Scoping Study Report

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EcoSMEnergy

Introduction

The EcoSMEnergy project helps SMEs in selected manufacturing sectors increase their energy efficiency. It addresses barriers like limited awareness, financial access, and complex support by providing practical tools (energy audits, training, monitoring platforms), simplified information, and facilitating financial solutions through collaboration with institutions. The primary objective is to enhance energy efficiency and sustainability in SMEs across key sectors, including chemical manufacturing (C20), pharmaceuticals (C21), rubber and plastic products (C22), metal products (C25), electronics (C26), electrical equipment (C27), machinery (C28), and automotive manufacturing (C29).

The EcoSMEnergy project anticipates to deliver substantial energy savings, boost renewable energy use, cut greenhouse gas emissions, and foster investments in sustainable energy. SMEs will benefit from reduced costs and increased competitiveness, while the project makes a vital contribution to EU energy efficiency targets. This holistic approach provides real-world solutions for SMEs, aligning with EU directives and accelerating the transition to clean energy. Ultimately, we envision SMEs as central to achieving the EU's energy goals, fostering a cleaner and more prosperous future.

For the project to develop and deliver business-oriented solutions that meet the needs of the targeted sectors, the project partners start by conducting a baseline energy consumption assessment and awareness level evaluation of SMEs in the selected sectors.

The present report presents the outcome of the baseline energy consumption assessment with SMEs operating under NACE codes C20-C22 and C25-C29. The assessment was carried out in several steps: First, desk research was conducted, existing research and projects were reviewed to establish a baseline understanding of energy consumption trends in these sectors. In a second step, the Chamber partners (CCIs) engaged with companies across the designated NACE sectors and gathered precise data through a standardized collection template. Finally, the collected data underwent rigorous analysis and discussion, resulting in aggregated insights that assess energy usage across the various sectors. The results serve as a critical foundation for developing targeted energy efficiency recommendations, interventions, and benchmarking strategies.

Scoping study from literature and existing reports

NACE sector C20

The manufacture of chemicals and chemical products, classified as NACE C20 within the European Union's statistical nomenclature, is a sector of considerable energy intensity. This characteristic stems from the diverse and often energy-demanding processes inherent in chemical production. The chemical industry ranks among the foremost industrial consumers of energy, necessitating substantial inputs for its operations. The sector draws upon a spectrum of energy sources, encompassing electricity, natural gas, and petroleum derivatives, which are utilized both to generate process heat and as feedstock materials.

The EU-MERCI project assessed that the Energy consumption within the EU28's chemical manufacturing sector (NACE C20) is dominated by petrochemicals and basic inorganic chemicals, which account for 72% of total energy use. These energy-intensive upstream processes provide crucial feedstocks for downstream subsectors like polymers, specialty chemicals, and consumer chemicals. Fossil fuels and biomass are heavily relied upon for both energy and feedstock, with key processes like steam cracking, ammonia production, and chlorine production (primarily within petrochemicals and basic inorganics) estimated to represent over 30% of the entire chemicals and pharmaceutical sector's energy consumption. The same project shows that the fuel mix profile for the chemical and pharmaceutical sectors reveals a complex energy landscape. Electricity dominates, comprising 56% of the total fuel sources, suggesting a reliance on electrically driven processes and machinery. Gas holds a significant share at 32%, likely used for both process heat generation and as a crucial feedstock in various chemical syntheses, such as ammonia production. Solid fuels, probably coal, contribute 5%, indicating a continued, though smaller, dependence on this more carbon-intensive source. Petroleum-based products, representing 4% of the mix, highlights the sector's reliance on oil-derived resources. The "Other" category, at 3%, potentially encompasses a range of energy sources, possibly including some renewable energy contributions, though their share remains relatively small. This distribution underscores the sector's current energy profile, characterized by a strong dependence on electricity and gas, with a smaller but notable reliance on solid fuels and petroleum products. The relatively low contribution from "Other" sources suggests potential opportunities for diversification and increased integration of renewable energy technologies.

Figure 1 illustrates the diverse applications of electricity within the chemical and pharmaceutical sectors. "Other motors" constitute the largest single category of electricity consumption at 17%, highlighting the significant role of motor-driven equipment in various processes. Pumps and process-specific applications each account for 16% of the total electricity use, emphasizing the specialized energy demands of chemical and pharmaceutical manufacturing. Steam boilers and steam systems utilize 14% of the electricity, reflecting the importance of steam for process heat, sterilization, and other critical functions. Compressed gas/air systems contribute 14% for process-related activities and an additional 4% for utilities, underscoring the reliance on compressed air in these industries. HVAC systems, essential for maintaining controlled environments for both manufacturing and research, consume 11% of the total electricity. Fans and blowers represent 13% of electricity use, likely for ventilation and air circulation. Cooling and refrigeration, crucial for certain processes and product storage, along with furnaces, kilns, ovens, and dryers, each account for 2% of the electricity consumed. Lighting represents 1% of electricity use, while the remaining 1% is classified as "Other," encompassing a variety of miscellaneous electricity applications within the chemical and pharmaceutical sectors. This detailed breakdown of electricity end-uses provides valuable insights into the energy consumption patterns of these sectors, offering opportunities for targeted energy efficiency improvements and highlighting the diverse technological needs of the industry.

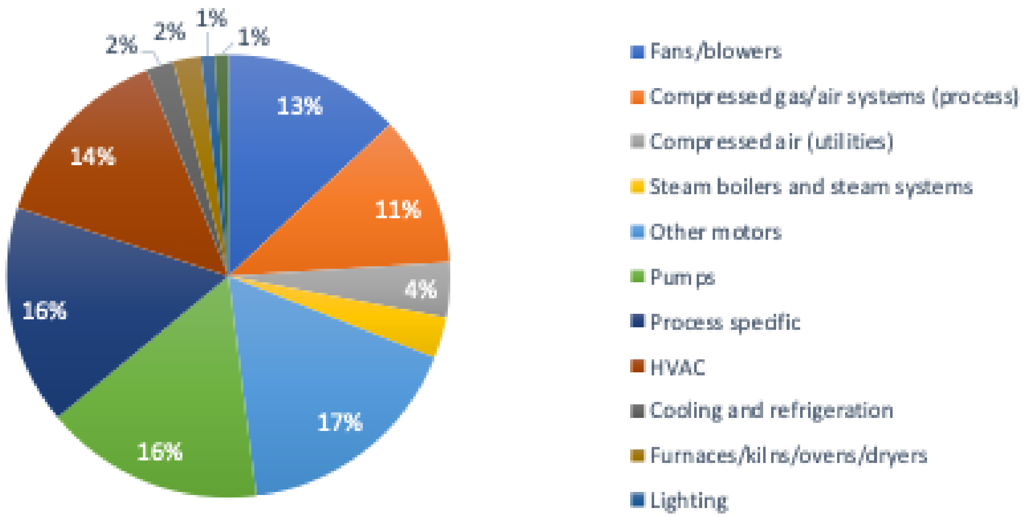

Figure 1. Electricity use profile in chemical and pharmaceutical sectors

Figure 2 illustrates the distribution of natural gas consumption within the chemical and pharmaceutical sectors. The largest proportion, 56%, is attributed to steam boilers and steam systems, indicating a substantial reliance on natural gas for steam generation. Furnaces, kilns, ovens, and dryers account for 26% of natural gas usage, reflecting the significant demand for process heat in manufacturing operations. HVAC systems consume 17% of the natural gas, highlighting the energy requirements for maintaining controlled environments. A small fraction, 1%, is designated as "Other," encompassing miscellaneous applications of natural gas within the sector. This distribution underscores the importance of natural gas as a primary energy source for both steam generation and direct heating processes in the chemical and pharmaceutical industries.

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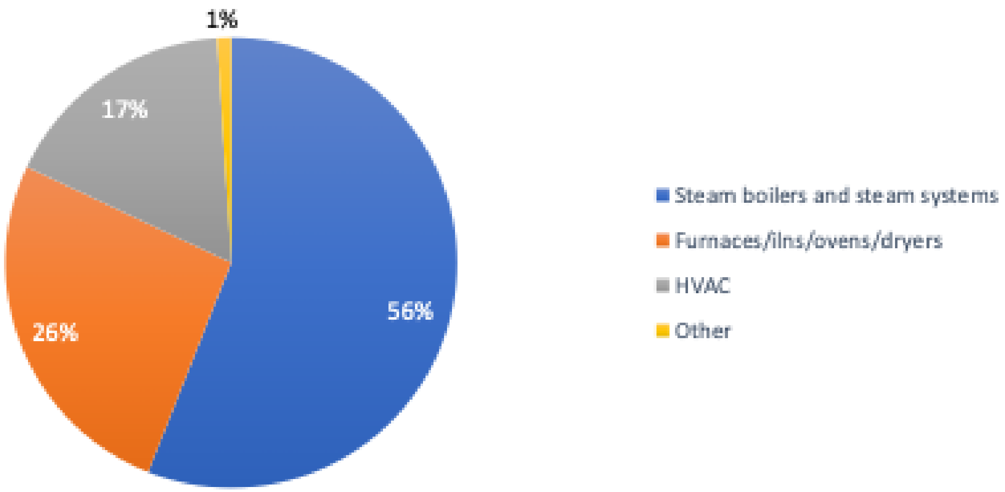

Figure 2. Natural gas use profile in the chemical and pharmaceutical sectors

NACE C20 is characterized by significant energy demands, though these vary considerably across subsectors. Basic chemical production, particularly the manufacturing of petrochemicals and inorganic chemicals, exhibits a notably high energy intensity. This contrasts with the production of specialty and consumer chemicals, which generally requires less energy input. This disparity in energy consumption arises from the inherent differences in the chemical processes involved and the nature of the final products.

Several key factors exert a strong influence on energy consumption within the NACE C20 sector. The specific chemical processes employed are a primary determinant of energy needs. Certain fundamental processes, such as distillation and cracking, which are essential for separating and transforming chemical substances, necessitate high temperatures and pressures. These extreme conditions translate directly into considerable energy consumption. Furthermore, the efficiency of the manufacturing technology and equipment utilized plays a crucial role in energy usage. Modern, state-of-the-art technologies offer the potential for substantial reductions in energy consumption compared to older, less efficient equipment. Economies of scale also have an impact on energy use. Larger-scale production operations often benefit from efficiencies in energy utilization, whereas smaller-scale or batch production may exhibit higher energy intensities. Finally, the types of chemical products manufactured significantly influence overall energy demand. C20.1, encompassing the manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics, and synthetic rubber in primary forms, is generally the most energy-intensive category. Within C20.1, sub-sectors such as the manufacture of industrial gases (C20.1.1), other inorganic basic chemicals (C20.1.3), other organic basic chemicals (C20.1.4), fertilizers and nitrogen compounds (C20.1.5), plastics in primary forms (C20.1.6), and synthetic rubber in primary forms (C20.1.7) are particularly energy-demanding due to the nature of their respective processes. These processes often involve high temperatures, pressures, and complex chemical transformations. The manufacture of dyes and pigments (C20.1.2) may also require significant energy input, though potentially less than other C20.1 sub-sectors.

Other categories within NACE C20 demonstrate varying levels of energy consumption. The manufacture of pesticides and other agrochemical products (C20.2), paints, varnishes, and similar coatings (C20.3), soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations (C20.4), and man-made fibres (C20.6) generally require less energy compared to basic chemical production. However, specific processes within these categories, such as the drying of coatings or the synthesis of certain agrochemicals, can still be relatively energy-intensive. The manufacture of other chemical products (C20.5) is a diverse category, and energy consumption will vary considerably depending on the specific products manufactured. For instance, the manufacture of explosives (C20.5.1) or glues (C20.5.2) may involve energy-intensive processes, while the manufacture of essential oils (C20.5.3) or other chemical products not elsewhere classified (C20.5.9) may have lower energy demands. It is important to note that energy consumption within each sub-sector is influenced by factors such as the specific technologies employed, the scale of production, and the overall efficiency of the manufacturing facility.

Binderbauer et al. (2023) suggest a relationship between specific energy consumption (SEC) and production capacity (C), expressed as $\log(e) = b - m \cdot \log(C)$, where 'e' represents SEC and 'C' represents production capacity, and 'b' and 'm' are the intercept and slope of the linear fit. Specifically, table 2 presents data concerning energy consumption within the chemical manufacturing sector, designated as NACE code C20. It details the relationship between energy consumption (both electricity and natural gas) and production capacity. The table includes the slope (m) and intercept (b) of linear regressions performed on the logarithm of specific energy consumption (SEC) and the logarithm of production capacity. For electricity, the slope is reported as 0.9910 and the intercept as 6.4982. For natural gas, the slope is 1.0222, and the intercept is 6.4784. The analysis is based on data collected from 99 locations or data points.

Table 2. Relation between specific energy consumption and production capacity for NACE C20.

NACE Code	Slope electricity m [kWh/t^2]	Intercept electricity b [log(kWh/t)]	Slope natural gas m [kWh/t^2]	Intercept natural gas b [log(kWh/t)]	Number of locations/ datapoints
C20	0.9910	6.4982	1.0222	6.4784	99

Energy efficiency is paramount within the NACE C20 sector (manufacture of chemicals and chemical products), driven by both economic and environmental necessities. The sector's inherent energy intensity makes energy efficiency improvements crucial for cost reduction, enhanced competitiveness, and minimizing environmental impact. Economically, energy expenses constitute a substantial portion of operational costs in the chemical industry. Increased energy efficiency directly translates to lower energy expenditures, thus improving profitability and market position. Optimized energy use can also lead to better process control, reduced downtime, and increased production. Efficient energy management contributes to conserving finite resources like fossil fuels, lessening dependence on volatile global energy markets.

Environmentally, the chemical industry's reliance on fossil fuels makes it a significant contributor to greenhouse gas emissions. Energy efficiency improvements are therefore essential for mitigating these emissions and addressing climate change. Fossil fuel combustion for energy also releases air pollutants, contributing to smog and respiratory problems. Energy efficiency measures are vital for minimizing these harmful emissions. Lower energy consumption also reduces the demand for raw materials used in energy production, such as coal, oil, and natural gas, supporting broader resource conservation.

The NACE C20 sector must balance its essential societal role with the inherent energy intensity of its operations. Significant energy efficiency improvements require a multifaceted approach addressing both fundamental chemical processes and broader energy management. Several strategies can enhance energy efficiency within NACE C20.

