was taken from WP3 estimates, since it was not included in the WP8 dataset.

Energy savings are key to understanding the long-term value of a measure and are incorporated within the **Net Present Value** (NPV), which accounts for the time value of money to capture lifecycle costs and benefits. Energy Savings data was primarily sourced from WP3, which provides estimates for most measures. WP8 includes savings data only for renewable energy measures, so those values were taken from WP8 to better reflect actual performance rather than projections. Since neither WP3 nor WP8 provide energy savings data for "industrial furnace" and "transportation," these measures were assigned a value of zero to reflect the absence of data. Similarly, NPV data was mainly drawn from WP3, except for the "industrial furnace" and "transportation" measures, which were excluded due to the same data limitations.

Although less comprehensive than NPV, **payback period** remains widely used due to its simplicity, providing a quick indication of how soon the initial investment will be recovered through energy savings. Since only WP3 provides payback period data, this dataset was used for the analysis.

To derive representative values for capital cost, NPV, energy savings, and payback period, the skewness of each distribution was first evaluated to inform appropriate summary statistics. Table1 in Appendix A report skewness values by measure type. The analysis showed consistent positive skewness, often exceeding 1, indicating that a few very high values were inflating the arithmetic mean. As such, the median was adopted as a more robust measure of central tendency, providing more reliable estimates less affected by extreme outliers.

Median Values

After removing non-numeric and zero entries, the graphs below present the median values for key metrics - including capital cost, NPV, payback period, and energy savings (disaggregated into primary and final energy savings) - across the analysed energy efficiency measures.

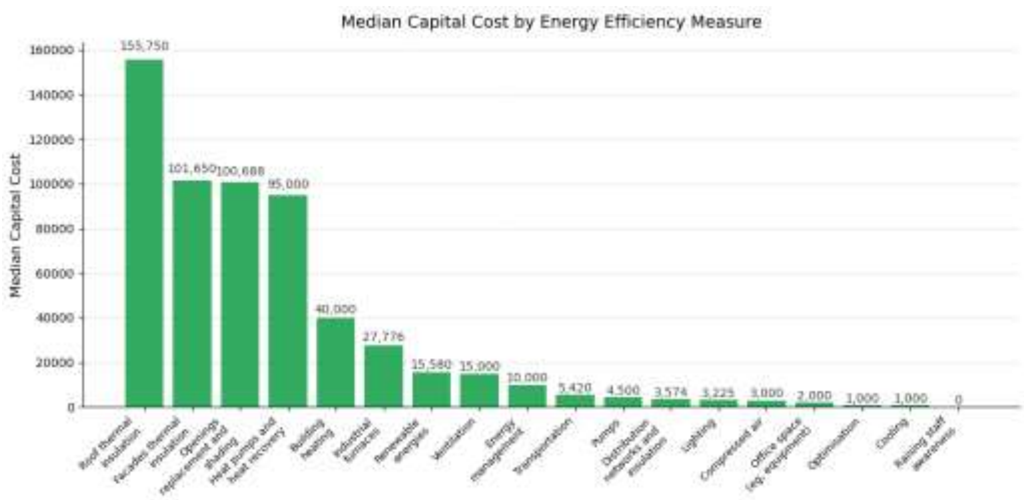
While this analysis focuses on medians as robust measures of central tendency, it is worth noting that variance metrics, such as Relative Mean Absolute Deviation (r-MAD)-calculated by dividing the MAD by the median and expressing it as a percentage-could provide further insights into data dispersion and the reliability of reported values.

The accompanying table shows r-MAD values for each measure across all key metrics. The results indicate that most measures have r-MAD values exceeding 60%, reflecting significant dispersion and variability in estimates. This high variability persists even when data is segmented by company size and recalculated, suggesting it is inherent to the dataset rather than influenced by company size differences.

A detailed investigation into the causes of this variability is beyond the scope of this study but may include data quality limitations, small or uneven sample sizes, and variations in cost estimation methodologies. Therefore, to maintain a focus on robust and interpretable findings, variance metrics have been excluded from the main analysis.

Measures	Capital Cost	NPV	Payback	Primary Energy Savings	Final Energy Savings
Optimisation	120.8	794.9	13223230000	681.1	597.6
Heat pumps and heat recovery	220.6	645.6	1330.1	7078641.9	11643460.5
Distribution networks and Insulation	161.9	73.3	62.7	263.3	321.3
Energy Management	90.8	566.4	237590.6	144.1	428.1
Lighting	6995.5	216.9	35351.6	358	516.9
Ventilation	55.1	552.9	703353	266	244.3
Openings replacement and shading	221.6	-416.7	100404	35272.1	294.1
Pumps	88.9	191.8	42319.9	734.9	327.8
Renewable Energies	1617.5	180.7	405978	713.3	1435.9
Façade thermal insulation	146.6	291.2	119666.9	182.6	123.4
Building heating	211.4	5875.4	510	416.2	16793880.8
Roof thermal insulation	191.0	1621.5	159759.4	2089.3	2493.2
Cooling	346848.2	307.7	142.8	242239.3	1368898.8
Compressed air	150.0	229.9	28.1	28.7	25.7
Office space (e.g., equipment)	435.0	79.7	150.4	16717.5	6211785.2
Industrial Furnace	71.5	0	0	0	0
Transportation	53.9	0	0	0	0
Raising staff awareness	0	0	0	0	

Source: EE4SMEs WP3 and WP8



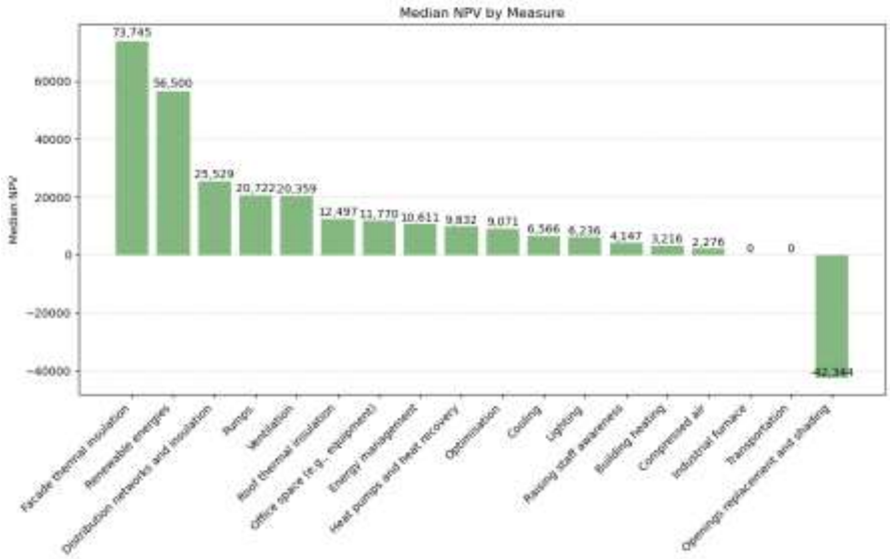
Measures	Median Capital Cost (EUR)
Roof thermal insulation	155,750
Facades thermal insulation	101,650
Openings replacement and shading	100,688
Heat pumps and heat recovery	95,000
Building heating	40,000
Industrial furnaces	27,776
Renewables energies	15,580
Ventilation	15,000
Energy management	10,000
Transportation	5,420
Pumps	4,500
Distribution networks and insulation	3,574
Lighting	3,225
Compressed air	3,000
Office space (e.g., equipment)	2,000
Optimisation	1,000
Cooling	1,000
Raising staff awareness	0

Source: EE4SMEs WP3 and WP8

The capital cost graph and table show significant variability across different energy efficiency measures. Envelope-related upgrades, such as roof insulation, façade insulation, and openings replacement – have the highest median capital costs due to the extensive structural work they require. Interestingly, heat pumps and heat recovery systems also show high capital costs, raising questions about why they are more expensive than other mechanical systems.

Mechanical system upgrades and renewable energy installations – like building heating, industrial furnaces, ventilation, and energy management – fall into a mid-range capital cost category. These still require notable investment but are generally less costly than major structural upgrades.

At the lower end of the spectrum are measures like compressed air improvements, operational optimisation, and raising staff awareness. These typically involve minimal upfront investment, making them more accessible for organisations with limited capital for energy efficiency measures.

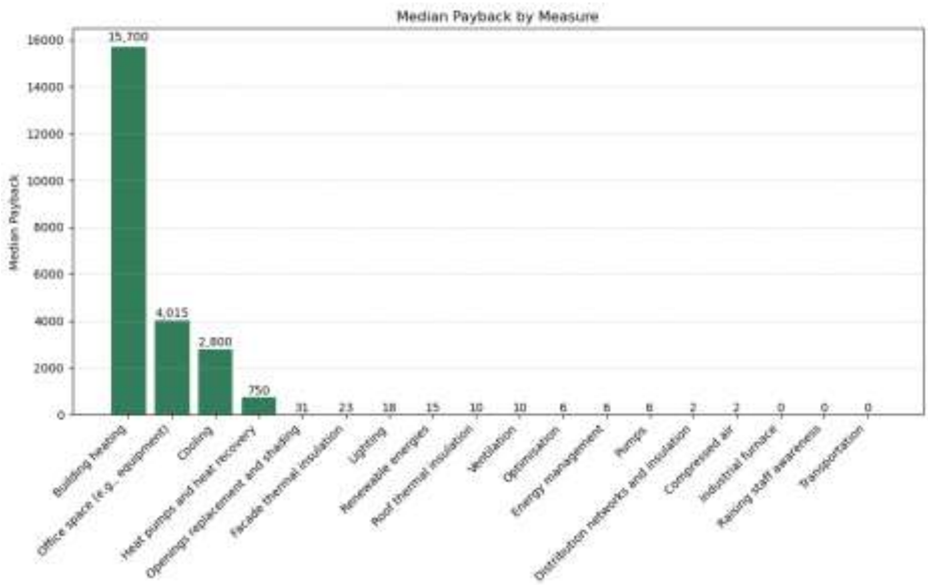


Measures	Median NPV (EUR)
Facades thermal insulation	73,745
Renewable energies	56,500
Distribution networks and insulation	25,529
Pumps	20,722
Ventilation	20,359
Roof thermal insulation	12,497
Office space	11,770
Energy management	10,611
Heat pumps and heat recovery	9,833
Optimisation	9,071
Cooling	6,566
Lighting	6,236
Raising staff awareness	4,147
Building heating	3,216
Compressed air	2,276
Industrial furnace	0
Transportation	0
Openings replacement shading	-42,344

Source: EE4SMEs WP3 and WP8

The NPV graph illustrates the long-term economic value of different energy efficiency measures. Measures such as façade thermal insulation and renewable energy installations show high positive median NPVs, indicating strong potential for long-term financial returns. Distribution networks and insulation, as well as pumps and ventilation, also yield solid positive NPVs, though slightly lower than the top-performing categories. In contrast, measures like cooling, lighting, raising staff awareness, and compressed air improvements show modest to low median NPVs, generally ranging from €2,000 to €8,000.

A notable exception is the replacement of openings and shading, which has a negative median NPV of -€42,344. This suggests that, on average, the financial benefits of this measure do not outweigh its upfront costs over the expected lifetime, raising concerns about its overall cost-effectiveness.

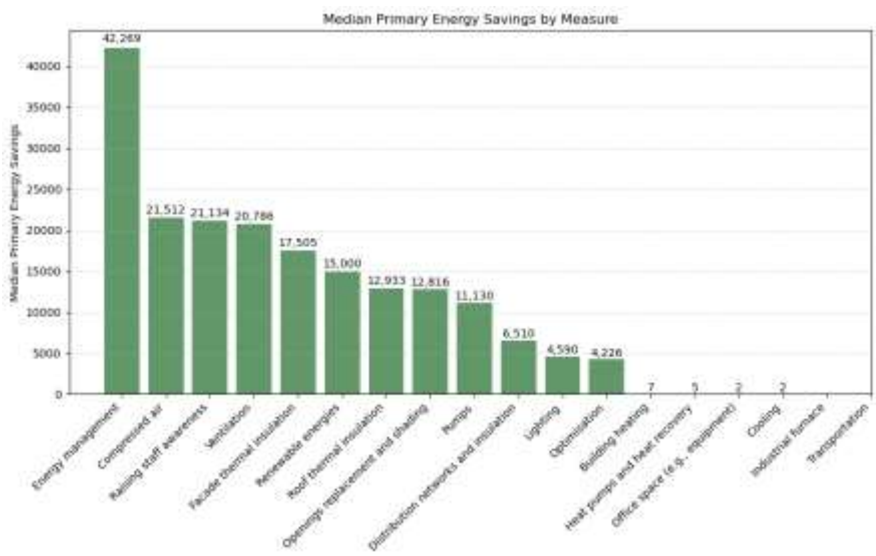


Measures	Median Payback Period [yr]
Building heating	15,700
Office space	4,015
Cooling	2,800
Heat pumps and heat recovery	750
Openings replacement and shading	31
Façade thermal insulation	23
Lighting	18
Renewable energies	15
Roof thermal insulation	10
Ventilation	10
Optimisation	6
Energy management	6
Pumps	6
Distribution networks and insulation	2
Compressed air	2
Industrial furnace	0
Raising staff awareness	0
Transportation	0

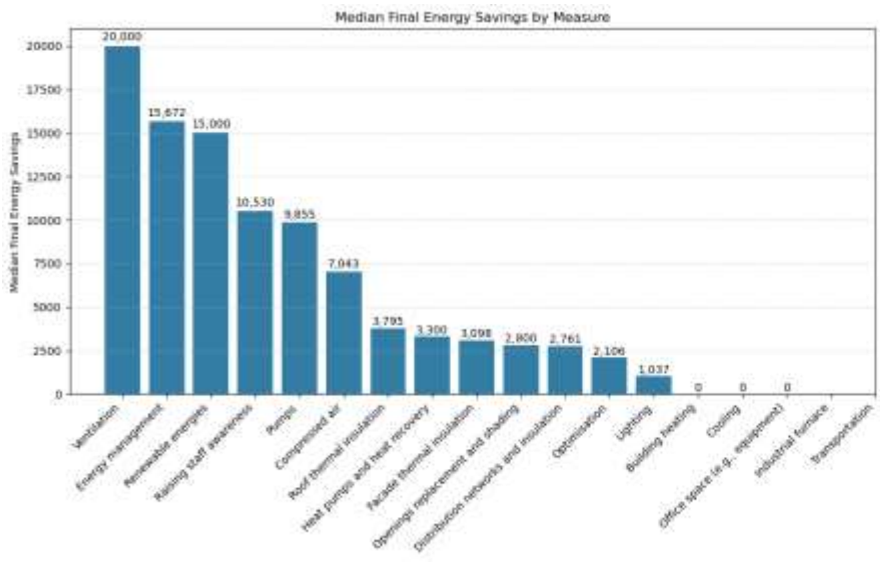
Source: EE4SMEs WP3 Energy Audit Data

The payback period graph and table reveal how quickly different energy efficiency measures recover their initial costs through energy savings. Measures such as building heating, office equipment upgrades, cooling systems, and heat pumps with heat recovery have the longest median payback periods, suggesting lower short-term financial appeal. In contrast, interventions like distribution network improvements, compressed air system upgrades, and staff awareness initiatives show the shortest payback periods, making them especially attractive to organizations seeking quick returns on investment.

Building renovation measures - such as openings replacement, façade insulation, and ventilation improvements - fall into a mid-range category, offering a balanced payback period between the fastest and slowest options.



Measures	Primary Energy Savings (kwh/a)
Energy management	42,269
Compressed air	21,512
Raising staff awareness	21,134
Ventilation	20,786
Façade thermal insulation	17,505
Renewable energies	15,000
Roof thermal insulation	12,933
Openings replacement and shading	12,816
Pumps	11,130
Distribution networks and insulation	6,510
Lighting	4,590
Optimisation	4,226
Building heating	7
Heat pumps and heat recovery	5
Office space	2
Cooling	2
Industrial furnace	0
Transportation	0



Measures	Final Energy Savings (kwh/a)
Ventilation	20,000
Energy management	15,672
Renewable energies	15,000
Raising staff awareness	10,530
Pumps	9,855
Compressed air	7,043
Roof thermal insulation	3,795
Heat pumps and heat recovery	3,300
Façade thermal insulation	3,098
Openings replacement and shading	2,800
Distribution networks and insulation	2,761
Optimisation	2,106
Lighting	1,037
Building heating	0
Cooling	0
Office space	0
Industrial furnace	0
Transportation	0

Source: EE4SMEs WP3 and WP8

In terms of primary energy savings – which account for total energy reductions including generation and transmissions losses – energy management, compressed air systems, raising staff awareness, and ventilation emerge as top performers, delivering median savings of up to 42,269 kWh/year. Other effective measures include façade insulation, renewable energies, roof thermal insulation, replacement of openings, and pumps, each achieving median savings above 10,000 kWh/year.

Primary Energy Savings: The total energy saved across the entire energy supply chain.

Final Energy Savings: Energy saved at the point of use – what companies consume.

Conversely, measures such as heat pumps and heat recovery, office space equipment, and cooling systems contribute negligible primary energy savings, indicating a limited impact on system-level energy reductions.

For final energy savings - representing energy consumed directly at the point of use - the ranking shifts slightly. Ventilation remains the leading measure with median savings of 20,000 kWh/year, while renewable energies, raising staff awareness, and energy management also stand out, delivering savings between 10,000 and 16,000 kWh/year. These findings highlight the practical efficiency of these measures in directly reducing operational energy use and associated costs.

Several measures - including building heating, cooling, and office space equipment - show minimal final energy savings. In general, final energy savings are lower than primary energy savings across most measures, indicating that a substantial portion of efficiency gains occurs upstream within the broader energy supply chain. Notably, while heat pumps and heat recovery show limited impact on primary energy savings, they deliver meaningful final energy savings of approximately 3,300 kWh/year. This suggests their efficiency benefits are more concentrated at the point of use. Alternatively, it may reflect greater variability or inconsistency in the available data for primary energy savings.

<u>Clustering</u>

To facilitate a more targeted and meaningful analysis while retaining key distinctions, energy efficiency measures were grouped for each economic indicator using thresholds derived from the underlying data distributions.

Metrics	Low	Medium	High
Capital Cost (EUR)	<10,000	10,000 – 50,000	>50,000
NPV (EUR)	<5,000	5,000 – 20,000	>20,000
Payback period (a)	<5	5-31	>31
Primary Savings (kwh/a)	<5,000	5,000 – 20,000	>20,000
Final Savings (kwh/a)	<3,000	3,000 – 8,000	>8,000

Source: EE4SMEs WP3 ad WP8

Environmental Impact

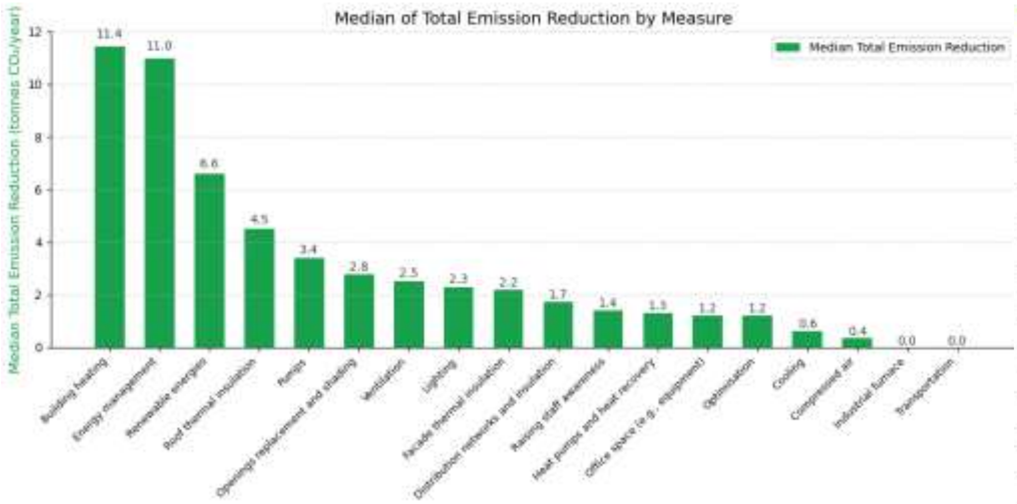
Measures	Skewness
Building heating	0.06
Compressed air	2.00
Cooling	2.14
Distribution networks and insulation	2.83
Energy management	5.57
Façade thermal insulation	2.19
Heat pumps and heat recovery	-3.32
Lighting	2.49
Office space	1.60
Openings replacement and shading	3.80
Optimisation	5.44
Pumps	3.44
Raising staff awareness	-0.80
Renewable energies	6.78
Roof thermal insulation	2.00
Ventilation	5.10
Industrial Furnace	N/A
Transportation	N/A

In addition to assessing the economic viability of energy efficiency measures, this study also evaluates their environmental impact using WP3 data on annual emissions reductions, measured in tonnes of CO_2 per year. It is important to note that, due to the absence of energy savings data for the "industrial furnace" and "transportation" categories in both WP3 and WP8, these measures were assigned a value of zero to reflect the lack of available information.

