Introduction to Panel 9 Energy efficiency and sustainability of industry

Panel leader: **Anna Realini**
OMCD Group
Italy
a.realini@ufficia.it

Panel leader: **Thomas Björkman**
Private consultant
Sweden
thomas.8.bjorkman@gmail.com

Introduction

Circular economy, resource efficiency/sufficiency, cooperation with local and regional stakeholders, company management, deep decarbonisation through electrification and use of hydrogen as well as efficient use of energy is all happening with industry stakeholders as key players. The industrial sector is responsible for 40 % of the global emission of greenhouse gases. The work towards climate neutrality faces challenges of industry being high energy-intensity, often with long reinvestment cycles and dependency on laws and regulations to succeed. With the latest policy developments, such as the "Fit for 55" package, Europe is trying to prove to the world that a climate-neutral industrial continent is feasible. This requires a deep rethinking of what energy efficiency in industry means and to find innovate paths ahead.

Panel 9 focuses on these aspects of the transition towards climate-neutral basic industries. Scientists, policy makers and industry practitioners as well as decision makers will exchange the latest approaches and findings and particularly benefit from the huge body of concepts and success stories from energy efficiency.

Energy efficiency is an essential tool to decarbonise industry but not enough to reach the targets. Other initiatives, such as electrification, use of renewable energy sources, circular economy and resource efficiency, energy communities and the production of green hydrogen need to be developed to succeed. Technological innovation in the field of energy and resource efficiency needs to be supported by policies and incentives to make interventions profitable. There is an increasing number of examples of cooperation between public and private sector, both locally and in a broader perspective (national or multi-national). Multi-level governance as a possibility to support initiatives is discussed in the panel.

The panel also explores how the integration of energy efficiency across the supply chain, including eventually circular economy principles, might be a necessary step to be able to share the benefits of energy efficiency and open opportunities for many companies, especially small and medium enterprises, that often lack the resources to act without some kind of cooperation or support.

Decarbonisation through electrification, green hydrogen, storage and flexibility

Industry pathways for EU with net-zero emissions to 2050 are presented by Khaled Al-Dabbas & Tobias Fleiter (extended abstract 9-102-24) starting from bottom-up modeling of energy demand and GHG emissions. The transformation to net zero requires substantial amount of green electricity and deep energy efficiency measures.

Four scenario pathways to a GHG-neutral German industry (2045) are developed in a modelling study by Markus Kaiser et al. (extended abstract 9-241-24). A reduction of final energy demand is attributed to more energy efficient production routes and technologies and sufficiency scenarios assume a reduction in consumption. Across all scenarios, direct electrification of process heat supply is important. Despite the German focus, general conclusions can be drawn for industrial sectors and process heat supply. Green Hydrogen and decarbonisation of feedstock are essential to meet the targets.

One of the highest consumers of energy in the industrial sector is compressed air, accounting for a 20 % of the total consumption. However, its saving potential, estimated at 60 %, is rarely achieved, while most "innovative technologies" allow

to reduce consumption by 10–15 %. Elvira Rakova (extended abstract 9-296-24) proposes a new approach that addresses the entire supply chain of compressed air systems, comprising generation, distribution, and demand sides. The key insight lies in prioritizing demand-side interventions before adjusting generation, through a digital modelling method and several case studies. The shift towards optimized compressed air systems carries profound implications. By unlocking the maximum potential savings, a consequential 10 % reduction in the overall energy demand for the industrial sector becomes a tangible reality, fostering sustainability and environmental responsibility.

Alongside with compressed air, electric motors are a significant contributor to energy consumption in the EU, accounting for more than half of the total electricity consumed. In order to reduce the environmental impact, there is a need to address the inefficiencies of existing motors. Antoine Durand & Robin Barkhausen (peer-reviewed paper 9-202-24) explore how early replacement of inefficient motors can reduce environmental impacts at the system level and compares this strategy with a base case, by using a combined material flow analysis and life cycle assessment approach. By utilizing a layered approach, material and environmental impacts are derived from product flows through a product database that defines physical properties for different product variants. The results of this study might have a strong implication on sustainability and energy efficiency policies in the EU, by providing policy makers and industrial stakeholders a tool to make informed decisions.