- **Process Optimization:**
    - **Heat Integration:** Recovering and reusing waste heat from one process to another, reducing the need for external heating.
    - **Process Intensification:** Developing more compact and efficient processes that require less energy and materials. Examples: microreactors, advanced separation techniques.
    - **Catalyst Development:** Developing more active and selective catalysts that enable reactions to occur at lower temperatures and pressures. This reduces the energy required for chemical transformations.
    - **Refining Catalytic and Steam Cracking (specific for olefin production):** Advanced furnace designs, optimized operating conditions, and maximized heat recovery.
    - **Catalytic Reforming (specific for high-octane gasoline components):** Advanced catalysts and efficient operating parameters.
    - **Ammonia Production (Haber-Bosch Process):** Optimization of the Haber-Bosch process, advanced catalysts, and effective waste heat recovery.
    - **Fertilizer Production:** Optimization of nitrogen, phosphate, and potash fertilizer production processes.
    - **Plastics Production:** Energy-efficient polymerization and exploration of renewable feedstocks.
- **Technology Upgrades:**
    - **High-Efficiency Motors and Drives:** Replacing standard motors with energy-efficient alternatives that reduce electricity consumption.
    - **Advanced Control Systems:** Implementing automation and control systems that optimize process parameters and minimize energy waste.
    - **Heat Recovery Equipment:** Installing heat exchangers, economizers, and other equipment to capture and reuse waste heat. Advanced insulation.
    - **Advanced Separation Technologies:** Membrane technology, advanced distillation, and other techniques that require less energy than traditional separation methods.
    - **Combined Heat and Power (CHP):** Generating electricity and heat

simultaneously, maximizing the overall efficiency of fuel utilization.
    - **Renewable Energy Integration:** Solar thermal or biomass for process heat to reduce fossil fuel dependence and lower emissions.
- **Energy Management Systems (EnMS):**
    - **Energy Audits:** Conducting thorough assessments of energy consumption to identify areas for improvement.
    - **Target Setting and Performance Tracking:** Establishing clear energy efficiency targets and monitoring progress through data collection and analysis.
    - ISO 50001 implementation.
    - **Real-Time Monitoring and Control:** Sensors and data analytics to identify energy waste and enable corrective actions.
    - **Predictive Maintenance:** Using data analysis to predict equipment failures and optimize maintenance schedules.
- **Behavioural Changes and Training:** Raising awareness among employees about energy conservation practices; Providing training on energy-efficient practices and equipment operation.
- **Collaboration and Knowledge Sharing:** Sharing best practices, case studies, and technological advancements; Developing industry standards.

Despite the significant potential benefits, challenges and opportunities remain. Capital investment for energy efficiency measures can be a barrier. Continued technological innovation is crucial for developing new, more efficient processes and technologies. Supportive government policies, including incentives and regulations, are vital for fostering energy efficiency. By embracing innovation, investing in advanced technologies, and implementing effective energy management, the chemical industry can achieve substantial cost savings, strengthen competitiveness, and contribute to a more sustainable future.

NACE sector C21

The manufacture of basic pharmaceutical products and pharmaceutical preparations, classified as NACE C21, exhibits a distinct energy consumption profile within the broader chemical industry. Unlike other chemical sub-sectors reliant on process heat derived from fossil fuels, NACE C21 demonstrates a greater dependence on electricity. Pharmaceutical manufacturing is an energy-intensive industry due to its stringent requirements and rigorous quality control standards. Precise temperature control is crucial for processes like reactions, fermentations, and storage, and electric heating and cooling systems are well-suited for this purpose. Maintaining sterile and contamination-free environments necessitates substantial electrically powered ventilation, air conditioning, and filtration systems. Specialized equipment, including that used for purification, separation (e.g., chromatography), and sterilization, further contributes to the sector's electricity dependence. These stringent standards also mandate high levels of environmental control, redundant systems (including backup power), and comprehensive testing procedures, all of which drive energy consumption. Several specific manufacturing processes are particularly energy-demanding. Maintaining stable temperatures for reactions, cell cultures, storage, and controlled environments requires significant heating and cooling. Ventilation and air conditioning systems, essential for clean and sterile production areas, are also major energy consumers. Purification and separation techniques like chromatography, filtration, and distillation, vital for isolating and purifying pharmaceutical compounds, can be energy-intensive depending on scale and methodology. Sterilization processes, regardless of the method used (heat, steam, etc.), require considerable energy input. Finally, water treatment and the use of compressed air for various operations add to the sector's overall energy footprint.

The relationship between energy consumption (both electricity and natural gas) and production capacity is defined in Table 3, which includes the slope (m) and intercept (b) of linear regressions performed on the logarithm of specific energy consumption (SEC) and the logarithm of production capacity Binderbauer et al. (2023).

Table 3. Relation between specific energy consumption and production capacity for NACE C21.

NACE Code	Slope electricity m [kWh/t^2]	Intercept electricity b [log(kWh/t)]	Slope natural gas m [kWh/t^2]	Intercept natural gas b [log(kWh/t)]	Number of locations/ datapoints
C21	1.0407	15.5050	0.9393	15.7362	176

Bruni et al (2023) provided some insights into the energy consumption of the pharmaceutical industry in Italy. They found that the high energy demand underscores the critical importance of implementing energy efficiency strategies. A significant challenge, however, is the scarcity of publicly accessible data regarding energy consumption within the pharmaceutical sector, which impedes thorough analysis and the development of targeted energy-saving initiatives. Research indicates that approximately 70% of energy use in pharmaceutical plants is attributable to auxiliary services, such as heating, ventilation, and air conditioning (HVAC) and compressed air systems, rather than the core production processes themselves. Furthermore, studies suggest that the size of the production area is a more reliable predictor of energy consumption than production volume, indicating that energy use is significantly influenced by the requirements for maintaining controlled environmental conditions. Despite these challenges, the sector possesses substantial potential for energy savings, particularly through optimizing HVAC systems, implementing heat recovery strategies, and improving the efficiency of compressed air systems. Energy audits are identified as a valuable instrument for pinpointing energy inefficiencies and formulating targeted energy-saving measures. Consequently, policy recommendations emphasize the need for promoting process-level energy monitoring and incentivizing energy efficiency improvements.

The pharmaceutical industry is increasingly prioritizing energy efficiency due to economic pressures and growing sustainability concerns. However, the industry faces challenges: stringent environmental and quality control requirements can limit flexibility; continuous operations hinder implementing energy-saving measures requiring downtime; and cost considerations regarding upfront investments in energy efficiency technologies must be balanced with production costs and product quality.

Energy consumption in pharmaceutical manufacturing (NACE C21) is driven by the need for precise control and sterile environments, with a strong reliance on electricity. While energy efficiency is a priority, the sector must navigate the complexities of regulatory compliance and continuous operation.

The pharmaceutical manufacturing sector has considerable potential for energy efficiency improvements, leading to significant cost reductions and environmental benefits. Key strategies include:

- **Process Optimization:**
    - **Reaction Optimization:** Employ highly selective catalysts to reduce energy input and maximize yield. Optimize reaction conditions (temperature, pressure, time) for minimal energy use and maximal product formation. Implement continuous flow chemistry for improved heat/mass transfer and reaction control.
    - **Separation and Purification Optimization:** Reduce or substitute solvents to lower energy use in recovery and waste treatment. Optimize crystallization for desired product properties with minimal energy. Utilize membrane technologies (e.g., nanofiltration, reverse osmosis) for energy-efficient separations.
    - Refining specific processes like freeze-drying through advanced controls can also yield substantial energy reductions.
- **Technological Upgrades:**
    - **Filtration and Purification:** Transition to advanced separation technologies like **membrane filtration** (e.g., reverse osmosis, ultrafiltration) and **chromatography**. These methods often require less energy than traditional thermal separation processes. Implement closed-loop purification systems to minimize water and solvent waste, further reducing energy demands associated with treatment and disposal.
    - Heating, Ventilation, and Air Conditioning - **HVAC Systems:** Install **high-efficiency filters** (e.g., HEPA, ULPA) to improve air quality while reducing fan energy consumption. Integrate **heat recovery systems** (e.g., heat exchangers, enthalpy wheels) to capture and reuse waste heat from exhaust air, reducing the need for external heating or cooling. Implement **demand-based ventilation** systems that adjust airflow based on occupancy and air quality, optimizing energy use. Ensure **optimized airflow** through proper duct design and maintenance, minimizing pressure drops and fan power requirements. Deploy **smart controls** (e.g., sensors, automation) to monitor and adjust HVAC system performance in real-time, maximizing efficiency.
    - **Efficient Equipment:** Replace standard electric motors with **high-efficiency motors** (e.g., IE3, IE4) to reduce electricity consumption in pumps, fans, and compressors. Transition to **LED lighting** throughout facilities, offering significant energy savings compared to traditional lighting technologies. Optimize **compressed air systems** by minimizing leaks, reducing operating pressure, and implementing variable-speed drives on compressors.
    - **Renewable Energy Sources:** Integrate **solar thermal** systems for process heating or hot water production, reducing reliance on fossil fuel-

based heating. Install **photovoltaic (PV) panels** on rooftops or available land to generate on-site electricity, supplementing grid power and reducing carbon emissions.
    - **Waste Heat Recovery:** Implement systems to capture and reuse waste heat from various processes, such as: Heat exchangers to transfer heat between process streams. Waste heat boilers to generate steam for heating or power generation. Organic Rankine Cycle (ORC) systems to convert low-grade waste heat into electricity.
- **Energy Management System:** Implementing energy audits, data analysis, target setting, performance tracking, and employee engagement programs is crucial for identifying and realizing energy efficiency opportunities. Real-time monitoring and control, along with building management systems for optimized lighting, heating, and cooling, are essential components.
- **Behavioural Changes and Training:** Raising awareness among employees about energy conservation practices; Providing training on energy-efficient practices and equipment operation.
- **Collaboration and Knowledge Sharing:** Sharing best practices, case studies, and technological advancements; Developing industry standards.

While the potential for energy efficiency within the pharmaceutical sector is substantial, several challenges impede its realization. Stringent regulatory requirements, particularly those concerning environmental control and product quality, can limit the flexibility in implementing certain energy-saving measures. This necessitates close collaboration with regulatory bodies to develop solutions that simultaneously satisfy both quality standards and energy efficiency objectives. Furthermore, the substantial upfront costs associated with many energy efficiency projects can present a significant financial barrier. Consequently, exploring alternative financing mechanisms, such as energy performance contracts, becomes essential. The continuous operation of many pharmaceutical facilities also poses a challenge, as it can be difficult to implement energy-saving measures that necessitate downtime. Therefore, careful planning and coordination are crucial to minimize disruptions to production during implementation. In summary, energy consumption within NACE C21 is driven by the specific demands of pharmaceutical manufacturing, including a strong reliance on electricity for precise control and the maintenance of sterile environments. While energy efficiency is an increasingly important priority, the sector must navigate the complex interplay of stringent regulatory requirements, the imperative for continuous operation, and the need to balance investment costs with other critical factors such as production costs and product quality.

NACE sector C22

The manufacture of rubber and plastic products (NACE C22) is a significant energy consumer within the chemical industry, utilizing a balanced mix of process heat and electricity. Process heat, typically derived from fossil fuels, is essential for plastics manufacturing, particularly for melting and processing resins and maintaining mold temperatures. Electricity is more prominent in rubber manufacturing, powering the mixing and processing of compounds and the operation of machinery used in tire production and other rubber products.

Energy intensity within NACE C22 varies depending on the specific products. Tire production, for example, is quite energy-intensive, while simpler plastic packaging production has lower energy demands. Key energy-consuming processes include plastic melting and processing, material mixing and compounding, molding and shaping (injection molding, extrusion, blow molding), tire building and curing, and heating and cooling for optimal temperatures. Compressed air generation also contributes to energy consumption.

Driven by rising energy costs and environmental concerns, the rubber and plastics industry is increasingly focused on energy efficiency. Strategies include process optimization, technology upgrades (replacing older equipment), waste heat recovery, material efficiency (minimizing waste), and renewable energy integration.

However, challenges exist. The sector's diverse range of products and processes makes standardized energy efficiency measures difficult to implement. Capital investment costs for new technologies can also be a barrier. Furthermore, while not directly related to manufacturing energy use, promoting rubber and plastic recycling can reduce the overall energy needed for new material production. In conclusion, energy consumption in NACE C22 is driven by the specific demands of rubber and plastic product manufacturing, relying on both process heat and electricity. Energy efficiency is a growing priority, with ongoing efforts focused on process optimization, equipment upgrades, and renewable energy exploration.

The relationship between energy consumption (both electricity and natural gas) and production capacity is defined in Table 4, which includes the slope (m) and intercept (b) of linear regressions performed on the logarithm of specific energy consumption (SEC) and the logarithm of production capacity Binderbauer et al. (2023).

Table 4. Relation between specific energy consumption and production capacity for NACE C22.

NACE Code	Slope electricity m [kWh/t^2]	Intercept electricity b [log(kWh/t)]	Slope natural gas m [kWh/t^2]	Intercept natural gas b [log(kWh/t)]	Number of locations/ datapoints
C22	0.6339	12.4199	0.8302	13.4126	378
C22.1	0.6775	12.7546	0.7482	13.4256	101
C22.21	0.5142	11.4198	0.7886	12.3529	81
C22.22	0.7100	13.0852	0.9539	14.4593	86

Piccioni et al (2024) offers insights into energy consumption and efficiency within the Italian rubber manufacturing industry (NACE Group C22.1): specifically on the manufacture of other rubber products (C22.1.9), such as gaskets and hoses, and the manufacture of rubber tires and tubes (C22.1.1). Both sub-sectors utilize energy-intensive processes like mixing, molding, vulcanization, and post-vulcanization, primarily relying on electricity and natural gas. For C22.1.9, natural gas constitutes over a third of total energy consumption, while for C22.1.1, it accounts for 50%. Specific energy consumption for C22.1.9 is 6,300 kWh of electricity and 1,800 kWh of natural gas per ton of product. For C22.1.1, electricity consumption is 1,800 kWh per ton, but natural gas consumption is not specified. Energy efficiency efforts in these sectors concentrate on production lines, compressed air systems, thermal power plants, and

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lighting, with interventions in compressed air and lighting often proving most cost-effective.

