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# THE STRATEGIC CHALLENGES OF THE DECARBONISATION OF THE MANUFACTURING INDUSTRY

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ABSTRACT: The paper presents the problematic scope of decarbonisation of the heavy processing of the energy and carbon-intensive industry in relation to Polish conditions. The paper is part of the ongoing discussion of scientists and practitioners on the strategic challenges of the decarbonisation of industry in Poland. The paper is the result of conceptual research carried out on the basis of a review of secondary sources of information. In line with EU requirements, the industrial strategy must include a 2050 decarbonisation vision. The ambitious "net zero" target – the prospect of zero CO2 emissions by 2050 – requires significant financial outlays and profound technological and organisational changes in many industries. The paper is an introduction to the discussion on the preparation of Polish industry for profound changes in decarbonisation.

KEYWORDS: decarbonisation, strategy, change, industry

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## Introduction

Ensuring the sustainability of economies and industries is one of the key challenges of overriding policies (NEPs, Paris Agreement). The measures taken in this regard have been intensified in recent years. Due to the increasing public pressure to limit global warming to 1.5 degrees C, national governments have set ambitious goals related to the decarbonisation of economies and manufacturing industries. At the 2019 UN Climate Summit, 66 countries announced their intention to achieve net-zero $CO_2$ emissions by 2050 (Masson-Delmotte et al., 2018). In EU countries, decarbonisation is part of the European Green Deal policy. Decarbonisation sets net-zero $CO_2$ emissions by 2050. The "net zero" strategy i.e. zero greenhouse gas emissions, will radically change existing business models. Radical change will be determined by technological innovations that need to be introduced in manufacturing companies by 2050 in order to significantly reduce $CO_2$ emissions. It should be noted that the radicality of these changes depends to a large extent on the planned technological innovations, which are today largely in the phases of research and prototypes and at this stage it is difficult to prepare a full cost account in this regard. If the plan is implemented, deep decarbonisation, because this is the path of the industry towards the net zero strategy, will not only be an industrial revolution, i.e. a coup that will demolish old solutions (process technologies, the organisation of production, energy supply, etc.) and build new decarbonised production systems, but also overriding change towards planned economies.

This transformation assumes that in the event of decarbonisation new solutions are new technological investments that will replace the current ones and become the driving force of manufacturing companies on their way to "net zero" (European Commission, 2023).

Full decarbonisation has already become an impetus for manufacturing companies (important players in industrial markets) to plan new technological investments, which, in the transition phase, will be low-emission and, over time, provide companies with zero environmental impact in terms of $CO_2$ emissions from production processes. A great number of new technologies will use hydrogen, but not fossil-based (natural gas, as a source of power) but green (renewable energy sources). Countries see opportunities for the use of hydrogen in numerous sectors, e.g. heat engineering, metallurgy, chemical industry, petroleum industry, synthetic fuels, personal or collective transport, the logistics of goods, industrial heating and energy security. Large and very large enterprises which conduct business activity in metallurgical, automotive, chemical, oil and gas, as well as heating industries consider low-emission hydrogen as an alternative to existing technologies (see, for example Report Linker, 2023). Citing the Energy Market Information Centre, to date 18 countries, the economies of which account for 70% of global GDP, have developed detailed strategies for the implementation of hydrogen energy solutions (Hydrogen Council, 2020). Hydrogen power gener-

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ation will be supported by other renewable energy sources and nuclear energy (Blackbun, 2023). It should be noted, however, that these solutions are largely in the initial phase, and their implementation on a large scale is a postulate today.

Deep decarbonisation will be a challenge for many manufacturing companies. Heavy industry produces products that are central to our modern lifestyles, but is also responsible for nearly 40% of global carbon dioxide ($CO_2$) emissions. Steel, cement and chemical industries are the three most carbon-intensive industries and among the most difficult to decarbonise, due to technical factors such as the need for very high heat and carbon emissions, and economic factors including low profit margins, capital intensity, long asset lives and exposure to trade (Gross, 2021). Other industries can have other problems, but in all industries, the implementation in manufacturing companies in various manufacturing industries will require the preparation of a multidimensional strategy. The pillars of decarbonisation include energy efficiency, the electrification of the industrial sector, low-carbon fuels, raw materials and energy sources (LCFFES) and carbon capture, utilisation and storage (CCUS), low-carbon and/or zero-emission generation technologies, as well as materials and products manufactured in these technologies. The main strategies and measures to decarbonise industry are focused on zero GHG emissions, not only $CO_2$, but also methane. A problem with water vapour occurs here (Waisman et al., 2019). Deep decarbonisation (net decarbonisation) must be adapted to the directions of the economic development of countries. Therefore, solutions implemented from outside should be verified in terms of the endogenous potential of national economies, taking into account their internal analyses. Economic policies and sectoral climate policies must be designed in such a way as to set the key directions for decarbonisation. In addition, synergies between decarbonisation objectives with other objectives such as energy security, economic growth, employment, quality of life, access to relatively low-cost energy sources, local air and water quality and others included in the sustainable development strategies of economies should be sought (Fay et al., 2015). At this stage, many countries have not analysed the social and economic impact of implementing the European zero-carbon policy. The European Council also has not published detailed analyses during the opinion phase of the European Green Deal and the Fit for 55 legislation.

The deep decarbonisation concerns specific industries with the economic activities of manufacturing companies. Individual industries on the path to "net zero" $CO_2$ emissions will be forced to build their own paths to achieve low and/or zero-emission targets. Paths may have common (and/or similar) economic and social conditions, legal and regulatory backgrounds, accessibility to financial resources, but the way the strategy is pursued may vary because it must be adapted to the resource capacity of specific manufacturing companies. Investment plans of manufacturing companies are their individual decisions, preceded by the collection of signals from inside and outside. The decision-making process for the decarbonisation of production must be consistent with management

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functions, from planning, through programme development, progress monitoring, to investment support and development.

The aim of the paper was to develop a general framework for the transformation of the manufacturing industry, which aims to achieve zero greenhouse gas emissions. Zero-emissions will be the strategic goal of industry by 2050. It is assumed for the purpose of research that the decarbonisation process creates a set of determinants, which constitute a kind of strategic framework for individual industries in their participation in "net zero" policy. The paper focuses on the strategic challenges of decarbonising the manufacturing industry, with an indication of the directions and problems of the transformation to "net zero".

The paper assumes that due to real risks, the decarbonisation objectives formulated and their timeframes require revision and critical verification in terms of real technological capabilities, social impact, cost-effectiveness for preserving structural order and building the equivalence of economies and societies. Today, the decarbonisation of the economy is a systemic change because it has a key impact on structural governance, the market, society and the maintenance of economic growth. Taking into account the economic development directions of countries, their endogenous potential, as well as the implementation of the adopted assumptions into sectoral policies results from the basics of strategic planning.

The paper does not use inductive and direct research into decarbonisation processes in particular types of companies. The authors tried to indicate the risk associated with the adopted assumptions of decarbonisation policy. Such a discussion is necessary not only in political terms, but also in science, which should not only examine ex-post reality, analysing the impact and effect, but above all, through agency, shape reality in the future. In this respect, a broad debate on the adopted decarbonisation assumptions, the pace of their implementation will shape the socio-economic costs and quality of life.

The paper consist of three parts. The first section discusses the general issues of changes towards deep decarbonisation and addresses changes in the sector (meso) category, while the second section deals with the location of strategic changes related to decarbonisation in companies. The third section discusses the barriers to and problems of the transformation to low-carbon technologies.

The paper uses the method of descriptive and critical analysis, with reference to expert knowledge. As a result, the paper was written based on the coherence of conclusions. The work is not detailed, but takes the form of a general discussion, which will require further detail with the introduction of changes in the energy industry and industries strongly linked to the energy sector, due to the energy intensity of processes, e.g. the steel sector, as well as industries that need to replace carbon-intensive technologies with low-carbon technologies.

The authors attempted to identify disparities and risks related to the misalignment of the pace of decarbonisation processes in relation to current eco-

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nomic barriers, including technological ones, with particular emphasis on carbon-intensive industries and manufacturing companies. This paper should provide an impetus to starting a solid debate on the real possibilities of implementing decarbonisation policy. Two trends in this debate are visible today: one which advocates decarbonisation as soon as possible, the other – criticising both the effectiveness of the actions taken and critical of the costs involved. In the opinion of the authors, there is no reliable scientific debate, which should not only investigate the event ex post, but shape the future with due diligence.

The paper adopts the following assumptions: the implementation of the objectives of a zero-emission economy; in order to ensure equivalence, it requires the adaptation of the objectives to technological and financial capabilities, the adaptation of the appropriate pace of implemented objectives, taking into account social costs.

