STUTTGARTER BEITRÄGE ZUR PRODUKTIONSFORSCHUNG

Stefan Markus Büttner

# »How can climate neutrality be achieved for industry? A multi-perspective analysis.«

Fraunhofer IPA

Universität Stuttgart

**STUTTGARTER BEITRÄGE ZUR PRODUKTIONSFORSCHUNG BAND 156**

**Stefan Markus Büttner**

# »How can climate neutrality be achieved for industry?

# A multi-perspective analysis.«


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**Bibliographische Information der Deutschen Nationalbibliothek**

Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der
Deutschen Nationalbibliographie; detaillierte bibliografische Daten sind im Internet über
http://dnb.de abrufbar.

Erstveröffentl.: Tübingen, Univ., Diss., 2023, http://hdl.handle.net/10900/145304

2023

**Druck und Weiterverarbeitung:**

Fraunhofer-Druckerei, Stuttgart
Für den Druck des Buches wurde chlor- und säurefreies Papier verwendet.

# How can climate neutrality be achieved for industry?

## A multi-perspective analysis.

**Dissertation**

zur Erlangung des Doktorgrades
der Wirtschafts- und Sozialwissenschaftlichen Fakultät
der Eberhard-Karls-Universität Tübingen

vorgelegt von
Dipl. Vw. Stefan Markus Büttner
aus Kirchheim unter Teck

*Tübingen*

2023

| | |
|---|---|
| 1. Betreuer: | Prof. Dr. Dr. h.c. mult. Eberhard Schaich |
| 2. Betreuer: | Prof. Dr. Jörg Baten |
| | |
| Tag der mündlichen Prüfung: | 02.05.2023 |
| Dekan: | Prof. Dr. Ansgar Thiel |
| 1. Gutachter: | Prof. Dr. Dr. h.c. mult. Eberhard Schaich |
| 2. Gutachter: | Prof. Dr. Jörg Baten |

*Greenhouse gas emissions keep growing.*
*Global temperatures keep rising.*
*And our planet is fast approaching tipping points*
*that will make climate chaos irreversible.*
*We are on a highway to climate hell with our foot on the accelerator.*

*—António Guterres, Secretary-General of the United Nations*

*The global fossil fuel crisis must be a game-changer.*
*So let us not take the "highway to hell"*
*but let's earn the clean ticket to heaven.*

*—Ursula von der Leyen, President of the European Commission*

# Abstract

Despite the many acute crises in recent years, each of which demands full attention: The increasing frequency of extreme weather events — droughts, storms, floods, extreme heat and cold — makes it clear that time is running out to mitigate the climate crisis. This dissertation shows why the industrial sector has a central role to play in reducing its own emissions and those of other sectors in order to halt climate change. In order to fulfil this role, it is necessary to find out how climate neutrality can be achieved for industry, which is the focus of this thesis.

In a multi-perspective approach, using various quantitative and qualitative sources, both general aspects and the systemic perspective are addressed in order to then shed light on challenges at the company level and to develop solutions for them.

This dissertation examines quantitatively which goals manufacturing companies set themselves in the context of climate neutrality, where they stand on the path to decarbonisation, and where they stand in determining their own status quo and addressing their own potential. What motivates companies and on the basis of which determinants decisions are made, as well as the objectives, differ significantly depending on company size, sector and energy intensity and show how diverse the industrial sector is, thus underlining that one-size-fits all approaches cannot (effectively) lead to success.

The derived results show what steps a company can take to become climate neutral, as well as what other companies are doing in this context and where they stand. Companies, the public and policy makers are shown how companies can be motivated to decarbonise, but also where bottlenecks need to be resolved in order not to slow down the pursuit of climate-neutral economic activity.