The rubber and plastics manufacturing sector offers substantial opportunities for energy efficiency improvements, leading to significant cost reductions, increased competitiveness, and a smaller environmental footprint. Key strategies include:

- **Process Optimization:** Includes optimizing molding and extrusion (mold design, melt temperatures, cycle times), efficient mixing and compounding, and reducing scrap and waste through **material Efficiency and product Design.** Emphasizes lightweight product design and materials, increasing the use of recycled materials, designing for recyclability, and implementing closed-loop recycling.
- **Technology Upgrades:** Focuses on investing in energy-efficient equipment (molding machines, extruders, mixers), advanced process control systems, improved insulation, heat recovery systems, and integrating renewable energy
- **Energy Management System:** Covers energy audits, data monitoring and analysis, setting energy efficiency targets, and employee engagement.
- **Behavioural Changes and Training:** Raising awareness among employees about energy conservation practices; Providing training on energy-efficient practices and equipment operation.
- **Collaboration and Knowledge Sharing:** Sharing best practices, case studies, and technological advancements; Developing industry standards.

Addressing challenges related to diverse processes, implementation costs, and operational integration is essential for realizing the full energy efficiency potential and creating a more sustainable industry.

NACE sector C25

The energy consumption within the NACE C25 sector, which encompasses the manufacture of fabricated metal products (excluding machinery and equipment), is of considerable interest to policymakers, industry stakeholders, and researchers alike. This sector's diverse activities, ranging from the production of structural metal components to the creation of metal packaging, contribute significantly to overall industrial energy demand. Understanding the specific energy consumption patterns within NACE C25 is crucial for developing effective strategies for energy efficiency improvements and decarbonization efforts.

When researching this topic, defining the specific area of interest within the NACE C25 classification is essential, as energy consumption can vary considerably depending on the particular manufacturing processes involved. NACE C25, holds the largest share of energy consumption within the machinery sector (EU-MERCI project). This can be attributed to the energy-intensive nature of the processes involved in producing fabricated metal products. Within NACE C25, specific subsectors stand out due to their significant energy demands: "Treatment and coating of metals; machining" (C25.6) and "Forging, pressing, stamping and roll-forming of metal; powder metallurgy" (C25.5). The former encompasses processes like surface treatment, heat treatment, and machining, all of which require substantial energy input. The latter involves shaping metal through force and/or heat, resulting in considerable energy consumption.

The key products manufactured under NACE C25 further contribute to its high energy consumption. These products include structural metal products (C25.1), tanks, reservoirs, and containers of metal (C25.2), steam generators (C25.3), weapons and ammunition (C25.4), cutlery, tools, and general hardware (C25.7), and other fabricated metal products (C25.9). The manufacturing of these products necessitates the energy-intensive processes mentioned earlier, thereby explaining the significant energy footprint of NACE C25.

The relationship between energy consumption (both electricity and natural gas) and production capacity is defined in Table 5, which includes the slope (m) and intercept (b) of linear regressions performed on the logarithm of specific energy consumption (SEC) and the logarithm of production capacity Binderbauer et al. (2023).

Table 5. Relation between specific energy consumption and production capacity for NACE C25.

NACE Code	Slope electricity m [kWh/t^2]	Intercept electricity b [log(kWh/t)]	Slope natural gas m [kWh/t^2]	Intercept natural gas b [log(kWh/t)]	Number of locations/ datapoints
C25	0.6812	5.1245	0.7035	5.3323	351
C25.11	0.6886	11.5488	0.7887	12.3043	106
C25.12	0.9568	13.9456	0.9466	14.2112	92
C25.5	0.6801	12.3737	0.7488	13.6044	96
C25.61	0.7927	12.8888	0.7177	13.6255	75

Given the high energy consumption of NACE C25, there is considerable room for improvement in energy efficiency.

- **Process Optimization:** Refining manufacturing techniques to minimize energy input. This can involve streamlining production flows, reducing material waste, and implementing advanced process control systems. Specific measures for:
  - **Forging, Pressing, Stamping, and Roll Forming:** Optimizing furnace operations (advanced designs, oxy-fuel combustion, waste heat recovery). Employing precision forging techniques to minimize material waste.
  - **Treatment and Coating of Metals:** Optimizing process bath usage (volume, temperature, heating methods). Implementing efficient drying technologies (infrared).
  - **Manufacture of Structural Metal Products:** Optimizing cutting and welding processes (laser cutting, friction stir welding, optimized arc welding). Investing in research and development for innovative technologies.
- **Technological upgrades:** Adopting energy-efficient equipment (induction furnaces, advanced forming technologies). Capturing and reusing waste heat (heat exchangers, waste heat boilers) for other purposes, such as preheating materials or heating buildings. Implementing combined heat and power (CHP) systems.

- **Energy Management Systems:** Energy audits for identifying areas for improvement and tracking progress over time. Monitoring, controlling, and optimizing energy use. Real-time monitoring and control of energy consumption. Utilizing predictive maintenance. Proper insulation of buildings and equipment. Minimizing compressed air leaks.
- **Behavioural Changes and Employee Training:** Raising awareness about energy conservation practices. Providing training on energy-efficient equipment operation. Fostering a culture of energy consciousness.
- **Collaboration and Knowledge Sharing:** Sharing best practices, case studies, and technological advancements. Accelerating the adoption of energy-efficient technologies and practices.

Challenges and limitations in accurately estimating energy consumption shares exist and are mainly due to the diverse range of products and processes within the machinery sector. Enhanced data collection and analysis could facilitate a more precise understanding of energy use patterns. Government policies and incentives, such as tax breaks, grants, and regulations, can play a significant role in encouraging businesses to invest in energy efficiency improvements.

NACE sector C26

The NACE C26 sector, encompassing the manufacture of computer, electronic, and optical products, represents a dynamic and technologically advanced segment of the manufacturing landscape. While often perceived as less energy-intensive than heavy industries, this sector nonetheless has a significant energy footprint, and understanding its consumption patterns is crucial for promoting sustainable practices. The energy demands within NACE C26 are driven by a variety of factors, including the operation of sophisticated manufacturing equipment, the maintenance of controlled environments for sensitive production processes, and the energy embodied in the complex supply chains associated with these products.

Focusing further on energy consumption within NACE C26, the manufacture of computer, electronic, and optical products reveals a complex interplay of factors influencing energy demand. While the sector is often characterized by its high-tech nature, the energy used is not solely related to the operation of final products. A significant portion of energy consumption occurs during the manufacturing processes themselves. For instance, the production of semiconductors, a critical component in many electronic devices, is notoriously energy-intensive, requiring substantial electricity for processes like etching, deposition, and cleaning in highly controlled cleanroom environments. These cleanrooms, essential for maintaining the ultra-pure conditions necessary for semiconductor fabrication, themselves consume significant energy for air filtration, temperature control, and lighting.Beyond semiconductor manufacturing, other segments within NACE C26 also contribute to energy demand. The production of printed circuit boards, the foundation of electronic devices, involves processes like etching, drilling, and soldering, all of which require energy input. The assembly of electronic components into finished products, while often less energy-intensive than component manufacturing, still requires energy for powering assembly equipment, lighting, and climate control in production facilities. Furthermore, the energy embodied in the materials used in these products should not be overlooked.

The extraction, processing, and transportation of raw materials, such as rare earth minerals used in electronics, contribute to the overall energy footprint of the sector. The complexity of global supply chains within NACE C26 means that assessing the full energy consumption requires considering the energy used at each stage of the product lifecycle, from raw material extraction to final assembly and even end-of-life recycling. The energy mix within NACE C26 is also a key consideration. While electricity is a primary energy source, other forms of energy, such as natural gas for heating and cooling, may also be used in manufacturing facilities. Understanding the specific energy sources used within the sector is crucial for developing strategies to reduce reliance on fossil fuels and transition to more sustainable energy options. Analyzing energy consumption data by sub-sector within NACE C26 can reveal specific areas of high energy demand and inform targeted interventions for energy efficiency improvements. For example, identifying the most energy-intensive processes in semiconductor manufacturing can guide research and development efforts focused on creating more energy-efficient fabrication techniques. Similarly, understanding the energy used in the production of specific types of electronic devices can inform product design choices that prioritize energy efficiency. A comprehensive understanding of energy consumption within NACE C26, therefore, requires a detailed analysis of the various manufacturing processes, the materials used, the energy sources employed, and the global supply chains involved.

The relationship between energy consumption (both electricity and natural gas) and production capacity is defined in Table 6, which includes the slope (m) and intercept (b) of linear regressions performed on the logarithm of specific energy consumption (SEC) and the logarithm of production capacity Binderbauer et al. (2023).

Table 6. Relation between specific energy consumption and production capacity for NACE C26.

NACE Code	Slope electricity m [kWh/t^2]	Intercept electricity b [log(kWh/t)]	Slope natural gas m [kWh/t^2]	Intercept natural gas b [log(kWh/t)]	Number of locations/ datapoints
C26	0.9673	14.5831	0.9971	13.9151	303
C26.11	1.0149	15.4412	1.0243	14.5664	77
C26.12	0.9596	14.5338	1.0596	14.3907	103
C26.51	0.9276	13.7743	0.9075	12.7882	94

The EU-MERCI project report offers a breakdown of energy consumption within the broader NACE C25-28 category (which includes C26). However, it doesn't provide specific insights into the energy consumption of the computer, electronic, and optical products sector (NACE C26) itself. The actual energy consumption within NACE C26 would depend on specific factors like:

- The types of electronic and optical products being manufactured
- The scale of production
- The energy efficiency of the manufacturing processes involved.

The NACE C26 sector holds significant potential for energy efficiency improvements. While often perceived as less energy-intensive than other manufacturing sectors, the complex and technologically demanding nature of its production processes presents numerous opportunities for optimization:

- **Process optimization:** Streamlining production flows. Implementing advanced process control systems (e.g., optimizing process gas utilization and reducing energy-intensive steps in semiconductor manufacturing). Optimizing cleanroom operations (advanced air filtration, temperature, and humidity control). Optimizing utilization of process gases in semiconductor manufacturing. Improving efficiency of etching and plating processes in PCB manufacturing. Optimizing soldering processes and minimizing compressed air use in electronic component assembly. Optimizing manufacturing processes for lenses and optical components. Minimizing material waste. Designing energy-efficient electronic products (energy-efficient components, optimized circuits, power management features). Promoting the use of recycled materials in electronic products.
- **Technological upgrades:** Developing and adopting more energy-efficient equipment (e.g., advanced lithography tools, energy-efficient lighting and climate control for cleanrooms); Investing in R&D for innovative, low-energy manufacturing technologies; Exploring alternative semiconductor manufacturing techniques (e.g., more efficient etching or deposition methods); Implementing more energy-efficient drying and curing methods for PCBs; Implementing robotic automation for assembly tasks; Implementing more efficient polishing and grinding techniques for optical instruments. Implementing energy-efficient building design (proper insulation, optimized heating, and cooling systems); Improving the efficiency of lighting, heating, and cooling systems in manufacturing facilities.
- **Energy Management Systems:** Monitoring, controlling, and optimizing energy use within facilities; Identifying areas of energy waste; Tracking energy consumption patterns; Implementing strategies for reducing energy losses.
- **Behavioural Changes and Training:** Raising awareness among employees about energy conservation practices; Providing training on energy-efficient equipment operation; Conducting regular energy audits.
- **Collaboration and Knowledge Sharing:** Sharing best practices, case studies, and technological advancements; Developing industry standards.

NACE sector C27

The NACE C27 sector, encompassing the manufacture of electrical equipment, plays a crucial role in modern society, providing the foundation for numerous industries and everyday technologies. This sector's energy consumption is significant, driven by the diverse range of products manufactured, from electric motors and generators to wiring devices and domestic appliances. Understanding the energy consumption patterns within NACE C27 is essential for promoting energy efficiency and sustainability within this vital sector.

Energy consumption in NACE C27 is influenced by various factors, including the energy intensity of specific manufacturing processes, the scale of production, and the types of materials used. The sector's diverse product portfolio, ranging from highvoltage transmission equipment to household appliances, necessitates a granular approach to understanding energy use. The manufacture of certain electrical equipment, such as large transformers or industrial motors, can be particularly energy-intensive, requiring substantial electricity for processes like metal melting, forming, and testing. Conversely, the production of smaller components or appliances may have a lower energy footprint per unit, but the sheer volume of production can still contribute to significant overall energy demand, particularly in processes involving copper drawing and insulation.

The manufacture of batteries, a rapidly growing segment within NACE C27, presents unique energy considerations. Battery production involves energy-intensive processes like electrode manufacturing, electrolyte preparation, and cell assembly. The energy required can vary significantly depending on the battery chemistry and manufacturing technology used. As demand for batteries, particularly for electric vehicles and renewable energy storage, continues to rise, optimizing the energy efficiency of battery production is crucial for minimizing the environmental impact of this growing industry. Lighting equipment manufacturing represents another significant segment within NACE C27. While modern lighting technologies, such as LEDs, are themselves more energy-efficient than traditional lighting sources, the manufacturing processes involved in producing these devices still require energy input. This includes the production of semiconductor materials for LEDs, the assembly of lighting fixtures, and the testing of finished products. Domestic appliance manufacturing also contributes to the overall energy consumption of NACE C27. While individual appliances may have relatively low energy consumption during use, the sheer volume of production and the energy embodied in the materials used contribute to significant overall energy demand. Manufacturing processes for appliances can include metal forming, plastic molding, and assembly operations, all of which require energy input. Beyond the manufacturing processes themselves, energy is also used within NACE C27 facilities for lighting, heating, ventilation, and air conditioning. Optimizing these building systems can further reduce overall energy consumption. The transportation of raw materials and finished products also contributes to the sector's energy footprint, highlighting the importance of considering the entire supply chain when assessing energy consumption.

The relationship between energy consumption (both electricity and natural gas) and production capacity is defined in Table 7, which includes the slope (m) and intercept (b) of linear regressions performed on the logarithm of specific energy consumption (SEC) and the logarithm of production capacity Binderbauer et al. (2023).

Table 7. Relation between specific energy consumption and production capacity for NACE C27.