In order to effectively and objectively achieve research objectives, descriptive analysis and critical analysis methodology and a deductive method were adopted. The reason for using the deductive approach is that it allows for the determination of directions for shaping management policy and setting priorities. It becomes a verifier for the real sphere. Sulmicki (1973) put it in a synthetic way: there is nothing better for practice than a good theory. It allows you to answer the question of how it should be, and the process of collecting and analysing data verified in relation to theory and only then is it subject to detailed and subjective modifications. Deduction-based methodology allows you to design the future and set priorities correctly.

The value added of the paper is an indication of research and information gaps, which are manifested in the lack of complementary solutions, conflicting diagnoses, goals which are unlikely to achieve, experimental and inefficient technologies, as well as in identifiable strategic threats. Filling this gap will allow for the development of integrated, sustainable and viable solutions for decarbonisation processes in strategic terms. This discussion is taking place today in politics behind the scene, the scientific community implements political indications into the scientific sphere, adopting them as mainstream solutions. However, it is the responsibility of science to seek the truth and build social well-being, as well as develop the right solutions for the real world, also for manufacturing companies.

## The strategic framework for the decarbonisation of the manufacturing industry

The specificity of the business strategy is determined by the scope of the company's activity, its resources, the market where the company operates, the type of consumer, employee competencies, etc. Strategies must be variable and over time they evolve more or less radically, depending on the dynamics of change in the environment in which companies operate. Companies rarely operate on a single strategy basis.

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The development of a strategy that is a combination of different directions of development is usually the most advantageous (David, 1979). The business development strategy is an important construct of the business model (Rudny, 2013; Piontek & Piontek, 2014). Business models are creations focused on creating value by companies in the existing business environment.

The paper assumes that the decarbonisation of industry will set a new business model that will be conditioned by the implementation of a "net zero" strategy by manufacturing companies, which will start transformational events within companies and their value chains or force the decision to terminate the activity of a given entity. The European decarbonisation policy directly advocates the need for a "departure from" or "extinction" of individual industrial and economic sectors. For example, the following should be mentioned: departure from the production of combustion cars until 2035, from meat and dairy consumption, and from the production of energy from coal.

This paper presents the strategic, i.e. core framework for the decarbonisation of the manufacturing industry. The presented framework is part of a wider range of strategic changes in business, such as sustainability (Evans et al., 2017; Brozovic, 2019; Kristoffersen et al., 2020), circularity and ecosystems (Kanda et al., 2021). The structure of the industrial decarbonisation framework was developed based on available knowledge of the course of the decarbonisation process, which is described in overriding documents (legislative and government programmes) as well as in scientific studies and industrial reports and documents. The backbone of the strategic transformation of manufacturing companies towards the radical reduction of $CO_2$ emissions is based on industrial decarbonisation technologies dedicated to various industries, around which activities related to value creation and business efficiency are focused. The relevant (core) constructs of the strategic decarbonisation of industry are low-carbon technologies, and in the future also (almost) zero-emission technologies, powered by renewable energy sources. The result of the activity is the value in the form of low-carbon products.

In the literature, the topic of the strategic business framework in decarbonisation process is presented in various terms of doing business and internal structure. According to Franca et al. (2023) in particular publication such scopes were analyzed: (1) why companies engage in climate change policies (e.g., Amran et al., 2016; Buettner et al., 2022; Finke et al., 2016; Sullivan & Gouldson, 2017); (2) what specific corporate actions have been deployed to reduce CO2 (e.g., Goldstein et al., 2019; Hafner et al., 2022), and (3) which business performance outcomes these initiatives have provoked (e.g., Brouwers et al., 2018; Capece et al., 2017; Haque & Ntim, 2022; Russo et al., 2021; Sartal et al., 2020).

The following occur at the beginning of the strategic transformation of industry towards "net zero" or at the beginning of building enterprise strategies: overriding policies and programmes, available power supply systems, renewable energy portfolio standards, support instruments and other conditions that

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encourage producers to depart from existing generation technology, which uses thermal energy production from coal, to implement cleaner technology, powered by renewable energy sources (RES) and new $CO_2$ storage and utilisation solutions CC(U)S.

In addition to the purchase of energy from external renewable energy sources (RES), strategic plans for the decarbonisation of companies in various processing industries include the directions of reduction of indirect emissions, including investments in own energy sources, solutions improving the energy efficiency of technologies and manufacturing processes. Energy efficiency and resource efficiency remain important in the manufacturing industry's decarbonisation strategy. Despite these assumptions, it should be noted that cobalt necessary for the development of low-carbon technologies is also extracted in African countries, which destroys the ecosystem. In poor countries, the postulates of "fair transformation", „sustainable industry" or "resource rationality" remain only postulates.

The Deloitte report (2020) identifies two energy supply pathways for the industry, namely the external one, which is to diversify energy forms (wind and solar energy and others), and the internal one, which is energy and heat production for the own needs of companies (zero-emission own sources). Renewable energy technologies are supported by enabling technologies called smart technologies (Rosa et al., 2020; Trzaska et al., 2021). Smart technologies that help to balance the electricity grid as the more irregular renewable energy sources or energy-efficient green hydrogen production methods are introduced. In manufacturing companies in various industries, digitalisation has changed business processes since the 1990s (Gajdzik & Wolniak, 2021). Processes are optimised by means of information and digital technologies (ICTs) in real time. Big Data, cloud computing and the Internet of Things (IoT) are a strong support for process technology control. Energy-intensive industries, e.g. the metallurgical industry (Gajdzik et al., 2021; Gajdzik & Sroka, 2021), save energy, thanks to new investments that build the smart manufacturing environment.

An important (strategic) direction for the decarbonisation of industry is the gradual reduction of direct emissions through the introduction (doping) of hydrogen in technological processes, as well as the implementation of energy efficiency solutions. This direction should be achieved by 2030, in line with the adopted target of reducing $CO_2$ emissions by 30% by 2030 compared to emissions in 2020. However, it is important to emphasise a certain disproportion, namely: 1. The objectives adopted, precisely defined in time; 2. The level of maturity of the technology in many solutions at the stage of prototypes and preliminary testing; 3. At the present stage, there is no possibility of implementing the technology in the reality at a specific scale; 4. Lack of estimates of the availability of raw materials needed to produce components at the desired scale, e.g. global cobalt stocks; 5. Lack of estimates of the costs and economic capacity of economies and societies to bear them, for example, in Poland: according to the calcula-

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tions by Mielczarski (Cukiernik, 2023) the total cost of the Energy Transition in Poland will be over PLN 1,000 billion. Almost PLN 600 billion (60%) will be allocated to renewable energy sources, assuming the RES share in electricity production at the level of 50% in 2050. The transformation of conventional power plants will cost PLN 240 billion, assuming that coal-fired power plants will only be replaced by CCGTs. This cost increases to PLN 340 billion if nuclear power plants are also built. The cost of electricity grid development is estimated at about PLN 210 billion (Biznes Alert, 2022). The increased share of renewable energy sources to 70-80 percent will increase the costs of RES to more than PLN 1000 billion before 2050. The European Union support for the costs of energy transition in Poland under the Just Transformation Mechanism will have provided PLN 17 billion by 2027. This will be about 5.5% of the total cost of transformation at that time , which means that 94.5% of these costs will have to be covered by society, with an average salary in Poland of PLN 5,330 net (June 2023) (Biznes Alert, 2022).

The EU document, High-RES scenario of the EU 2050 energy roadmap (European Commission, 2011), which is a roadmap for zero $CO_2$ emissions, specifies a few megatrends of energy diversification, namely nuclear energy, green energy, grids transmission and distribution (Grid energy storage (grids) means that electricity is stored when there is more electricity (especially renewable electricity from wind, tidal and solar power) or when demand is low and then returned to the grid as demand increases), smart (passive) buildings and homes, electric transport (electric cars), the development of new heat sources (e.g. heat pumps), internal energy sources in industry, and building the hydrogen economy. It is assumed that building the hydrogen economy will create a scale effect that will reduce the costs of green hydrogen and make it competitive with fossil-based hydrogen and natural gas. The assumption of achieving the appropriate scale of hydrogen production and electrolysers seems to be debatable in view of the expected reduction in the cost of producing green hydrogen. It is sufficient to analyse the so-called bottlenecks of the entire process. The process will require unimaginable quantities of critical raw materials, the resources of which are limited. This is often attributed to destabilised markets with a tendency to increase this negative trend. Also, the supply of critical raw materials is limited and demand is growing disproportionately to the capacity of mining and even the planet. These raw materials are likely to be more expensive instead of the assumed fall in prices. In addition, increased RES, which destabilise the system of energy production and transmission, are accompanied by the increased cost of network maintenance not only in Poland, but throughout the EU.