To ensure accurate interpretation, the distribution of emissions reduction data was analysed for each measure. The results revealed that most measures exhibit significant positive skewness - often exceeding a value of 1-indicating that a small number of exceptionally high-performing cases are pulling the average upward. In particular, renewable energy measures and energy management demonstrated notably high skewness values of 6.78 and 5.57, respectively.

Given this skewed distribution, the median was adopted as a more robust indicator of typical environmental performance, providing a realistic reflection of emissions reductions that most organisations can expect to achieve.

The median emissions reduction chart offers valuable insights into the environmental impact of the evaluated measures. Building heating, energy management, and renewable energy installations show the highest median reductions in emissions, underscoring their significant contribution to climate mitigation. In contrast, measures such as cooling, compressed air systems, office space equipment, and optimisation each achieve relatively modest reductions - no more than 1.2 tonnes of CO_2 per year - when considered individually.



Measures	Median emission reduction (tCO2/a)
Building heating	11.4
Energy management	11.0
Renewable energies	6.6
Roof thermal insulation	4.5
Pumps	3.4
Openings replacement and shading	2.8
Ventilation	2.5
Lighting	2.3
Façade thermal insulation	2.2
Distribution networks and insulation	1.7
Raising staff awareness	1.4
Heat pumps and heat recovery	1.3
Office space	1.2
Optimisation	1.2
Cooling	0.6
Compressed air	0.4
Industrial furnace	0
Transportation	0

Source: EE4SMEs WP3 Energy Audit Data

Clustering

A three-tier threshold system was developed to categorise environmental performance, mirroring the clustering methodology used for economic indicators.

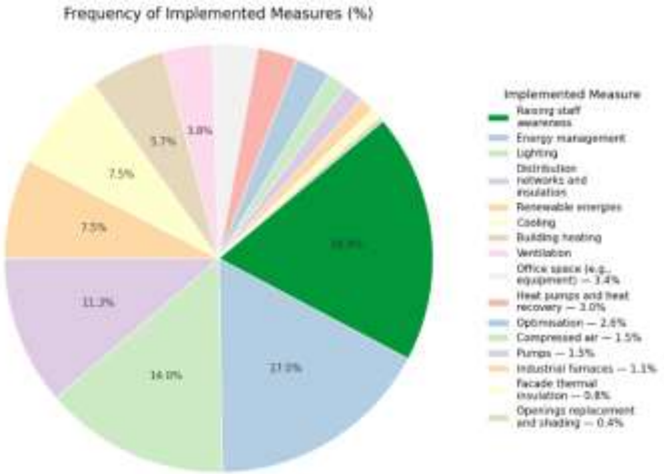
Metrics	Low	Medium	High
Emission Reduction (tCO_2/a)	<2.5	2.5-5	>5

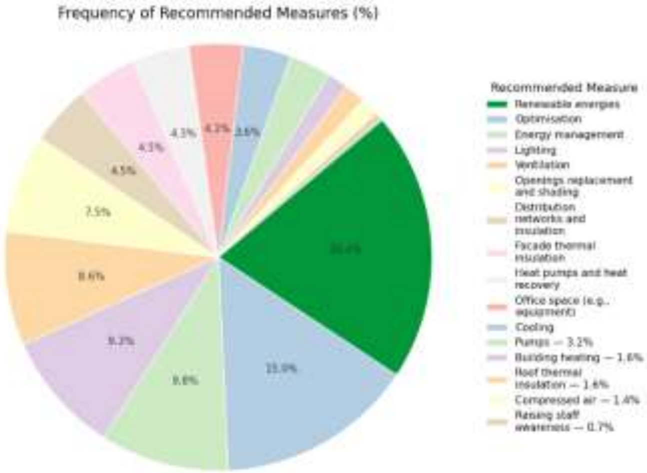
Source: EE4SMEs WP3 Energy Audit Data

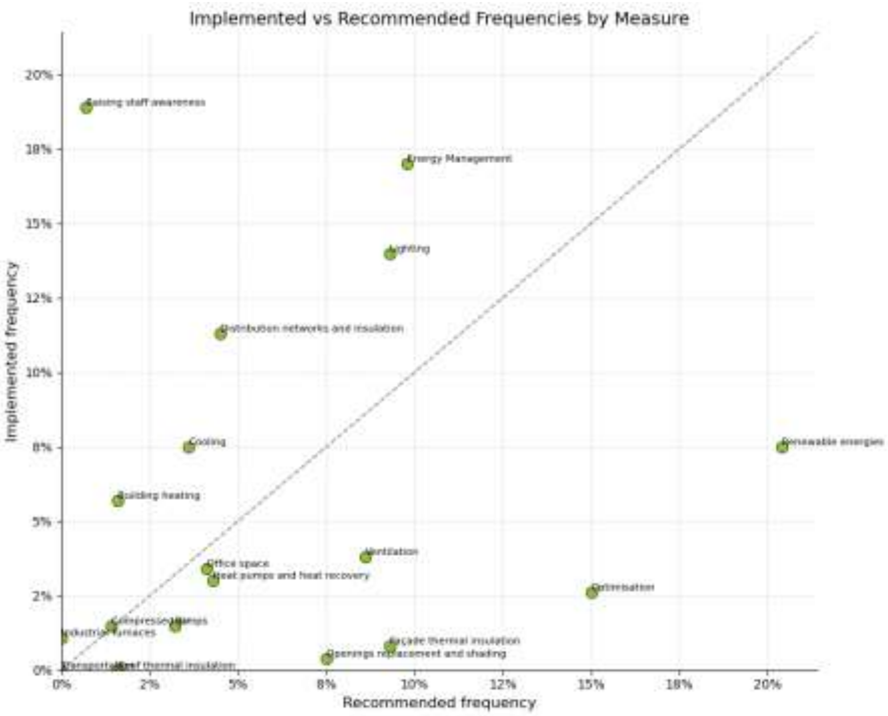
Implemented vs. Recommended Energy Efficiency Measures

After standardising the measures from WP3 and WP8 and defining their key attributes, the analysis identified the most and least frequently reported measures to reveal adoption trends and practical insights.

Adoption Patterns



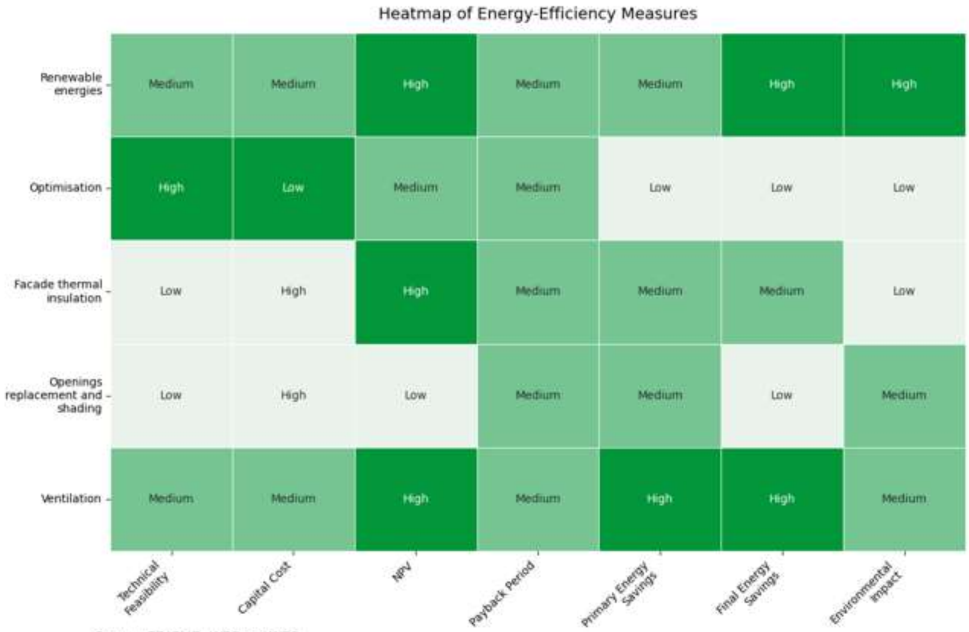




Source: EE4SMEs WP8 and WP3

The scatter plot shows a clear imbalance between what's implemented and what's recommended. Raising staff awareness (18.9% vs 0.7%), Energy management (17.0% vs 9.8%), Lighting (14.0% vs 9.3%), Distribution networks & insulation (11.3% vs 4.5%), Cooling (7.5% vs 3.6%), and Building heating (5.7% vs 1.6%) all sit well above the diagonal, indicating they are implemented far more often than they're recommended.

In contrast, several measures lie below the diagonal, meaning they are under-implemented relative to recommendations: Renewable energies (7.5% vs 20.4%), Optimisation (2.6% vs 15.0%), Façade thermal insulation (0.8% vs 9.3%), Openings replacement & shading (0.4% vs 7.5%), and Ventilation (3.8% vs 8.6%) show the largest gaps. Office space (3.4% vs 4.1%), Compressed air (1.5% vs 1.4%), Pumps (1.5% vs 3.2%), and Heat pumps & heat recovery (3.0% vs 4.3%) are closer to alignment. Industrial furnaces (1.1% vs 0%) and Transportation (0% vs 0%) are edge cases.



Source: EE4SMEs WP8 and WP3

Among the under-implemented measures, renewable energies and ventilation stand out as near-term priorities: both having high NPV and high final energy savings (ventilation also shows high primary savings), while their medium technical feasibility and medium capital cost suggest the implementation gap is more about delivery frictions than economics.

Optimisation is the opposite profile: high feasibility and low capex but low energy and environmental impact, making it a sensible baseline or enabling action rather than a major emissions lever.

Building-envelop measures explain much of the shortfall below the diagonal. Façade thermal insulation combines high NPV with high Capex and low feasibility, indicating strong value that is best captured when aligned with refurbishment cycles or bundled financing. Openings replacement and shading carries high Capex but only low NPV and low final savings, so it warrants selective deployment – typically when comfort, daylighting, or compliance benefits are also required.

Overall, the insights points to a need to scale renewables and ventilation now, run continuous low-cost optimisation, and schedule façade upgrades with lifecycle projects to unlock value despite delivery hurdles.

Objective 2:

Contextual Analysis

Source: Templafy library from Deloitte internal

Contextual Analysis

Exploring the broader socio-economic benefits of energy savings, studying energy production trends, estimating environmental externalities, and assessing current and future energy costs.

Socio-Economic Benefits of Energy Savings Measures

Investments in energy efficiency deliver not only direct energy cost reductions but also a wide array of broader socio-economic benefits. This is particularly evident within the Accommodation and Food Service Activities sector, as well as in Agri-food and Metalwork Manufacturing, where the deployment of efficient technologies and operational practices can enhance business performance while generating positive externalities for employees and surrounding communities. Key benefits include improvements in health and comfort, productivity, operational resilience, and even job creation and regional economic development.

Sector Specific Impacts

Accommodation and Food Service Sector

SMEs in the hospitality industry benefit significantly from energy efficiency measures, particularly through improved indoor environments and greater cost stability. For instance, upgrading heating, ventilation, and air-conditioning (HVAC) systems or enhancing insulation in hotels improves indoor air quality and thermal comfort, leading to better health outcomes for staff and guests, such as fewer respiratory issues and discomfort-related sick days. In restaurants, efficient kitchen appliances and upgraded ventilation systems reduce waste heat and fumes, creating safer, cleaner, and more comfortable workspaces for employees. These enhancements in workplace conditions can boost staff morale, productivity, and service quality.

Reducing energy costs is also critical in this low-margin sector. Lower utility bills make businesses less vulnerable to energy price fluctuations, enabling them to maintain stable operations even during cost spikes. The savings can be reinvested in areas such as facility upgrades, marketing, or staff development, which supports job retention and creation. For example, a restaurant that cuts energy costs might expand its workforce or improve employee wages.

At a regional scale, clusters of energy-efficient hotels and restaurants enhance local development by strengthening the area's reputation as a sustainable or "green tourism" destination. They also stimulate local supply chains, including contractors and service providers involved in energy retrofits and maintenance.

Agri-Food Manufacturing Sector

In agri-food processing and manufacturing – encompassing dairies, bakeries, and beverage producers – energy efficiency upgrades deliver diverse operational and economic benefits. Modernised refrigeration systems, boilers, and process controls help maintain optimal temperatures, which improves product quality and reduces spoilage or waste. Enhanced insulation and heat recovery systems contribute further to maintaining consistent production environments, which is critical for food safety and quality assurance.

Upgrading to efficient motors and drives in food processing lines can lower downtime and maintenance requirements, increasing overall throughput. These measures not only reduce energy use but also strengthen operational resilience, making facilities less vulnerable to energy supply interruptions. This resilience is especially vital in food processing, where even brief power outages can ruin entire production batches. By lowering production costs per unit, firms improve their competitiveness, opening pathways for business growth, such as expanding production capacity or diversifying into new product lines. This growth, in turn, creates jobs both within the business and across its supply chains, benefiting farmers and logistics providers. In many rural regions, agri-food SMEs are major employers, so improving their competitiveness and sustainability supports regional development, farm incomes, and rural employment.

Moreover, energy-efficient upgrades can reduce local pollution. For example, replacing an old diesel generator with an electric chiller system cuts noise and exhaust emissions, improving environmental and community health.

Metalwork and Manufacturing Sector

Metalworking and general manufacturing SMEs – including metal fabrication, casting, and machining workshops – are highly energy-intensive, meaning efficiency improvements can yield particularly large benefits. Installing high-efficiency electric arc furnaces, variable-speed drives on machinery, or waste-heat recovery systems significantly reduces fuel and power consumption. These measures lower production costs while also enhancing productivity and output quality.

Modern energy-efficient equipment provides greater precision and reliability, which can translate into faster production times and higher-quality finished products. Additionally, such equipment emits less waste heat and fewer pollutants within workshops, improving indoor air quality and reducing ambient temperatures. Enhanced working conditions contribute to lower injury and illness rates and better staff morale and efficiency. For instance, installing effective dust-collection and ventilation systems minimises airborne particles, safeguarding workers' respiratory health.

Energy efficiency also builds operational resilience for manufacturing SMEs. By reducing overall energy demand, businesses become less exposed to volatile electricity and gas prices, maintaining stable production costs despite market fluctuations. Some SMEs further strengthen their resilience by adopting on-site renewable energy systems, such as solar panels, which provide partial self-supply and additional cost savings. These financial benefits can be reinvested into expanding operations, hiring new staff, or upskilling employees to operate advanced machinery.

Collectively, such improvements foster job creation and skills development in the manufacturing sector while generating demand for local services, including energy auditors, equipment installers, and maintenance contractors, thereby stimulating regional economies. Indeed, studies indicate that regions with more carbon-efficient industries often experience lower pollution-related economic burdens and more robust economic growth (3).

Wider Economic and Social Impacts

When multiple SMEs improve their energy efficiency, the cumulative benefits can be substantial at both regional and national levels. Reduced energy consumption leads to lower greenhouse gas and pollutant emissions, which improves public health by decreasing pollution-related illnesses in communities and reducing pressure on healthcare systems. For example, if hospitality businesses and manufacturing facilities across a region upgrade to cleaner and more efficient equipment, air quality can improve over time. This, in turn, results in socio-economic gains such as fewer workdays lost to illness and higher productivity across the broader economy.

Moreover, implementing energy efficiency measures is labour-intensive and typically relies on local workers. Activities such as energy audits, building retrofits, and equipment installation create jobs in the energy services and construction sectors. Analysts note that investments in energy efficiency generate more jobs per euro spent than investments in energy supply, because much of the expenditure goes towards local skilled labour, including engineers, installers, and contractors (3).

In the long term, a more energy-efficient SME sector strengthens national competitiveness. Lower energy costs and improved productivity enable businesses to innovate and expand. Regions with thriving, efficient companies are more likely to attract additional investment, creating a positive feedback loop that drives regional development. For instance, in many Eastern European countries, heavy industries and utilities have historically imposed significant pollution costs on society. As these countries improve energy efficiency and transition to cleaner energy sources, they not only reduce emissions but also free up economic resources previously spent on healthcare and environmental damage (3).

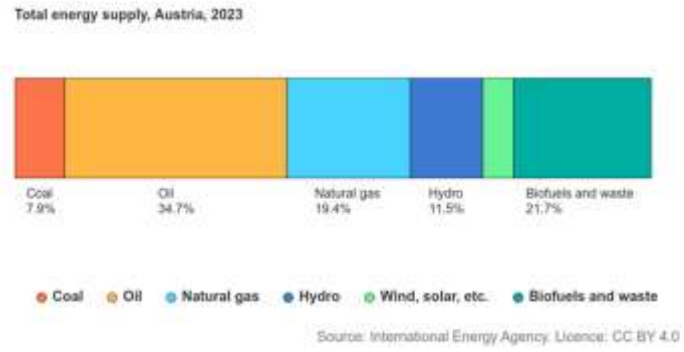
In summary, energy efficiency serves as a catalyst for healthier workplaces, stronger SME performance, and broader economic resilience. It aligns environmental sustainability with economic growth, making local industries more competitive and communities more liveable.

Energy Production Methods and Trends in Partner Countries

The partner countries – Austria, Bulgaria, Cyprus, Estonia, France, Germany, Italy, Malta, and Spain – have diverse energy supply profiles shaped by their natural resource endowments and national policies. In recent years, most have experienced gradual shifts from fossil fuels towards renewable energy, although oil and gas still often dominate their total energy supply (TES).

Below is an overview of each country's primary energy sources, recent trends in fossil fuel, renewable, and nuclear contributions, as well as key policy or external factors – such as import dependence and geopolitical events – that influence their energy supply landscapes.

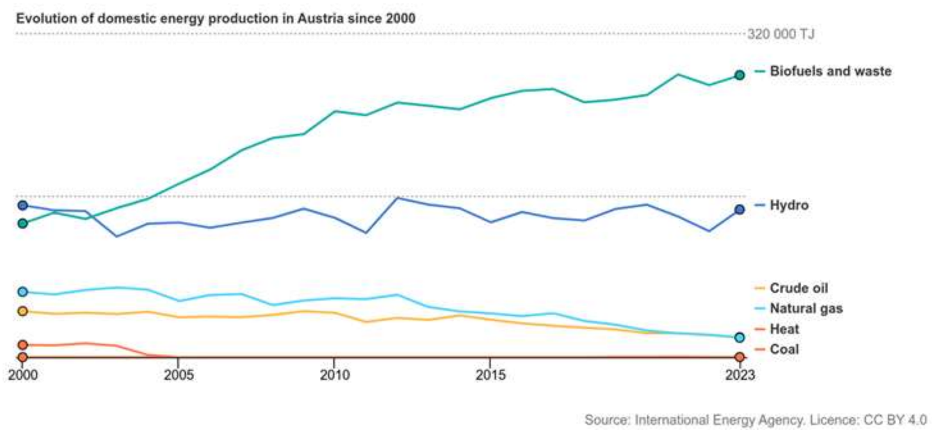
Austria



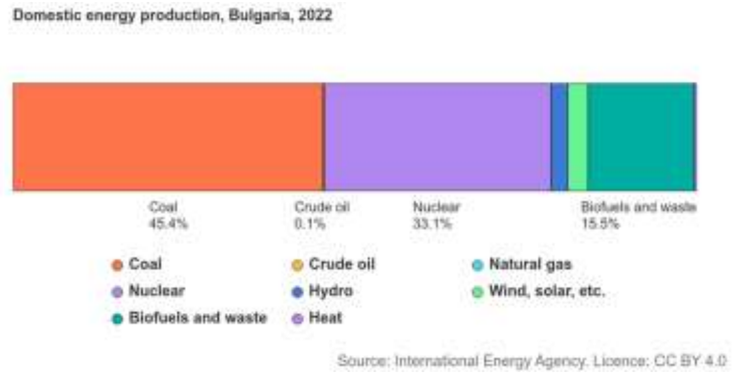
Austria's total energy supply (TES) remains dominated by fossil fuels, with oil accounting for approximately 35% in 2023, primarily used for transport and heating (47). Biofuels and waste represent the second-largest share at around 22%, reflecting a growing shift towards renewables. Hydropower also plays a significant role in electricity generation (47).