NACE Code	Slope electricity m [kWh/t^2]	Intercept electricity b [log(kWh/t)]	Slope natural gas m [kWh/t^2]	Intercept natural gas b [log(kWh/t)]	Number of locations/ datapoints
C27	0.8739	13.1759	0.9849	14.2369	102

Given the diverse range of products manufactured within this sector, from heavy industrial equipment to consumer appliances, a multi-faceted approach is required to unlock the full potential for energy savings:

- **Process optimization:** This involves streamlining manufacturing operations, minimizing material waste, and implementing advanced process control systems to reduce energy consumption at each stage of production. For instance, optimizing the melting and casting processes for large electrical components can significantly decrease energy requirements. Process specific strategies:
    - **Electrical Motors and Generators:** Optimizing design and material selection to reduce energy losses. Utilizing high-efficiency materials for windings and laminations. Minimizing friction and improving cooling systems. Implementing variable speed drives (VSDs) for optimized energy use.
    - **Batteries:** Optimizing electrode manufacturing processes. Improving energy efficiency in cell assembly. Researching advanced battery chemistries and manufacturing techniques. Implementing closed-loop recycling processes for battery materials.
    - **Lighting Equipment:** Promoting the adoption of energy-efficient lighting technologies (LEDs). Optimizing LED fixture design and light extraction efficiency. Integrating smart lighting controls (occupancy sensors, daylight harvesting).
    - **Wiring and Cabling:** Optimizing conductor materials and design to reduce energy losses. Utilizing high-conductivity materials (copper, aluminium with optimized cross-sections). Improving insulation materials and manufacturing processes.
    - **Domestic Appliances:** Improving the energy efficiency of individual appliances. Better insulation. More efficient compressors (refrigerators). Optimized heating elements (ovens). Improved motor designs (washing machines). Implementing smart features (energy-saving modes, remote control).
- **Technological upgrades:**
    - **Technological Innovation: Research and Development Investment:** Allocate resources for R&D focused on creating and implementing cutting-edge, energy-efficient equipment. This includes advanced winding machines for electric motors, optimized power supplies for electronic devices, and next-generation battery manufacturing technologies. **Alternative Materials and Processes: Investigat**e and adopt innovative materials and manufacturing techniques that reduce energy intensity. This may involve exploring new conductive materials, advanced coatings, or additive manufacturing methods. **Automation and Smart Technologies:** Incorporate automation and smart technologies, such as IoT-enabled sensors and AI-driven control systems, to enhance energy consumption optimization in real-time.
    - **Heat Recovery: Implementation of Heat Exchangers:** Install heat exchangers to capture and reuse waste heat from various manufacturing processes, such as metal melting, soldering, or heat treatment. **Waste Heat Boilers:** Utilize waste heat boilers to generate steam or hot water

from recovered heat, which can be used for other industrial processes or building heating. **Organic Rankine Cycle (ORC) Systems:** Where appropriate, implement ORC systems to convert low-grade waste heat into electricity. **Cascade Heat Use:** Design processes so that the waste heat of one process becomes the input heat of another process.

  - **Energy Waste Reduction: Enhanced Building Insulation:** Improve the insulation of buildings and facilities to minimize heat loss or gain, reducing the energy required for heating and cooling. **Compressed Air Leak Minimization:** Implement regular inspections and maintenance programs to identify and repair compressed air leaks, which can account for significant energy losses. **Equipment Insulation:** Insulate all heat generating equipment, and heat carrying pipes, and tanks. **Lighting Optimization:** Implement LED lighting, and lighting controls, such as motion sensors, and daylight harvesting. **Variable Speed Drives:** Implement VSDs on all applicable motors, to reduce energy consumption during partial load operation.

- **Energy management systems:** Regular energy audits can help identify areas for improvement and track progress over time. Monitoring, controlling, and optimizing energy use within manufacturing facilities. These systems can identify areas of energy waste, track energy consumption patterns, and implement strategies for reducing energy losses.
- **Behavioural changes and employee training:** Raising awareness among employees about energy conservation practices and providing training on energy-efficient operation of equipment can contribute to a culture of energy consciousness within organizations.
- **Collaboration and knowledge sharing:** Sharing best practices, case studies, and technological advancements can accelerate the adoption of energy-efficient technologies and practices across the sector.

NACE sector C28

The NACE C28 sector, encompassing the manufacture of machinery and equipment not elsewhere classified, represents a significant consumer of energy within the broader industrial landscape. This sector's diverse activities, ranging from the production of metalworking machinery and construction equipment to the manufacturing of engines and turbines, contribute substantially to overall energy demand. Understanding the specific energy consumption patterns within NACE C28 is crucial for developing effective strategies for energy efficiency improvements and promoting sustainable manufacturing practices.

Energy consumption within NACE C28 is influenced by a multitude of factors, including the energy intensity of specific manufacturing processes, the scale of production, and the types of machinery and equipment being produced. The manufacture of heavy machinery, such as large engines or industrial presses, often involves energy-intensive processes like metal casting, forging, and machining, requiring significant electricity consumption. Conversely, the production of smaller or more specialized equipment may have a lower energy footprint per unit, but the cumulative energy demand can still be substantial due to the volume of production.

Expanding on the details of energy consumption within NACE C28, the manufacture of machinery and equipment not elsewhere classified, reveals a complex interplay of factors influencing energy demand. The sector's broad scope, encompassing everything from agricultural machinery to specialized industrial robots, necessitates a nuanced understanding of energy use across diverse manufacturing processes. For instance, the production of heavy construction equipment, such as excavators and bulldozers, often involves energy-intensive processes like welding large metal structures, requiring substantial electricity. The manufacture of engines and turbines, crucial for power generation and transportation, also contributes significantly to energy demand, particularly in processes involving high-precision machining and testing.
The production of agricultural machinery, while potentially less energy-intensive per unit than heavy construction equipment, still represents a significant energy consumer due to the scale of production and the materials used. Manufacturing processes for agricultural machinery can include metal forming, casting, and assembly, all requiring energy input. Furthermore, the energy embodied in the materials used in these machines, such as steel and aluminium, should not be considered. The extraction, processing, and transportation of these materials contribute to the overall energy footprint of the sector.
Machine tool manufacturing, a critical sub-sector within NACE C28, also has specific energy considerations. The production of machine tools, used in various manufacturing industries, involves precise machining operations, often requiring high-speed cutting and grinding, which can be energy-intensive. The testing and calibration of machine tools also contribute to energy demand.
Beyond the specific manufacturing processes, energy is also used within NACE C28 facilities for lighting, heating, ventilation, and air conditioning. The transportation of raw materials and finished products contributes to the sector's energy footprint, underscoring the importance of considering the entire supply chain when assessing energy consumption. The energy mix within NACE C28 is also a key consideration. While electricity is a primary energy source, other forms of energy, such as natural gas for heating and cooling, may also be used in manufacturing facilities.

The NACE C28 sector presents a complex landscape of energy efficiency opportunities due to the diverse nature of its activities. While broad strategies like process optimization and technological advancements are relevant, more specific approaches are crucial for maximizing energy savings within this sector.

- **Process Optimization:**
    - **Optimizing Cutting Fluid Application:** Implementing Minimum Quantity Lubrication (MQL) or dry machining techniques. Optimizing cutting fluid recirculation and filtration.
    - **Improving Hydraulic System Efficiency:** Optimizing hydraulic circuit design. Reducing hydraulic system pressure and flow rates. Implementing regenerative hydraulic circuits.
    - **Optimizing Combustion Processes (Engines/Turbines):** Implementing lean burn and exhaust gas recirculation (EGR) technologies. Optimizing fuel injection and air intake systems.
    - **Optimizing Machining Operations:** Implementing advanced control systems for machine tools to minimize idle time. Optimizing cutting

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parameters to reduce energy consumption. Implementing precision manufacturing to minimize material waste.
    - **Optimizing Assembly Processes:** Streamlining assembly lines to reduce material handling and transportation. Implementing automated assembly processes to improve efficiency.
    - **Optimizing Design for Reduced Rolling Resistance (Agricultural Machinery):** Optimizing tire design and pressure. Optimizing drive train efficiency.
    - **Implementing Precision Agriculture Techniques:** Variable rate seeding and fertilization.
- **Technology Upgrades:**
    - **High-Efficiency Hydraulic Components:** Implementing efficient hydraulic pumps, valves, and actuators.
    - **Alternative Power Sources:** Exploring and implementing electric or hybrid powertrains for construction and mining equipment.
    - **Advanced Combustion Technologies:** Implementing advanced combustion technologies for engines and turbines.
    - **Advanced Control Systems:** Utilizing advanced control systems for machine tools and equipment. Implementing smart sensors and control systems for hydraulic systems.
    - **Energy-Efficient Motors and Drives:** Implementing high-efficiency electric motors and variable speed drives (VSDs).
    - **Advanced Materials:** Utilizing lighter and stronger materials to reduce equipment weight.
    - **Heat Recovery Systems:** Implementing heat exchangers to capture and reuse waste heat from engines and processes.
    - **LED Lighting:** Upgrading facility lighting to LED.
    - **Building and Equipment Insulation:** Insulating buildings and equipment to reduce heat loss.
- **Energy Management System (EnMS):**
    - **Energy Audits:** Conducting regular energy audits to identify areas for improvement.
    - **Real-Time Monitoring and Control:** Implementing sensors and data analytics to monitor energy consumption. Utilizing predictive maintenance to prevent equipment failures.
    - **Target Setting and Performance Tracking:** Establishing energy efficiency targets and tracking progress.
    - **Compressed Air Leak Management:** Regular inspection and repair of compressed air leaks.
    - **ISO 50001 Implementation:** Formalizing an energy management system.
- **Behavioural Changes and Employee Training:**
    - **Energy Awareness Programs:** Educating employees on energy conservation practices.
    - **Training on Energy-Efficient Equipment Operation:** Providing training on proper operation and maintenance of machinery and equipment.
    - **Incentive Programs:** Rewarding employees for energy-saving ideas.
- **Collaboration and Knowledge Sharing:**

- **Industry Partnerships:** Collaborating with suppliers, customers, and research institutions.
- **Research and Development Collaboration:** Partnering with universities and research organizations.
- **Industry Associations and Networks:** Participating in industry associations and sharing best practices.
- **Government and Regulatory Collaboration:** Working with government agencies to promote energy efficiency.
- **Sharing best practices related to the full lifecycle of the products:** Repairability, recyclability, and end-of-life management.

NACE sector C29

The NACE C29 sector, encompassing the manufacture of motor vehicles, trailers, and semi-trailers, represents a significant energy consumer within the broader manufacturing landscape. This sector's activities, ranging from the production of passenger cars and commercial vehicles to the manufacturing of components and parts, contribute substantially to overall energy demand.

Energy consumption in NACE C29 is influenced by a variety of factors, including the energy intensity of specific manufacturing processes, the scale of production, and the types of vehicles and components being produced. The manufacture of vehicles involves a range of energy-intensive processes, such as metal stamping, welding, painting, and assembly, all of which require significant electricity and other energy inputs. The production of certain components, such as engines and transmissions, can also be particularly energy-intensive.

The sheer scale of the automotive industry, coupled with the intricate manufacturing processes involved, makes understanding energy consumption patterns crucial for driving sustainability. For instance, the body-in-white (BIW) production, where the vehicle's structural shell is assembled, involves extensive welding, a process requiring significant electrical energy. The type of welding used, such as resistance spot welding or laser welding, can influence energy consumption. Furthermore, the materials used in BIW construction, such as steel or aluminium, impact the energy required for forming and joining.

The paint shop, another significant energy consumer within automotive manufacturing, requires precise temperature and humidity control for optimal paint application and drying. This involves substantial energy for heating, ventilation, and air conditioning (HVAC) systems. The type of paint used and the painting process itself can also influence energy consumption. Powder coating, for example, can be more energy-efficient than traditional liquid painting in certain applications.

Powertrain manufacturing, encompassing the production of engines and transmissions, is often particularly energy-intensive. Processes like metal casting, forging, and machining require significant electricity and other energy inputs. The type of engine being manufactured, whether internal combustion, hybrid, or electric, influences the specific energy requirements. As the automotive industry transitions towards electric vehicles, the energy used in battery production becomes increasingly relevant. Battery manufacturing involves energy-intensive processes like electrode production, electrolyte preparation, and cell assembly.

Beyond the core manufacturing processes, energy is also consumed in other areas within NACE C29 facilities. Lighting, heating, and cooling of production halls, offices, and other buildings contribute to overall energy demand. Compressed air systems, used for various purposes in vehicle assembly, can also be significant energy consumers if not properly maintained and optimized. The transportation of parts and finished vehicles, both within the factory and along the supply chain, also contributes to the sector's energy footprint.

- **Process Optimization:**
  - **Welding Process Optimization:** Optimizing resistance spot welding parameters. Implementing friction stir welding for aluminium joining. Reducing welding cycle times and energy intensity.
  - **Paint Shop Optimization:** Optimizing paint application schedules and sequences. Minimizing overspray and paint waste. Optimizing drying oven temperatures and airflow.
  - **Powertrain Manufacturing Optimization:** Optimizing metal casting and forging process parameters. Implementing near-net-shape forming and cryogenic machining. Optimizing machining parameters to reduce material waste and energy consumption.
  - **Assembly Line Optimization:** Streamlining material flow and reducing transportation distances. Optimizing assembly line speeds and cycle times. Implementing just-in-time inventory management.
  - **BIW (Body-in-White) Production:** Optimizing material usage and reducing scrap.
- **Technology Upgrades:**
  - **Welding Technology Upgrades:** Implementing advanced welding control systems. Adopting energy-efficient welding equipment.
  - **Paint Shop Technology Upgrades:** Implementing high-efficiency HVAC systems. Adopting advanced paint application technologies (e.g., electrostatic spraying). Installing heat recovery systems for drying ovens.
  - Switching to waterborne paints, or powder coating.
  - **Powertrain Technology Upgrades:** Implementing advanced machining tools and control systems. Adopting energy-efficient metal casting and forging equipment.
  - **Electric Vehicle (EV) Battery Production Upgrades:** Implementing advanced electrode manufacturing technologies. Adopting energy-efficient cell assembly equipment.
  - **General Manufacturing Upgrades:** Implementing high-efficiency compressed air systems. Installing LED lighting. Integrating renewable energy sources (solar panels, wind turbines). Implementing advanced robotic systems, for more precise work, and less waste.
  - **Vehicle Design Upgrades:** Implementing lightweight materials (high-strength steel, aluminium, composites). Improving vehicle aerodynamics. Optimizing engine and electric motor performance. Implementing smart charging systems for EVs.
- **Energy management systems:** Regular energy audits can help identify areas for improvement and track progress over time. Monitoring, controlling, and optimizing energy use within manufacturing facilities. These systems can

identify areas of energy waste, track energy consumption patterns, and implement strategies for reducing energy losses.