Industrial technologies that use hydrogen generated from non-GHG energy are core strategies to decarbonise manufacturing companies in many industries. The vast majority of hydrogen will be necessary to decarbonise the steel industry, which consumes all coke and most natural gas (Gajdzik et al., 2023a, 2023b). A more ambitious direction is the total reduction of indirect emissions, namely

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electricity and heat exclusively from non-emission sources (transition to zero-emission own sources) (IREA, 2018). This direction requires changes to the existing energy mix from coal to wind farms, photovoltaic cells (PV), heat pumps (HP), etc.

The EU document (Opinion, 2022) states that for the green transition in the manufacturing industry to be successful, the sufficient and appropriate blend of renewable energy for electrification and production of green hydrogen is necessary. Carbon removal technologies (CDR), carbon capture and storage (CCS) and carbon capture and utilisation (CCU) will help industry achieve climate neutrality. The use of renewable energy across Europe is essential to achieve the Green Deal objectives. Changes must be comprehensive (systemic) within companies and throughout supply chains. The path of decarbonisation of industrial (business) processes is, at the beginning, the reduction of the carbon footprint and eliminating "black" (carbon-based) energy sources and ultimately producing products "without $CO_2$ emissions" (Zero CO2 emissions are attributed to technologies that reduce emissions by 90% or 95% compared to current ones). The decarbonisation of supply chains is a core component of the business transformation strategy to achieve the climate targets set in the manufacturing industry ("Fit for 55" emission reductions by 55% by 2030 compared to 1990 emissions and neutrality by 2050 (European Commission, 2011). It will be more effective to coordinate the efforts of companies in supply chains rather than act alone. Automation and digital decarbonisation solutions are extremely helpful to eliminate the carbon footprint in supply chains and to reduce $CO_2$ emissions.

In the "net zero" strategy (a target to be achieved in 2050), companies in the various processing industries will seek the maximum reduction of direct emissions, plan investments in hydrogen technologies, improve electromobility, deploy advanced technologies within the production line, and use CCU and CCS technologies (European Commission, 2018a). CC(U)S technologies are generally understood as $CO_2$ capture technologies (e.g. the possibility of congesting brine layers or basalt formations into natural gas deposits). These technologies have been popularised for more than a decade but have not been implemented due to the lack of economic justification (low cost of rights in the ETS). This has resulted in a 60% increase in energy prices in Poland at the first stage. It is only the rise in ETS prices, as well as the ambitious climate targets adopted in the EU policy, that have forced business interest in CC(U)S projects. Carbon removal technologies (CDR) from the atmosphere are embedded in strategies for "negative" emissions. An important part of negative emissions technologies are also technologies for the production of bioenergy with carbon capture and storage (BECCS) and direct air capture and storage (DACCS) (Opinion, 2022). However, the energy impoverishment of societies is accelerating. According to the forecasts of the TNO Institute, almost 700 thousand Dutch farms are affected by energy poverty (Energetyka24, 2021). In turn, according to the Ministry of Climate and the Environment, if it were not for the $CO_2$ price, the cost of generating electricity in Poland

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would be 60% lower. This means that this cost is borne by society (Ministerstwo Klimatu i Środowiska, 2022). The implementation of the industrial decarbonisation strategy will be based on investments in low-carbon and zero-emission technologies used in production processes (manufacturing) and/or carbon capture and storage technologies (CC(U)S). The strategic objective of the manufacturing industry is not to produce $CO_2$ in manufacturing processes. Technologies using hydrogen produced from renewable energy sources (green hydrogen) are a challenge for the manufacturing industry (Hydrogen Council, 2020). However, one should ask about the real possibilities of implementing these technologies and their cost.

The high costs of zero-emissions, the projected increase in ETS charges will effectively reduce the competitiveness of the economy and individual manufacturing companies. For example, one of the first stages is ESG reporting, which many companies are currently completely unprepared for (PWC Poland report – 70 % of companies are ready for ESG reporting), next limiting availability to capital, and higher cost of capital. Achieving zero greenhouse gas emissions by 2050 requires an investment of $5 to $7 trillion per year in the global energy transition, according to the Deloitte report (2023). One must be fully aware that the financing of this transition will come at the expense of financing other objectives such as health, education, etc. This cost will be borne by governments, which means that society and business as well. It should also be noted that this 52-page report devotes a total of 1.5 pages to political, market and transformation barriers, completely disregarding technological barriers as well as social costs. For example, 85 % of the Germany's 2023 budget was allocated to climate issues, at the expense of spending on health, safety, education and development, as shown below (Figure 1).

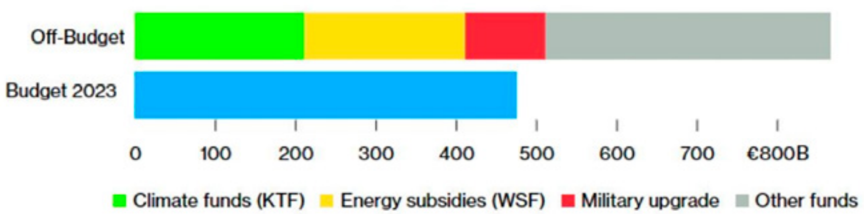


**Figure 1.** Germany's Special Funds Exceed Regular Budget
Source: German Finance Ministry (2023).

Strategies for the deep decarbonisation of industry are complemented by actions regarded as a potential offset of other emissions. This direction means the reduction of the adverse impact of numerous processes and technologies associated with them in terms of other emissions to the environment.

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Strategic decarbonisation directions must not mean a cut in production, but on the contrary, they should create the conditions for increasing it while respecting the principles of sustainable development and climate protection (Piontek & Piontek, 2014). . At the same time, it should be noted that decarbonisation directions can lead to cuts in production. The path of companies to “net zero” must be supported by EU funds for climate and innovation. Manufacturing companies will face the profound transformation of industrial activity over the next 30 years. Although low-carbon technologies are already being tested, their technological readiness (TRL) (Technology Readiness Levels are different points on the scale used to measure the progress or maturity of a given technology) the level is increasingly higher (but not in all industries and countries). Strong government support instruments for various processing industries will be needed to ensure that action plans for new technologies that are expected to significantly reduce CO2 emissions during manufacturing processes are realistic (Opinion, 2022). Over the years, we have often witnessed that government support instruments do not guarantee the development of such significant innovations. Moreover, industrial flight outside the EU has been observed for years, and due to decarbonisation, it can degrade sciences responsible for creating innovation.

Demand-related measures will also be necessary to promote low-carbon products and new business models (industrial symbiosis, circularity, demand response), as well as real opportunities to acquire them, thus not only curbing current impoverishment trends, but even enriching societies so that they can afford to finance decarbonisation processes without compromising the quality of life.

Technological transformations in the manufacturing industry will be accompanied by changes in the working methods, skills and competencies of employees in the industry. The reorganisation of the human factor in the process of industry decarbonisation is primarily new competencies and new jobs in new sectors of the economy, referred to as “green jobs”. New skills will be needed, as well as staff up skilling and reskilling. In the just transition, citizens and employees, SMEs, social organisations and regional experts are encouraged to play an active role in the inevitable changes in their homes (Just Transition Fund).

Deep decarbonisation will require greater synergies between politics and business. Synergy is inscribed in the process of deep transformation due to the importance of change for the development of economies and industries. Companies without external support (financial, research, information, advisory, etc.) would not be able to go through a process of deep decarbonisation. This means that this process is not a natural business change, but involves a departure from the market economy (external support) and free competitiveness. This process will significantly influence the development of both supply and demand in strategic markets for economies. In addition, internal changes would be ineffective if there were no thematic platforms, research centres, test centres for new technologies, as well as the entire infrastructure to supply industry with renewable

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energy and nuclear energy (the latter is necessary to meet the growing energy demand of economies and industries). Decarbonisation means creating the conditions for unlocking huge financial, technological and intellectual resources for investments in low-carbon technologies, including carbon removal technologies, which should be implemented quickly. The question is how these proposal will be applied. In addition to programmes offering financial support for research and development (R&D), new partnerships and exchange of information are necessary to achieve ambitious climate targets.

This strategic framework aims to help to better understand the deep decarbonisation of the manufacturing industry and to build internal strategies for the decarbonisation of manufacturing processes in companies.