Decarbonization is studied in a systems perspective with focus on the potential of energy storage and demand-side flexibility by Stefan Büttner et al. (extended abstract 9-324-24). Interconnection of energy systems in a complex context requires a better understanding of potentials, requirements, and other aspects. Furthermore, support resources related to energy storage need to be developed and the energy consumer must be encouraged be more flexible through demand side management.

Addressing a similar topic, Michael Fell (extended abstract 9-088-24) explains how to enhance flexibility through power-service decoupling, by analysing two key linkages: between power delivery and energy service delivery (delivering electricity from the grid to a battery, and only later using it to deliver an energy service such as heating); and between energy service delivery and end service experience (delivering the energy service of heating – e.g. an oven, and only later experiencing the end service – e.g. eating cake). While both linkages have socio-technical elements, the former is principally a technical one of energy storage. The latter is primarily social, can be framed in terms of "service storage", and varies with the nature and quality of the service.

Electrification as an alternative to the use of fossil fuels is also deeply investigated, with two main focuses: flexibilization of electricity use and heating purposes.

Stefan Büttner et al. (peer-reviewed paper 9-313-24) first address the issue of systemic efficiency. A significant portion of energy efficiency in industry could be achieved with the exploitation of unused waste heat potential and electrification of processes, that allow to significantly reduce the GHG impact of processes. However, this potential remains often untapped, due to a lack of knowledge. With a heuristic approach, hampered by the inputs of several experts and stakeholders, this paper sheds light on the concept of systemic efficiency, that allows to overcome the barrier of untapped heat recovery potential.

Barriers to the electrification of industrial processes and flexibilization is the main focus of Jessica Berneiser et al. (extended abstract 9-291-24). In a large study, involving interviews to stakeholders and representatives from energy-intensive companies, finding show that major constraints for electrification include, among others, high investment costs and long payback periods for process technologies, technological complexity and immaturity, a lack of stable policy frameworks, and transitional barriers related to operational procedures. Flexibility can be the solution to several issues, but there are challenges such as production-related factors and organizational factors. However, only few companies agreed that the flexibilization of industrial processes will be a relevant topic in the future. This is in contrast to the majority of companies that emphasized the goal of direct electrification measures.

Simon Bussmann & Matthias Rehfeldt (extended abstract 9-209-24) examine the technical potential for direct electrification of industrial process heat in the EU27 and the barriers to electrification. The study assesses seven electric heating technologies that are currently available or expected to be available by 2035, such as electric boilers and resistance heating, that can be applied to a wide range of processes, taking into account a variety of technical requirements. The technical assessment is integrated with stakeholder interviews, to provide practical insights into technologies and processes, as well as barriers to electrification. As a conclusion, since electric industrial heating technologies are central to the decarbonisation of industry, policymakers should prioritise overcoming barriers and guiding technology development to enable a carbon-neutral production system, ensuring the availability of abundant and cost-effective carbon-neutral electricity.

Ammi Amarnath et al. (peer-reviewed paper 9-122-24) focus on the commercialization of high-temperature industrial heat pumps designed for the recovery of waste heat in the U.S. industrial sector. According to estimates by the U.S. Department of Energy, a significant portion, approximately 35 %, of energy input for process heating in industrial applications is lost as waste heat in various forms. Harnessing this waste heat emerges as a key strategy for improving energy efficiency and achieving sustainable industrial practices. The emerging technology of high-temperature heat pumps is investigated in terms of technological innovations, economic considerations, incentives and regulatory frameworks in the USA, in order to understand the challenges faced during commercialization, and the potential for widespread implementation across various industrial sectors.

Focusing on the dairy sector, also Beatrice Marchi & Simone Zanoni (peer-reviewed paper 9-269-24) are investigating how heat pumps can support the heating and cooling needs of the second-largest agricultural segment within the EU. Conventional dairy processes necessitate heating for milk processing and refrigeration for storage, posing a challenge in optimizing energy utilization. Among different energy efficient solutions, heat pumps that generate both hot water and cold air emerge as a promising avenue that allow substantial energy savings. Integrating heat pumps enables the efficient utilization of waste heat from refrigeration systems to fulfil heating requirements, establishing a synergistic relationship between the two process-

es, and the replicability of the study in different companies is ensured by a tool for the analysis of the potential implementation of heat pumps in the dairy industry.