Austria does not use nuclear energy domestically and relies on imported natural gas and coal, though these make up smaller portions of its TES. Recent trends show a gradual increase in bioenergy and renewable energy shares, alongside a decline in coal consumption (48).

From a policy perspective, Austria is among the EU's frontrunners in climate ambition. The government has set a target for climate neutrality by 2040, a decade earlier than the EU's 2050 goal. This target has driven substantial investments in renewable energy capacity and energy efficiency initiatives. Energy security has also become a key focus, especially due to Austria's high dependence on imported gas from a single source. Recent geopolitical tensions in Europe have accelerated efforts to diversify gas supplies and expand domestic renewable energy projects.



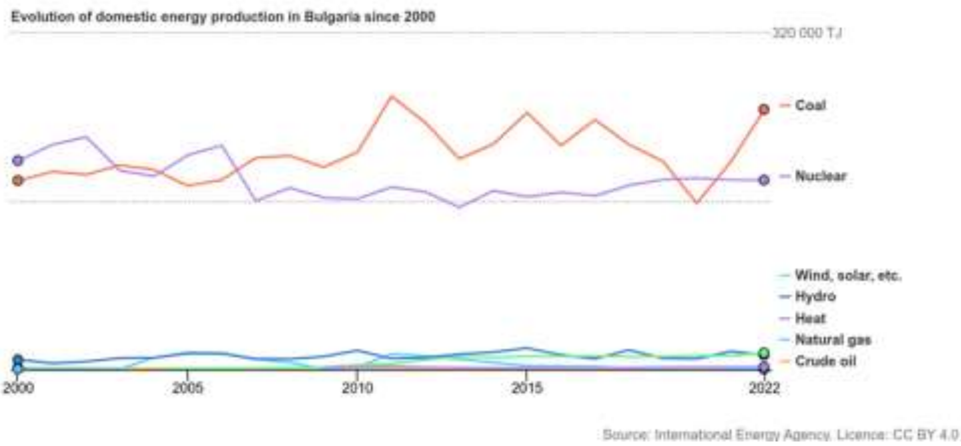
Bulgaria



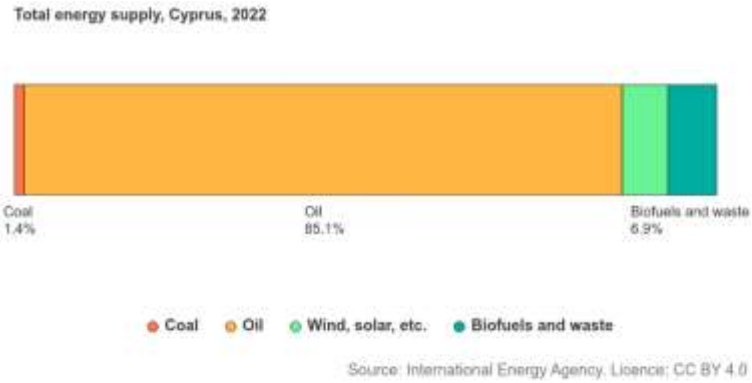
Bulgaria's energy supply relies on a mix of domestic coal and imported fuels. Lignite coal is the country's primary domestic energy source, powering much of its electricity generation. In contrast, oil and natural gas are almost entirely imported. Nuclear energy, generated at the Kozloduy Nuclear Power Plant, is the second major contributor, accounting for about one-third of electricity production in 2022. This share is projected to exceed 40% by 2030 as Bulgaria maximises output from its existing reactors (50). While renewables currently play a smaller role in the energy mix, the country has plans to expand them significantly.

In recent years, Bulgaria's total energy supply (TES) has remained heavily dependent on coal and imported fossil fuels. However, some trends indicate a gradual shift. Older coal plants are scheduled for retirement to reduce emissions and align with EU climate targets, while investments in renewable energy are increasing. The national Electricity System Operator is investing in 4,500 MW of new renewable capacity and upgrading the grid, supported by over €25 million in funding, to improve integration of green energy. Energy security has also been strengthened by the completion of a new 2 GW interconnector with Greece in 2023, enabling cross-border electricity trade (49).

Under its Recovery and Resilience Plan, Bulgaria has set ambitious targets: installing 1.4 GW of renewables with storage, tripling renewable electricity generation by 2026, cutting power sector emissions by 40% by 2025, and gradually phasing out coal. However, domestic politics have introduced uncertainty. In 2023, the Bulgarian Parliament reversed interim coal reduction commitments and voted to keep coal plants operational until 2038, aiming to protect jobs and grid stability despite risking EU funding. Additionally, concerns over energy security, particularly dependence on imported Russian gas, have driven efforts to diversify supply sources, including through LNG terminals in neighbouring countries and stronger regional grid connections (49).

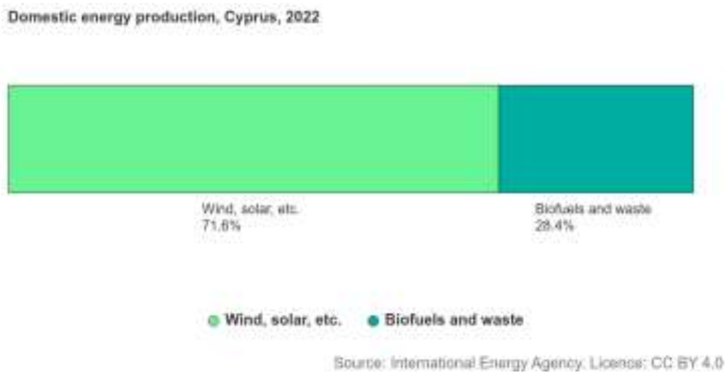


Cyprus



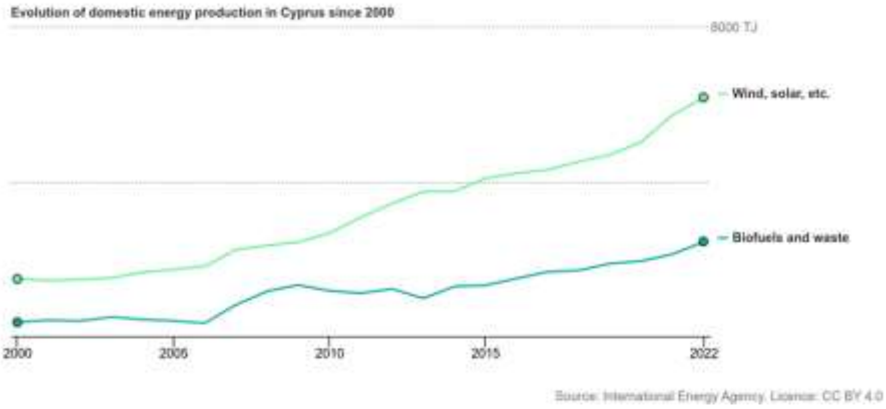
Cyprus is unique within the EU as it has no domestic fossil fuel resources, making it highly dependent on imported oil to meet its energy needs (51). Oil-derived fuels continue to dominate the country's total energy supply (TES), particularly for transport and electricity generation in oil-fired power plants, despite recent growth in renewables.

Notably, most of Cyprus's domestic energy production now comes from renewable sources. In 2022, wind and solar accounted for roughly 72% of the island's home-grown energy production. However, since overall energy supply is still largely reliant on imported fuels, renewables represent only a portion of the total supply (51).



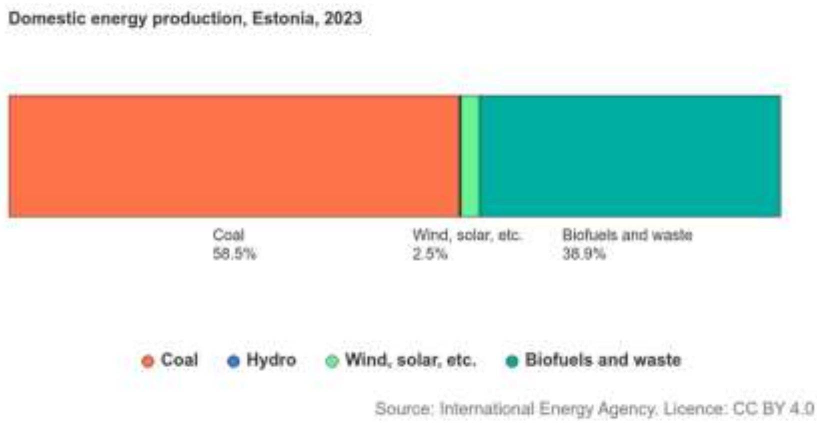
In effect, although Cyprus generates a considerable amount of renewable electricity relative to its size, oil remains the main energy source for the economy as a whole, especially for transport and remaining oil-based power generation. This trend is beginning to shift. Solar photovoltaic capacity has expanded rapidly due to Cyprus's abundant sunshine, and new wind farms have come online, steadily increasing the renewable share in electricity generation. Additionally, Cyprus plans to utilise its offshore natural gas discoveries and is developing an LNG import terminal to transition its power plants from oil to cleaner natural gas (51).

Key policy goals include increasing the share of renewables in the energy mix to align with EU targets and reducing electricity costs, which remain high due to reliance on imported fuels. Cyprus's energy strategy is also closely linked to regional cooperation. For example, the planned EuroAsia Interconnector, which will connect the electricity grids of Israel, Cyprus, and Greece, aims to enhance energy security by integrating Cyprus into the European electricity network (51). Geopolitical developments in the Eastern Mediterranean – such as new gas discoveries and regional tensions – continue to shape Cyprus's options for diversifying its energy supply.

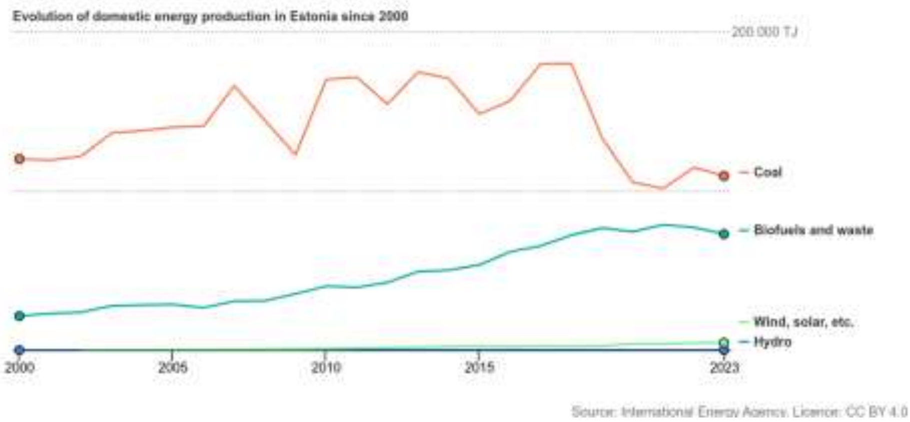


Estonia

Estonia has a distinctive energy profile dominated by oil shale, a domestically mined fossil fuel that has served as the backbone of its energy supply for decades (52). Oil shale, a type of sedimentary rock burned similarly to coal, has historically provided a large share of Estonia's electricity and energy, making the country one of the most carbon-intensive in Europe.



In recent years, however, Estonia has made significant progress in reducing its oil shale use to lower emissions (52). Electricity generation from oil shale has been scaled back, resulting in a notable decline in Estonia's greenhouse gas emissions. Despite this progress, oil shale and its by-products remain the main energy source in the country's total energy supply (TES). As of 2023, oil shale and its derivatives still accounted for well over half of Estonia's domestic energy production (52).

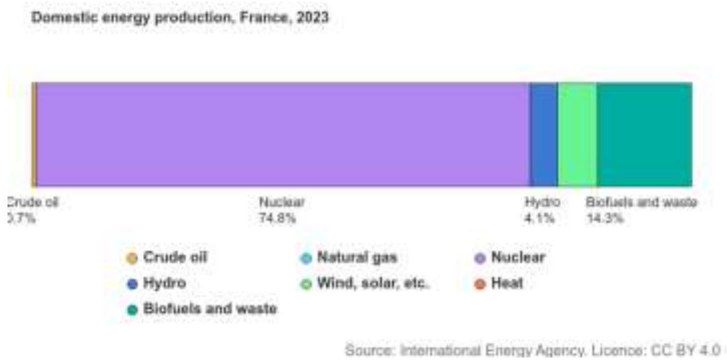


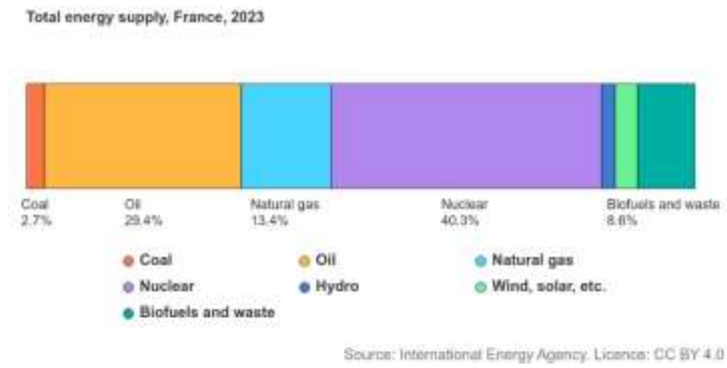
Imported fossil fuels also play a role, particularly oil products for transport and some natural gas for heating. However, Estonia has significantly reduced its reliance on Russian natural gas since 2022, shifting instead to LNG imports and regional grid solutions. The overall trend in Estonia is a rapid transition toward cleaner energy. The government has set an ambitious goal to cover 100% of annual electricity demand with renewables by 2030, as part of its broader plan to achieve climate neutrality by 2050 (53).

There is a strong policy drive to expand wind energy – both onshore and planned offshore – alongside solar investments, supported by EU funding and national strategies. Estonia already ranks among Europe's highest per-capita adopters of heat pumps for home heating, which reduces reliance on oil and gas heating systems. Energy security concerns, particularly following geopolitical events in 2022, have reinforced Estonia's commitment to diversify away from both oil shale and imported gas (53). To support this transition, the country is investing in grid upgrades and enhancing cross-border connections with neighbours such as Finland and Latvia to accommodate greater shares of renewable electricity and to end dependence on the Russian grid.

In summary, Estonia is shifting from a highly fossil fuel-dependent system toward one dominated by renewables. However, managing this transition – including addressing the economic impacts on the oil shale sector and ensuring a reliable energy supply – remains a critical challenge.

France





France's energy supply is characterised by its heavy reliance on nuclear power for electricity alongside continued dependence on oil in other sectors. Nuclear energy is by far the largest domestic energy source; as of 2023, nuclear reactors provided roughly 60–70% of the nation's electricity, positioning France as a low-carbon electricity leader (54).

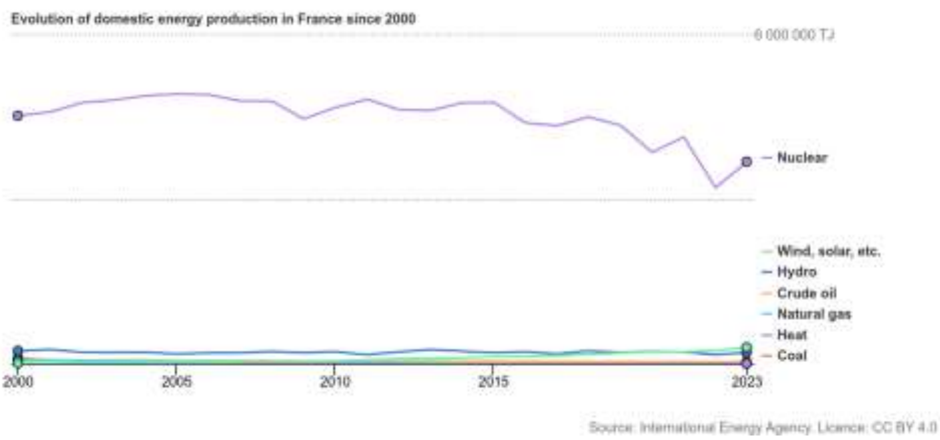
However, when looking at total energy supply (TES) – which includes transport and heating fuels in addition to electricity generation – oil remains a major contributor, accounting for about 29% of France's TES (54). This highlights a key challenge: while France has largely decarbonised its power sector through nuclear energy, oil remains prevalent in transport, industry, and heating, making decarbonisation beyond electricity its main task (55).

In terms of recent trends, France has maintained a high output from its nuclear fleet and plans to extend the lifetimes of existing reactors while building next-generation units to ensure long-term energy security. Meanwhile, renewable energy capacity has been expanding, particularly in wind and solar, which are contributing an increasing share of electricity generation with the aim of supplementing nuclear and gradually replacing fossil fuels in other sectors (55).

Oil consumption has been slowly declining as energy efficiency improves and electric vehicles gain market share. Nevertheless, oil continues to power most cars, trucks, airplanes, and is still used in some industrial processes and for heating (55).

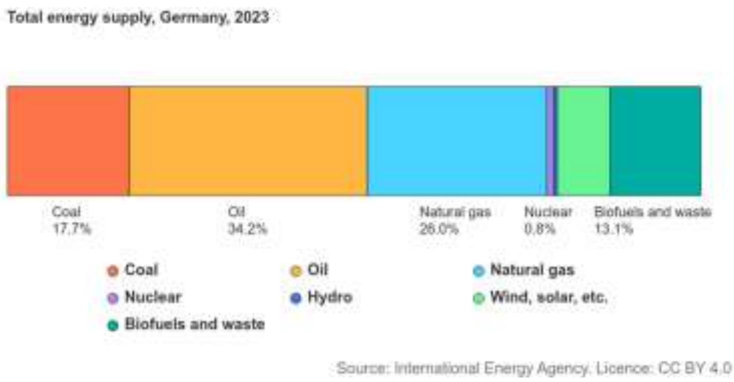
To accelerate the transition away from oil, the government has implemented policies such as incentives for electric vehicle adoption, biofuel blending mandates, and bans on new oil boilers for heating. France is also investing in green hydrogen and other decarbonisation technologies to reduce fossil fuel use in industry. While France's energy security in electricity is robust due to its domestic nuclear capacity, it remains reliant on imports for oil and gas. This means that global oil price fluctuations and geopolitical events, such as OPEC decisions or conflicts, continue to affect French consumers. In response, France aligns with EU energy security strategies, maintaining strategic petroleum reserves and ensuring diversified supply sources.

Overall, France's policy framework, as outlined in its National Low-Carbon Strategy and energy roadmaps, focuses on maintaining its nuclear advantage while ramping up renewables and electrification to reduce oil and gas dependency (56).