## Strategy of neutrality in manufacturing companies

The net zero goal, which will have to be achieved by 2050, will be achieved gradually, but will radically change the technologies of the manufacturing industry. Current production methods will be changed by the implementation of new manufacturing technologies, the digitalisation of processes and the full automation of activities (operations). New products and services will be available on the market. The market will change, both in terms of supply and demand. The model of decarbonisation of the manufacturing industry will require many new market and protective regulations against third country markets (countries where the decarbonisation of industry will be delayed). The markets of countries with deep decarbonisation need to be protected in order to ensure that prices are stable and competitive.

The internal process of transformation begins with the initiatives of R&D departments, where innovations are created. R&D departments receive support in the form of ready-made (tested) solutions of low-carbon and climate-neutral technologies dedicated to individual industries. In some industries, decarbonisation innovations do not necessarily have to be radical and revolutionary. Companies can use existing or new technologies in their processes to achieve almost zero greenhouse gas emissions. In addition, in the initial phase of decarbonisation, companies can make changes to some processes like production, supply and other. However, in the net zero perspective, further research and development (R&D) will be necessary to adapt current technology (i.e. used in the company ) to the zero $CO_2$ emissions technology.

The ways in which companies reach climate neutrality depend on the specificities of the industry, the type of economic activity, the size of companies, the markets of suppliers and customers, the natural production potential of countries and regions, and other factors. Very large and large manufacturing companies have a market advantage over other technological and organisational innovations at the stage of planning due to access to capital and knowledge (own,

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large R&D centers). In the Polish context, it should be mentioned that there are no global companies, which at the ex ante stage allow for a question about the opportunities for countries like Poland to be leaders in the decarbonisation process.

Examples of companies promoting net zero strategies: Viessman (Rzeczpospolita, 2023), Sheel Company (Shell, n.d.), Bosch Company (Bosh, n.d.), Orlen (Orlen, n.d.).

“Net zero” strategies in companies are and will be part of the business decarbonisation model. Deep decarbonisation will not be achieved without defining the vision of a company to achieve process neutrality. The company vision should be based on a model or strategy for decarbonising the entire value chain. The decarbonisation of value chains in particular manufacturing industries requires an understanding of the scope of greenhouse gas emissions. When adopting a “net zero” strategy, companies focus primarily on $eCO_2$ emissions directly from manufacturing technology. The higher level includes indirect emissions from purchased energy generated outside the production company. The broadest level includes indirect emissions from the entire company value chain, both up and down the chain (Impact Economist, 2020). Therefore, both cross-sectoral and vertical transfer of knowledge should be supported and facilitated by creating a favourable business environment. However, in the real world, the opposite trend can be seen. Volkswagen is moving its production to the United States. In Chattanooga, a factory is being built in 5.2 $km^2$ with a production potential of 150 thousand cars per year. The scope of work carried out at the factory in the production of the U.S. version of Passat models will cover 85% of the total production process. There are currently 1,700 employees employed directly by Volkswagen at the Chattanooga plant. Another 10 thousand jobs will be created at the factory suppliers from the United States (Auto Świat, 2011). According to the assumptions, decarbonisation going beyond the production company allows it to focus on the needs and technologies of suppliers (chain input) and on the needs and technologies of customers (chain output). Many suppliers of raw materials and energy are on the front line of climate policy and deep decarbonisation will begin with them. Joint decarbonisation strategies for suppliers and manufacturers will foster more efficient reductions in $CO_2$ emissions and increase the protection of resources that both suppliers and manufacturers care about and contribute to a more resilient and fair supply chain. In turn, cooperation with consumer markets will result in better adaptation of products to their expectations. The decarbonisation of industry will accelerate when participants in value chains are the initiators of interconnected investment projects. However, a question arises of whether the decarbonisation estimates take into account the decreasing availability of raw materials and how the increased protection of resources should be understood, since zero-emission requires many times greater extraction of copper, cobalt, nickel or lithium.

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Depending on the type of economic activity, companies have several roads (paths) leading the decarbonisation of their processes (Impact Economist, 2020). The first path is to implement completely new generation technologies (energy supply installation) and switch to new and less carbon-emission, internal and external types of energy. This path is the most difficult and capital-intensive and incorporating it into the company's decarbonisation strategy will almost be a technological revolution, which will entail the restructuring of all areas of the company activity. The technology classified as carbon-intensive will be decommissioned. These companies will be actively involved in testing new climate-neutral technologies. Very strong capital groups, which are renowned on the global market of a given product will decide to follow this path.

Another path to the climate neutrality of manufacturing companies is the modernisation of existing technologies of generation and installation of energy supply of processes and improvement of the energy efficiency of processes. As new, external "green" energy sources emerge, companies will adapt their technology to new energy and process requirements. This group of companies will wait until manufacturing technologies, dedicated to a given industry in its deep decarbonisation process, obtain the status of commercial technologies.

The third path, which emerges from the first and second paths, will be a combination of new and old generation technologies (energy supply installation) with strong diversification of energy sources. This path towards climate neutrality will be followed by numerous companies that will gradually innovate, replacing existing technologies, on their path to the full decarbonisation of their processes until the entire machinery fleet is replaced.

The fourth path refers to the ways of exchanging and/or modernising technologies described in paths two and three, but is strongly supported by outsourcing of production towards low-carbon technologies. Companies will search for suppliers of low-carbon components that will feed into their processes.

Strategic management all starts with a vision that determines the direction of decarbonisation of a production company. The strategy itself, as a key plan for the decarbonisation of the company, is based on a detailed analysis of the greenhouse gas emission ranges inside and outside the company. The analysis of internal and external conditions of the decarbonisation process should be supported by a technological audit.

Technological audit is a form of answer to the following questions: What technology does the company have? What are the opportunities for companies to invest in new technologies? What technologies are considered crucial for business development? What are the areas of possible applications for technological innovation? What benefits can be expected from the implementation of the changes? (Gajdzik, 2022). But above all, an audit is a contribution to the cost analysis and calculation of the internal rate of return on investment. The technology audit on decarbonisation assesses the technological state of the company, together with procedures applied and investment needs in pursuit of neutrality.

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A well conducted technological audit before the preparation of investment projects in companies makes it easier for them to achieve success. The audit of process decarbonisation is usually conducted with the participation of external consultants, who closely cooperate with the management and employees of the audited company. The result of the audit is to determine the directions of technological changes, in line with the provisions of the "net zero" strategy.

Manufacturing companies should find opportunities to reduce the cost of transformation in the financial plans of decarbonisation. A question about the cost of business decarbonisation should be answered in the transition process as part of the implementation of the "net zero" strategy. The internal valuation of carbon dioxide emissions from the technologies used is one of the components of investment planning and $CO_2$ emission financing that companies can adopt to attribute "decarbonisation costs" to all activities.

The implementation of the decarbonisation strategy, which is defined by the "net zero" strategy, in line with the EU climate policy objective, must be based on radical technological innovation. Works on new low-carbon manufacturing technologies are taking place, and depending on the industry, they are at the stage of testing or pilot projects. Pilot projects enable the creation of decarbonisation areas and the implementation (after confirming the effects) of solutions on a massive scale. In programmes of this type, the level of available resources is crucial as a catalyst for change. However, in many aspects, their high-scale implementation prospects are indeterminate, which creates a significant imbalance in relation to the time horizon of the decarbonisation process. The implementation of the "net zero" strategy could be jeopardised by the gap between ambitious targets and the availability at this stage of the transformation of new technologies for manufacturing companies.

The strategic performance of companies is assessed and reported, which, in the decarbonisation process, focuses on the $eCO_2$ emission indicators of the company technology and installation and the entire supply chain (the blockchain technology and product life cycle assessment, LCA, may be a helpful solution).

Technological innovations, which are considered necessary in the process of decarbonising the manufacturing industry in order to achieve climate neutrality, must be economically justified and related to the social dimensions of business activity. However, it is not entirely clear what such technological innovation is and what is not. For each group of factors (technological, economic, social, political, legal, environmental, and market) a list of possible interactions of the company with the environment in the context of positive or adverse impact is created.

During the implementation of the decarbonisation strategy, the company should be in constant contact with stakeholders. Dialogue with stakeholders facilitates the process of technological transformation. Companies expect financial and instrumental support in the process of deep decarbonisation.