# Zusammenfassung

Trotz der vielen akuten Krisen die letzten Jahre, die jeweils die volle Aufmerksamkeit fordern: Die zunehmende Häufigkeit extremer Wetterereignisse — Dürren, Stürme, Überschwemmungen, extreme Hitze und Kälte — macht deutlich, dass die Zeit zur Eindämmung der Klimakrise knapp wird. In dieser Dissertation wird aufgezeigt, weshalb dem Industriesektor eine zentrale Rolle zukommt, wenn es darum geht, seine eigenen Emissionen, sowie die anderer Sektoren zu reduzieren und so dem Klimawandel Einhalt zu gebieten. Um dieser Rolle nachkommen zu können, gilt es herauszufinden, wie Klimaneutralität für die Industrie möglich wird, was im Fokus der vorliegenden Arbeit steht.

In einem multiperspektivischen Ansatz werden unter Verwendung verschiedener quantitativer und qualitativer Quellen sowohl allgemeine Aspekte als auch die systemische Perspektive betrachtet, um anschließend die Herausforderungen auf Unternehmensebene zu beleuchten und Lösungen dafür zu erarbeiten.

Die Dissertation untersucht quantitativ, welche Ziele sich produzierende Unternehmen im Kontext der Klimaneutralität setzen, wo sie auf dem Weg zur Dekarbonisierung stehen und wo sie bei der Bestimmung des eigenen Status quo und der Adressierung der eigenen Potenziale stehen. Was die Unternehmen motiviert und auf Basis welcher Determinanten Entscheidungen getroffen werden, sowie die Ziele unterscheiden sich je nach Unternehmensgröße, Branche und Energieintensität deutlich und zeigen, wie vielfältig der Industriesektor ist und unterstreichen damit, dass one-size-fits-all-Ansätze nicht (effektiv) zum Erfolg führen können.

Die abgeleiteten Ergebnisse zeigen, welche Schritte ein Unternehmen ergreifen kann, um klimaneutral zu werden, und was andere Unternehmen in diesem Zusammenhang tun und wo sie dabei stehen. Den Unternehmen, der Öffentlichkeit und den politischen Entscheidungsträgern wird aufgezeigt, wie Unternehmen zur Dekarbonisierung motiviert werden können, aber auch, wo Flaschenhälse beseitigt werden müssen, um das Streben nach klimaneutralem Wirtschaften nicht auszubremsen.

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# Abbreviations

| | |
|---|---|
| #EEBarometer | Energy Efficiency Barometer of Industry (international pendant to EEI) |
| ° C | degree Celsius |
| ACEEE | American Council for an Energy-Efficient Economy |
| adj. | adjusted |
| Art. | Article |
| BDI | Bundesverband der deutschen Industrie (English: Federation of German Industries) |
| BECCS | bioenergy with carbon capture and storage |
| BEHG | Bundesemissionshandelsgesetz (English: German Fuel Emission Trading Act) |
| BIP | Bruttoinlandsprodukt (English: Gross Domestic Product) |
| cat. | category |
| CBAM | EU Carbon Border Adjustment Mechanism |
| CC BY | Creative Commons Attribution license |
| CCCE | European Covenant of Companies for Climate and Energy |
| CCS | Carbon Capture and Storage |
| CCU | Carbon Capture and Utilisation |
| CCUS | Carbon Capture, Utilisation and Storage |
| CDM | Clean Development Mechanism |
| CDR | Carbon Dioxide Removal |
| CEO | Chief executive officer |
| CERs | certified emission reductions |
| cf. | confer (English: compare) |
| $CH_4$ | Methane (chemical compound and greenhouse gas) |
| $CO_2$ | Carbon Dioxide (chemical compound and greenhouse gas) |