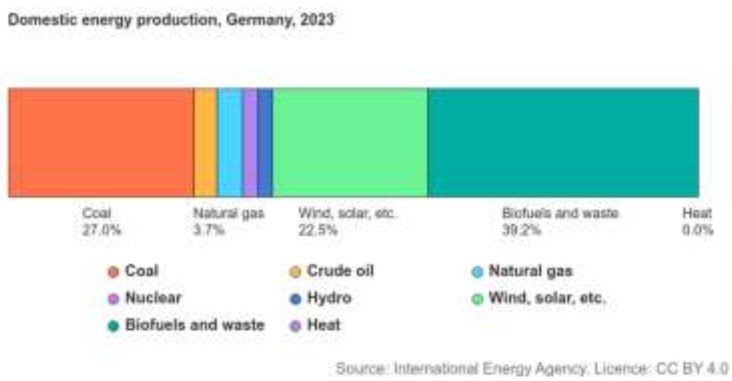


Germany

Germany is in the midst of its energy transition (Energiewende), which has significantly expanded renewable energy, particularly in electricity generation. However, its total energy supply (TES) remains dominated by fossil fuels (57). As of 2023, oil is Germany's largest single energy source, accounting for about 34% of TES, while natural gas contributes roughly 26% (57). Coal – a combination of domestically mined lignite and imported hard coal – also continues to play a substantial role, particularly in industry and the remaining coal-fired power generation.

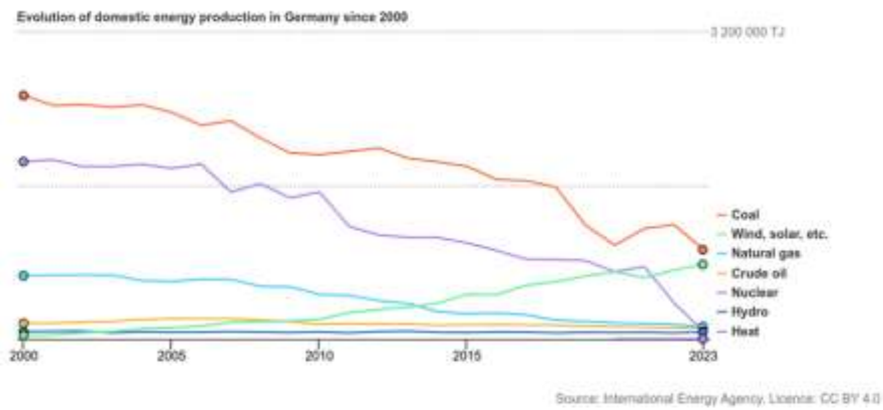


In contrast, Germany's electricity sector has transformed rapidly. Renewables, led by wind power, now generate a large share of electricity. In 2023, wind energy became Germany's top electricity source, producing around 27%, a share comparable to that of coal in power generation (57). A major milestone in Germany's energy policy was the completion of its nuclear phase-out in April 2023, when the country shut down its last nuclear plants (58). This decision reflects a societal consensus reached after the Fukushima disaster.



To compensate for the loss of nuclear capacity and to further decarbonise, Germany has set ambitious targets: achieving 80% renewable electricity by 2030 and 100% by 2035, with an overall economy-wide net-zero emissions goal by 2045. Meeting these targets requires massive expansion of renewable capacity, including over 100 GW of onshore wind, 30 GW of offshore wind, and 200 GW of solar PV by 2030 (57), alongside major investments in energy storage and grid infrastructure.

Despite the growth of renewable electricity, Germany's TES continues to rely heavily on oil and gas, particularly in transport, heating, and industrial processes that are more challenging to electrify. The 2022 energy crisis, triggered by Russia's gas supply cuts, highlighted Germany's vulnerability due to its dependence on imported fossil fuels. In response, Germany secured alternative gas supplies via LNG imports and new supplier agreements, and temporarily increased coal-fired power generation to compensate for gas shortages (57). This crisis accelerated policy measures for energy diversification and efficiency.

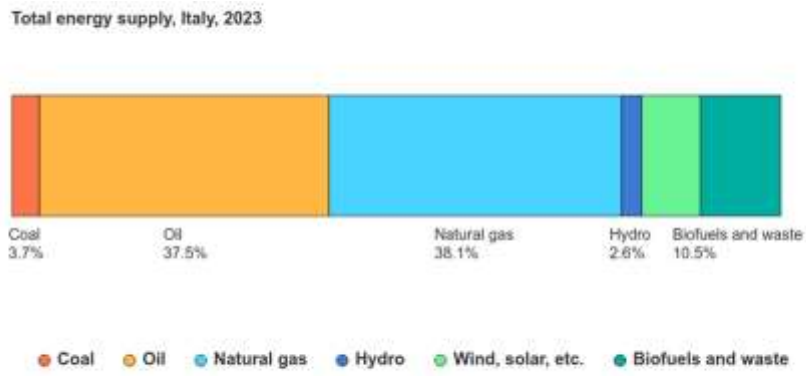


Looking ahead, Germany is investing heavily in electric mobility, heat pumps for heating, and green hydrogen for industrial decarbonisation to reduce oil and gas use. Energy security considerations are also shaping infrastructure development, with new LNG terminals built to ensure short-term gas supply, even as long-term policies aim to phase down natural gas use.

Italy

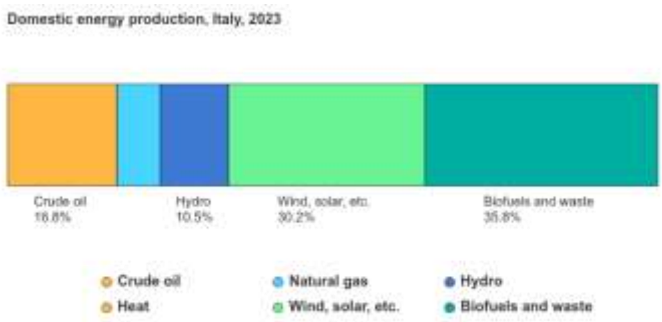
Italy is steadily advancing its energy transition, though natural gas continues to underpin much of its energy supply. In recent years, Italy has significantly expanded renewable energy capacity, particularly in solar photovoltaics and onshore wind, and is on track to meet its 2030 targets of approximately 30% renewables in total final energy consumption and 55% in electricity generation (59).

This progress is evident in Italy's electricity mix, where solar and wind production have grown, and grid integration has improved. However, natural gas remains the cornerstone of Italy's energy system. It fuels a large share of electricity generation – with gas-fired power plants providing baseline and balancing power – and is widely used for residential heating and industrial processes (59).



Source: International Energy Agency. Licence: CC BY 4.0

Oil is the next major component of Italy's TES, mainly consumed in transport and certain industries. Its share has been gradually declining as vehicles become more efficient and as biofuels and electrification gain traction (59). Italy has low domestic oil or gas production, leading to a historic dependence on imports, particularly pipeline gas from Russia and North Africa.



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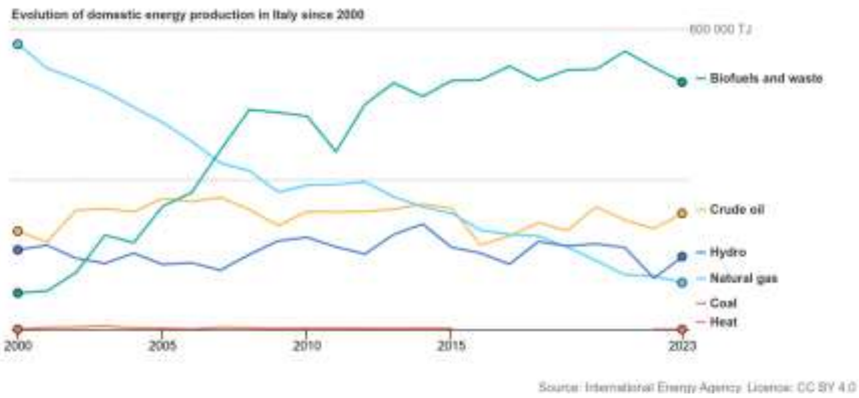
Following recent supply disruptions and price spikes, Italy has taken active steps to diversify its gas supply. Leveraging its geographic position, it increased imports from Algeria and other Mediterranean suppliers, expanded LNG import capacity, and fast-tracked agreements with new suppliers, such as Azerbaijan and Egypt (60). These actions aimed to strengthen energy security after the 2022 Russia–Ukraine conflict exposed Europe's vulnerabilities in gas supply.

Looking ahead, Italy's long-term strategy, aligned with the EU's Green Deal and REPowerEU, focuses on reducing reliance on natural gas by the 2030s through two main approaches: accelerating renewable energy deployment and enhancing energy efficiency (60). The government is promoting solar installations on buildings and industrial sites, expanding wind farms (particularly in southern Italy and offshore in the Mediterranean), and supporting emerging renewables such as green hydrogen. Concurrently, energy-saving measures – including building retrofits and the electrification of heating with heat pumps – are being pushed to curb gas demand.

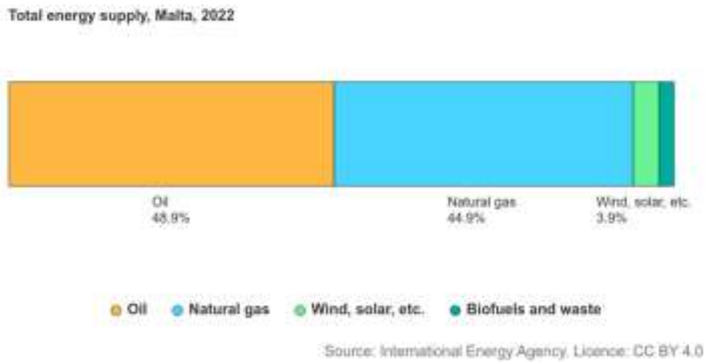
Italy aims for carbon neutrality by 2050. Beyond 2030, it is expected to see a further shift towards electric vehicles, a continued decline in oil use, and potential growth in geothermal energy utilisation, given its domestic geothermal resources (59).

Overall, Italy's TES is gradually shifting away from imported fossil fuels towards domestically harnessed renewable energy. However, managing this transition while ensuring energy reliability – given the entrenched role of natural gas – remains a central challenge for Italy's energy policy in the 2020s.



Malta

Malta is a small island nation with very limited domestic energy resources, resulting in a heavy reliance on imported fuels (61). Virtually all of Malta's energy is imported in the form of fossil fuels, predominantly natural gas in recent years.



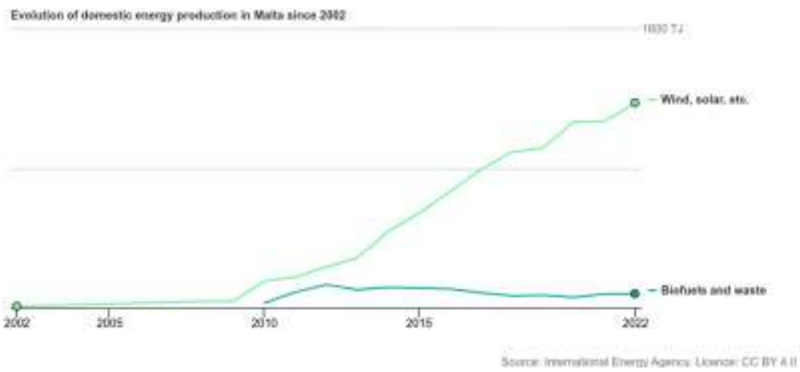
After 2017, Malta transitioned its electricity generation from oil-fired power plants to a new natural gas power plant (and an LNG import facility), which now provides the bulk of the country's power (61). This switch from heavy fuel oil to natural gas significantly reduced Malta's emissions and air pollution. Today, natural gas accounts for almost all electricity generation in Malta, while oil products are still used in transport and some industry. Renewable energy contributes only a small fraction of Malta's TES, due in part to geographic constraints, the islands have limited land area for wind or large solar farms.

The main renewable source is solar photovoltaic (PV) installations on rooftops and small spaces; by 2023, these achieved roughly 10–12% of Malta's electricity generation (61). In terms of overall energy (including transport), Malta's renewables share is modest, but the country is striving to increase it to meet EU obligations, targeting at least 11.5% of gross final energy consumption from renewables by 2030 (62).

Malta is continuing to add solar capacity where possible (taking advantage of its high solar irradiance) and exploring offshore solar or wind technologies on a small scale, though options are limited. Energy efficiency improvements are also a focus, to reduce the volume of imports needed. A critical enhancement for Malta's energy security was the introduction of the Malta–Italy electricity interconnector, a subsea high-voltage cable to Sicily (63).

This interconnector (operational since 2015) allows Malta to import electricity from the European grid, providing backup supply, improving grid stability, and enabling better integration of intermittent renewables. It effectively diversifies Malta's supply away from sole reliance on its domestic power plant.

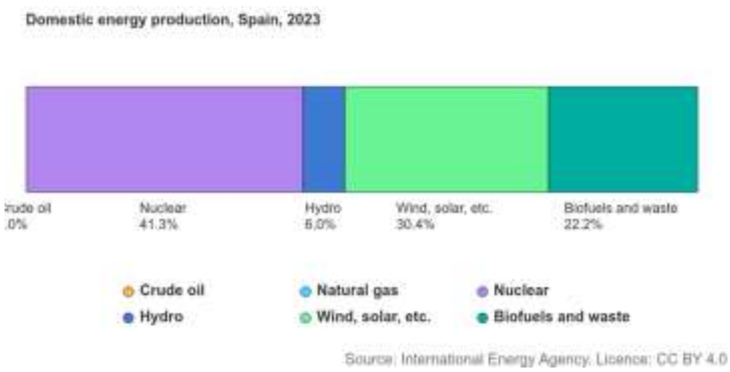
Additionally, Malta plans to invest in energy storage (like battery systems) to help manage solar PV output and further stabilise the grid. Given Malta's dependence on global fuel markets, it is very sensitive to price volatility in oil and gas; thus, recent global energy price spikes have had direct effects on Malta's energy costs (62). This has reinforced Malta's interest in renewables and interconnection as a buffer against volatile import prices.



Spain

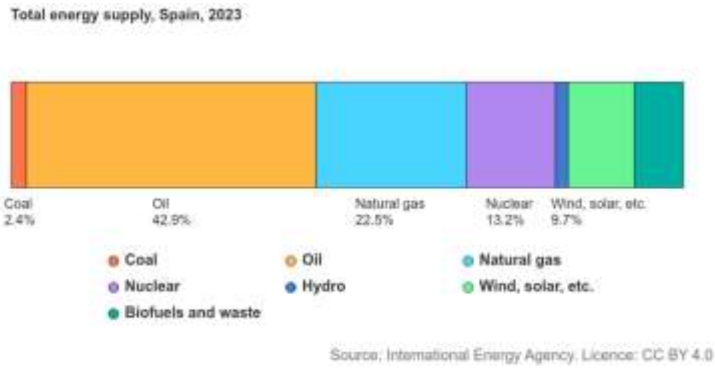
Spain is at the forefront of the energy transition in this group of countries, driven by ambitious policies and plentiful renewable resources. The Spanish government has set clear long-term targets for decarbonization: by 2050, Spain aims to achieve climate neutrality with 100% renewable electricity and roughly 97% of total energy coming from renewable sources (64).

To progress toward these goals, Spain in the 2020s is rapidly expanding its capacity of solar and wind power. Large-scale solar photovoltaic farms have been booming (taking advantage of Spain's high solar irradiance, especially in the south and center), and wind farms – both onshore (notably in regions like Aragón and Castile) and offshore (planned) – are key pillars of growth (64).



Spain's National Energy and Climate Plan (PNIEC 2021–2030) outlines substantial additions in renewables, along with measures to improve energy efficiency and electrify end-uses like transport (65). As a result, the trend in Spain's energy supply is a fast-rising share of renewables.

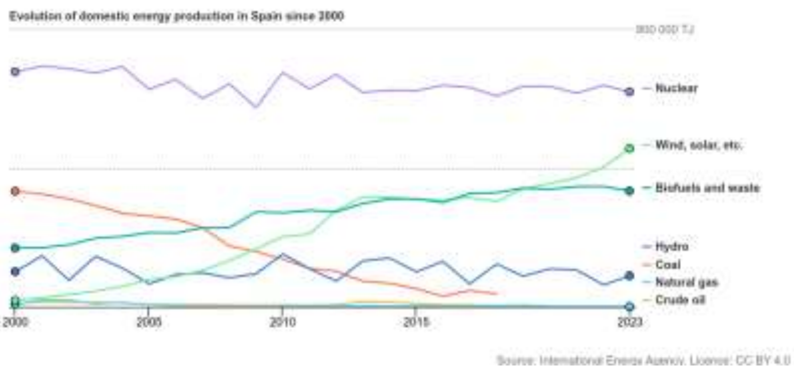
Already, renewables (including wind, solar, hydro, and biomass) account for a significant portion of electricity generation (in recent years often around 40–50%), and this will only increase with new projects. Spain is also investing in emerging technologies such as renewable hydrogen (power-to-hydrogen from surplus solar/wind) which can be used for energy storage and in industries like steel or chemicals.



Despite these advances, Spain's total energy supply still includes a considerable share of fossil fuels, particularly oil (64). Oil remains substantial mainly because of the transport sector – Spain has a large fleet of vehicles running on gasoline and diesel, and while EV adoption is growing, it will take time to replace the existing fleet. Additionally, certain industrial processes and heavy transport (shipping, aviation) continue to depend on oil-based fuels.

Natural gas also plays a role in Spain's energy mix (for power backup, industry, and heating), though Spain has diversified gas import sources (pipeline gas from Algeria and a network of LNG terminals sourcing globally) and is somewhat less vulnerable than some European neighbors in terms of gas supply (64). Coal use in Spain has plummeted over the past decade; most coal power plants have closed or are scheduled to close by 2030, in line with EU emissions directives and lack of competitiveness.

Spain's proactive renewables push is partly aimed at reducing energy import dependence – historically, Spain imported the majority of its fossil fuels, spending significant sums on oil and gas. By developing domestic solar, wind, and other renewable technologies, Spain improves its energy sovereignty and can shield itself from volatile global fuel prices (64). The energy transition is also seen as an economic opportunity: Spain expects growth in green jobs and industries (e.g., solar panel manufacturing, wind turbine production, grid infrastructure, and research and innovation in energy). The government has introduced auctions for renewable power, incentives for home solar, and EV subsidies to accelerate these changes. Additionally, Spain collaborates with EU partners on interconnections (e.g., enhancing grid links with France and Portugal) to export surplus renewable power and ensure security of supply.



External Costs of Energy Production

While the direct costs of energy (such as fuel, generation, and infrastructure expenses) are accounted for in market prices, there are substantial external costs (externalities) associated with different energy sources that are not fully reflected in those prices. These externalities include impacts on public health (from air pollution and other emissions), environmental degradation (affecting air, water, and soil through pollution and ecosystem damage), and productivity losses (for example, work days missed or crop yield reductions due to pollution and climate change).

Quantifying these external costs in monetary terms provides insight into the true societal cost of various energy production methods. Below is an overview of the externalities tied to major energy types – coal, natural gas, nuclear, renewable sources like wind and solar, and bioenergy.

Overview of External Costs

In Europe, air pollution and greenhouse gases from energy production impose a heavy financial burden on society. The European Environment Agency (EEA) has estimated that in a single year (2009), emissions from industrial facilities, largely from power plants and heavy industry, caused damage costs of at least €102 billion (and up to €169 billion) to health and the environment (3).

Notably, the power generation sector was the largest contributor to these damages. Emissions from electricity and heat production (mainly from burning fossil fuels) were responsible for an estimated **€66–112 billion** of those annual damage costs (the range reflecting different valuation approaches), underscoring how costly polluting energy sources can be for society (3).

Even excluding the impacts of carbon dioxide (climate change costs), air pollutants from the power sector alone caused about €26–71 billion in health and environmental damage per year (3). These costs come in the form of respiratory and cardiac illnesses, hospital visits, lost productivity from sick leave, ecosystem harm (acidified soils, damaged crops, etc.), and climate-related damages.