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## Barriers to and problems with decarbonising the manufacturing industry

Given the ever-increasing urgency to limit global warming by 2050 to well below 2 degrees Celsius above the industrial level, companies are starting to make bold commitments in terms of environmental protection, social affairs, governance (ESG) and net zero emissions. While it is quite simple to set decarbonisation targets, the means to achieve them may be less obvious. New technological investments to ensure a radical reduction of $CO_2$ emissions into the atmosphere are very capital-intensive. The financial barrier, understood as the cost of changing generation technology and power technology, is considered a decarbonisation-related challenge (Duon, 2023). Companies are concerned about the lack of available alternatives to invest in low-carbon and climate-neutral technologies, e.g. steelworks are somehow forced to switch from BF+BOF technology (Blast Furnace + Basic Oxygen Furnace) to DRI (direct reduced iron) and new generation electric arc furnaces (EAF) (Gajdzik et al., 2023a; Gajdzik et al., 2023b). To stay on the market, manufacturing companies need to agree to new manufacturing technologies and low-carbon energy sources, which are considered necessary for individual manufacturing industries to reduce $eCO_2$ emissions from manufacturing processes.

It is always risky to design and implement changes, especially so profound in decarbonisation by 2050. A critical part of the decarbonisation of the business model of manufacturing companies is the understanding of risks associated with climate change affecting manufacturing activities and ultimately their impact on the financial performance of companies. Many scientific communities have significantly different positions in this regard (Gajdzik et al., 2023c; Gilchrist & Mouzas, 2016). When setting the costs of decarbonising the manufacturing process and related processes, companies include risks associated with new investments (IIR), markets for suppliers of materials and energy, consumer markets, as well as many external circumstances (e.g. the region where the company operates, or whether the region is covered by the Just Transition Fund) (Fulton & Weber, 2012; Haslam et al., 2014; Lohmann, 2009; Pattberg, 2012). Technical constraints related to the supply of "green" energy (logistics, new switches, etc.) as well as challenges faced by service providers of new technologies and power supply infrastructure are also barriers to the implementation of new investments towards decarbonisation of production. If companies consider making their own investments to power generation technology, they should have access to land for new investments in addition to providing resources (Madeja, 2021). In addition to technical conditions, the problem may be the mentality of staff and the need for reorganisation. New technologies need new skills and qualifications. Deep decarbonisation can create new jobs that are referred to as "green" because they concern professions that aim to protect the environment directly or to minimise the environmental impact of economies and industries. In the United Nations

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Environment Programme (UNEP), green jobs are defined as "work in agricultural, manufacturing, research and development (R&D), administrative, and service activities that contribute(s) substantially to preserving or restoring environmental quality". In other words, green jobs aim to protect and promote the environment or always take into account their impact on the health of the planet and strive to minimise it (UNEP, 2020). The circular economy, which includes product reuse, repair or recycling, will also create green jobs. In addition to reducing waste, the circular economy will help save energy and prevent irreversible damage to the environment caused by the exploitation of resources at too rapid a pace (Allwood et al., 2011). The path to "net zero" strategy requires a change in the managers' mindset. A holistic approach to management is necessary, and linear-type thinking must be replaced by circular thinking. Internal management transformation can bring energy and cost savings. Circularity means looking at the entire life cycle of a product, from how it is produced to how it is potentially disposed of, and redesigning it in such a way that it can last longer, be reused or reprocessed into something else. According to the Circle Economy global organisation, moving away from the linear economy could reduce greenhouse gas emissions by 39%, reducing 22.8 billion tons of annual emissions from the creation of new products from primary materials. In addition to the focus on circularity, companies use regenerative models, i.e. ways to protect, strengthen and support the environment and communities within their value chains, and preventive models, i.e. preempting the adverse environmental impact of doing business (Gajdzik & Wyciślik, 2017). With the acceleration of deep decarbonisation, companies will intensify transformative thinking aimed at reducing $eCO_2$ emissions. Investment in the latest generation of low-carbon technologies and renewable energy sources should take place within the capacity of the company and its supply chains.

It should be noted that in the case of the energy industry, there is no stable source of zero-emission energy at this time. And many technologies like nuclear fusion are in the experimental phase.

Mielczarski draws attention to doubts regarding the technological capacity of storage (Cukiernik, 2023). In his opinion, electricity cannot be stored. Physicists know this very well. Einstein repeatedly said that electricity is the movement of electrons and movement cannot be stored. Prof. Mielczarski (Cukiernik, 2023) points to the possibilities of storing energy only in intermediate forms: 1) in the form of potential energy through the construction of a pumped-storage plant; 2) in chemical, e.g. lithium-ion warehouses, like in cars; 3) another new idea is hydrogen. All of these solutions do not translate into energy security. For example, if a pumped-storage plant was filled in May or June and wait until January to use stored water, it would perform one cycle per year, and the cost of energy would not be PLN 2,000/MWh, but PLN 200 thousand/MWh. Readers should evaluate the validity of such decisions.

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In turn, the consumption of lithium (the so-called white gold) is associated with the consumption of a large amount of water, environmental pollution and social protests. Australia is currently the largest producer of lithium, and Chile has the richest deposits. Argentina, Bolivia, China and the United States also have large deposits. Lithium, although it is quite common, requires a lot of money and long preparation. *For this purpose, impressive "lithium fields" are used – rows filled with ponds, the views of which from the bird's eye delight with shades of yellow, turquoise and green. However, experts emphasise the risks associated with this method of extraction – 500 thousand litres are needed to obtain one tonne of lithium, and according to some sources up to 2 million litres of water. According to the Bank of America, demand for lithium, which in 2020 amounted to 300 thousand tonnes per year, will have increased to 3 million tonnes by 2030. Fitch Solutions analysts predicted that demand would grow faster than production, so the world could face a shortage of lithium by 2025* (Bankier.pl, 2023). According to Benchmark Mineral Intelligence analyses, by 2040, the entire lithium extracted in 2021 will be enough to meet the monthly demand, even with the delivery of recycled batteries, and by 2050 we will have to extract 20 times more lithium than today. The annual production of lithium must increase to 11.2 million tonnes (Magazyny.pl, 2022).

For the purpose of further discussion, the authors proposed a tabular layout of the proposed argumentation structure for introducing sectoral changes within the framework of "Deep Decarbonisation". At this stage of access to knowledge of the transformation taking place, the table could not be filled in due to too many legal, organisational and systemic gaps at the levels of the overriding policies as well as the strategic levels of companies. The proposed table (Table 1) can be used as a tool at the stage of analysis prior to the feasibility study of technological projects.

In order for the deep decarbonisation of the manufacturing industry to be an opportunity, it is necessary to make policy assumptions realistic, assess the availability of raw materials (as well as value them) with the plausibility of technological processes, but above all, calculate to what extent the costs and pace of these changes will be socially accepted. The impoverishment of societies already in many countries raises decision-making dilemmas at the government level. Business, in turn, faces large increases in energy and raw materials costs (e.g. high scrap prices in the steel sector). Without ordering and ensuring acceptable economic stability, it is difficult to understand the decarbonisation of technologies and identify opportunities to reduce $eCO_2$ emissions and identify potential opportunities to move to a decarbonisation model and invest in new low-carbon technologies.

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**Table 1.** Example tool for analysing the conditions of the sector/industry transformation to net zero strategy

<table>
<tr><th colspan="6">Stages of implementation of zero-emission policy to the real sphere from the perspective of the economy, industries,and manufacturing companies</th></tr>
<tr><th>LP.</th><th>STAGES</th><th></th><th>Expected environmental, economic, and social EFFECT (E)</th><th>Estimate environmental, economic, and social EXPENDITURE (N)</th><th>E/N RELATIONSHIP related to a properly defined criterion</th></tr>
<tr><td>1.</td><td>Determination of the degree of emissivity of the economy/industry/process</td><td rowspan="11">EXPERT D E B A T E – Multivariate assessment of cost actions</td><td colspan="3">Necessary condition</td></tr>
<tr><td>2.</td><td>Identification of the objectives of the zero-emission economy for industries, taking into account the strategic dimension</td><td>Setting $CO_2$ emission reduction targets</td><td>Expenditure to be made to achieve the target in these terms, taking into account emission inputs</td><td>Necessary condition</td></tr>
<tr><td>3.</td><td>Share of economy/industry emissions in GDP</td><td colspan="3">Necessary condition</td></tr>
<tr><td>4.</td><td>Replacement value of zero-emission economy in GDP/for the industry/the company</td><td>Restoring the current GDP value of the liquidated industry</td><td>Expenditure to be incurred to restore the value of GDP together with flows</td><td>Necessary condition</td></tr>
<tr><td>5.a</td><td>Technological availability for industries</td><td>Determination of the decarbonisation effect</td><td>Cost of existing or planned technology taking into account environmental and social risks</td><td>Necessary condition – determination of technological risk</td></tr>
<tr><td>5.b</td><td>Transfer of green technologies (implementation of technologies available at laboratory/pre-industrial scale – scale-up)</td><td>Implementation of technology at TRL<9 level</td><td>Investment costs depending on the technology and the level of readiness of the solution</td><td>Unnecessary condition</td></tr>
<tr><td>6.</td><td>Social and environmental costs and inputs</td><td>Multi-option valuation of social and environmental benefits</td><td>Multi-option valuation of the social and environmental costs necessary to bear</td><td>Necessary condition</td></tr>
<tr><td>7.</td><td>S&G supply chain assessment (human rights, sanctions, sustainable management)</td><td>Social impact assessment of subcontractors, raw material suppliers, and ESG due diligence</td><td>Impact on social factors</td><td>Necessary condition</td></tr>
<tr><td>8.</td><td>Identification of internal links between industries and identification of critical points</td><td colspan="3">Necessary condition (elimination of contradictions, consistency of the pace of change)</td></tr>
<tr><td>9.</td><td>Determination of the pace of deployment of zero-emission technologies for industries</td><td>Technology availability (research, design, experimental, multi-implementation phases)</td><td>Cost of technology discounted by time</td><td>Necessary condition</td></tr>
</table>