| | |
|---|---|
| $CO_2$-eq. / $CO_2$-e | Carbon Dioxide equivalents |
| COP21 | United Nations Framework Convention on Climate Change, 21st Conference of the Parties |
| COP25 | United Nations Framework Convention on Climate Change, 25th Conference of the Parties |
| COP26 | United Nations Framework Convention on Climate Change, 26th Conference of the Parties |
| COP27 | United Nations Framework Convention on Climate Change, 27th Conference of the Parties |
| COVID-19 | Coronavirus disease 2019 |
| CS | Corporate Sustainability |
| CSE | UNECE Committee on Sustainable Energy |
| CSR | Corporate Social Responsibility |
| CTAS / #CTAS | Change through anticipative steering |
| DACCS | Direct Air Carbon Capture and Storage |
| DEHSt | Deutsche Emissionshandelsstelle (English: German Emissions Trading Authority at the German Environment Agency) |
| DFG | Deutsche Forschungsgesellschaft (English: German Research Foundation) |
| DFGE | Institut für Energie, Ökologie und Ökonomie (English: Institute for Energy, Ecology and Economy) |
| e | energy (in context of equation, here: a given source of energy) |
| E | all energy sources used (in context of equation) |
| e.g. | for example |
| E10 | Ethanol 10 % (the fuel contains up to 10 % ethanol) |
| ECE | [United Nations] Economic Commission for Europe |
| ECEEE | European Council for an Energy Efficient Economy |
| EE | energy efficiency |

| | |
|---|---|
| EEA | European Economic Area |
| EEFIG | Energy Efficiency Financial Institutions Group |
| EEI / #EEIndex | Energy Efficiency Index of German Industry |
| EEP | Institut für Energieeffizienz in der Produktion (English: Institute for Energy Efficiency in Production, University of Stuttgart) |
| EFDB | Emission Factor Database |
| ESG | Environmental, Social, and Governance |
| etc. | et cetera |
| ETS | Emission Trading System |
| EU | European Union |
| EU ETS | EU Emission Trading System |
| EU27 / EU-27 | The 27 European Union countries after the United Kingdom left the EU |
| EUR | Euros (currency) |
| EWI | Energiewirtschaftliches Institut an der Universität zu Köln (English: Institute of Energy Economics at the University of Cologne) |
| Fraunhofer IAO | Fraunhofer Institut für Arbeitswirtschaft und Organisation (English: Fraunhofer Institute for Industrial Engineering) |
| Fraunhofer IPA | Fraunhofer Institut für Produktionstechnik und Automatisierung (English: Fraunhofer Institute for Manufacturing Engineering and Automation IPA) |
| G20 | The Group of Twenty |
| GCF | The Green Climate Fund |
| GDP | Gross Domestic Product |
| GEEE | UNECE Group of Experts on Energy Efficiency |
| GHG | Greenhouse gas |
| GW | Gigawatt |
| GWh | Gigawatt hour |

| | |
|---|---|
| GWP | Global Warming Potential |
| HFCs | Hydrofluorocarbons (fluorinated greenhouse gases with global warming potential) |
| i.e. | id est (English: that is) |
| IEA | International Energy Agency |
| IHK | Industrie- und Handelskammer (English: Chamber of Industry and Commerce) |
| INDCs | Intended Nationally Determined Contributions (in context of COP21) |
| IPCC | Intergovernmental Panel on Climate Change |
| IRR | Internal Rate of Return (economics) |
| ISIC | International Standard Industrial Classification of All Economic Activities |
| ISO 9001 | International standard on Quality Management Systems |
| IW | Institut der deutschen Wirtschaft (English: German Economic Institute) |
| KPI | key performance indicator |
| kWh | Kilowatt hour |
| $kW_p$ | Kilowatt peak |
| LED | Light emitting diode |
| LULUCF | Land Use, Land Use Change and Forestry |
| $m^2$ | square metre |
| MSMEs | micro-, small-, and medium-sized companies |
| MWh | Megawatt hour |
| N | intended period of use /useful life (in context of equation) |
| N | Nitrogen (chemical element) |
| N | Total population, here: total number of companies |
| n | Sample size, here: number of companies responding to the question |
| n‘ | Number of responses provided by the companies responding to the question |