The magnitude of external costs varies by country depending on their energy mix: countries with heavy coal and oil use tend to incur higher damage costs, whereas those with cleaner or more efficient energy systems incur less. According to EEA data, Germany, Poland, the UK, France, and Italy have the highest total external costs from industrial air pollution in Europe (owing to their size and industrial activity) (3). In contrast, when adjusted for the size of the economy, several smaller countries with carbon-intensive energy (such as Bulgaria, Romania, Estonia, and Poland) suffer the greatest damage costs relative to their GDP.

This indicates that the latter countries bear a disproportionate burden from energy-related externalities, largely due to reliance on older, polluting technologies. For example, Bulgaria and Estonia, which depend heavily on coal and oil shale respectively, experience very high health and environmental costs per unit of economic output. On the other hand, countries like France (with a high share of nuclear and renewable power) and Austria (with significant hydropower and biomass) have comparatively lower external costs from their energy sectors in terms of air pollution (3).

Breakdown by Source

Coal

Impacts:

Coal combustion is generally the most costly energy source in terms of externalities. Burning coal (including lignite, a soft brown coal used in some countries) releases large amounts of air pollutants, notably sulfur dioxide (SO_2), nitrogen oxides (NO_x), and fine particulate matter (PM_2.5), as well as carbon dioxide (CO_2).

The health impacts of coal pollution are severe: fine particulates and other pollutants from coal-fired power plants contribute to respiratory illnesses (asthma, bronchitis), cardiovascular diseases (heart attacks, stroke), and premature deaths. Coal power plants in Europe have historically been a major source of such pollution. For instance, before recent phase-down efforts, coal emissions were estimated to cause 22,900 premature deaths per year EU-wide, with significant healthcare costs (5).

In addition to health impacts, environmental damage from coal includes acid rain (from SO_2 and NO_x depositing in soils and water, harming forests and aquatic life) and climate change (coal is the most carbon-intensive major fuel, emitting roughly 0.9–1 tonne of CO_2 per MWh of electricity) (3, 6).

Monetary Costs:

The external cost of coal-fired electricity is the highest among common fuels, reflecting the combination of health, environmental, and climate damages. European studies (such as the EU's ExternE project and updates by national environmental agencies) have placed the external cost of coal power in the range of 2 to 22 euro-cents per kWh of electricity. This equates to roughly €50–100 per MWh (and potentially more under high valuation scenarios for health and carbon impacts) (4). As a concrete illustration, the EEA's analysis for 2009 showed that a large portion of the €66–112 billion damage from the power sector came from coal-burning plants (3).

Natural Gas

Impacts:

Natural gas is a cleaner-burning fossil fuel than coal or oil, but it still generates significant external costs. When burned for power or heat, natural gas emits nitrogen oxides (NO_x) (which can form smog and contribute to PM_2.5 formation) and CO_2 (roughly about half the CO_2 per MWh compared to coal). Gas combustion produces negligible sulfur dioxide and far less particulate matter than coal; thus, the direct air-pollution health impacts of gas are lower.

However, NO_x emissions from gas power plants and boilers can worsen ozone and particulate pollution downwind, affecting respiratory health (e.g. NO_x is a precursor to ground-level ozone, which can cause lung irritation and exacerbate asthma). Another concern with natural gas is methane leakage during production and transport: methane is a potent greenhouse gas, and leaks reduce the climate advantage gas has over coal. These upstream leaks are part of gas's external environmental impact (for example, leakage from pipelines or LNG terminals can offset some of the CO_2 reduction benefit). Gas infrastructure (like pipelines) can also pose safety risks (explosions, though rare, are high-impact events), contributing to occasional social costs.

Monetary Costs:

The external cost per unit of energy for natural gas is moderate, lower than coal's, but still notable. Studies have estimated the external cost of gas-fired electricity in the EU on the order of €20–50 per MWh. This includes health impacts from air pollution and a valuation of CO_2 emissions (32). The EEA data from 2009, for instance, showed that while coal plants dominated damage costs, natural gas facilities also contributed a share of the €26–71 billion in non-CO_2 damage from the power sector (3).

Nuclear

Impacts:

Nuclear power presents a very different externality profile. In normal operation, nuclear plants emit no greenhouse gases or air pollutants, which means negligible direct health impacts from operational emissions (no soot, smog, or CO_2). This is reflected in the low air-pollution damage costs for nuclear-heavy countries; for example, France's electricity sector external costs are low in large part due to its 70% nuclear share, which avoids most of the air pollution that coal or gas would produce (33).

However, nuclear energy's externalities are associated with radiological risks and long-term waste management. The key external factors are the potential for accidental releases of radiation (as in the Chernobyl or Fukushima disasters) and the challenge of safely containing radioactive waste for very long periods. A severe nuclear accident, while highly unlikely, can have catastrophic and widespread health and environmental consequences – increased cancer rates, contaminated land and water, large-scale evacuations – with economic costs reaching hundreds of billions of euros.

These extreme events represent a low-probability, high-impact externality. In terms of more routine external costs: the nuclear fuel cycle (mining, processing, waste storage) has environmental impacts like any mining activity (uranium mining can cause local water and soil contamination) and leaves waste that must be isolated to avoid harm. Most of these costs (waste storage, decommissioning) are typically internalized by requiring nuclear operators to manage them, but if anything goes wrong, the external cost can emerge (e.g. if a waste repository leaked in the far future, that would impose an environmental cost on society).

Monetary Costs:

Under normal conditions, the monetized external cost of nuclear energy per kWh is very low – various studies (including those by the OECD Nuclear Energy Agency) have found it to be on the order of €1–€2 per MWh or even less for routine operation (34). This essentially comes from the near-zero air pollution (thus near-zero health cost) and minimal greenhouse gas emissions (nuclear's life-cycle CO_2 emissions are among the lowest of any source, ranging from 3.7 to 12 grams of CO_2 equivalent per kilowatt-hour (gCO_2e/kWh)) (35). For perspective, in the EEA's damage cost analysis, countries with a high share of nuclear (like France) had far lower total damage costs from the power sector than those with fossil-heavy mixes, implying nuclear was not contributing significant immediate external burdens (3).

However, if one attempts to account for the risk of accidents, the calculus changes: one way to monetarily evaluate this is to consider the expected cost of accidents (probability-weighted). Historically, catastrophic accidents are rare – Chernobyl (1986) and Fukushima (2011) are the two major civil nuclear power accidents – but their damages are enormous (for instance, between 1991 and 2003, Belarus alone spent over $13 billion on Chernobyl-related expenses (36), and the Japan Center for Economic Research estimated the total costs for Fukushima's could range between ¥50 trillion and ¥70 trillion (approximately $470 to $660 billion) (37). If an economist spreads that cost over all nuclear kWh ever generated, the added cost per kWh is still small. For instance, the World Nuclear Association reports that, even when factoring in potential accident costs, the external cost of nuclear energy remains around 0.4 euro cents per kilowatt-hour (kWh), or €4 per MWh (38).

Wind and Solar

Impacts:

Wind turbines and solar photovoltaic (PV) panels generate electricity without any direct fuel combustion, which means no direct air pollution or greenhouse gas emissions during operation. This is a tremendous advantage in terms of externalities: there are effectively zero ongoing health-damaging emissions, and zero CO_2 emitted when the wind turbine or solar panel is producing power.

The external impacts of wind and solar are mostly associated with their manufacturing, installation, and end-of-life stages, as well as some land use and ecological considerations. Manufacturing solar panels and wind turbines involves mining and processing of materials (silicon, rare metals, steel, concrete, etc.), which has environmental impacts (often in the form of energy use and some pollution in the manufacturing countries, which might be outside Europe). These life-cycle impacts are relatively small per unit of energy generated over the system's lifetime, but they are not zero. For solar PV, there is also concern about end-of-life waste (old panels need recycling to prevent heavy metals from leaching) – the EU is working on PV recycling programs (such as the Waste Electrical and Electronic Equipment (WEEE) Directive (39)), which, if successful, will mitigate this potential external issue.

Wind turbines can have local environmental impacts: large wind farms may affect bird and bat populations (collisions with turbines) and cause noise and visual amenity concerns for nearby residents. These are typically localized externalities and can be managed by careful siting (for example, avoiding major bird migration routes and maintaining setback distances from homes to reduce noise disturbance). Solar farms use land that could have other purposes, but often they can be placed on rooftops or low-value land; in any case, they generally do not pollute land or water during operation.

Monetary Costs:

Because wind and solar have minimal direct external costs, studies often assign them a very low external cost per kWh (often under €5 per MWh, sometimes just €1–€2) (40). This residual cost accounts for manufacturing emissions and minor ecological impacts.

Life-cycle assessments show wind and solar have among the lowest greenhouse gas footprints (on the order of 10–50 g CO_2 per kWh for solar, and 5–20 g CO_2 per kWh for wind, versus ~400–1000 g for fossil fuels) (41). Air pollution life-cycle (e.g., some sulfur or particulates from manufacturing processes) is similarly tiny compared to operating a coal plant. The EEA's analyses implicitly reflect this – countries with high renewables have much lower damage-cost figures (3).

Bioenergy (Biomass and Biofuels)

Impacts:

Bioenergy covers a range of energy sources derived from biological materials – including burning solid biomass (wood logs, pellets, agricultural residues) for heat or power, biogas from anaerobic digestion, and liquid biofuels like biodiesel or ethanol. The external impacts of bioenergy can vary widely depending on the type and how it's produced and used.

Solid biomass combustion (e.g. wood-burning in stoves, boilers, or power plants) has impacts similar to those of other combustion sources: it emits particulate matter, NO_X, carbon monoxide, and other organic compounds. In fact, wood smoke can be a major source of fine particulate pollution. It's sometimes assumed to be "clean" because it's natural, but in reality traditional wood burning can produce as much or more PM_2.5 as coal per unit of heat if not properly controlled (42). Modern biomass boilers with emissions controls can sharply reduce these pollutants, but small-scale and older wood stoves are often uncontrolled. A striking fact is that residential wood-burning has become the single largest source of particulate matter pollution in Europe (43) – even exceeding emissions from traffic or industry in many countries. This is because many households in countries like France, Germany, Italy, Austria, and the Nordics use wood for heating, especially in winter, and the cumulative smoke from millions of chimneys is significant.

The health externalities of this are large: wood smoke contributes to the PM_2.5 that causes respiratory and cardiovascular problems. For example, a recent assessment highlighted that wood-burning in European cities and villages poses cancer and lung disease risks comparable to those in cities afflicted by traffic smog (43). Thus, while bioenergy is renewable in a carbon sense (plants regrow), it is not necessarily benign for air quality.

On the climate side, bioenergy is often considered "carbon neutral" at the point of combustion because the CO_2 released is theoretically taken up by new plant growth. However, in practice there can be a carbon debt: if forests are harvested for energy, it may take decades for regrowth to reabsorb the CO_2, and in the meantime that CO_2 contributes to climate change. Moreover, processing and transporting biomass consumes energy. Still, bioenergy typically has a lower net climate impact than fossil fuels if sourced sustainably (for instance, using wood waste or fast-growing residues).

Biogas and biofuels have their own profiles: burning biogas (in engines or turbines) emits NO_x and some particulates but far less than coal/biomass, and it offsets methane that might have been released from manure or landfills (so it can even be a net win for climate if it captures methane that would otherwise escape).

Liquid biofuels burn cleaner than crude oil fuels in terms of sulfur (low sulfur content) but still emit NO_x and particulates (especially biodiesel in engines can emit similar NO_x as diesel). The production of biofuels (e.g. farming crops for ethanol) has land use implications (fertilizer runoff, etc.) which are environmental externalities to consider (water pollution, biodiversity loss if forests are cleared for bio-crops).

Monetary Costs:

Assessing the external costs of bioenergy is complex because of these nuances. However, generalization can be done: Traditional residential wood burning, especially in open fireplaces or outdated stoves, can produce fine particulate matter ($PM_{2.5}$) levels comparable to or exceeding those from coal per unit of heat. This leads to substantial health-related external costs, estimated between €100–200 per megawatt-hour (MWh) of heat. In the UK alone, home wood burning is responsible for approximately £0.9 billion in annual health-related damages, with EU-wide costs reaching around €9 billion (44).

Conversely, large-scale biomass power plants equipped with advanced emission controls, such as filters and scrubbers, exhibit significantly lower external costs. Studies indicate that such facilities can have external costs as low as €20–50 per MWh, primarily due to reduced emissions of pollutants like SO_2 and $PM_{2.5}$ (45).

The climate impact of biomass energy is also contingent on feedstock sustainability. When sourced from sustainably managed forests or agricultural residues, biomass combustion can be nearly carbon-neutral, as the CO_2 released is offset by regrowth. However, if biomass sourcing leads to deforestation or unsustainable land-use changes, the resulting CO_2 emissions can rival those of fossil fuels (46).

In conclusion, bioenergy's external costs are highly context-dependent: sustainably managed and cleanly burned biomass can be a low-externality solution (especially if it displaces coal, yielding net health gains), but inefficient bioenergy use can impose large hidden costs on public health and the environment.

Current and Projected Costs of Energy Production

The cost of energy supply is a crucial factor influencing national strategies across Europe. In recent years, the cost per unit of energy for various sources has shifted dramatically – renewable technologies like solar and wind have seen steep declines in cost, while fossil fuel prices have been volatile and increasingly affected by carbon pricing. This section examines the current cost estimates for major energy sources (oil, gas, coal, nuclear, and renewables such as bioenergy, solar thermal, geothermal, etc.), trends in these costs (e.g. €/GJ or €/MWh), and projections toward 2030–2035. It also analyse how price volatility, especially in fossil fuels, is shaping policy decisions, and how countries are gravitating toward lower-cost or locally sourced energy options to improve affordability and energy security.

Solar and Wind Energy

Over the last decade, renewable electricity costs have plummeted, making solar and wind power the most cost-effective new sources of energy in many cases. Technological improvements, economies of scale, and competitive auctions have sharply reduced the levelized cost of energy (LCOE) for these sources. According to recent analyses, the average cost of electricity from newly commissioned utility-scale solar PV in the EU was around €40 per MWh in 2023, and for onshore wind it was even lower – roughly €30 per MWh (66).

These figures represent a remarkable decline and mean that in 2023, over 90% of new solar and wind projects in Europe could generate power more cheaply than even the most efficient new fossil-fuel power plants (66). In leading countries like Spain, Germany, and Denmark, renewables have already become the backbone of the power mix largely because of this cost advantage.

The trend is expected to continue: industry projections suggest that by 2030, solar and wind costs may drop further (due to ongoing innovations and mass deployment), potentially reaching ranges of €20–€30 per MWh for the best projects. This downward cost trajectory is encouraging countries to upscale their renewable energy targets, since cheaper renewable electricity not only helps meet climate goals but also lowers energy bills and reduces exposure to fuel price shocks. Moreover, the predictability of renewables' costs (mostly upfront capital, with very low operating costs and no fuel price risk) contrasts with the volatility of fossil fuel-based generation, making wind and solar attractive for improving long-term energy price stability (66).

Natural Gas

Natural gas remains a key component of energy supply – especially for heating, industry, and as a backup in power generation – but its price has been highly volatile, causing economic challenges and prompting strategic shifts. In the early 2020s, Europe experienced extreme gas price fluctuations. The European benchmark gas price (TTF) spiked to unprecedented levels in 2021–2022 amid supply crises (exacerbated by the Russia–Ukraine conflict), at times reaching several hundred euros per MWh. Governments and consumers faced surging energy bills, and gas-intensive industries struggled with higher costs. By early 2024, gas prices had fallen back from those peaks: the TTF spot price averaged about €47 per MWh in the first quarter of 2024 (67), a significant drop from the 2022 crisis heights, but still above long-term historical averages.

This volatility – largely driven by geopolitical risks and global LNG market dynamics – has made planning difficult and underscored gas as a costly necessity: essential in the short term, but risky. As a result, many European countries (such as Germany, Italy, and others heavily reliant on gas) have accelerated policies to reduce their gas dependence. These include investing in renewables (to replace gas in electricity generation), promoting heat pumps and district heating (to cut gas use in buildings), and diversifying gas import sources and routes to avoid over-reliance on any single supplier.

However, despite high prices, gas has proven hard to quickly substitute due to infrastructure and the need for dispatchable energy; gas-fired plants also play a role in balancing the grid when wind or solar output fluctuates.

Looking ahead, projections for gas prices to 2030 are uncertain – they depend on global supply expansion, LNG markets, and climate policies. The EU's push to cut gas consumption (aiming for a substantial reduction by 2030 under REPowerEU) could dampen demand and ease prices domestically, but global competition for LNG might keep prices elevated compared to the 2010s. Moreover, the introduction of carbon prices on gas (in heating and transport via the new EU ETS2 by 2027) will add to its effective cost (67).

Oil

Oil prices have historically been volatile, and this volatility continues to influence energy costs and policy in Europe, especially in the transport sector. Crude oil is traded on a global market, and European countries import virtually all the oil they consume, exposing them to international price swings.

In the past few years, oil has seen sharp price movements: recovering demand in 2021 and geopolitical tensions in 2022 pushed prices very high – Brent crude spiked above $120 per barrel in mid-2022 – contributing to inflation and high gasoline/diesel prices for consumers. By 2023, prices moderated as markets adjusted; Brent crude oil averaged about $83 per barrel in 2023, down from ~$101 in 2022 (68), thanks to new trade patterns (Russian oil finding other markets) and slightly lower global demand than expected.

Despite this easing, oil remains prone to supply-demand imbalances and OPEC+ production decisions, which can send prices upward. Looking ahead to 2030, many forecasts predict that global oil demand will plateau or start to decline as electric vehicles and alternative fuels gain market share. This could relieve some upward pressure on prices in the long term (68).

However, during the transition period, volatility may persist – for example, if investments in oil production lag while demand is still relatively high, prices could spike, or conversely, a faster-than-expected demand drop could lead to oversupply and price dips.

For European nations, oil price volatility is a major motivator to reduce oil consumption. High and unpredictable fuel costs hurt consumers and economies, so governments are promoting fuel efficiency, public transport, and electrification of transport to cut oil use. Some countries have also adjusted taxes or strategic reserves to buffer short-term price shocks. Additionally, biofuels are being used as a supplement (though their cost can be higher, they provide a domestic alternative to pure oil).

The cost per unit energy of oil (when converted to €/MWh) fluctuates with the oil price: at $80/barrel, oil equates to roughly €45–50 per MWh; at $120/barrel, it's around €70/MWh – far above the cost of producing a MWh of renewable electricity, for instance. By 2030, if policies succeed, Europe's oil consumption will be lower, and electric vehicles with much lower "fuel" costs (electricity per km) will replace some oil demand, thereby reducing the impact of oil price swings on consumers and improving energy security.

Nuclear Energy

Nuclear power offers a stable and low-carbon energy output, but the costs of nuclear energy are relatively high and heavily front-loaded. The construction of nuclear plants involves very large capital investments, long lead times (often a decade or more), and complex regulatory and safety requirements – all of which contribute to high overall costs. The levelized cost of electricity from new nuclear projects in Europe is estimated to range widely, roughly from €50 to €100 per MWh (69), depending on the project specifics.

This range reflects factors like construction cost overruns, financing costs, and differences in reactor technology. For instance, countries building new reactors (such as the UK or Finland) have often seen costs on the upper end of this range. On the other hand, once a nuclear plant is built and running, its operating costs are relatively low and stable (fuel costs are a minor part, and uranium prices have little effect on per-MWh costs).

France – which generates over 60% of its electricity from an aging but well-maintained fleet of nuclear reactors – benefits from comparatively low production costs for existing nuclear power, which has kept French electricity prices for industry and consumers lower than in many neighboring countries. However, even France now faces the high expense of life-extension upgrades and plans for next-generation reactors. In contrast, countries like Germany and Spain have chosen to phase out nuclear power entirely, largely due to political and public opposition and concerns over safety and waste, despite nuclear's climate benefits and stable output (69).