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| Stages of implementation of zero-emission policy to the real sphere from the perspective of the economy, industries,and manufacturing companies | | | | | |
|---|---|---|---|---|---|
| LP. | STAGES | | Expected environmental, economic, and social EFFECT (E) | Estimate environmental, economic, and social EXPENDITURE (N) | E/N RELATIONSHIP related to a properly defined criterion |
| 10. | Implementation tools | EXPERT D E B A T E – Multivariate assessment of cost actions | Expected zero-emission effect discounted by lost benefits | Public and private expenditure | Necessary condition |
| 11. | Development and evaluation of industry standards (policies) in the context of S&G | | Multidimensional assessment of business policies and management (e.g. AML, Cyber-sec, Agile, etc.) | Multi-option assessment of the implementation of new business practices, policies and management | Necessary condition |
| 12. | Multidimensional assessment of the impact of ESG regulations on the financial performance of the sector/industry/companies | | Modelling the impact of identi-fied risks, gaps and opportunities in assessing the financial situation of the company/industry/sector in accordance with ESRS/IFRS guidelines | The value of investments specific to the industry and identified gaps | Necessary condition |

## Conclusions

To sum up, the manufacturing industry is a core link in the decarbonisation of economies. Overriding policies set very ambitious targets for reducing eCO2 emissions over the next three decades. However, there are no necessary comprehensive analyses of the economic and social impact of achieving the objective of zero-emissions in 2050. New production technologies, which are classified as innovations in the field of climate neutrality of industry, as well as technologies which improve energy efficiency and solutions to optimise processes powered by renewable energy, are examples of the industrial transition by 2050. To achieve the objective of carbon neutrality by 2050, investments in research and development (R&D) as well as financial and instrumental support for innovations that are part of the decarbonisation of industry will be needed. However, first of all, mature technologies will be necessary, which can be implemented on the desired scale. For the manufacturing industry such as cement, chemical, metallurgy, CCS and CCU technologies (of $CO_2$ capture) are also important. The last

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decades, in which decarbonisation in the EU has been gaining momentum, have shown the effects of the process, namely industrial and human resource flight, as well as a significant decline of EU countries in creating global innovation. Currently, there are still large differences between carbon-intensive industries, e.g. energy, aviation, and the agricultural sector which produces the least CO2 from large sectors, from the carbon structure of the economy, access to low-carbon technologies and the cost of acquiring them, etc. This approach has its roots in the strategic planning of companies of various industries. Each industry must have a reference in overriding policies, in the form of decarbonisation pathways, step by step. Numerous publications emphasise the need to develop effective pathways for achieving low carbon emissions (Gajdzik et al., 2023a; Gajdzik et al., 2023b; Bataille et al., 2016a; Bataille et al., 2016b; Mathy et al., 2016). The authors point out that this is not a general path, but a path supported by tools for assessing efficiency, as indicated in the title of the publication (Bataille et al., 2016a; Bataille et al., 2016b). There are still too many barriers in energy-intensive sectors and important for economies to make changes quickly (Gajdzik et al., 2023a; Gajdzik et al., 2023b; Bataille, 2019). The process must be well planned because it already has symptoms of a technological revolution.

However, deep decarbonisation involves not only changes in technology through low carbon innovation, but requires a broader sociotechnical transition that also entails changes in user behavior, culture, policy, industry strategies, infrastructure and science (Fais et al., 2016; Markard et al., 2012; Geels, 2002; Grin et al., 2010; Wesseling et al., 2017).

The discussion presented in the paper seems to be a simplified scheme of thought, as it concerns only the strategic framework for the deep decarbonisation of the manufacturing industry, but it can encourage scientists and practitioners to develop knowledge of the deep decarbonisation of the manufacturing industry. The general knowledge of the decarbonisation of the manufacturing industry will develop with technological advances, economic changes, investments made, etc. On the basis of the overall strategic framework, cross-sectoral and sectoral decarbonisation solutions will be built, accompanied by the examples of good business practices in conducting the deep decarbonisation process effectively.

## The contribution of the authors

Conceptualization, B.G. and B.P.; literature review, B.G. and B.P.; methodology, B.G. and B.P.; formal analysis, B.G. and B.P.; writing, B.G. and B.P.; conclusions and discussion, B.P. and B.G.

The authors have read and agreed to the published version of the manuscript.

## References

Allwood, J. M., Ashby, M. F., Gutowski, T. G., & Worrell, E. (2011). Material efficiency: A white paper. Resources, Conservation and Recycling, 55(3), 362-381. http://doi.org/10.1016/j.resconrec.2010.11.002

Amran, A., Ooi, S. K., Wong, C. Y., & Hashim, F. (2016). Business strategy for climate change: An ASEAN perspective. Corporate Social Responsibility and Environmental Management, 23(4), 213-227. https://doi.org/10.1002/csr.1371

Auto Świat. (2011). *Volkswagen otworzył nową fabrykę w USA.* https://www.auto-swiat.pl/wiadomosci/aktualnosci/volkswagen-otworzyl-nowa-fabryke-w-usa/0hs5xeq (in Polish).

Bankier.pl. (2023, December 31). *Paradoks litu, czyli ciemna strona transformacji energetycznej.* https://www.bankier.pl/wiadomosc/Paradoks-litu-czyli-ciemna-strona-transformacji-energetycznej-8671770.html (in Polish).

Bataille, C. (2019). *Low and Zero Emissions in the Steel and Cement Industries: Barriers, Technologies and Policies.* OECD Green Growth and Sustainable Development Forum. https://www.oecd.org/greengrowth/GGSD2019_Steel%20and%20Cemement_Final.pdf

Bataille, C., Waisman, H., Colombier, M., Segafredo, L., Williams, J., & Jotzo, F. (2016a). The deep decarbonization pathways project (DDPP): insights and emerging issues. Climate Policy, 16, S1-S6. https://doi.org/10.1080/14693062.2016.1179620

Bataille, C., Waisman, H., Colombier, M., Segafredo, L., Williams, J., & Jotzo, F. (2016b). The need for national deep decarbonization pathways for effective climate policy. Climate Policy, 16(1), 7-26. https://doi.org/10.1080/14693062.2016.1173005

Biznes Alert. (2022). *Mielczarski: Koszty transformacji energetycznej w Polsce (ANALIZA).* https://biznesalert.pl/mielczarski-koszty-transformacji-energetycznej-w-polsce-analiza/ (in Polish).

Blackbun, M. (2023, March 6). *Making trade-offs on the road to net zero.* https://www.linkedin.com/pulse/making-trade-offs-road-net-zero-mitchell-blackburn

Bosh. (n.d.). *Environmental protection along the value chain.* https://www.bosch.com/sustainability/environment/

Brouwers, R., Schoubben, F., & Van Hulle, C. (2018). The influence of car-bon cost pass through on the link between carbon emission and corporate financial performance in the context of the European Union Emission Trading Scheme. Business Strategy and the Environment, 27(8), 1422-1436. https://doi.org/10.1002/bse.2193

Brozovic, D. (2019). Business model based on strong sustainability: Insights from an empirical study. Business Strategy and the Environment, 29(2), 763-778. https://doi.org/10.1002/bse.2440

Buettner, S. M., König, W., Vierhub-Lorenz, F., & Gilles, M. (2022). *What motivates companies to take the decision to decarbonise?* https://doi.org/10.20944/preprints202210.0395.v2

Capece, G., di Pillo, F., Gastaldi, M., Levialdi, N., & Miliacca, M. (2017). Examining the effect of managing GHG emissions on business performance. Business Strategy and the Environment, 26(8), 1041-1060. https://doi.org/10.1002/bse.1956

CIRE. (2021). *Pełna dekarbonizacja wymaga wodoru.* https://www.cire.pl/artykuly/wodor-materialy-problemowe/pelna-dekarbonizacja-wymaga-wodoru (in Polish).