- **Behavioural changes and employee training:** Raising awareness among employees about energy conservation practices and providing training on energy-efficient operation of equipment can contribute to a culture of energy consciousness within organizations.
- **Collaboration and knowledge sharing:** Sharing best practices, case studies, and technological advancements can accelerate the adoption of energy-efficient technologies and practices across the sector.

Scoping Study from interviews

Sample of companies

Table 8 lists the companies participating in the scoping studies through direct interviews.

#	MS	NACE CODE	Description	Size
1	Cyprus	C20.2	Manufacture of chemicals	Small
2	Cyprus	C20.2	Manufacture of chemicals	Small
3	Cyprus	C20.2	Manufacture of crop protection, crop nutrition, animal health & public health products	Medium
4	Malta	C21.2	Chemical Synthesis (APIs)	Medium
5	France	C22	Manufacture of other plastic products	Small
6	Malta	C22.2	Plastic production and assembly for battery components	Medium
7	Estonia	C22.2	Manufacture of polyurethane products	Medium
8	Estonia	C22.2	Manufacture of polyethylene products	Small
9	Spain	C22.22	Manufacture of plastic packing goods	Small
10	Malta	C22.29	Polystyrene Manufacture	Medium
11	Malta	C22.29	Plastic packaging manufacturing	Small
12	France	C25	Manufacture of metal building components	Small
13	France	C25	Manufacture of fabricated metal products	Small
14	Latvia	C25.11	Manufacture of fabricated metal products and parts	Medium
15	Latvia	C25.11	Manufacture of fabricated metal products and components; structural metal products and parts	Medium
16	Estonia	C25.11	Manufacture of other metal structures and parts	Small
17	Spain	C25.12	Manufacture of doors and windows of metal	Medium
18	Estonia	C26.1	Manufacture of electronic components	Medium
19	Latvia	C26.11	Manufacture of electronic components	Medium
20	Latvia	C26.11/12	Manufacture of electronic components	Medium
21	Spain	C26.11	Manufacture of electronic systems and components	Medium
22	France	C27	Manufacture of electric lighting equipment	Small
23	Cyprus	C28	Manufacture of auto spare parts and filters	Small
24	Latvia	C28.22	Manufacture of lifting and handling equipment	Medium
25	Spain	C28.91	Manufacture of machinery for metallurgy	Small
26	Cyprus	C28.93	Manufacture of food processing machines	Medium
27	Estonia	C29	Manufacture of trailers, semi-trailers and containers	Medium
28	Spain	C29.31	Manufacture of electrical and electronic equipment for motor vehicles	Small

Table 8. Sample of companies participating to the scoping study interview.

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Figure 3 illustrates the proportional distribution of the companies' manufacturing sectors, from NACE codes C20 to NACE code C29. Notably, the manufacture of rubber and plastic products (C22) represents the largest segment, constituting 25% of the distribution, thereby indicating its significant prevalence within the sample of companies. Sector C25 (manufacture of fabricated metal products, excluding machinery and equipment) accounts for 21% of the distribution. C26 (manufacture of computer, electronic and optical products), and C28 (manufacture 1 of machinery and equipment n.e.c.) each account for 14% of the distribution; while, sectors C20 (manufacture of chemicals and chemical products), constitutes 11% of the distribution. The manufacture of motor vehicles, trailers and semi-trailers (C29) represents 7% of the sample. Finally, the manufacture of basic pharmaceutical products and pharmaceutical preparations (C21) and the manufacture of electrical equipment (C27) each represent 4% of the distribution.

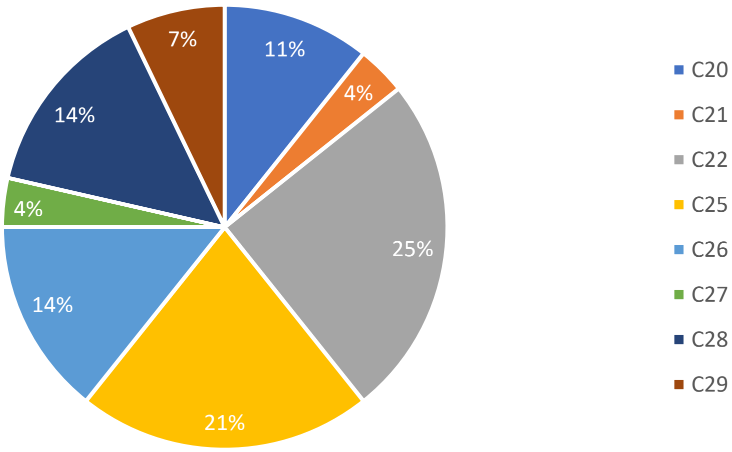

Figure 3. Share of companies as per NACE code sector

Figure 4 delineates the distribution of company sizes within the sample, categorized as "Small" and "Medium," reflecting a slight predominance of medium-sized enterprises within the surveyed population. Specifically, 54% of the entities represented are classified as medium-sized, while the remaining 46% are categorized as small.

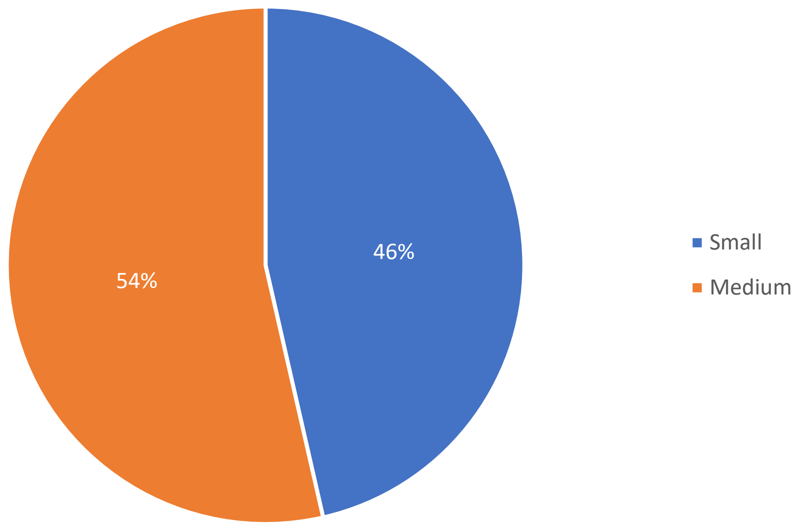

Figure 4. Size of the companies involved in the scoping study

Figure 5 delineates the distribution of companies across six distinct European countries: Cyprus, Estonia, France, Malta, Latvia, and Spain, within a specific dataset or sample. The percentages provided within the chart represent the proportional representation of companies from each respective country relative to the aggregate number of companies included in the sample. The overall distribution is characterized by a relative balance, with each country contributing a substantial proportion of companies. This suggests that the sample is not heavily skewed towards any single country.

Cyprus, Estonia, Latvia, and Spain each account for 18% of the total distribution. Five companies from Cyprus participated in the Scoping Study and submitted their data using the provided template. The participating companies are primarily located in Nicosia, Cyprus, and exhibit diverse production capacities, with some operating one work shift per day while others run a three-shift system to meet production demands. Some companies reported a higher level of automation and energy-intensive processes, while others relied more on manual operations. The Estonian sample consists of five SMEs operating in different manufacturing sectors. All participating companies have undergone energy audits. All responding companies from Latvia are located either in the capital city or in urban areas close to the capital (within one hour by car). All responding companies are medium-sized enterprises. Overall, the required data was quite difficult to access, and one respondent explained that the energy audit, conducted at their company, did not separately assess office and production space. Four respondents are companies that have already performed energy audits. One respondent had not performed an energy audit at the time of data collection but is planning to have one later in the year and was therefore able to provide the necessary information. However, none of the responding companies have the ISO50001 certification. The entirety of the sampled companies from Spain is geographically located within the province of Barcelona, Catalonia, spanning various municipalities. Specifically, the sample comprised three small enterprises and two medium-sized enterprises. An extensive outreach effort, targeting over thirty companies, was conducted to solicit participation in this study. However, acquiring requisite data proved exceptionally challenging. The observed difficulties in obtaining responses during interviews were attributable to a range of factors, most notably the absence of effective energy management practices and a perceived lack of intensive energy consumption within the initially targeted NACE sectors. This deficiency resulted in a paucity of detailed energy consumption data, including the absence of sectorized information and specific analyses of consumption relative to production, thereby preventing the provision of the requested information. Consultations with the energy department of the local public administration, three energy consulting firms, and a certification body corroborated the finding that enterprises within these NACE sectors generally do not implement efficient energy management systems and consequently lack the data necessary to respond to the survey questions. Notably, none of the surveyed companies had conducted formal energy audits.

France and Malta each constitute 14% of the total. Within the national context, a series of interviews were conducted with companies representing diverse manufacturing sectors. Specifically, a manufacturer operating under NACE code C21.2, specializing in pharmaceutical and medicine products, was interviewed. This company's focus is on chemical process development and the industrialization of new generic Active Pharmaceutical Ingredients (APIs). Additionally, a leading developer and manufacturer of advanced battery accessories and components for energy storage systems, classified under NACE code C22.2, was included in the interviews. A global manufacturer of specialty Polystyrene (PS) foam, utilized as a base material for insulating labels, tamper-evident labels, non-slip tray mats, and hair highlighting wraps, operating under NACE code C22.1, was also interviewed. Furthermore, a plastic packaging manufacturer specializing in a wide range of food and non-food custom plastic packaging solutions worldwide, classified under NACE code C28.99, participated in the interviews. In France, the geographical distribution of the interviewed enterprises was confined to the Aix-Marseille-Provence Metropolis area, spanning diverse locations within the region. The proximity of these enterprises ranged from the city of Marseille to La Ciotat, a distance of approximately thirty minutes by vehicular transport. All participating companies were classified as small-sized enterprises, exhibiting a workforce ranging from five to forty employees. An extensive outreach initiative, involving contact with over one hundred companies from a qualified database and encompassing NACE codes C20 through C22 and C25 through C29, was undertaken. However, the procurement of data proved challenging despite the breadth of the outreach effort. A proportion of contacted enterprises expressed disinterest in data sharing, while others cited time constraints as a barrier to questionnaire completion. Furthermore, a subset of enterprises did not prioritize ecological transition initiatives. Consequently, the data collection yielded responses from only four companies. Notably, only one participating enterprise had previously conducted an energy audit, which its parent company performed.

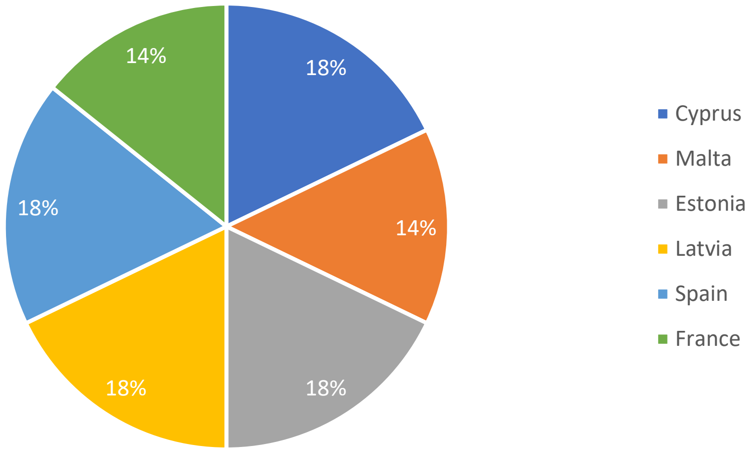

Figure 5. Share of companies by country

Energy consumptions trends

NACE 20

Energy consumption data highlight the dominance of electricity as an energy source. The use of natural gas was minimal among the participating companies, with most reporting zero or negligible consumption.

Figure 6 presents a comparative analysis of energy consumption across three distinct companies belonging to NACE sector C20. The data is presented in percentage terms, reflecting the proportional energy consumptions across various operational categories. Each segment within a given bar represents a specific category of electricity usage, expressed as a percentage of the company's total electricity consumption. The vertical axis denotes the percentage of electricity consumed, while the horizontal axis corresponds to a specific company belonging to the NACE code subsectors. The chart's legend provides a color-coded key to the various electricity consumption categories, encompassing production, process cooling, compressed air, space heating, cooling, and ventilation (for office, warehouse, and production areas), lighting (similarly categorized), lift equipment/crane operation, water pumping, wastewater treatment, and a residual "other" category. As can be observed, the second company provided information only for a limited share of the overall electricity consumption.

A discernible pattern emerges from the data, revealing variations in energy consumption across the three companies within each category. Notably, the "Production" category demonstrates a significant range of values, indicating differing production intensities or efficiencies across the companies. This category is the most relevant for the two companies from subsector C20.2, covering more than 65%. Similarly, the "Space Heating/Cooling and Ventilation" and "Air Extraction/Fume Extraction/Capture Hood" categories exhibit fluctuations, suggesting variations in environmental control and exhaust management practices. The "Lighting" category also shows a notable range, potentially reflecting differences in lighting technologies or operational hours. Conversely, categories such as "Process Cooling," "Compressed Air," "Lift Equipment/Crane," "Water Pumping," "Waste Water Treatment," and "Other" demonstrate relatively consistent percentages across the three companies, indicating a degree of uniformity in these operational aspects. The "Other" category consistently registers a low percentage, suggesting that the primary energy consumption drivers are captured within the explicitly defined categories. The data presented facilitates a comparative assessment of energy consumption profiles across the three companies, enabling the identification of potential areas for energy efficiency improvements and the adoption of best practices.