The trend in nuclear costs going forward is complex: while new small modular reactors (SMRs) and next-gen designs promise lower costs, they won't be deployed at scale until the 2030s. In the interim, the few European countries pursuing new nuclear (France, Finland, UK, Poland, etc.) are trying to standardize designs to avoid past cost escalations. By 2030 or 2035, we may see initial SMR units operating, but their economic competitiveness versus ever-cheaper renewables remains uncertain (69). Nuclear's value often lies in providing firm, dispatchable power and enhancing energy security (as domestic generation), but financing remains a key hurdle.

Bioenergy, Geothermal, and Other Renewable Sources

Beyond wind and solar PV, several other renewable energy sources contribute to Europe's energy supply, each with its own cost profile and trends:

Bioenergy

This includes biomass (wood pellets, agricultural waste) and biogas used for heat and power. In terms of electricity generation cost, modern biomass power plants have an LCOE that has modestly declined over time but not as dramatically as solar/wind. Globally, the average cost of bioenergy electricity was about $0.07 per kWh (≈€0.06–0.07) in 2023, down roughly 14% from 2010 levels (70).

Bioenergy costs can vary depending on feedstock prices (which in turn are linked to agricultural markets and supply logistics). In Europe, biomass is often used in combined heat and power (CHP) plants; when waste heat is utilized, the overall efficiency can make it cost-effective. For heating, biomass (like wood chips or pellets) can be a relatively low-cost fuel per GJ, sometimes cheaper than fuel oil or gas, although prices have risen with higher demand and sustainability constraints. Biofuels for transport (ethanol, biodiesel) generally remain more expensive per unit energy than fossil fuels, but policy support (subsidies, blending mandates) bridges some of that gap (70).

Geothermal

Geothermal energy provides both electricity (in regions with high-temperature resources) and heating (via geothermal heat pumps and district heating). The cost for geothermal power is site-specific – where high-quality reservoirs exist (e.g., in Italy, Turkey, or Iceland, albeit Iceland is outside the EU), geothermal electricity is quite competitive. However, in much of Europe, geothermal power potential is limited or requires enhanced technology. Recent data show the global average LCOE for geothermal power was around $0.07 per kWh in 2023, but this actually represented an increase of nearly 20% from the previous year due to a few expensive projects and modest new capacity (70).

The upfront drilling and exploration costs are significant, which can drive costs up if the resource is uncertain. For geothermal heating (ground-source heat pumps), the metric is different – it's about cost per installed capacity and the electricity to run the pumps, which is generally quite economical over the system's life. Many European countries (France, Germany, Nordic countries) are expanding geothermal heating solutions as a way to provide low-carbon heat at a stable cost, despite high initial installation costs for infrastructure (70).

Hydropower

Conventional hydropower has long been one of the cheapest sources of electricity where available. Many European countries tapped their hydro resources decades ago, so most growth now comes from upgrading existing plants or small-scale projects. The cost of existing large hydro is very low (often well below €0.05 per kWh) (70). According to IRENA data, the global average cost of hydropower was about $0.057 per kWh in 2023, up from around $0.043 in 2010 due to higher investment costs for new projects.

In Europe, environmental regulations and limited remaining sites make new large dams difficult; thus, hydro capacity is nearly maxed out in countries like France, Italy, and Spain. Pumped hydro storage, however, is being invested in for energy storage, which has its own cost considerations but is crucial for integrating cheap solar/wind. Overall, hydro's cost is low and stable, but its growth is limited.

Coal: Increasingly Unviable Under Climate Policies

Coal has historically been a cheap and abundant energy source, but its true cost has been rising in Europe due to climate policies and market changes. In pure fuel terms, coal can produce electricity at a cost equivalent to roughly €50–€100 per MWh (fuel + operation) for a typical power plant – often on the lower end of that range for lignite (which is cheaper but dirtier) and higher for imported hard coal (71).

This base cost used to make coal one of the least expensive ways to generate electricity. However, the EU Emissions Trading System (ETS) has added a significant cost for carbon emissions. With CO_2 allowances trading around €80 per ton in 2023, the effective cost of coal-fired electricity increases dramatically – burning coal emits roughly 0.9 to 1 ton of CO_2 per MWh, so an €80/ton carbon price adds up to €72–€80 per MWh to coal's cost. That means the total cost of coal power (including carbon) can exceed €120–€150 per MWh, making it economically unattractive compared to renewables or gas in many cases (71).

This trend will likely continue as the EU tightens climate targets; carbon prices could remain high or climb further, and many financial institutions are unwilling to fund new coal projects. As a result, coal is rapidly being phased out of the energy mix. Countries such as Spain and France have already closed most coal plants. Germany, which traditionally had large coal usage, has committed to phase out coal by 2038 (and is even considering 2030 if feasible, as per recent coalition discussions), although in the short term it kept some plants on standby during the 2022 gas crisis. Poland and some Eastern European countries still use coal heavily (for power and district heating), but even there, economics are shifting – EU funds and national policies are increasingly directed at replacing coal with renewables, gas as a bridge, or nuclear (71).

The price volatility of coal itself has also been notable: international coal prices spiked in 2022 as Europe sought alternatives to Russian gas (and some countries temporarily burned more coal), but this was a short-term effect. Over the next decade, coal demand in Europe is expected to plummet, which should keep coal prices moderate; however, the overriding carbon costs will render coal-fired generation uneconomical most of the time.

The strategic response by countries has been clear: invest in lower-cost and cleaner alternatives. Renewable energy and natural gas (with the intent to later move to green gas or hydrogen) have filled the gap, and capacity mechanisms ensure security of supply during the transition.

Objective 3 & 4:

Evaluate Socio-Economic Impact, and Shortlist Recommendations.

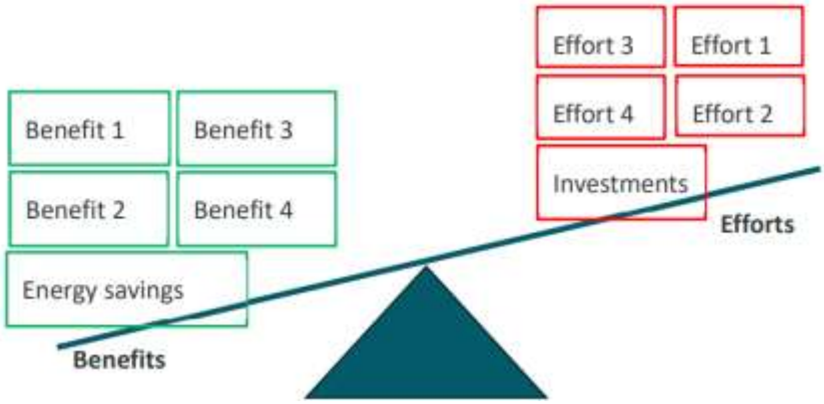
Source: Templafy library, Deloitte Internal

Evaluate Socio-Economic Impact, and Shortlist Energy Efficiency Measures.

Assess the socio-economic costs and benefits of energy efficiency measures across different uptake and implementation scenarios.

Socio-Economic Impacts of Energy Efficiency Measures

Energy efficiency measures (EEMs) deliver a wide range of impacts beyond direct energy savings, commonly referred to as Non-Energy Impacts (NEIs). These include positive non-energy benefits (NEBs) and negative non-energy efforts (NEEs) (73). NEBs capture the added value that EEMs bring, such as improved indoor air quality, healthier and more comfortable work environments, enhanced competitiveness and productivity, a stronger green corporate image, and reduced maintenance requirements. Conversely, NEEs refer to the additional efforts or costs associated with implementing these measures, including process downtime, staff training needs, design and implementation overheads, or rebound effects where efficiency gains lead to increased usage (73). Ultimately, a company will choose to implement an EEM only if the combined energy and non-energy benefits outweigh the associated efforts and costs, as illustrated in the figure below.



Source: KNOWnNEBs Methodology (73)

Non-Energy Benefits (NEBs)

Integrating NEBs into energy efficiency measure (EEM) evaluations is critical to capturing their full value, though their nature and magnitude vary significantly based on each company's operational, organisational, and sectoral context.

NEBs can be broadly categorised as follows:

- **Quantified (Monetised) NEBs** – These benefits can be directly translated into monetary terms, such as reduced machine downtime leading to increased production output, lower procurement costs from decreased material waste, or avoided regulatory fines through improved emissions control. Because they are monetisable, these benefits can be incorporated directly into financial analyses to strengthen the business case for energy efficiency investments (73).
- **Non-Quantified (Non-Monetised) NEBs** – While these benefits may not easily convert into precise financial values, they remain highly impactful. Examples include enhanced thermal comfort for employees, improved brand reputation through sustainable practices, or reduced occupational hazards due to better lighting or ventilation. This category also encompasses benefits measurable in physical or operational terms-such as a 15% reduction in equipment vibration or a six-point improvement in employee satisfaction scores-that, while not readily monetised, offer substantial operational value (73).

Non-Energy Efforts (NEEs)

NEEs refer to the negative side effects or additional burdens associated with implementing energy efficiency measures (EEMs). These impacts can offset some of the benefits created by NEBs, thereby reducing the overall net value of an EEM.

NEEs can be categorised based on when they occur during the lifecycle of an EEM:

- **Initial NEEs** – These arise during the planning and installation phases. Examples include technical design and engineering costs (quantifiable), temporary productivity losses during installation (quantifiable), increased pressure on management or staff due to organisational changes (not easily quantifiable), noise disturbances during implementation (non-quantified), and staff training expenses to operate new technologies (quantifiable) (73).

- **Recurring (Annual) NEEs** – These are ongoing costs or drawbacks that persist each year after implementation. Examples include annual software licensing fees for energy monitoring systems (quantifiable) and increased maintenance needs for new installations, such as servicing mechanical ventilation systems (quantifiable) (73).
- **Periodic NEEs** – These occur at specific intervals post-implementation, such as scheduled maintenance or replacements (e.g., façade cleaning every 10 years following thermal insulation installation) or periodic technical training to ensure compliance and maintain operational efficiency (73).

In summary, while energy savings are a major driver for EEM adoption, the true economic and organisational value of a measure can only be assessed by considering both its non-energy benefits and efforts.

Assessing NEIs of EEMs

Building on the definitions of NEBs and NEEs outlined above, the socio-economic impacts associated with each targeted energy efficiency measure (EEM) can now be identified and assessed. For reference, the relevant EEMs are re-listed below.

Lighting	Building Heating	Renewable Energies	Heat Pumps and Heat Recovery
Compressed Air	Optimisation	Ventilation	Cooling
Energy Management	Office Space (e.g. Equipment)	Façade Thermal Insulation	Roof Thermal Insulation
Openings Replacement and Shading	Industrial Furnaces	Distribution Networks and Insulation	Pumps
Raising Staff Awareness	Transportation		

Source: EE4SMEs WP3 and WP8

Limitations of the NEI Assessment

Identifying and assessing the NEBs and NEEs (both quantified and non-quantified) associated with each energy efficiency measure (EEM) is highly context-dependent. Generating reliable, generalised estimates of these impacts would require extensive primary data collection, including large-scale surveys and structured stakeholder workshops across all nine target countries, to ensure statistical validity and representativeness.

However, designing and implementing a data collection effort of this scale was beyond the practical scope and timeframe of the current study. Given these constraints, the study adopted the following pragmatic approach:

1. Applied Tool 1 from the KNOWnNEBs project, which is based on over 130,000 data points, to assign relevant NEBs to each EEM.
2. Compiled NEEs for each EEM through targeted desk research, drawing on peer-reviewed literature, policy documents, and expert insights.
3. Provided clear and replicable methodologies for quantifying these NEIs, where feasible, and converting them into monetary terms, enabling future analysis to build on this foundation as additional data becomes available.

KNOWnNEBs

To systematically identify and assess NEIs, the KNOWnNEBs project, funded under the EU's LIFE programme, developed a structured methodology operationalised through two Excel tools: *Tool 1: Identification of NEBs and Tool 2: Financial analysis of EEIs*.

Identification and Assessment of NEBs

The KNOWnNEBs methodology employs two complementary approaches to identify non-energy benefits (NEBs). The first is a qualitative method that involves stakeholder engagement, which is most effective when there is an existing understanding within an organisation of how specific energy efficiency measures (EEMs) generate NEBs. The second approach is a structured, data-driven method using Tool 1, which systematically screens and evaluates NEBs commonly associated with each EEM. Tool 1 is built on a robust dataset comprising over 130,000 data points collected across various sectors and countries by the KNOWnNEBs consortium (73).

Tool 1 operates in two stages (73).

Stage 1. Selection and Initial Ranking

Users begin by selecting an energy efficiency measure from a categorised menu within the tool. The tool then generates a ranked list of NEBs typically associated with the chosen measure, including example methodologies for quantification where applicable. These rankings reflect the empirical likelihood of each NEB occurring, based on the underlying dataset. Users can further tailor the output by selecting a primary beneficiary-such as management, employees, or regulators-to align results with specific organisational priorities.

Source: KNOWnNEBs Methodology (73)

Stage 2. Screening and Monetary Conversion

In the second stage, the ranked NEBs are screened for materiality. For NEBs deemed material, the following steps are undertaken:

- If a material NEB is quantifiable, it is first categorized by its timing-whether it represents an initial, annual, or periodic impact-and is then assigned an appropriate unit of measurement along with an estimated value in that unit. Monetary conversion is then carried out using a unit cost expressed in EUR per unit.

- If the NEB is not directly quantifiable, it is first evaluated using a qualitative importance score on a scale from 1 (very low) to 5 (very high). This score is then integrated into the monetary valuation process using Tool 2, which is described in later section.

NEB category	NEB	Include in calculations	Quantified/not quantified	Initial/yearly	Unit of measurement	Cost of unit, EUR/unit (for initial) and	Amount of units	Importance (1-low; 5-very high)
NEB category	NEB	Include in calculation	Quantified/not quantifi	Initial/year	Unit of measuremen	Cost of unit, EUR/unit (for initial) and EUR/unit per year (for yearly)	Amount of uni	Importance (1-low; 5-very hig
Environment	Emission reduction	Yes	Quantified	Initial	t CO2	5	100	
Economic	Improvement of competitiveness	Yes	Not quantified					5
Economic	Reduction of (operating) costs	Yes	Quantified	Initial	employee	2000	3	
Environment	Reduced emissions (dust, CO2, chemical agents etc.)	Yes	Not quantified					2
Economic	Reduction of emission or disposal fees	Yes	Quantified	Yearly	items	100	10	
Security & Safety	Energy security	Yes	Not quantified					4
Environment	Reduced use of non-renewable resources	No						
Economic	Reduction of (maintenance) costs	No						

Source: KNOWnNEBs Methodology (73)

Identification and Assessment of NEEs

It is important to note that Tool 1 is designed exclusively for identifying and assessing NEBs associated with energy efficiency measures; it does not address NEEs. Instead, the KNOWnNEBs methodology tackles the identification of NEEs separately through a qualitative framework rather than a dedicated tool. This framework relies on in-depth discussions with company stakeholders and uses targeted questions to explore potential negative or unintended impacts, such as rebound effects, upfront capital risks, operational challenges, technology compatibility issues, regulatory uncertainty, and possible environmental trade-offs (73).

Once material NEEs have been identified, they are further categorised-similar to the approach used in Tool 1-according to their timing and whether they are quantifiable. For quantifiable NEEs, an appropriate unit of measurement is assigned along with an estimated value, which is then converted into monetary terms using a unit cost factor expressed in EUR per unit. Non-quantifiable NEEs are assessed using qualitative importance scores at this stage.

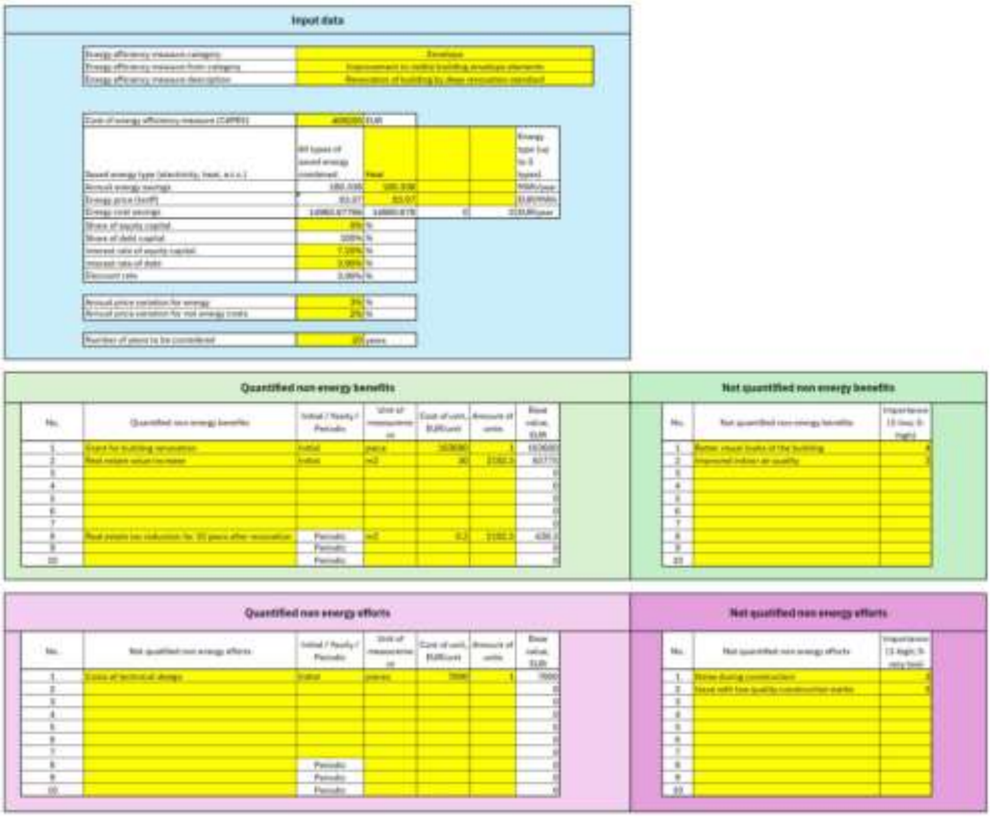
Beyond the scope of the KNOWnNEBs project, the broader literature shows strong alignment with this qualitative approach. Most studies use qualitative methods-such as case studies, interviews, and surveys-to identify NEEs in energy efficiency projects. For example, Sanguinetti et al. (74) proposed an “Occupant Non-Energy Impact Identification Framework” for residential retrofits, which categorises NEEs into five dimensions: physiological, psychological, financial, practical, and sociological. This framework provides a structured, qualitative way to link specific EEMs with related non-energy impacts.

While these frameworks highlight the importance of systematically identifying NEEs, they often lack a consistent, standardised structure. Unlike the structured, data-driven approach provided by Tool 1 for NEBs, no comparable tool currently exists-according to our literature review-to systematically identify NEEs. Although developing such a tool is beyond the scope of this study, future research should prioritise creating a robust, tool-based methodology for NEE identification. This would help integrate NEEs more consistently and at scale into energy efficiency planning and decision-making processes.

Assessing Non-Quantified NEIs – Tool 2

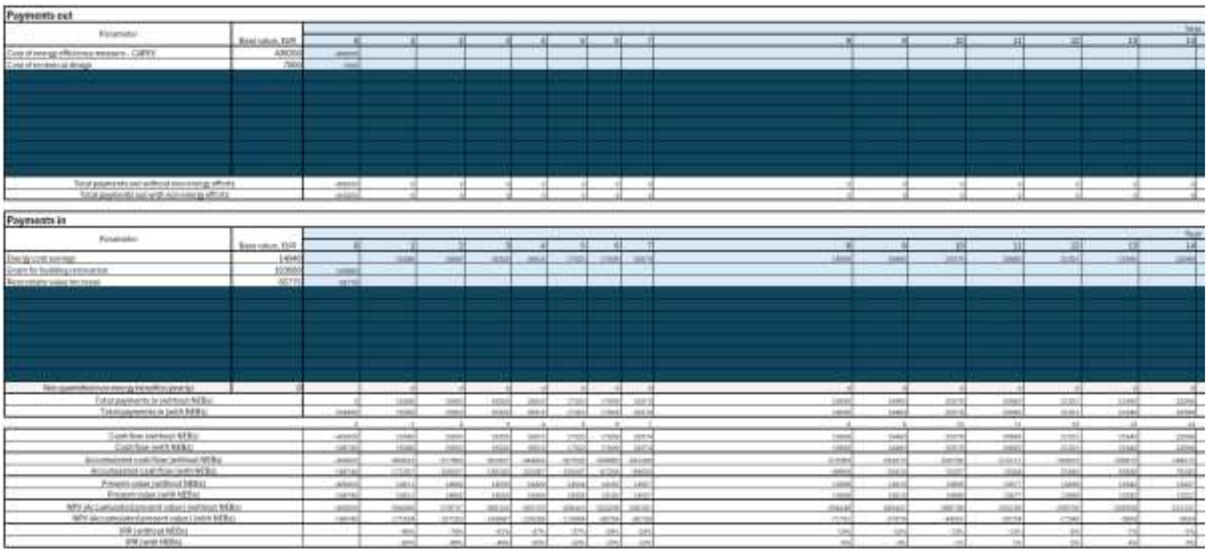
After all quantified impacts have been assessed, Tool 2 is used to estimate the monetary value of any remaining unquantified impacts.