DOI: 10.34659/eis.2023.87.4.680

Cukiernik, T. (2023). *Miliardami euro UE nie zmieni praw fizyki, bo one są nieprzekupne [WYWIAD].* https://fpg24.pl/miliardami-euro-ue-nie-zmieni-praw-fizyki-bo-one-sa-nieprzekupne-wywiad (in Polish).

David, F. R. (1979). *Strategic management: Concepts and Cases.* Strickland: Thompson.

Deloitte. (2020). *The 2030 decarbonization challenge. The path to the future of energy.* https://www2.deloitte.com/pl/pl/pages/energy-and-resources/articles/dekarbonizacja-i-rozwoj-odnawialnych-zrodel-energii.html

Deloitte. (2023). *Financing the green Energy transition: A US$50 trillion catch.* https://www2.deloitte.com/content/dam/Deloitte/global/Documents/deloitte-financing-the-green-energy-transition-report-2023.pdf

Duon. (2023). *Transformacja energetyczna w polskich firmach produkcyjnych.* https://duon.pl/lepiejnagaz/transformacja-energetyczna-w-polskich-firmach-produkcyjnych-najnowszy-raport/ (in Polish).

Energetyka24. (2021). *Holandia: rośnie liczba osób dotkniętych ubóstwem energetycznym.* https://energetyka24.com/elektroenergetyka/holandia-rosnie-liczba-osob-dotknietych-ubostwem-energetycznym (in Polish).

European Commission. (2011). *Energy Roadmap 2050. Impact assessment and scenario analysis.* https://energy.ec.europa.eu/system/files/2014-10/roadmap2050_ia_20120430_en_0.pdf

European Commission. (2018a). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank, A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, Pub. L. No. 52018DC0773. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773

European Commission. (2018b). *National energy and climate plans.* https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#national-energy-and-climate-plans-2021-2030

European Commission. (2021). *European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions.* https://ec.europa.eu/commission/presscorner/detail/en/ip_21_3541

European Commission. (2023). *Net-Zero Industry Act.* https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan/net-zero-industry-act_en

Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., Silva, E. A., & Barlow, C. Y. (2017). Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models. Business Strategy and the Environment, 26(5). https://doi.org/10.17863/CAM.6382

Fais, B., Sabio, N., & Strachan, N. (2016). The critical role of the industrial sector in reaching long-term emission reduction, energy efficiency and renewable targets. Applied Energy, 162, 699-712. http://dx.doi.org/10.1016/j.apenergy.2015.10.112

Fay, M., Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Narloch, U., & Kerr, T. T. (2015). *Decarbonizing Development: Three Steps to a Zero-Carbon Future.* Washington: World Bank Group.

Finke, T., Gilchrist, A., & Mouzas, S. (2016). Why companies fail to respond to climate change: Collective inaction as an outcome of barriers to interaction. Industrial Marketing Management, 58, 94-101. https://doi.org/10.1016/j.indmarman.2016.05.018

França, A., López-Manuel, L., Sartal, A., & Vázquez, X. H. (2023). Adapting corporations to climate change: How decarbonization impacts the business strategy–performance nexus. Business Strategy and the Environment, 32(8), 5615-5632. https://doi.org/10.1002/bse.3439

Fulton, M., & Weber, C. L. (2012). *Carbon Asset Risk: Discussion Framework.* https://www.unepfi.org/fileadmin/documents/carbon_asset_risk.pdf

Gajdzik, B. (2022). *Diagnoza kierunków transformacji przemysłu stalowego w Przemyśle 4.0.* Gliwice: Wydawnictwo Politechniki Śląskiej. (in Polish).

Gajdzik, B., & Sroka, W. (2021). Resource Intensity vs. Investment in Production Installations-The Case of the Steel Industry in Poland. Energies, 14(2), 443. https://doi.org/10.3390/en14020443

Gajdzik, B., & Wolniak, R. (2021). Digitalisation and innovation in the steel industry in Poland-selected tools of ICT in an analysis of statistical data and a case study. Energies, 14(11), 3034. https://doi.org/10.3390/en14113034

Gajdzik, B., Wyciślik, A. (2007). Environmental strategies as the system of action – chronological order and market classification. Journal of Engineering Annals of Faculty of Engineering Hunedoara, 5(3), 116-121.

Gajdzik, B., Sroka, W., & Vveinhardt, J. (2021). Energy Intensity of Steel Manufactured Utilising EAF Technology as a Function of Investments Made: The Case of the Steel Industry in Poland. Energies, 14(16), 5152. https://doi.org/10.3390/en14165152

Gajdzik, B., Sujová, E., & Biały, W. (2023a). Decarbonisation of the steel industry: theoretical and practical approaches with analysis of the situation in the steel sector in Poland. Acta Montanistica Slovaca*,* 28(3), 621-636. https://doi.org/10.46544/AMS.v28i3.08

Gajdzik, B., Wolniak, R., & Grebski, W. (2023b). Process of Transformation to Net Zero Steelmaking: Decarbonisation Scenarios Based on the Analysis of the Polish Steel Industry. Energies, 16(8), 3384. https://doi.org/10.3390/en16083384

Gajdzik, B.; Wolniak, R.; Nagaj, R.; Grebski, W.W.; Romanyshyn, T. (2023c). Barriers to Renewable Energy Source (RES) Installations as Determinants of Energy Consumption in EU Countries. Energies, 16, 7364. https://doi.org/10.3390/en16217364

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy, 31(8-9), 1257-1274. https://doi.org/10.1016/S0048-7333(02)00062-8

German Finance Ministry. (2023). *German Budget Mess Could Inflict Big Growth Hit in 2024, BE Says.* https://www.bnnbloomberg.ca/german-budget-mess-could-inflict-big-growth-hit-in-2024-be-says-1.2002568.amp.html

Gilchrist, A.; Mouzas, S. Why companies fail to respond to climate change: Collective inaction as an outcome of barriers to interaction. In *Industrial Marketing Management*; Elsevier Inc.: Amsterdam, The Netherlands, 2016; Volume 58, pp. 94101. https://doi.org/10.1016/j.indmarman.2016.05.018.

Goldstein, A., Turner, W. R., Gladstone, J., & Hole, D. G. (2019). The private sector's climate change risk and adaptation blind spots. Nature Climate Change, 9(1), 18-25. https://doi.org/10.1038/s41558-018-0340-5

Grin, J., Rotmans, J., & Schot, J. (2010). *Transitions to sustainable development: new directions in the study of long term transformative change.* New York: Routledge.

Gross, S. (2021). *The challenge of decarbonising heavy industry.* https://www.brookings.edu/wp-content/uploads/2021/06/FP_20210623_industrial_gross_v2.pdf

Hafner, S., Speich, M., Bischofberger, P., & Ulli-Beer, S. (2022). Governing industry decarbonisation: Policy implications from a firm perspective. Journal of Cleaner Production, 375, 133884. https://doi.org/10.1016/j.jclepro.2022.133884

Haque, F., & Ntim, C. G. (2022). Do corporate sustainability initiatives improve corporate carbon performance? Evidence from European firms. Business Strategy and the Environment, 31(7), 3318-3334. https://doi.org/10.1002/bse.3078

Haslam, C., Butlin, J., Anderson, T., Malamatenios, J., & Lehman, G. (2014). Accounting for carbon and reframing disclosure: A business model approach. Accounting Forum, 38(3), 200-211. https://doi.org/10.1016/j.accfor.2014.04.002

Hydrogen Council. (2020). *Path to hydrogen competitiveness. A cost perspective.* https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf

ILO. (2016, April 13). *What is a green job ?* https://www.ilo.org/global/topics/green-jobs/news/WCMS_220248/lang--en/index.htm

Impact Economist. (2020). *Decarbonising business models and navigating net zero.* https://impact.economist.com/sustainability/net-zero-and-energy/decarbonising-business-models-and-navigating-net-zero

IREA. (2018). Global *Energy Transformation: A Roadmap to 2050.* https://www.irena.org/publications/2018/Apr/Global-Energy-Transition-A-Roadmap-to-2050

Kanda, W., Geissdoerfer, M., & Hjelm, O. (2021). From circular business models to circular business ecosystems. Business Strategy and the Environment, 30(6). https://doi.org/10.1002/bse.2895

Kristoffersen, E., Blomsma, F., Mikalef, P., & Li, J. (2020). The smart circular economy: A digital-enabled circular strategies framework. Journal of Business Research, 120, 241-246. https://doi.org/10.1016/j.jbusres.2020.07.044

Lohmann, L. (2009). Toward a different debate in environmental accounting: The cases of carbon and cost–benefit. Accounting, Organizations and Society, 34(3-4), 499-534. https://doi.org/10.1016/j.aos.2008.03.002

Madeja, J. (2021). *Elektryfikacja hutnictwa to perspektywa dekady.* https://www.wnp.pl/hutnictwo/elektryfikacja-hutnictwa-to-perspektywa-dekady,499386.html (in Polish).