Also in metallurgy sector, Christian Schwotzer et al. (peer-reviewed paper 9-145-24) analyse different ways of accomplishing the required thermal processes while reducing their impact. One of the main factors is that however, energy and system availability, product quality and cost-effectiveness must be guaranteed. Two promising solutions are the use of hydrogen and electric heating technologies: they are analysed in the context of downstream processing of metals, with an example from aluminium remelting process. A model is used, that dynamically maps the key figures energy efficiency, greenhouse gas emissions and heat production costs over a period of several decades and allows for a quantitative assessment of new technologies for process heat generation, highlighting possible pathways for electric and hydrogen heating technologies, that enable reaching CO_2 emissions reduction targets within the next decades.

Circular economy, sustainability and resource efficiency

Meta Thurid Lotz et al. (extended abstract 9-016-24) are using modelling techniques to study how circular economy actions can contribute to decarbonize the building industry. The potential to reduce the climate impact is estimated as well as the decarbonisation of basic material production in the industry sector. The study implies that increased recycling, substitution, demand reduction and material efficiency in a circular context in the industry contributes to reduced climate impact and final energy demand. And also, to a reduced overall cost.

Karsten Weinert et al. (peer-reviewed paper 9-083-24) study the effect of a new element of resource efficiency in the German funding program on actual implementation of measures. A study of 55 cases the new element makes a difference. Both SMEs and non-SMEs are using the new opportunity. Resources saved include primary metal, water, stainless steel sheet, polypropylene and paper. Resource efficiency lies at the intersection of several policy areas. It is recommended to compare and harmonize different goals and measures in policy packages.

Measures aimed at increasing the use of decarbonized input products such as secondary raw materials achieve high GHG savings. In terms of abatement costs, these measures are highly economical, but this type of measure does not always lead to material cost savings.

Recycling of materials is essential to build a decarbonised circular economy. Anna Realini et al. (peer-reviewed paper 9-198-24) study the potential for material recycling in the hard metal industry. The paper also quantifies the energy saving potential and environmental impact of the recycling approach. Although to maintain physical properties of the material and productivity are challenges, substantial reduction of CO_2 emissions and energy use were realised.

Life Cycle Assessment (LCA) is a very useful tool to assess the impacts of potential sustainable technologies and energy sources. Vanessa Schindler & Nele Friedrichsen (peer-reviewed paper 9-029-24) analyse the effects of hydrogen import in the European political context. The paper aims to be an early decision support for hydrogen electrolysis, by analysing six scenarios for hydrogen production in Algeria (as a representative for MENA region) and export to Europe via the European Hydrogen Backbone. It highlights that power consumption is a main driver for the impacts, despite considering the future increase of renewable electricity generation, especially due to the energy needs of the compression for transport. Impacts are decreasing in all scenarios over time driven by the assumptions on decarbonising the EU electricity mix and efficiency increases of all relevant processes in the future. This underlines the importance of decarbonising the power system for low-carbon hydrogen transport.

Governance, local cooperation and management

Maike Keil & Katrin Arning (peer-reviewed paper 9-044-24) study the relevance of leaders' psychological factors in promoting sustainable practices within corporations. A quantitative online study was conducted to investigate the sustainability behavior and psychological factors of leaders as potential influencing variables for decision-making. Sustainability behaviour was measured with the Organizational Citizen Behaviour for the environment scale. The result shows that corporate managers pro-environmental behavior and leadership play an important role for decision making.

Hannah Bamford & Sam Hampton (peer-reviewed paper 9-057-24) present a narrative account which demonstrates that businesses can adopt a range of roles and activities in addressing climate change. Besides mitigating their environmental impacts from direct emissions, businesses are the principal actors responsible for developing and disseminating low carbon goods and services which enable the broader population to make pro-climate choices. They are also often pioneering early adopters, yield significant influence among their social and professional networks, and act as citizens to protect local environments and communities.