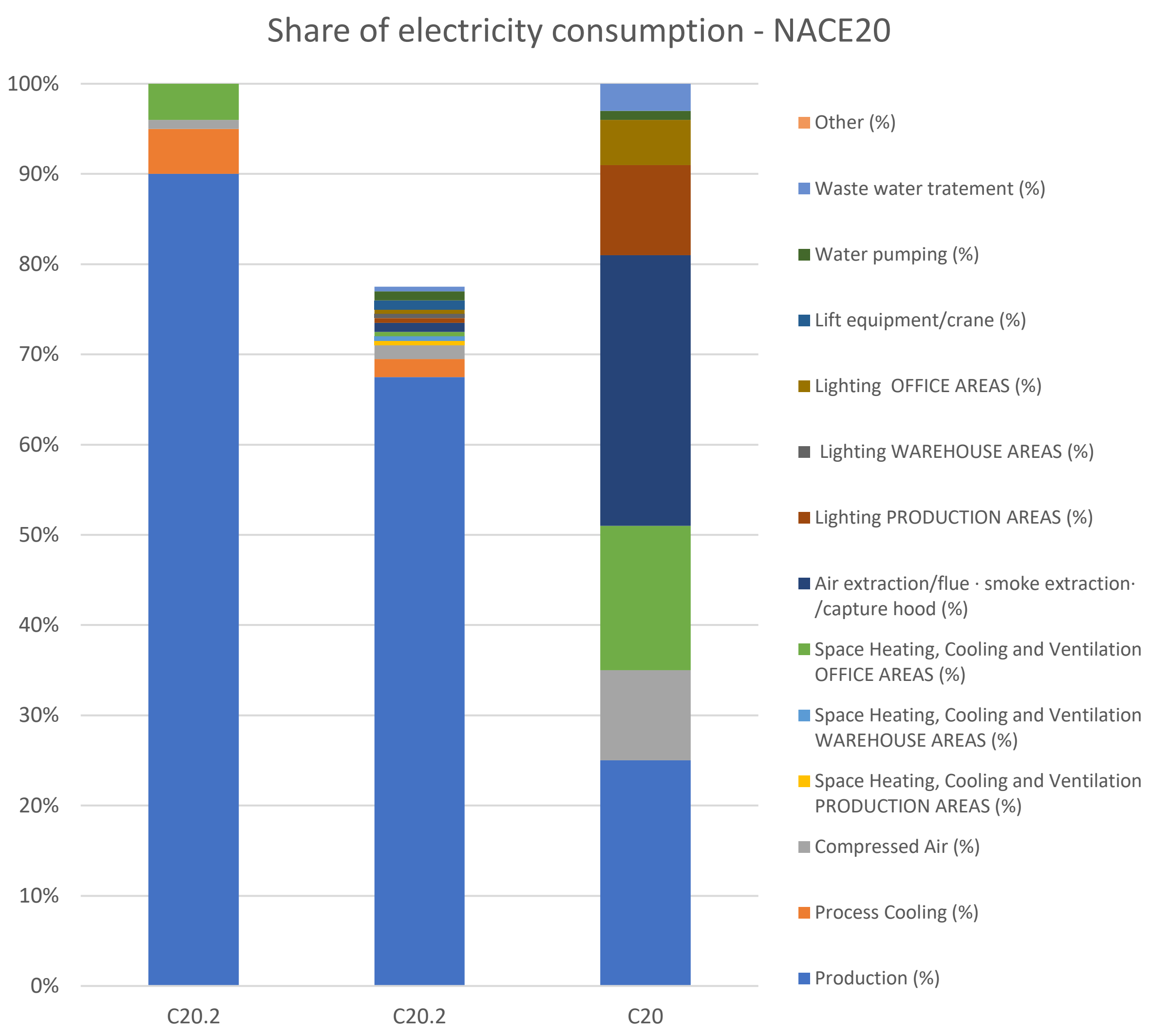

Figure 6. Share of electricity consumption per usage for NACE C20 companies.

NACE 21

Energy consumption data highlights the dominance of electricity as an energy source. The use of natural gas was minimal among the participating companies, with most reporting zero or negligible consumption.

Figure 7 presents a detailed breakdown of energy consumption for a single company, expressed as percentages across various operational categories. The "Production" category exhibits the highest percentage, indicating it as the primary driver of energy consumption within the company. Similarly, the "Space Heating/Cooling and Ventilation" category demonstrates a significant percentage, suggesting substantial energy expenditure related to environmental control. The "Compressed Air" and "Air Extraction/Fume Extraction/Capture Hood" categories also present measurable percentages, indicating energy usage associated with pneumatic systems and exhaust management. The "Lighting" category shows a moderate percentage, reflecting energy consumption related to illumination.
Categories such as "Process Cooling," "Lift Equipment/Crane," "Water Pumping," and "Waste Water Treatment" exhibit relatively lower percentages, suggesting that these areas contribute less significantly to the overall energy consumption. The "Other" category shows a minor percentage, indicating that the majority of energy consumption is captured within the explicitly defined categories.
The detailed data provided enables a comprehensive understanding of its energy consumption patterns, facilitating the identification of potential areas for energy efficiency improvements and the implementation of targeted energy management strategies.

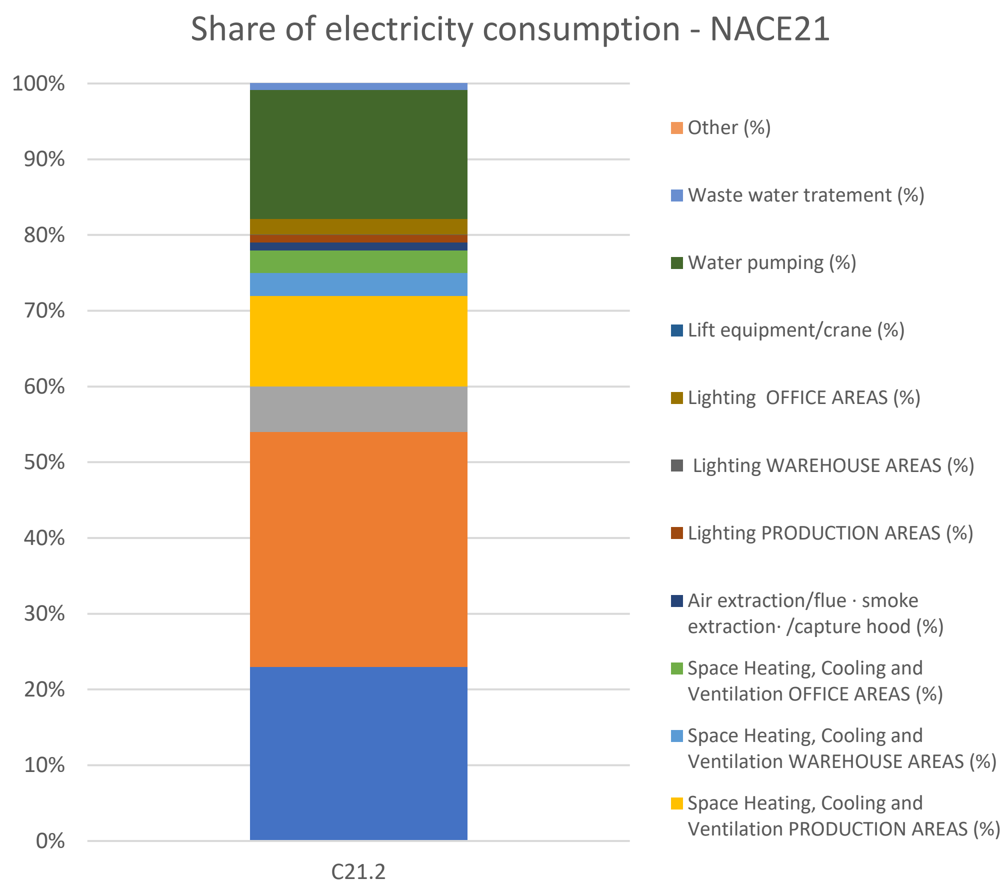

Figure 7. Share of electricity consumption per usage for NACE C21 companies.

NACE 22
Energy consumption data highlight the dominance of electricity as an energy source. The use of diesel was depicted by two companies among the participating companies: covering the 38% and 8%, respectively.

Figure 8 presents a comparative analysis of energy consumption across five distinct companies from NACE sector C22. The data, expressed in percentage terms, reflects the proportional energy consumption across various operational categories. The figure reveals significant variations in energy consumption patterns across the five companies. The analysis of the chart reveals that "production" constitutes the dominant electricity consumption category across the different companies, a typical characteristic of manufacturing industries. However, notable company-specific variations are apparent. Specifically, Company 1 demonstrates a significant allocation of energy resources towards the generation of compressed air, suggesting a reliance on pneumatic systems within its operational framework. Company 2, in contrast, exhibits a dual focus on both process cooling and compressed air, indicating a manufacturing or processing environment where temperature regulation and pneumatic power are critical. Company 3's energy consumption is predominantly directed towards space heating, cooling, and ventilation, implying a substantial emphasis on environmental control within its facilities. Finally, Companies 4 and 5 demonstrate a concentration of electric energy usage in lighting, suggesting a potential focus on illumination-intensive activities or a comparatively larger illuminated area. These distinct patterns underscore the varied operational requirements and energy management priorities of each company.
The "Other" category shows a null percentage for all companies, suggesting that the primary energy consumption drivers are adequately captured within the specified categories. The data presented facilitates a comparative assessment of energy consumption profiles across the five entities, highlighting the need for complete data sets for a more comprehensive analysis. The variations observed across the companies suggest differing operational focuses and energy management strategies.

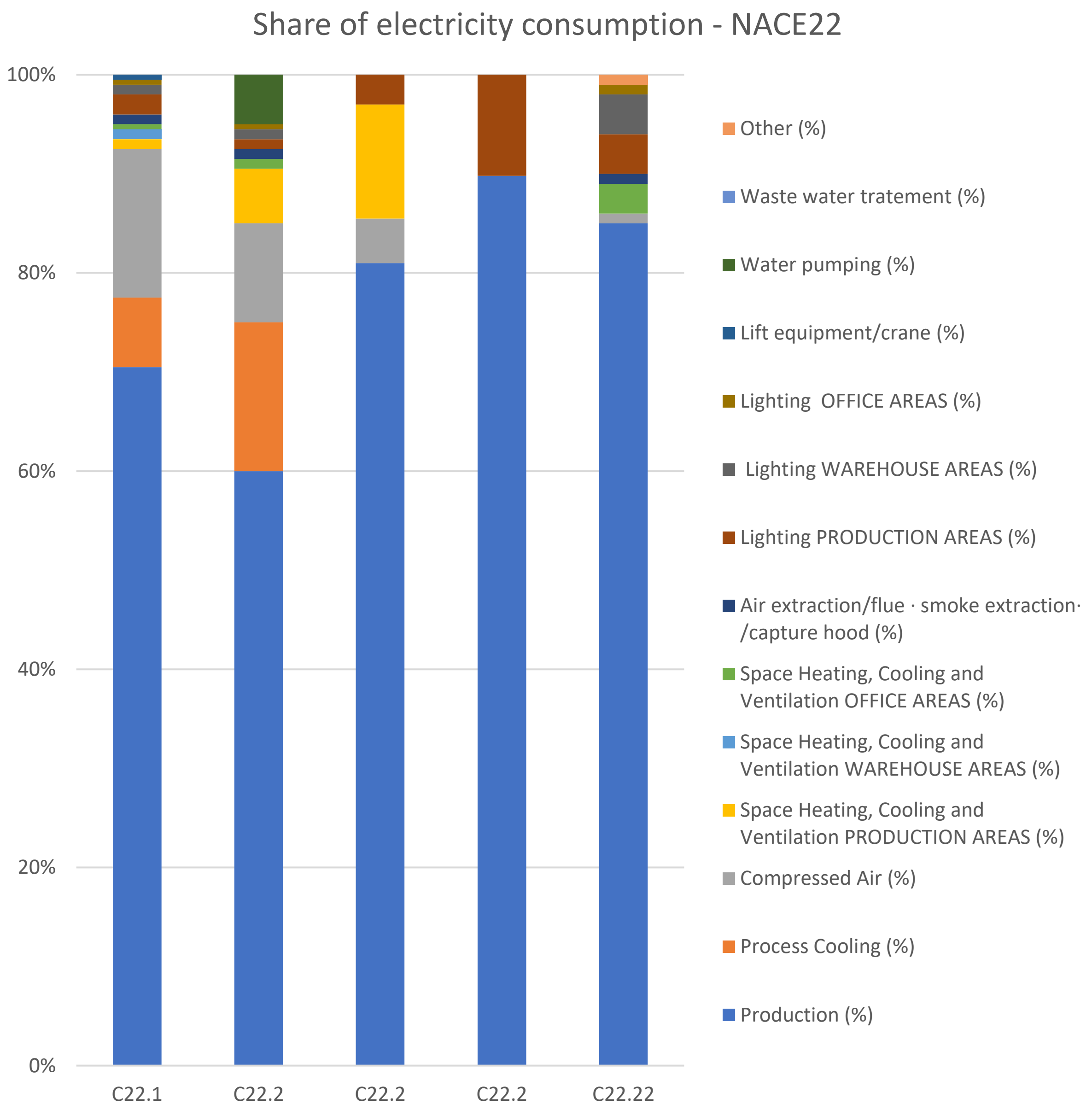

Figure 8. Share of electricity consumption per usage for NACE C22 companies.

NACE 25

Energy consumption data highlight a significant difference between different companies while considering the energy sources. Two companies fully rely on electricity, one fully relies on natural gas, while the last one sources a mix of energy carriers: i.e., 69% electricity and 31% natural gas.

Figure 9 presents a comparative analysis of electricity consumption across four distinct companies, expressed as percentage shares of total electricity usage and categorized by operational functions. As can be observed, the first company provided information only for a limited share of the overall electricity consumption.

Company 1 exhibits a primary electricity consumption in Production, accounting for 17% of its total usage. Compressed Air represents 2%, and Space Heating, Cooling and Ventilation 7%. Lighting constitutes 5%, and Other 5%.
Company 2 demonstrates a significantly higher electricity consumption in Production, with 64% of its electricity usage attributed to this category. Compressed Air accounts for 9%, and Space Heating, Cooling and Ventilation for 5%. Air extraction/flue-smoke extraction/capture hood is recorded at 1%, Lighting 20%, and Lift equipment/crane 1%.
Company 3's electricity consumption is characterized by a 71% share for Production. Space Heating, Cooling and Ventilation represents 22% of its usage. Lighting contributes 7%. Company 4 shows a high electricity consumption for production (48%). Compressed air accounts for 20% of the overall electricity consumption, while space heating accounts for 17%. Lighting, air extraction, lift equipment and waste water treatment are responsible for lower shares: i.e., 8%, 1%, 5% and 1%, respectively.
The data reveal substantial variations in electricity consumption patterns across the four companies, indicating disparities in operational processes, technological applications, and environmental requirements. Notably, Companies 1 and 4 exhibit a significantly lower percentage of electricity consumption in Production compared to Companies 2 and 3, while demonstrating a relevant share in compressed air and Space Heating, Cooling and Ventilation. This suggests a potential focus on climate control or building environment management for Companies 1 and 4. Companies 2 and 3 show the highest percentage of electricity consumption in Production. The variations in Compressed Air, Air extraction/flue-smoke extraction/capture hood, and Lighting across the companies may reflect differences in equipment efficiency, operational hours, or other factors.