Magazyny.pl. (2022). *Jak wzrośnie światowe zapotrzebowanie na lit?* https://e-magazyny.pl/aktualnosci/magazyny-energii/jak-wzrosnie-swiatowe-zapotrzebowanie-na-lit/ (in Polish).

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: an emerging field of research and its prospects. Research Policy, 41(6), 955-967. http://dx.doi.org/10.1016/j.respol.2012.02.013

Masson-Delmotte, V., Zhai, P., Pörtner, O.-H., Roberts, D., Skea, J., Shukla, R. P., Pirani, A., Moufouma Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., & Waterfield, T. (2018). *Global Warming of 1.5°C.* https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_Low_Res.pdf

Mathy, S., Criqui, P., Knoop, K., Fischedick, M., & Samadi, S. (2016). Uncertainty management and the dynamic adjustment of deep decarbonization pathways. Climate Policy, 16, S47-S62. https://doi.org/10.1080/14693062.2016.1179618

Ministerstwo Klimatu i Środowiska. (2021). *Gdyby nie opłata za emisję CO2, koszt wytworzenia energii elektrycznej w Polsce byłby mniejszy o 60%.* https://www.gov.pl/web/klimat/gdyby-nie-oplata-za-emisje-co2-koszt-wytworzenia-energii-elektrycznej-w-polsce-bylby-mniejszy-o-60 (in Polish).

Niemczyk, J., & Jasiński, B. (2021). Digitalization business strategies in energy sector: Solving problems with uncertainty under Industry 4.0 conditions. Energies, 14(23), 7997. https://doi.org/10.3390/en14237997

Oleszko-Pyka, B. (2022, December 8). *W 2050 roku będziemy musieli wydobywać 20 razy więcej litu niż obecnie*. https://swiatoze.pl/w-2050-roku-bedziemy-musieli-wydobywac-20-razy-wiecej-litu-niz-obecnie/ (in Polish).

Opinion of the European Economic and Social Committee on the role of carbon removal technologies in decarbonising European industry, Pub. L. No. 52022IE1057, 486 OJ C (2022). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022IE1057

Orlen. (n.d.). *Strategia dekarbonizacji.* https://www.orlen.pl/pl/zrownowazony-rozwoj/odpowiedzialnosc-za-klimat/strategia-dekarbonizacji (in Polish).

Pattberg, P. (2012). How climate change became a business risk: Analyzing non-state agency in global climate politics. Environment and Planning: Government and Policy, 30(4), 613-626. https://doi.org/10.1068/c1179

Piontek, B.; Piontek, F. (2017). *Development from theory to practice*. Shaker Verlag, 55-78.

Piontek, F., & Piontek, B. (2014). The Contemporary Concepts of Development in Terms of the Diversifying Criteria. Problems of Sustainable Development, 9(1), 47-62.

ReportLinker. (2023). *Hydrogen in Poland Market Overview 2023-2027.* https://www.reportlinker.com/market-report/Refined-Products/6828/Hydrogen

Rosa, P., Sassanelli, S., Urbinati, A., Chiaroni, D., & Terzi, S. (2020). Assessing relations between Circular Economy and Industry 4.0: a systematic literature review. International Journal of Production Research, 58(6), 1662-1687. https://doi.org/10.1080/00207543.2019.1680896

Rudny, W. (2013). Model biznesowy a tworzenie wartości. Studia Ekonomiczne / Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach, 141, 98-108. (in Polish).

Russo, A., Pogutz, S., & Misani, N. (2021). Paving the road toward eco-effectiveness: Exploring the link between greenhouse gas emissions and firm performance. Business Strategy and the Environment, 30(7), 3065-3078. https://doi.org/10.1002/bse.2789

Rzeczpospolita. (2023). *Strategia klimatyczna Viessmann – zerowa emisja netto do 2050 r.* https://klimat.rp.pl/walka-o-klimat/art39491441-strategia-klimatyczna-viessmann-zerowa-emisja-netto-do-2050-r (in Polish).

Sartal, A., Rodríguez, M., & Vázquez, X. H. (2020). From efficiency driven to low-carbon operations management: Implications for labor productivity. Journal of Operations Management, 66(3), 310-325. https://doi.org/10.1002/joom.1060

Shell. (n.d.). *Our climate target.* https://www.shell.com/energy-and-innovation/the-energy-future/our-climate-target.html

Sullivan, R., & Gouldson, A. (2017). The governance of corporate responses to climate change: An international comparison. Business Strategy and the Environment, 26(4), 413-425. https://doi.org/10.1002/bse.1925

Sulmicki, P. (1973). *Planowanie i zarządzanie gospodarcze.* Warszawa: Państwowe Wydawnictwo Ekonomiczne. (in Polish).

Trzaska, R., Sulich, A., Organa, M., Niemczyk, J., & Jasiński, B. (2021). Digitalization business strategies in energy sector: Solving problems with uncertainty under Industry 4.0 conditions. Energies, 14(23), 7997. https://doi.org/10.3390/en14237997

UNEP. (2020). *Green Jobs – UNEP Factsheet.* https://wedocs.unep.org/20.500.11822/32281

United Nations. (n.d.). *The Paris Agreement. What is the Paris Agreement?* https://unfccc.int/process-and-meetings/the-paris-agreement

Waisman, H., Bataille, C., Winkler, H., Jotzo, F., Shukla, P., Colombier, M., Anandarajah, G., Boer, R., Cho, Y., Criqui, P., Denis Ryan, A., Dhar, S., Fischedick, M., Gaeta, M., Gesteira, C., Haley, B., Hourcade, J. C., Kainuma, M., La Rovere, E. L., Liu, Q., Lugovoy, O., Masui, T., Mathy, S., Oshiro, K., Parrado, R., Pathak, M., Patshnikov, V., Pye, S., Safonov, G., Samadi, S., Sawyer, D., Siagian, U., Spencer, T., Teng, F., Tovilla, J., Trollip, H., Virdis, M. R., Williams, J., & Young, S. (2019). A pathway design framework for national low greenhouse gas emission development strategies. Nature Climate Change, 9, 261-268. https://doi.org/10.1038/s41558-019-0442-8

Wesseling, J. H., Lechtenböhmer, S., Åhman, M., Nilsson, L. J., Worrell, E., & Coenen, L. (2017). The transition of energy intensive processing industries towards deep decarbonization: Characteristics and implications for future research. Renewable and Sustainable Energy Reviews, 79, 1303-1313. https://doi.org/10.1016/j.rser.2017.05.156

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# BUDOWANIE ODPORNOŚCI EUROPEJSKICH ŁAŃCUCHÓW DOSTAW W OBSZARZE ŻYWNOŚCI: WYNIKI BADANIA DELFICKIEGO

STRESZCZENIE: W publikacji przedstawiono problematykę dekarbonizacji ciężkiego przemysłu przetwórczego, energochłonnego i wysokoemisyjnego w odniesieniu do polskich warunków. Praca wpisuje się w toczącą się dyskusję naukowców i praktyków na temat strategicznych wyzwań dekarbonizacji przemysłu w Polsce. Praca jest rezultatem badań konceptualnych zrealizowanych na podstawie przeglądu wtórnych źródeł informacji. Zgodnie z wymogami UE, strategia przemysłowa musi zawierać wizję dekarbonizacji w perspektywie 2050 roku. Przyjęty ambitny cel „net zero" – perspektywa wyzerowania emisji CO2 do 2050 roku – wymaga dużych nakładów finansowych i głębokich zmian technologicznych i organizacyjnych w wielu branżach przemysłu. Praca stanowi wprowadzenie do dyskusji o przygotowaniu polskiego przemysłu do głębokich zmian dekarbonizacyjnych.

SŁOWA KLUCZOWE: dekarbonizacja, strategia, zmiana, przemysł

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