Energy and resource efficiency in local decarbonisation plans are analysed by Imogen Rattle & Peter Taylor (extended abstract 9-093-24). Applicants to UK industrial funding programs in clusters at local and regional levels were interviewed to understand what approaches encourages decarbonisation efforts in areas of dispersed industry. It was found crucial to build a vision and partnerships, providing advice and develop strategies and implementation plans to involve companies for decarbonisation activities.

Energy efficiency is a cornerstone in the energy transition. Under the framework of the European Directive on Energy Efficiency German all large enterprises submit an online declaration of results from mandatory energy audits (article 11). Paurmina Atul Kulkarni & Dominik Rau (peer-reviewed paper 9-200-24) study the energy efficiency potential starting from the results reported in the database. An energy audit cannot ensure a continual energy efficiency for an enterprise. In addition to monitor energy consumption and implement measures, a more systematic approach like an energy management system is required to maintain a continual process of improvement. Article 11 of EED will require large energy users to implement an energy management system in the coming years.

Multiple benefits (MB) assessment plays an important part in the evaluation of energy efficiency measures. Carlos Herce et al. (peer-reviewed paper 9-314-24) analyse the issue of identifying

multiple benefits in the Italian plastics industry, in two steps. First, with a general multi-sectoral characterization of MB, with a survey targeted to both public and private stakeholders. Then, by developing a framework that quantifies the MB associated to different Energy Performance Improvement Actions (EPIAs), with a focus on the plastics manufacturing industry. The model can be replicated in other sectors, and it can be useful to National Authorities when implementing the transposition of EED Articles 3, 11(7) and in support of Articles 9 and 10.

João Fong et al. (extended abstract 9-052-24) explore how EU policies can improve the replacement rate of inefficient electric motors. Enterprises and public services tend to operate electric motors for much longer than their intended lifespan, typically opting for replacement only when failure occurs and repair is no longer feasible. Through swift action, the replacement rate of old motors by high-efficient ones can be raised significantly. A total of 61 existing policy measures that directly or indirectly aim at accelerating motor replacement have been identified and analysed for their approach, impact and lessons learnt, leading to an initial set of general observations and policy recommendations.

Also, the perspective of companies is important in understanding how energy management works. In particular, it is needed to identify the most appropriate energy efficiency measures, to implement them and to monitor their impact. Simon Hirzel et al. (peer-reviewed paper 9-272-24) investigate how the use of sensors, monitoring and control equipment helps to enhance transparency, by collecting empirical data about the use of these technologies and about the expectations for achievable energy savings across a large sample of companies. The results seem to underline that there are various ways how energy-related measurement infrastructure and control technologies are used and implemented in practice.

Global outlook

Hongyou Lu et al. (peer-reviewed paper 9-037-24) explore different pathways to decarbonize the Chinese cement industry by 2060: a circular economy pathway and an energy technology pathway using both supply and demand-side strategies to achieve near net-zero emissions in China's cement industry by 2060. Combinations of material efficiency, alternative materials, clean energy supply, CCS and circular approaches are studied. There are significant policy implications, for both China and other emerging economies, as their cement production is expected to rise driven by population growth and economic development in the years to come. The analysis shows that both the circular economy pathway and a supply-side focused pathway can achieve near-zero emissions by 2060.

Zhenxi Li et al. (extended abstract 9-042-24) address the issue of decarbonizing Asian steelmaking sector, where 73 % of the global steel production is now realized. One of the most important issues is the large use of blast furnaces (BF) and the plan to increase steel production with the installation of new BFs. To mitigate the CO_2 emissions caused by producing BOF steel, carbon capture and storage (CCS) may be an option. Another way is to import green Hot Briquetted Iron (HBI) from countries with large iron ore reserves and a large renewable electricity potential. This paper presents a long-term cost minimal optimization model to study the steel production pathway of the eight Asian countries/region under the goal of achieving their own decarbonization goals, and most importantly, the impacts of green HBI trading on both HBI importer and exporters. Several sustainability KPIs are considered, together with geopolitical difficulties, and policy recommendations are proposed.