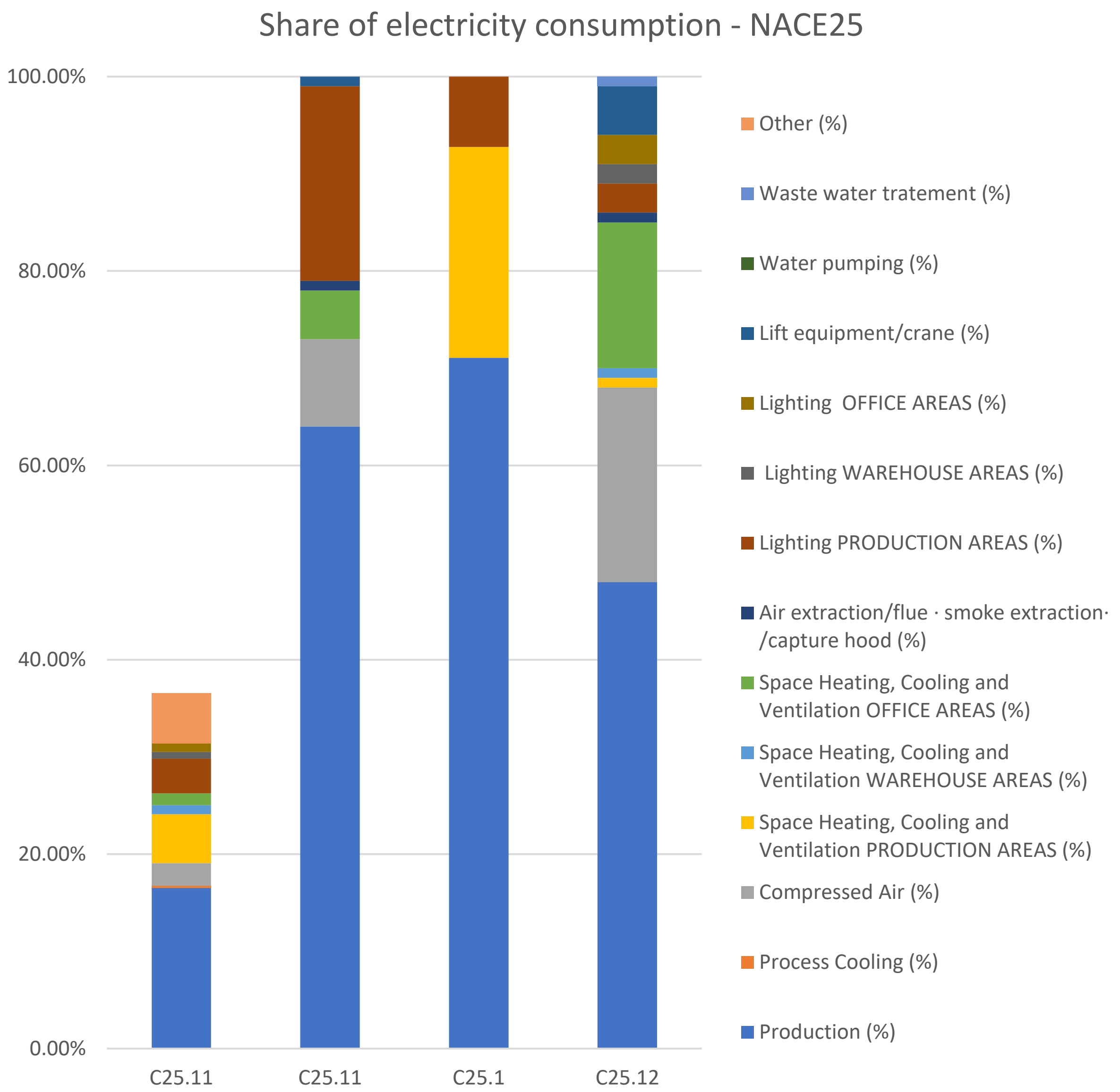

Figure 9. Share of electricity consumption per usage for NACE C25 companies.

NACE 26

Energy consumption data highlight a significant difference between different companies while considering the energy sources. Two companies fully rely on electricity, one fully relies on natural gas, while the last one sources a mix of energy carriers: i.e., 38% electricity and 62% natural gas.

Figure 10 presents a comparative analysis of electricity consumption across four distinct companies, articulated as percentage shares of total electricity usage and categorized by operational functions.
In Company 1, electricity consumption in Production prevails, accounting for 60% of its total usage. Process Cooling represents 4%, Compressed Air 5%, and Space Heating, Cooling and Ventilation 16%. Air extraction/flue-smoke extraction/capture hood constitutes 10%, Lighting 5%, while the other usages 0%.

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Company 2, even if not all data are provided, exhibits a similar pattern of high electricity consumption for Production, with 50% of its electricity usage attributed to this category, while process cooling accounts for 1%.
Company 3's electricity consumption shows a 36% share for Production. Space Heating, Cooling and Ventilation represents a significant 21% of its usage, Compressed Air contributes with 3%, and Other with 34%.
Finally, Company 4's electricity consumption is characterized by a 40% share for Production. Space Heating, Cooling and Ventilation represents a significant 33% of its usage. Compressed Air contributes with 12%, and lighting with 15%.
The data highlight significant variations in electricity consumption patterns across the four companies, suggesting disparities in operational processes, technological applications, and environmental requirements. Notably, Production represents a substantial portion of electricity usage in Companies 1 and 2, while it is lower for Companies 3 and 4. The notably high share of electricity consumption in the "Other" category of Company 3 points towards potential unique operational demands or data classification variations. The absence of Process Cooling consumption in Company 2 and the lack of Air extraction/flue-smoke extraction/capture hood in Companies 2 and 3 warrant further investigation to ascertain the specific operational characteristics of these entities. The variations in Space Heating, Cooling and Ventilation across the companies may reflect differences in climate control needs or building design.

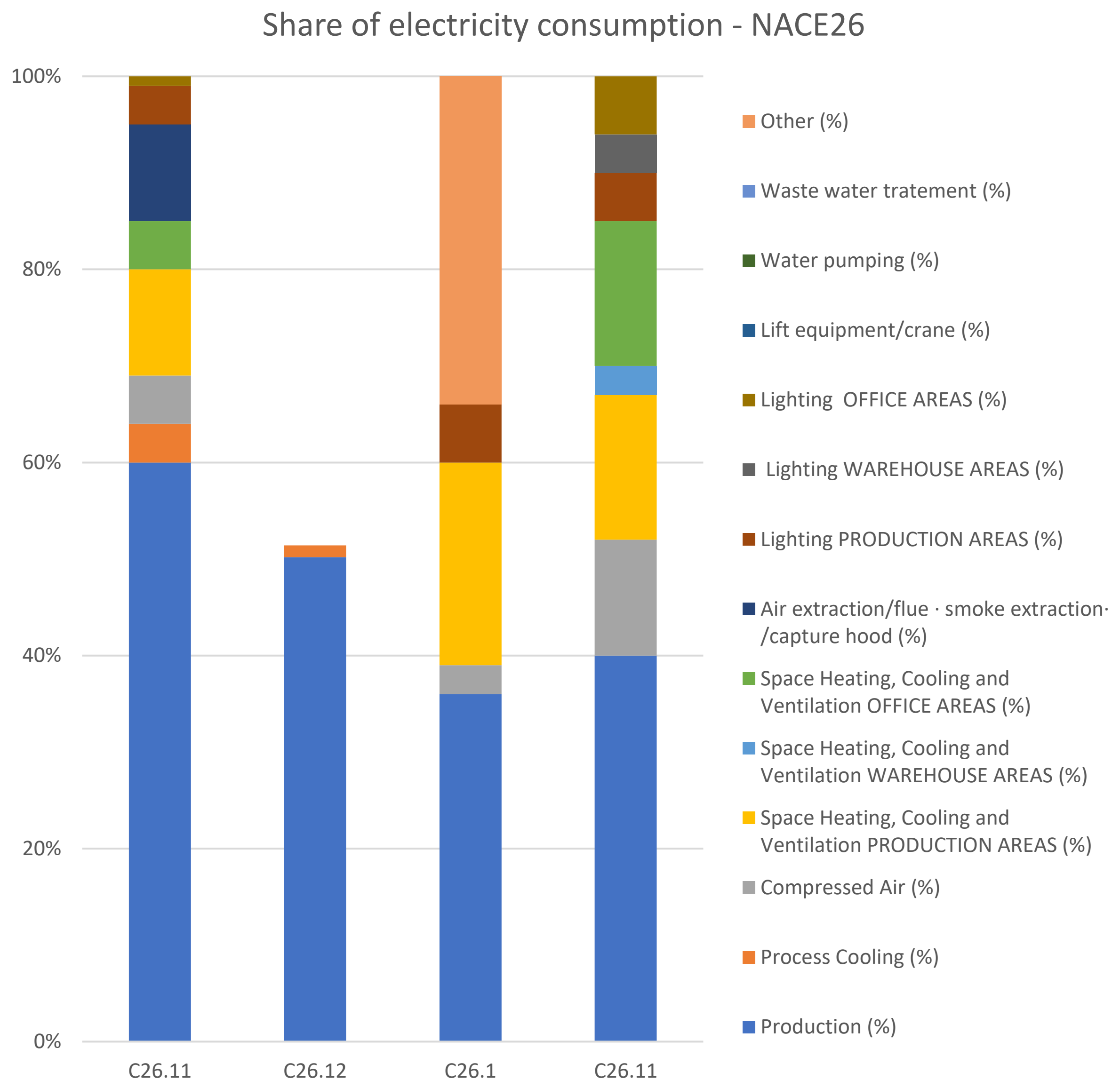

Figure 10. Share of electricity consumption per usage for NACE C26 companies.

NACE 28

Only two companies among the NACE sector C28 sample provided details on the energy sources showing a full dependence on electricity.
Figure 11 presents a comparative analysis of electricity consumption across four distinct companies from NACE C28 sector. Company 1 exhibits a predominant electricity consumption in Production, accounting for 78% of its total usage. Space Heating, Cooling and Ventilation represents 10% of its consumption, while Air extraction/flue-smoke extraction/capture hood constitutes 1%. Compressed Air contributes 5%, Lighting 3%, Lift equipment/crane 3%, and Water pumping 0%. Notably, Process Cooling is recorded as 0% for this company.
Company 2 demonstrates a similar pattern of high Production consumption, with 60% of its electricity usage attributed to this category. Process Cooling accounts for 1%, Compressed Air for 9%, and Space Heating, Cooling and Ventilation for 18%. Air

extraction/flue-smoke extraction/capture hood is recorded at 1%, Lighting at 7%, Lift equipment/crane at 4%, and Water pumping at 0%.

Company 3's electricity consumption is characterized by a 63% share for Production. Space Heating, Cooling and Ventilation represents a significant 31% of its usage. Compressed Air contributes 1%, Air extraction/flue-smoke extraction/capture hood is at 0%, Lighting at 3%, Lift equipment/crane at 1%, and Water pumping at 2%. Process Cooling is recorded as 0%.

Finally, company 4 demonstrates a lower share of production consumption, with 40% of its electricity usage attributed to this category. Space heating, cooling, and ventilation, compressed air, and lighting account for a relevant share of the electricity consumption, i.e., 27%, 15%, and 13%, respectively.

The data reveals variations in electricity consumption patterns across the four companies, indicating differences in operational processes, technologies employed, or environmental conditions. Notably, production consistently represents a substantial portion of electricity usage in all four companies. Company 3 demonstrates a particularly high share of electricity consumption in Space Heating, Cooling and Ventilation, suggesting potential variations in climate control requirements or building design. The variations in Compressed Air, Lighting, Lift equipment/crane, and Water pumping consumption across the companies may reflect differences in equipment efficiency, operational hours, or other factors.