Based on the EN 17463:2021 VALERI framework and enhanced by the KNOWnNEBs consortium to include NEI considerations (73), Tool 2 first gathers a comprehensive set of inputs for each targeted measure. These inputs include the valuation timeframe, baseline energy and cost data, CAPEX and OPEX assumptions, all quantified impacts, and importance scores for any non-quantified impacts.



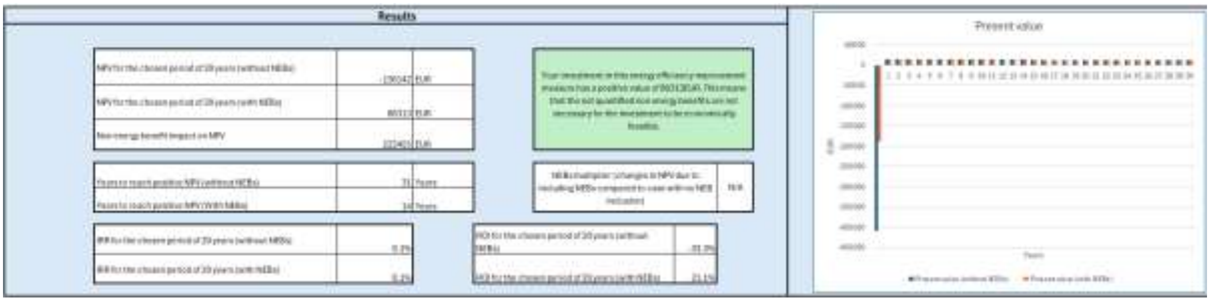
Source: KNOWnNEBs Methodology (73)

Tool 2 then automatically calculates the cash inflows (“Payment in”) and cash outflows (“Payment out”) associated with implementing the selected measure. All quantified positive impacts are added as inflows, while quantified negative impacts are recorded as outflows.

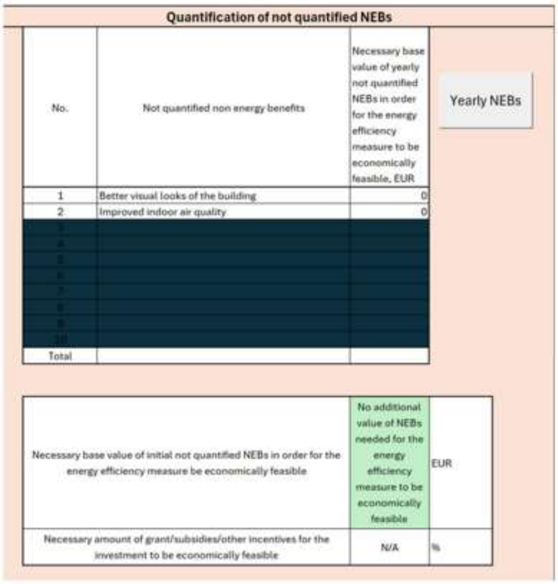


Source: KNOWnNEBs Methodology (73)

Results are presented in a table and visualised with accompanying graphs, showing key financial indicators such as net present value (NPV), internal rate of return (IRR), and payback period, both with and without the inclusion of additional benefits. To support decision-making, the tool includes a colourcoded feasibility indicator: green if the measure meets financial thresholds (even without unquantified benefits) and red if it does not.



Source: KNOWnNEBs Methodology (73)



Source: KNOWnNEBs Methodology (73)

If the indicator is red, Tool 2 calculates the monetary value that unquantified benefits would need to provide to make the investment viable. It assigns a hypothetical value just sufficient to shift the feasibility indicator from red to green. This “benefit gap” is expressed in two figures:

- Annual value (recurring each year)
- One-time (initial) value

Together, these values define the additional savings or one-off benefits required for the measure to meet the organisation’s financial targets.

Assigning NEBs to Each EEM

Using Tool 1, developed under the KNOWnNEBs project, NEBs were identified for each targeted EEM. Before assigning NEBs for this analysis, three key adjustments were made to ensure methodological consistency:

Terminology alignment

The EEM labels in Tool 1 differ from those used in WP3 and WP8 of the EE4SMEs project, as well as from the standardised list presented earlier in this report. To address this, a cross-referencing process was carried out to align the standardised EEMs with their closest equivalents in Tool 1. Where a single standardised EEM corresponded to multiple Tool 1 categories, the common denominator was selected. This approach ensured that each measure was appropriately matched to its corresponding NEBs in the tool’s database. Full details of this alignment process are provided in Appendix A.

Selection of Beneficiary Perspective

Tool 1 ranks NEBs based on their perceived value to three stakeholder groups: top management, employees, and legislators/regulators. In line with the KNOWnNEBs methodology, this analysis prioritised the management perspective, as senior decision-makers are typically the primary audience for energy investment decisions in SMEs (73). Tool 1’s default settings also reflect this prioritisation by ranking NEBs according to their relevance to management.

NEB Selection Threshold

Under standard application of the KNOWnNEBs framework, decisions on which NEBs to include in cost-benefit analyses are informed by stakeholder engagement, such as interviews or workshops with SMEs. However, due to the scope and timeframe of this study, large-scale surveys with firms across nine countries were not feasible.

Instead, a proxy approach was adopted: all NEBs per EEM with a management relevance score of 5 or above in Tool 1 were selected. This threshold aligns with KNOWnNEBs guidance, which recommends: "If the company does not specify their own NEBs, the NEBs with scores 5 and above are recommended for further evaluation" (73).

Based on these adjustments, the NEBs associated with each EEM-along with their definitions and example quantifiable parameters, as identified in Tool 1-are presented in the table below.

NEB Matrix:

EEMs	NEBs	EEMs	NEBs
Lighting	Emission reduction	**Renewable Energies**	Emission reduction
	Increased real estate value		Reduced emissions (dust, CO2, chemical agents etc.)
	Reduction of (operating) costs		Reduced use of non-renewable resources
	Improved lighting		Improvement of competitiveness
Compressed Air	Emission reduction		Reduction of emission or disposal fees
	Improvement of competitiveness		Increased real estate value
	Reduced emissions (dust, CO2, chemical agents etc.)		Reduction of (operating) costs
	Reduction of costs		Energy security
Energy Management	Emission reduction		Increased corporate image
	Reduced emissions (dust, CO2, chemical agents etc.)	**Ventilation**	Emission reduction
	Improvement of competitiveness		Reduced emissions (dust, CO2, chemical agents etc.)
	Increased real estate value		Reduction of (operating) costs
	Reduced use of non-renewable resources		Increased real estate value
	Reduction of emission or disposal fees		Reduction of emission or disposal fees
	Reduction of (operating) costs		Improved air quality
	Energy security		Employee satisfaction
Openings Replacement and Shading	Emission reduction	**Façade Thermal Insulation**	Emission reduction
	Employee satisfaction		Increased real estate value
	Increased real estate value		Reduction of (operating) costs
	Reduced use of non-renewable resources		Reduced use of non-renewable resources
	Reduction of (operating) costs		Energy security
	Energy security	**Distribution Networks & Insulation**	Emission reduction
Building Heating	Emission reduction		Reduced emissions (dust, CO2, chemical agents etc.)
	Reduced emissions (dust, CO2, chemical agents etc.)		Increased real estate value
	Reduced use of non-renewable resources		Reduced use of non-renewable resources
	Improvement of competitiveness		Improvement of competitiveness

	Reduction of emission or disposal fees
	Increased real estate value
	Energy security
Optimisation	Emission reduction
	Improvement of competitiveness
	Reduced emissions (dust, CO2, chemical agents etc.)
	Reduction of emission or disposal fees
	Reduced use of non-renewable resources
	Reduction of (operating) costs
	Increased real estate value
	Energy security
	Employee satisfaction
	Increased productivity
Office Space (e.g. Equipment)	Emission reduction
	Reduced emissions (dust, CO2, chemical agents etc.)
	Improvement of competitiveness
	Reduction of (operating) costs
	Reduction of emission or disposal fees
Industrial Furnaces	Emission reduction
	Reduced emissions (dust, CO2, chemical agents etc.)
	Reduced use of non-renewable resources
	Improvement of competitiveness
	Reduction of emission or disposal fees
	Increased real estate value
	Energy security
Raising Staff Awareness	Employee satisfaction
	Emission reduction
	Reduced emissions (dust, CO2, chemical agents etc.)
	Improvement of competitiveness
	Reduction of operating costs
	Increased productivity
	Reduction of emission or disposal fees

	Reduction of emission or disposal fees
	Energy security
Heat Pumps and Heat Recovery	Emission reduction
	Reduced emissions (dust, CO2, chemical agents etc.)
	Increased real estate value
Cooling	Reduced emissions (dust, CO2, chemical agents etc.)
	Emission reduction
	Reduction of (operating) costs
	Energy security
	Reduced use of non-renewable resources
	Reduction of emission or disposal fees
	Improvement of competitiveness
	Increased real estate value
Roof Thermal Insulation	Emission reduction
	Employee satisfaction
	Increased real estate value
	Increased corporate image
	Customers (new, satisfaction, etc.)
	Reduced use of non-renewable resources
	Reduction of (operating) costs
	Energy security
Pumps	Emission reduction
	Reduced emissions (dust, CO2, chemical agents etc.)
	Reduced use of non-renewable resources
	Improvement of competitiveness
	Reduction of emission or disposal fees
	Increased real estate value
	Energy security
Transportation	Improvement of competitiveness
	Emission reduction
	Reduced emissions (dust, CO2, chemical agents)
	Reduction of operating costs

Source: KNOWnNEBs Tool 1 (73)

Definitions and Examples of Quantifiable Parameters for the NEBs:

NEBs	Description	Quantifiable Parameters
Emission reduction	Emissions related to any impact categories - climate change, ozone depletion, acidification, eutrophication, etc. (LCA) or individual metrics for CO, CO2, NOx, SOx and so on.	Quantitative - M Number of particles /m2
Increased real estate value	Spending money on energy efficiency measures can increase the real estate value of buildings	Quantitative - Assets value
Reduction of (operating) costs	Reduction of cost due to increased efficiency, productivity and right first time. Reduced manual labour costs.	N/A (Qualitative)
Improved lighting	The level of lighting is improved at the workspace, resulting in an improved working environment.	N/A (Qualitative)
Improvement of competitiveness	Improved image of a region/ country; can also be a quantified indicator as well. Higher customer satisfaction.	N/A (Qualitative)
Reduced emissions (dust, CO2, chemical agents etc.)	The harmful emissions of the processes and/or HVAC systems are reduced.	Quantitative - M Number of particles /m2
Reduced use of non-renewable resources	Reducing the non-renewable energy use in processes/building systems	N/A (Qualitative)
Reduction of emission or disposal fees	Reduction of emission or disposal fees.	N/A (Qualitative)
Energy security	Reduced import dependency, impact on RES integration, supplier diversity, etc.; Herfindahl-Hirschman Index.	Price forecast
Employee satisfaction	Increased employee satisfaction can appear as fringe benefits, making the company competitive with even less wages. Furthermore, can ease recruitment through the increased years spent at the workplace, etc. Employee satisfaction provides better value proposition. This includes improved working conditions and reduced staff turnover as well.	1. Quant./qualitative - Well-being 2. Quant./qualitative - Well-being - productivity 3. Qualitative - average nr of years that employees work at the company 4. Quantitative - Employee satisfaction (based on survey)
Increased productivity	Increased income due to better productivity.	N/A
Increased corporate image	By better corporate image new customers can be reached and also the staff turnover can be reduced as it is a prestige to work there.	N/A
Improved air quality	The air quality is improved at the workspace, resulting in an improved working environment.	Quantitative - Number of particles /m2

Source: KNOWnNEBs Tool 1 (73)

Assigning NEEs to Each EEM

To complement the NEB analysis, each EEM was screened for potential NEEs that could reduce or offset the anticipated benefits. This screening involved a focused desktop review of peer-reviewed literature, European Union guidance documents, and supplier case studies (76–92). Only NEEs substantiated by at least one credible and documented source were included.

The identified NEEs reflect common themes outlined in the KNOWnNEBs methodology, including rebound effects, upfront capital risks, operational challenges, technology compatibility issues, regulatory uncertainty, and environmental trade-offs (73). Each NEE was categorised based on its occurrence within the lifecycle of an EEM: Initial, Recurring, or Periodic.

Where quantification methodologies were available in the literature, NEEs were marked as quantifiable.

The full NEE matrix, detailing all identified NEEs, their classifications, and quantification status, is presented in the table below.

NEE Matrix:

EEMs	Time Period	NEE
Lighting	Initial	Retrofit Disruption and Downtime
		Upfront Design and Consultancy Costs
		Replacement Waste Disposal
	Recurring	Ongoing Maintenance
		Nuisance Glare, Flicker, and Sensor Mis-Triggers
	Periodic	Driver/Control-Gear Replacement
		Technology-Upgrade Capital and Installation Disruptions
		End-Of-Life Fixture Recycling Logistics
Building Heating	Initial	Capital and Design Costs
		Installation Disruption and Switchover Downtime
		Regulatory Permitting and Paperwork
	Recurring	Specialised Servicing and Parts
		Annual Safety/Emissions Inspections
		User Confusion Leading to Sub-Optimal Use
		Component Reliability Maintenance
	Periodic	Major Replacements
		Recalibration and Cleaning
Renewable Energies	Initial	Investment and Site-Preparation Constraints
	Recurring	Cleaning and Maintenance
		Insurance, Monitoring, and Feed-In Administration
		Power-Quality Equipment Upkeep
	Periodic	Inverter Replacements and Battery Swaps
		End-Of-Life Recycling and Disposal Logistics
Heat Pumps and Heat Recovery	Initial	Upfront Capital and Specialist Design
		Building Disruption
		Permitting and Structural/Vibration
	Recurring	Annual Servicing
		Higher Electricity Capacity Demands

		Commissioning Adjustments
	Periodic	Major Component Overhauls and System Recommissioning
Compressed Air Systems	Initial	Audit and Leak-Repair Labour Downtime
		Capital Costs for VSD Compressors and Power Upgrades
		System Re-Engineering
	Recurring	Filter/Dryer Maintenance and Condensate Management
		Continuous Leak-Detection Program Technician Hours
	Periodic	Compressor/Dryer Overhauls or Replacements
		Harmonic Filter Upgrades
		Insulation-Induced Corrosion Inspections
Optimisation	Initial	Consultant Studies, Data-Science Modelling, Software Licensing
		Staff Training and Change Management
		Initial Tuning Output Dips
	Recurring	Continuous Data Analysis and Energy-Manager Labour
		Sensor Calibration and Cybersecurity Updates
		Maintenance Of Advanced Control Software
	Periodic	Re-Optimisation Studies as Processes Change
		Audit/Verification Cycles
		Technology Obsolescence Upgrades
Ventilation	Initial	Complex Bespoke Design and Higher Engineering Fees
		Retrofit Disruption (Ductwork, Ceilings)
	Recurring	Frequent Filter/Fan Maintenance
		Sensor/Actuator Replacements
		Commissioning Recalibrations
		Occupant Comfort Complaints
	Periodic	VAV and HRV Component Replacements
		IAQ Investigations and Mold Remediation
		System Rebalancing and Control Updates
Cooling	Initial	High Chiller and Infrastructure Retrofit Costs
		Crane and Permit Logistics
		Refrigerant Safety Training
	Recurring	Coil Cleaning, Water Treatment, BMS Tuning
		Legionella Prevention Inspections
		Water Use Management for Evaporative Systems
	Periodic	Chiller Overhauls/Replacements
		Refrigerant Retrofits
		Cooling-Tower Refurbishments and Drift-Eliminator Upgrades

Energy Management System	Initial	Sub-Metering, Software, Audit and Certification Fees
		Energy-Team Formation and Training
		IT Integration and Cybersecurity Setup
	Recurring	Data Analysis and Reporting
		Procedural Audits and Documentation Upkeep
		Software License Renewals and Meter Calibration
	Periodic	Recertification Audits
		System Upgrades and Recertification Preparation
		Strategic Revisions and Program Re-Selling
Office Space (e.g., Equipment)	Initial	Higher Procurement Costs
		IT Compatibility and Power-Save Configuration Effort
		E-Waste Disposal and Data Wipes
	Recurring	Maintenance Of Smart Devices and Power Strips
		User Inconvenience from Sleep Modes
		Behavioural Reinforcement Campaigns
	Periodic	Refresh-Cycle Procurement and Disposal
		Office Re-Layouts and Recommissioning of Lighting/Control Systems
		Policy Compliance Updates
Building Envelop (Insulation, Windows, Shading)	Initial	Very High Retrofit Capital and Engineering Design
		Scaffolding, Noise/Dust Disruption
		Heritage and Planning Constraints
	Recurring	Maintenance Of Renders and Seals
		Moisture Monitoring and Facade Upkeep
		Shading Device Repairs and Motor Servicing
	Periodic	Window and Seal Replacements
		Facade Recladding or Insulation Renewal
		Compliance With Updated Fire and Aesthetic Regulations
Industrial Furnaces	Initial	Production Downtime for Retrofit
		Capital and Engineering Costs for Burners/Recuperators
		Commissioning Training and Yield Losses
	Recurring	Fouling Maintenance, Valve Calibration
		Sensor and Control System Monitoring
		Risk-Mitigation Maintenance for Added Components
	Periodic	Refractory Relining and Major Overhauls
		Burner and Control Upgrades
		Emissions-Driven Retrofits
	Initial	Labour, Scaffolding, and Shutdowns for Installation

Distribution Networks and Insulation		Engineering Design and Material Costs
	Recurring	Routine Inspection and Repair
		Corrosion-Under-Insulation Monitoring and Remediation
		Control-Setpoint Adjustments
	Periodic	Re-Insulation Projects
		Asbestos Or Waste-Disposal Compliance Updates
		Insulation Standard Upgrades
Pumps	Initial	Capital and Electrical Works for IE3/IE4 Pumps and Vfds
		System Re-Engineering and Harmonic Mitigation
	Recurring	VFD and Motor Maintenance (Fans, Capacitors, Bearings)
		Power-Quality Audits
		Operator Training and Performance Monitoring
	Periodic	Drive and Motor Replacements
		Re-Optimization Studies
		Technology Refreshes to Meet New Efficiency Standards
Raising Staff Awareness	Initial	Program designs: needs assessment, branding, material development
		Training launch sessions and staff time away from core duties
		Change management effort
	Recurring	Ongoing communications and refresher trainings
		Program administration and participation fatigue/attention cost
		Incentives and recognition
	Periodic	Pulse surveys and program re-designs
		Periodic train-the-trainer or onboarding revamps
		Occasional workplace changes for campaigns
Transportation	Initial	Policy and governance setup with legal/privacy review and internal comms
		Mobility platform and facilities procurement and configuration
		Launch training and change-management activities (temporary productivity losses during rollout)
	Recurring	Administration of benefits, compliance, licenses, contracts
		Ongoing employee training and schedule adjustments
		Routine upkeep of mobility assets
	Periodic	Hardware refreshes/upgrades (EV chargers, telematic units)
		Vendor retenders and contract renewals with mobility providers
		Compliance and safety audits, periodic re-certifications

Source: (76)-(92)

Definitions and Examples of Quantifiable Parameters for the "Summarised" NEEs:

The NEEs listed in the matrix above were grouped into clusters, and their quantifiable parameters were identified where available.