Changing continent, Onay Geylan et al. (extended abstract 9-248-24) analyse how to increase energy efficiency in South Africa, one of the largest carbon emitters in Africa. Despite the recognized need to decarbonize, South Africa is facing other structural challenges, such as the ongoing energy crisis, which has significant negative impacts on productivity and safety, in the forms of load shedding, high energy prices (+450 % between 2007 and 2022), power shortage and increased need of electricity generation capacity. Energy Efficiency becomes thus crucial to ensure energy security and uninterrupted power supply. Geylan's approach investigates how the introduction, piloting, and promotion of energy management systems (EnMS) and energy systems optimization (ESO), especially in SMEs, can help solving the country's energy issues and to boost the overall economic development, with positive social co-benefits such as the creation of jobs, the reduction of costs for industries, improved air quality and enhanced energy security.

Another issue in Southern Africa is the large use of transformers and switchgear that are using polychlorinated biphenyls (PCBs), highly carcinogenic compounds. Michael Scholand et al. (peer-reviewed paper 9-332-24) propose an energy-saving measure that allows simultaneously to remove PCBs and to enhance the efficiency of transformers. A software model, that incorporates the results of the study, has been created and distributed to utilities in Africa to support national programmes of PCB removal from transformers. The model is adjustable by each utility, designed to take into consideration their installed stock of contaminated units and plan for their removal and replacement with new, more energy efficient models. Summarising the techno-economic model and key findings, this paper concludes that cost-effective industrial efficiency measures can be applied to electric power transformers to achieve economic and climate goals while simultaneously addressing public health objectives such as the elimination of PCBs.

SMEs

Small and Medium Enterprises (SME) are often incapable to implement energy saving measures, due to several barriers, both technical and financial. Several studies address how to solve these issues and not leave anyone behind in industrial energy efficiency,

Bo Shen et al. (extended abstract 9-064-24) analyse the barriers hindering SMEs from embracing energy-efficient practices, by presenting five compelling case studies that exemplify promising strategies for advancing energy efficiency within manufacturing SMEs. The case studies constitute the basis of a "closed-loop strategy" that creates an enabling ecosystem for SMEs in developing countries to pursue energy efficiency. The strategy comprises both internal decisions and commitments, partnerships with university and market-based solutions (EPCs and third-party financing), in order to reduce the cost of energy efficiency improvements in SMEs.

Industry–research partnership is addressed also by Marta Maia et al. (peer-reviewed paper 9-153-24), that analyses en-

gagement strategies to involve SMEs in energy efficiency projects led by universities and research institutes. Through different stakeholder feedback, it appears that the first step of the strategy should be to build trust and to establish a two-way knowledge flow. This has the double positive effect of increasing energy efficiency in SMEs and improving the overall relevance of the research work.

The cooperation between industry and research is finally analysed by Richard Bull et al. (peer-reviewed paper 9-233-24), that presents the results of the ERDF-funded Sustainability in Enterprise (SiE) project. This project is an example of partnership working between local Nottingham-based SMEs and a University that engaged with over 200 SMEs and reduced their emissions by almost 1,000 tonnes of CO_2. Evidence shows that collaboration between universities and businesses can be mutually beneficial, supporting students in gaining sustainability competencies and offering businesses the expertise and resources they often lack to reduce their carbon footprints. This shall be clear also to policymakers, businesses, and universities, that have the power to foster cooperation.

Including Multiple Benefits (MB) and energy efficiency in the decision-making for investments in enterprises is well known since before. Sangiorgio et al. (peer-reviewed paper 9-210-24) report on the positive fostering effects achieved in the DEESME project (co-funded under the Horizon 2020 Programme for SMEs). The primary objective was to integrate MBs and energy efficiency in the company's core business process for investments. Experiences from four countries show that the approach requires support from qualified experts to navigate initial technical and managerial challenges supports SME to overcome barriers well-known from several studies.

Energy services to foster decarbonization in the SME sector is studied in a presentation by Dimitris Karamitsos et al. (extended abstract 9-252-24). From a starting point in the perspective of technology providers and clients SMEs some examples of successful as-a-service projects in terms of decarbonisation are presented. Applying a pay-per-use or outcome approach to critical and energy-intensive systems like heating, cooling or compressed air systems can have a significant impact on energy efficiency gains.