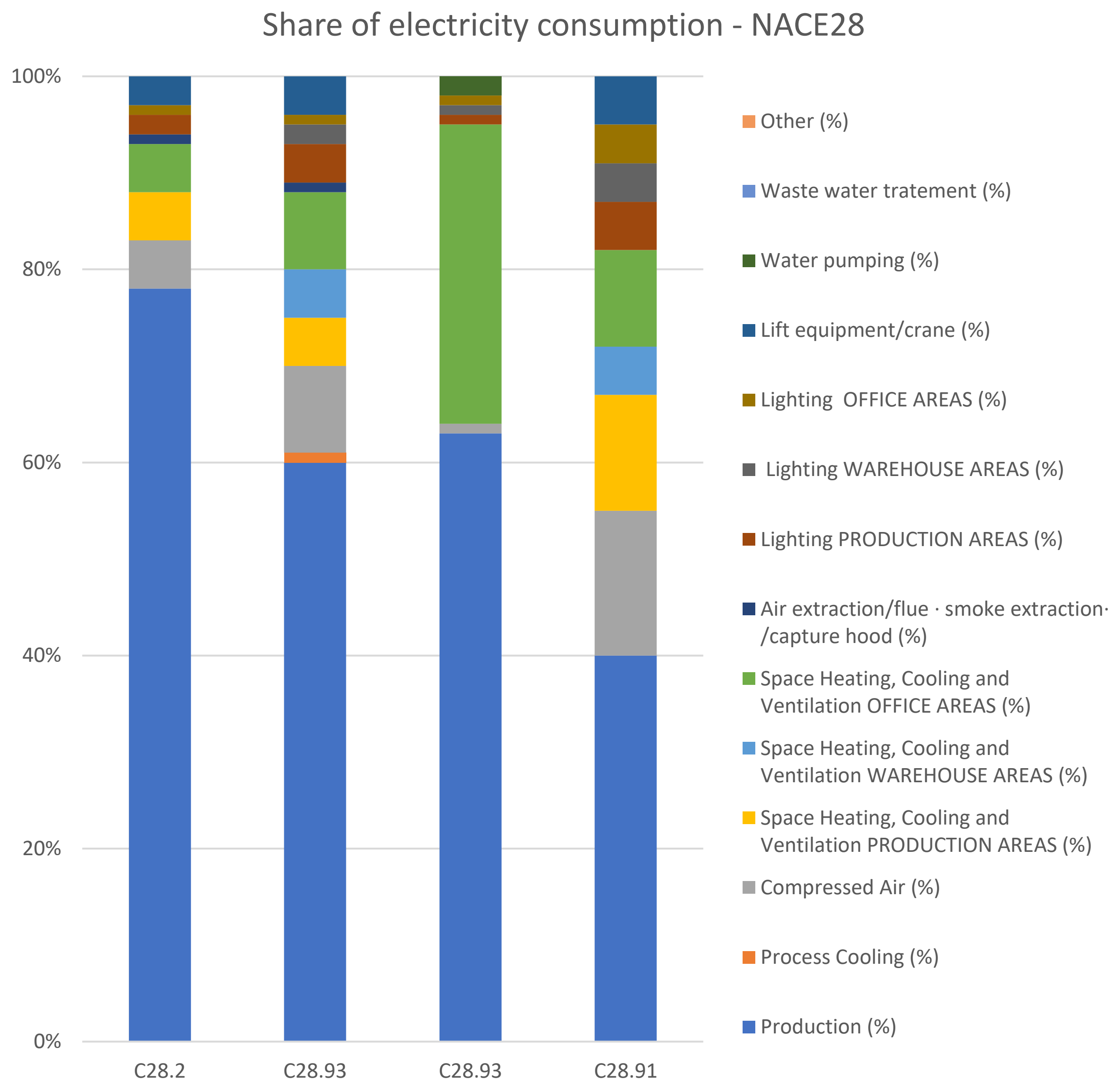

Figure 11. Share of electricity consumption per usage for NACE C28 companies.

NACE 29

The partners could obtain energy data from two companies in NACE sector 29. Figure 12 presents a quantitative breakdown of energy consumption across diverse operational sectors.

Company 1 exhibits a dominant energy allocation towards production, accounting for 78% of its total consumption. This is followed by space heating, cooling, and ventilation, which constitutes 7%. Air extraction and fume/smoke extraction collectively represent 2%, while lighting consumes 7%. Lift equipment/cranes and water pumping each account for 1%, and a residual 6% is categorized as "other." Significantly, process cooling, compressed air, and wastewater treatment are reported as negligible for Company 1.

Conversely, Company 2 demonstrates a more diversified energy consumption profile. Production accounts for 30% of its total energy usage, a considerably lower percentage compared to Company 1. Space heating, cooling, and ventilation represent 14%, while air extraction and fume/smoke extraction consume a considerable 44%. Lighting constitutes 10% of energy usage, and lift equipment/cranes and water pumping each represent 1%. Similar to Company 1, process cooling, compressed air, and wastewater treatment are reported as negligible, with a residual 6% categorized as "other."
The disparity in energy allocation between the two companies suggests distinct operational priorities and potentially different industrial sectors. Company 1's focus on production implies a manufacturing-intensive operation, while Company 2's significant energy usage in air extraction and fume/smoke extraction may indicate a focus on processes involving gaseous emissions or particulate matter, potentially in industries such as chemical processing or metalworking. The differences in space heating, cooling, and ventilation also reflect variations in operational environments or climate control requirements. Further investigation into the specific activities and processes of each company would be necessary to fully understand the underlying factors contributing to these energy consumption patterns.

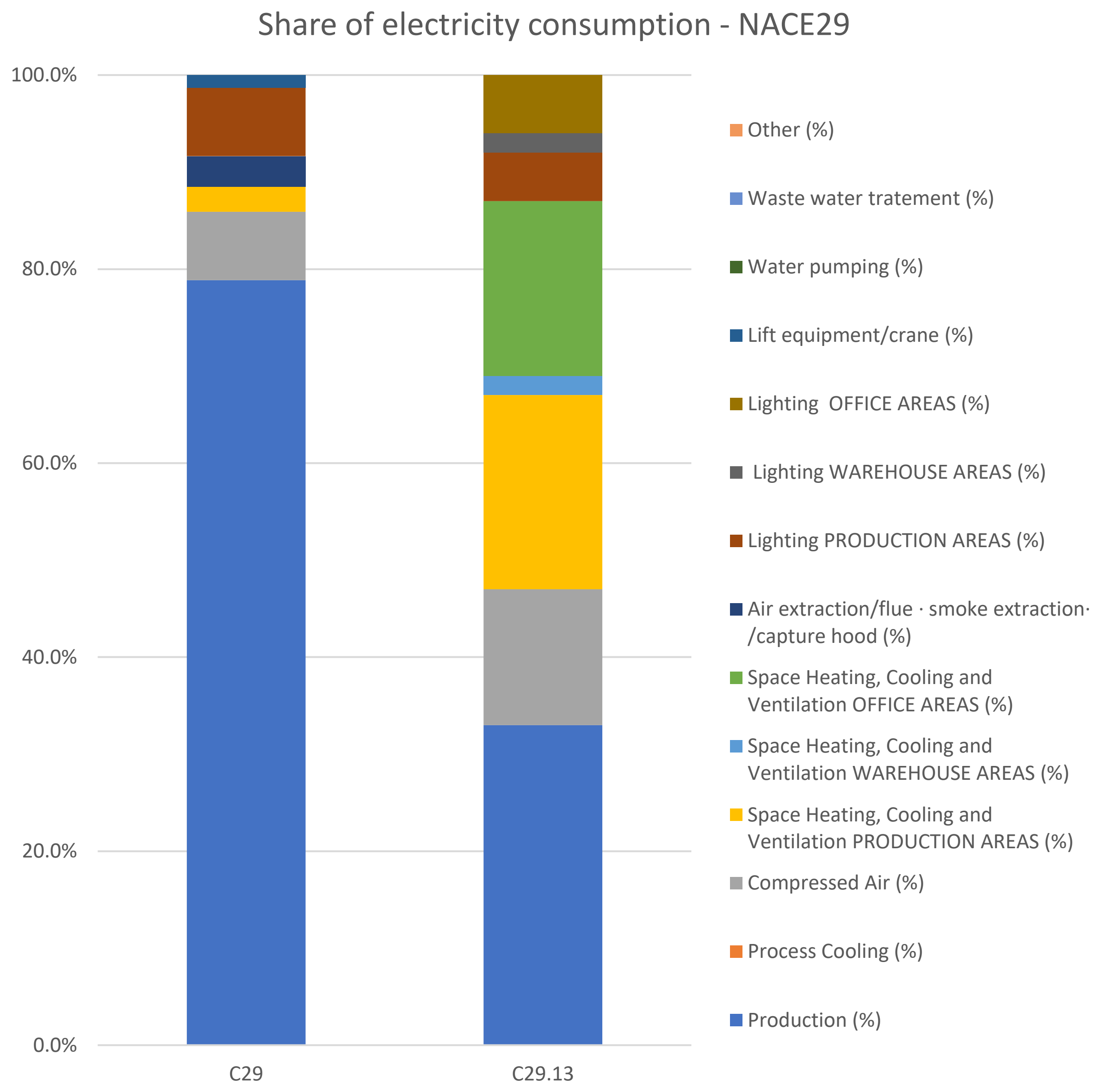

Figure 12. Share of electricity consumption per usage for NACE C29 companies.

Energy costs and investment trends

A striking feature of the dataset is the pronounced heterogeneity in energy costs across the diverse NACE sectors and varying company sizes represented. Within the plastics manufacturing sector (C22), for instance, the annual electricity expenditure demonstrates a wide spectrum, ranging from a minimal €5,000 for a small enterprise achieving a 96% renewable energy source (RES) utilization rate, to a substantial €528,655 for a similarly sized entity relying entirely on conventional energy sources. This disparity underscores the pivotal role of RES adoption in mitigating electricity costs within a single industrial classification. Furthermore, the calculated electricity cost per megawatt-hour (€/MWh) for C22 companies spans from €112 to €319, suggesting

divergent strategies in energy procurement or operational efficiencies that influence the final cost.
In sector C25, a medium-sized company stands out for its 97% RES utilization, coupled with an annual electricity expenditure of €84,000, indicative of a strong commitment to sustainable energy practices. Notably, the €/MWh electricity cost for this entity is €127, which is relatively moderate when juxtaposed with other sectors and countries. Additionally, the data reveals significant natural gas consumption among companies in the electronic components sector (C26), with expenditures ranging from €23,706 about to €37,000 annually. The variability in €/MWh natural gas costs, from €65.95 to €152.86, suggests disparities in gas procurement strategies or operational efficiencies. The inclusion of diesel and woodchip costs within the machinery manufacturing sectors (C28 and C29) highlights the prevalence of alternative energy sources. Specifically, a medium-sized company in C29 reports annual diesel costs of €100,414 and woodchip costs of €80,676, indicating a significant reliance on these fuels. The presence of heat costs, such as the €19,278 reported by a medium-sized company in C22, further illustrates the diverse energy portfolios employed across various NACE sectors and countries.

The data also sheds light on the impact of energy expenditures on company turnover. The analysis reveals a considerable degree of variability in the share of electricity costs across different NACE sectors. For instance, companies classified under C22, which encompasses the manufacture of plastics products, exhibit a range of electricity cost to turnover ratios. Three companies show a share between 3% and 3.4%. While one company reports a share of 1.2% and two other companies a share lower than 0.5%. This variation suggests differences in operational efficiency, energy management practices, or product mix within the same sector. Notably, a small company in C20 reports a significantly higher share of electricity costs at 6.7% of turnover, indicating a potentially high energy intensity relative to its revenue. This figure underscores the impact of energy costs on the profitability of businesses within this sector. In contrast, several companies across various sectors, including C25, C26, and C28, report relatively low shares of electricity costs, ranging from 0% to 1.2%. This suggests that these sectors, or specific companies within them, have more efficient energy management or lower energy intensity compared to sectors like C20.

Regarding natural gas costs, the data indicates that a significant majority of the listed companies report a 0% share of natural gas costs relative to turnover. This suggests a predominant reliance on electricity as the primary energy source for these businesses or potentially a low consumption of natural gas in their operations. However, two companies in the electronic components sector (C26) report a 0.5% share of natural gas costs, indicating a moderate utilization of natural gas in their processes. This variation highlights the diverse energy portfolios employed across different NACE sectors.

Data were provided on the absolute investment amounts in energy efficiency in the last three years, expressed in Euros. Their proportional representation as a percentage of the turnover has been assessed, offering insight into the investment patterns within different sectors.

The analysis reveals a considerable degree of variability in both investment amounts and their shares across the listed NACE sectors. For instance, companies classified under C22 exhibit a wide range of investment amounts and corresponding shares. One company reports an investment of €60,000, representing 1.2% of the turnover, another company in the same sector invests €1,000,000, accounting for 33.3% of the turnover, respectively, while one company did not invest in energy efficiency in the last three years. This disparity highlights the diverse investment strategies and capital expenditure patterns within the plastics manufacturing sector. Notably, a significant investment of €1,800,000, representing 26.5% of the turnover, is also observed in C22, further emphasizing the variability in investment intensity.

In contrast, several companies across various sectors, including C28 and C20, report zero investment, indicating a period of potentially low capital expenditure or a focus on operational expenditures rather than capital investments. This observation contrasts with the substantial investments observed in sectors like C29, where a company reports an investment of €1,400,000, representing 3.8% of the turnover.

The data also reveals instances of moderate investment, such as the €15,000 investment in the electronic components sector (C26), accounting for 0.2% of the turnover, and the €108,140 and €174,000 investments in C25, representing 0.4% and 1.9% of the turnover, respectively. These figures suggest varying levels of capital expenditure depending on the specific needs and strategic priorities of companies within these sectors.

Conclusions

The analysis of energy consumption across the NACE C20-C22 and C25-C29 sectors reveals distinct patterns and trends.

- Electricity serves as the primary energy source across the participating companies, while natural gas usage is notably low, with many companies reporting minimal or no consumption.
- Energy intensity varies significantly across sectors. NACE C20, particularly in basic chemical production, is characterized by high energy demands due to energy-intensive processes like distillation and cracking.
- NACE C21 also demonstrates substantial energy consumption, primarily in the form of electricity, to maintain precise temperature control, sterile environments, and power specialized equipment.
- In contrast, NACE C22 utilizes a more balanced mix of process heat and electricity, with energy intensity varying based on the specific products manufactured.
- The analysis reveals variations in energy consumption across companies within each NACE sector, with the most impactful categories being "Production," "Space Heating/Cooling and Ventilation," and "Lighting." These variations indicate differences in production intensities, the efficiency of environmental control practices, and the adoption of diverse lighting technologies among the participating companies.
- In most companies, the "Production" category represents the highest share of energy consumption. This is consistent with the energy-intensive nature of manufacturing activities.
- The analysis also highlights the influence of production capacity on energy consumption, with larger-scale operations often demonstrating greater energy efficiency.
- Investments in energy efficiency and renewable energy are crucial for reducing energy costs, enhancing competitiveness, and minimizing environmental impact.
- Various strategies, including process optimization, technology upgrades, energy management systems, and behavioural changes, can be implemented to improve energy efficiency across these sectors.

The current shortage of energy audits presents a significant initial challenge in data collection, yet it also underscores a substantial, unrealized potential for improvement. While this situation offers EcoSMEnergy the opportunity to engage with a broad range of companies, it's crucial to acknowledge that this potential can only be realized if SMEs demonstrate sufficient interest and engagement. The project's effectiveness in serving as a facilitator, by providing resources and expertise for audit implementation and sustainable energy management practices, will be determined by its capacity to overcome the fundamental challenge of SME disinterest. Therefore, while the initial data gap highlights the need for intervention, it's important to temper expectations. The true test of the project's success will be its ability to actively cultivate SME participation and address the underlying reasons for their current lack of interest, which ultimately poses a greater obstacle than the initial data scarcity.

In conclusion, the report underscores the importance of targeted energy efficiency measures and the potential for significant energy savings across various manufacturing sectors.

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