NEEs	Quantifiable Parameters	Sources
Increased consumption due to cost savings (rebound effect)	Quantifiable – can be measured as a rebound effect (e.g. comparing actual vs. expected energy use)	93
Behavioural changes (less vigilant energy use)	Quantifiable – contributes to rebound effect; has been observed and quantified in studies of efficiency rebound	73
Financing challenges (funding strain/opportunity cost)	N/A – no specific formula; impacts are context-specific (considered qualitatively in investment decisions)	N/A
Costs of technical design	Quantifiable – can be calculated as part of project costs (e.g. design labour hours * rate)	73
Complexity and downtime (implementation disruptions)	Quantifiable – downtime/interruptions can be monetized via lost production or delay costs	73
Loss of productivity during implementation	Quantifiable – valued by estimating output lost during the EEM installation period	73
Training and skill requirements (need for new skills)	N/A – no direct metric; addressed via training programs (only training cost is quantifiable, see below)	N/A
Training costs for employees (to operate new systems)	Quantifiable – training expenses can be calculated (hours of training * wage, etc.)	73
Additional stress on staff during implementation	N/A – no standard quantification; typically assessed qualitatively (e.g. via surveys)	N/A
Noise pollution during implementation (construction)	N/A – no explicit method to monetize short-term noise nuisance (usually treated qualitatively)	N/A
Additional software costs (e.g. new BMS licenses)	Quantifiable – added software expenses can be directly tallied in operational costs	73
Higher maintenance costs (post-EEM upkeep)	Quantifiable – increased maintenance needs are measurable as added annual cost	73
Periodic maintenance costs (e.g. scheduled major upkeep)	Quantifiable – future periodic servicing (e.g. facade cleaning every 10 years) can be projected and costed	73
Ongoing training costs for staff (refresher training)	Quantifiable – recurring training requirements can be estimated as periodic costs	73
Technology obsolescence (risk of early outdated equipment)	N/A – no fixed metric; handled via scenario analysis or shorter assumed asset life (case-by-case)	N/A
System compatibility issues (integration problems)	N/A – no standard quantification; impacts vary and are addressed through engineering evaluation rather than formula	N/A
Changing standards and incentives (policy/regulatory risk)	N/A – no explicit quantification method; typically handled via qualitative risk assessment or compliance scenario planning	N/A
Market fluctuations in energy prices (energy price risk)	Quantifiable – can be analysed via scenario or risk models (e.g. Value-at-Risk for energy cost volatility)	94

Material and resource inputs (rare materials footprint)	Quantifiable – environmental impacts can be quantified by Life Cycle Assessment (LCA) standards (e.g. ISO 14040)	95
Disposal and decommissioning issues (end-of-life impacts)	Quantifiable – end-of-life costs and impacts can be accessed via LCA or life cycle costing frameworks	95

Source: (72,93,94,95)

Conclusion:

Conclusion

As part of our engagement with the Malta Business Bureau (MBB), we have performed and delivered on the four objectives set out in the Call for Quotation document titled *"Economic Study on Energy Efficiency in Hotels & Manufacturing" (EE4SMEs Grant Agreement No. 101076459 LIFE21-CET-AUDITS)*.

Objective 1: Examine Energy Efficiency Measures

We analysed the EEMs recommended in 151 energy audits and assessed their implementation status using responses from the WP8 survey. This analysis revealed adoption trend, the financing mechanisms used or available in the market (including EU grants, bank loans, EPCs, ESCO agreements, green leasing, and white certificates), and the main barriers to implementation. The most common barriers cited were lack of funds (27% of respondents), time constraints (15%), and a perceived low need for action (15%). We also evaluated each measure's implementation cost, expected energy savings, net present value (NPV), payback period, greenhouse gas (GHG) reduction potential, and technical feasibility.

Objective 2: Conduct a Contextual Analysis

Through comprehensive desktop research using sources including EU studies, national policies, peer-reviewed publications, and supplier case studies, we:

- Explored the broader socio-economic benefits of energy savings, including health improvements, job creation, productivity gains, and regional development.
- Analysed energy production methods and trends across Austria, Bulgaria, Cyprus, Estonia, France, Germany, Italy, Malta, and Spain, detailing each country's dominant fuels, renewable penetration, and policy goals.
- Identified reference materials to monetise externalities (e.g. CO_2, SO_2, NO_x, particulate matter) for coal, oil, gas, nuclear, and renewables, and evaluated current and projected levelised costs of energy to inform comparative assessments.

Objective 3 & 4: Generate and Shortlist Recommendations; Evaluate and Prioritise Socio-Economic Impact

We developed a standardised shortlist of 18 EEM categories based on WP3 audit data and WP8 survey results. Using the KNOWnNEBs Tool 1, we identified the non-energy benefits associated with each measure, prioritising them from a management perspective to ensure relevance for decision-making. Additionally, we carried out desktop research to identify non-energy efforts, classifying them by timing (initial, recurring, or periodic) and by their quantifiability. Where data was available, we outlined methodologies to incorporate these non-energy impacts into financial decision-making.

Limitations

While this study establishes a robust analytical baseline, several limitations constrain the interpretation and application of its findings:

- **Data representativeness and quality**: All analyses under Objective 1 are based entirely on client-supplied energy audit and survey data. These datasets mainly represent micro and small enterprises in the hospitality sector, with limited coverage of medium-sized firms or heavy industry. The reported indicators exhibit strong positive skew and wide variability. While we used medians to reduce the influence of outliers, we did not explore the underlying causes of this dispersion, and variance metrics were excluded from headline results to maintain clarity.
- **Context-specific nature of NEIs**: Both non-energy benefits and non-energy efforts linked to energy efficiency measures are highly context-dependent. Their type and magnitude vary based on site-specific factors such as building conditions, business operational practices, and the technologies used. Generating robust, cross-company valuations for these impacts would

require extensive primary data collection, including large-scale surveys, structured interviews, and stakeholder workshops across all nine partner countries-activities that were beyond the scope of this study. While the KNOWnNEBs Tool 1 provides a structured approach for identifying NEBs, no equivalent tool exists for systematically identifying NEEs. Consequently, NEEs in this study were identified through targeted literature reviews.

- **Simplified technical feasibility assessment:** The technical feasibility scoring used in Objective 1 to assess energy efficiency measures was intentionally simplified. It applied equal-weighted criteria and did not account for detailed site-specific engineering, permitting requirements, or operational constraints. While this approach enables high-level comparisons across measures, it is not adequate for supporting detailed retrofit decision-making.

Recommended Next Steps

In light of these limitations, we recommend the following actions for MBB to build on the analytical foundation established in this report:

- **Enhance data representativeness and quality**
  Expand data collection efforts for energy audits and surveys to achieve broader and more balanced representation across enterprise sizes, industry sectors, and countries. Ensure consistency by aligning the categorisation of energy efficiency measures used in both audits and surveys. Additionally, incorporate supplementary attributes related to energy efficiency measures within the energy performance surveys to align them with audit data. Finally, conduct targeted analyses to investigate the underlying causes of data variability and dispersion.
- **Develop robust valuations for NEBs and NEEs**
  Conduct extensive primary research, including structured interviews, large-scale surveys, and stakeholder workshops across all partner countries, to generate reliable and context-specific data on the types and valuations of non-energy benefits and non-energy efforts across company profiles. Additionally, develop a dedicated, structured tool similar to the KNOWnNEBs Tool 1 to systematically identify and quantify NEEs.
- **Refine technical feasibility assessment**
  Transition from the simplified feasibility assessment used in Objective 1 to a more detailed and nuanced methodology that incorporates a multi-criteria decision-making framework. Ensure that future feasibility assessments accurately reflect real-world implementation challenges by including site-specific engineering evaluations, detailed permitting requirements, and operational constraints.

Appendix A:

Appendix A

Skewness Tables (Across company sizes)

Measures	Capital Cost Skewness	NPV Skewness	Payback Period Skewness	Primary Energy Savings – Electricity	Final Energy Savings – Electricity	Primary Energy Savings - Fuel	Final Energy Savings – Fuel
Optimisation	4.4	3.7	7.3	3.1	3.7	3.1	3.0
Energy management	1.6	2.8	4.5	2.4	1.7	1.7	2.3
Lighting	6.5	1.4	2.8	2.5	4.6	2.4	0.0
Office space (eg, equipment)	4.1	2.4	1.6	2.2	2.8	N/A	N/A
Distribution networks and insulation	3.0	-0.07	0.8	3.0	3.3	2.2	N/A
Building heating	4.4	2.2	2.4	2.0	2.2	N/A	N/A
Cooling	4.5	-1.3	1.1	2.2	1.2	N/A	N/A
Compressed air	3.4	1.7	-1.7	1.3	2.1	0.0	0.0
Ventilation	3.0	2.6	3.9	-0.5	2.9	2.2	0.9
Pumps	4.1	3.0	3.8	2.8	2.0	0.5	N/A
Industrial furnaces	3.0	N/A	N/A	N/A	N/A	N/A	N/A
Renewable energies	3.7	3.4	4.2	7.8*	7.8*	7.8*	7.8*
Heat pumps and heat recovery	3.8	1.7	2.6	1.6	2.2	0.9	1.1
Roof thermal insulation	1.9	-1.8	2.0	2.0	2.4	N/A	N/A
Openings replacement and shading	3.0	2.3	3.8	1.1	3.4	0.8	1.4
Facades thermal insulation	3.6	1.6	3.0	1.9	1.8	-0.1	N/A
Transportation	3.4	N/A	N/A	N/A	N/A	N/A	N/A
Raising Staff Awareness	0	N/A	0	N/A	1.7	N/A	N/A

* Energy savings for renewable energy measures were sourced from WP8. Since WP8 reports total energy savings without distinguishing between energy sources or between primary and final energy, the same skewness value was applied across all categories.

Detailed Alignment Procedure and Mapping of Energy Efficiency Measures

Step 1: Standardise measures originally listed under 'Other' in WP8

Measures originally listed under 'Other' in WP8.	Measures Reclassified
insulation and change of frame - new building	Facade thermal insulation
Insulation part of the building	Facade thermal insulation
replacing windows for more energy efficient	Openings replacement and shading
bath room renovation	Office space (e.g., equipment)
roaster	Industrial furnaces
Hot Water Flow Inhibitors	Distribution networks and insulation
Hot Water Flow Angle Valve Adjust	Distribution networks and insulation
Hot Water	Distribution networks and insulation
Hot Water angle valve adjust	Distribution networks and insulation
Hot Water Flow Management	Distribution networks and insulation
efficiency of production processes, as production has increased 8-9%	Optimisation
alignment to apply for Green Key certification	Optimisation
increasing efficiency of production processes	Optimisation
Monitoring	Energy Management
Adjustment of the controls	Optimisation
New hiring regulation heating, ventilation, cold	Optimisation
Hot Water Heater Switch-Off in unoccupied rooms	Optimisation
Raising staff awareness	Raising staff awareness
Voltage reduction	Optimisation
new fittings	Distribution networks and insulation
Buildingmanagementsystem / Monitoring	Energy management
District heating optimization, Voltage reduction	Building heating
Awareness-raising	Raising staff awareness

Step 2: WP3 Measures Remapped

Original WP3 Measures	Measures Reclassified
Lighting replacement w/ led	Lighting
Lighting replacement with led	Lighting
Cogenerator	Building heating
Cover for swimming pools	Optimisation
Heating system	Building heating
Hybrid boiler	Building heating

New boiler (pellets) with pipe isolation & circulation pumps	Building heating
Biomass boiler	Renewable energies
Cuadro generación teórica fotovoltaica	Renewable energies
New energy efficient biomass boiler	Renewable energies
New renewables system production	Renewable energies
Photo voltaic panels 12kwp	Renewable energies
Photovoltaic	Renewable energies
Photovoltaic plant	Renewable energies
Photovoltaic plant with storage	Renewable energies
Photovoltaic system	Renewable energies
PV	Renewable energies
PV battery storage	Renewable energies
PV panels x12	Renewable energies
Solar domestic hot water	Renewable energies
Solar thermal	Renewable energies
Solar thermal 300l x 2	Renewable energies
Solar thermal collectors	Renewable energies
Trigeneration system with biomass	Renewable energies
Direct evaporation heat pump	Heat pumps and heat recovery
Heat pump	Heat pumps and heat recovery
Heat pump for hot water	Heat pumps and heat recovery
Heat pump to replace 75% bolier	Heat pumps and heat recovery
Heat pumps x3 for hot water	Heat pumps and heat recovery
Heat recovery on compressors	Heat pumps and heat recovery
Heat recovery ventilation	Heat pumps and heat recovery
Kitchen hood heat recovery	Heat pumps and heat recovery
Moving the aerotherm	Heat pumps and heat recovery
Recuperación calor compresores	Heat pumps and heat recovery
Reversible heat pumps	Heat pumps and heat recovery
Study energy recovery from equipment	Heat pumps and heat recovery
Study heat recovery	Heat pumps and heat recovery
Using waset heat from chiller	Heat pumps and heat recovery
Waste heat recovery of filter cleaning water	Heat pumps and heat recovery
Auditoría de fugas aire comprimido	Compressed air
Carry out leaks detection and sealing campain for the compressed air network	Compressed air
Carry out regular leak detection campaign	Compressed air
Estudio fugas aire comprimido	Compressed air

Find/repair the compressed air network leaks	Compressed air
Optimizing the compressed air network	Optimisation
Sectorización red aire comprimido	Compressed air
Electronic devices should be switched off or on stand by	Raising staff awareness
Implement best practices in the kitchen (oven)	Raising staff awareness
Indoor pool lowering temperature	Optimisation
Optimise the operating times of electrical appliances	Optimisation
Optimize device operating time	Optimisation
Optimize device operation	Optimisation
Put electric devices on standby if possible	Optimisation
Regulate the temperature as closely as possible	Optimisation
Temperature adjustement	Raising staff awareness
HVAC optimization (incl. pipe insulation)	Distribution networks and insulation
HVAC replacement	Ventilation
Replace x6 vrf units	Ventilation
New vrv sistems	Ventilation
Switching from gas boiler to cmv	Building heating
VRF	Ventilation
VRV/vrf replacement	Ventilation
Centralize cold production	Cooling
Cerrar precámara de frío	Cooling
Cooling plant, free cooling	Cooling
Defrost more regularly & clean condensors	Cooling
New chiller	Cooling
New energy efficient chillers	Cooling
New energy efficient refrigerators	Cooling
Optimise cold distribution	Cooling
Refrigiration equipment upgrade	Office space (e.g., equipment)
Relocation of cold room compressor (new)	Cooling
Replacement refrigerant	Cooling
Ac temperature remote control	Optimisation
Automation installation	Energy management
Bms	Energy management
Bms - building management system	Energy management
Cambio de potencia contratada	Energy management
Do undercounting	Optimisation
Energy inspection	Energy management

Energy management system implementation (e.g iso 50 001 or similar)	Energy management
Monitoring elettric energy system	Energy management
Monitoring system for energy consumption	Energy management
Programación uso termos con fotovoltaica	Energy management
Set up a gtb	Energy management
Optimización potencia	Optimisation
Factura electrica	Optimisation
Ahorro factura electrica	Optimisation
Installing submeters	Energy management
Installing sub-competitor	Energy management
New setting building technology	Optimisation
New settins boiler regulation	Optimisation
Cambiar transformador de potencia a 100 kva	Optimisation
Electric car charging stations	Office space (e.g., equipment)
Eletric kitchens	Office space (e.g., equipment)
Induction cooking	Office space (e.g., equipment)
Eliminate mini-bars	Office space (e.g., equipment)
Covering and insulating baths	Office space (e.g., equipment)
Façades thermal insulation	Facade thermal insulation
Membrane on the windows	Openings replacement and shading
Membrane on windows	Openings replacement and shading
Openings replacement	Openings replacement and shading
Roof thermal insulation	Roof thermal insulation
Solar film on apertures	Openings replacement and shading
Sun shading devices	Openings replacement and shading
Walls and roof insulation	Facade thermal insulation
Walls and rooftop insulation	Roof thermal insulation
Windows replacement	Openings replacement and shading
Windows replacement (only shed)	Openings replacement and shading
Cambio seccion de cable	Distribution networks and insulation
Flow reducers on faucets & showers	Distribution networks and insulation
Insulating floor pipes	Distribution networks and insulation
Insulating the network	Distribution networks and insulation
Islotion pipes	Distribution networks and insulation
Isolation pipes	Distribution networks and insulation
Isolation pips	Distribution networks and insulation
Pipe insulation basement	Distribution networks and insulation

Pipe isolation	Distribution networks and insulation
Pipes isolation	Distribution networks and insulation
Tube insulation	Distribution networks and insulation
Ac temperature correct setting	Optimisation
Dejar el ge de backup	Optimisation
Domestic water heater switch-off when no demand	Optimisation
Domestic water heater swithc-off when no demand	Optimisation
Domestic water heaters switch-off at no demand	Optimisation
Domestic water heaters switch-off when no demand	Optimisation
Equipment upgrade	Optimisation
Hydraulic balancing	Optimisation
Regulation boiler	Optimisation
Circulation pumps	Pumps
Circulationpumps (heating and hot watewr)	Pumps
Freguency converters	Pumps
Frequency converters	Pumps
Inverter insertion	Pumps
New efficient pumps	Pumps
Variable speed drives on pumps	Pumps
Water supply pumps with inverter	Pumps
Industrial furnaces	Industrial furnaces

Detailed Mapping of Standardised EEMs with Tool 1 EEMs

Standardised Measures	Measures in Tool 1
Lighting	Energy Efficient Lights (e.g. LED), Level of Illumination, Control Optimisation
Compressed Air	Regular Maintenance of the Compressor, Regular Check for Leakage, Check the Required Pressure
Energy Management	Energy Management System, BMS, Measured Consumption, Improved Smart-Readiness
Openings Replacement and Shading	Replacement of Windows, Shading Install
Building Heating	New, More Efficient Heat Generation, Insulation of Distribution Network
Optimisation	Improved Energy Management, Roomwise Temperature Control, Zoning Optimisation, Schedule Optimisation, Setpoint Temperature Optimisation, Control Optimisation, System Balancing
Office Space (e.g. Equipment)	Energy Efficient Appliances, Reducing Stand-by Consumption, Optimal Usage, on Demand Operation
Industrial Furnaces	New, More Efficient Heat Generator, Insulation of Distribution Network
Renewable Energies	Solar PV, Wind Turbines, Solar Collector System, Geothermal Heat Pump, Passive Measures
Ventilation	Schedule, Control, Velocity, Inlet Temp Optimisation, Heat Recovery, Energy Efficient Fans
Façade Thermal Insulation	Improvement to Visible and Non-Visible Building Envelope Elements
Distribution Network and Insulation	Insulation and Balancing of the Distribution Network
Heat Pumps and Heat Recovery	Energy Efficient Equipment, Heat Recovery
Cooling	Room wise Temperature Control, Zoning Optimisation, Optimisation of the Cooling Schedule, Increasing Setpoint Temperature, Control Optimisation, Insulation of the Distribution Network, Hydraulic Balancing of the Distribution Network, New, More Efficient Heat Generator, Energy Efficient Pumps, Utilisation of Free Cooling
Roof Thermal Insulation	Improvement to Visible Building Envelope Elements
Pumps	Energy Efficient Pumps
Raising Staff Awareness	Employment Engagement and Training, Motivation, Reduction of Demand, Improved environmental awareness at the management level
Transportation	Optimisation of timetables, optimisation of routes, optimisation of loads, optimisation of the fleet, promote electromobility, promotion of modal shift for freight, regular maintenance, driver training