| | |
|---|---|
| $N_2O$ | Nitrous Oxide (chemical compound and greenhouse gas) |
| NACE | Nomenclature générale des activités économiques dans les Communautés Européennes (English: General Industrial Classification of Economic Activities within the European Communities) |
| NAZCA | Non-State Actor Zone for Climate Action (in context of COP21) |
| nETS | National Emission Trading Scheme |
| NETs | Negative Emission Technologies |
| $NF_3$ | Nitrogen Trifluoride (fluorinated greenhouse gases with global warming potential) |
| $NH_3$ | Ammonia (chemical compound and greenhouse gas) |
| $NO_x$ | Nitrous oxides (chemical compounds contributing to air pollution) |
| NRW | Nordrhein-Westfalen (English: North Rhine-Westphalia, federal state in Germany) |
| NZC | NetZeroCities (initiative) |
| OECD | The Organisation for Economic Co-operation and Development |
| OEM | Original Equipment Manufacturer |
| OPEX | Operational expenditure |
| p. | page |
| p.a. | per annum |
| P2X | power-to-x |
| PCF | product carbon footprint |
| PFCs | Perfluorocarbons (fluorinated greenhouse gases with global warming potential) |
| PJ | Petajoule |
| pp. | pages |
| PPA | Power Purchase Agreement |
| PR | Public relations |

| | |
|---|---|
| Prio | Priority |
| PT | Payback time |
| PV | Photovoltaics |
| REZ | Reutlinger Energiezentrum für Dezentrale Energiesysteme und Energieeffizienz (English: Reutlingen Energy Center for Distributed Energy Systems and Energy Efficiency, Reutlingen University) |
| RoI | Return on Investment |
| SBTi | Science Based Target Initiative |
| SDM | Sustainable Development Mechanism |
| $SF_6$ | Sulphur hexafluoride (fluorinated greenhouse gases with global warming potential) |
| SMEs | Small- and Medium-sized Enterprises (usually including also micro-enterprises) |
| $SO_2$ | Sulphur Dioxide (chemical compound) |
| STEPS | Stated Policies Scenario (of the International Energy Agency) |
| t | time in years (in context of equation) |
| $tCO_2$-eq | Tonnes of Carbon Dioxide equivalents |
| TWh | Terawatt hours |
| $TWh_{el}$ | Terawatt hours electric energy |
| $TWh_{th}$ | Terawatt hours thermal energy |
| UN | United Nations |
| UNECE | United Nations Economic Commission for Europe |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| USD | US Dollars (currency) |
| Wh | Watt hours |
| WRI | World Resource Institute |

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# Acknowledgements

I would like to extend my gratitude to all those who have directly or indirectly, consciously or unconsciously, enabled and supported this work — far too many individuals, institutions, and fora to comprehensively list. Numerous conversations, discussions, and presentations, some of which were quite challenging, spanning several years, have inspired me to continue thinking, to recognize connections, and to kindle a deeper interest in comprehending and delving further.

The announcement by Bosch in the spring of 2019 that they aimed to become $CO_2$ neutral by 2020 »because it is possible, here and now« sparked my curiosity to explore why, and whether other companies were considering similar endeavours. In combination with the European election results, the rise of Fridays for Future, and the shift in global finance at the UN Climate Week in September 2019, this formed the conviction that the topic of "decarbonization" would hold a central significance in shaping a positive future.

Special thanks are due to former Dean Josef Schmid, who encouraged me to pragmatically shift my original dissertation topic (in the realm of university management / institutional research) to a subject I had already published extensively about and clearly had a passion for, thus making the successful completion possible. Equally, this gratitude extends to Professor Schaich and Professor Baten, my doctoral advisors, who supported me across both topics and endorsed the change in focus.

Without the support of the Karl Schlecht Foundation and the Heinz and Heide Dürr Foundation, notably Heinz Dürr, this work would not have come into existence. It was he who directed me to the EEP. Likewise, it would not have been possible without its institute director, Professor Sauer, who invented the Energy Efficiency Index of the German industry and with this provided me with the means to scrutinize the considerations of myself and previous project leaders Diana Wang and Christian Schneider across more than 1,000 manufacturing companies. Therefore, a special thank you to the three of them, who offered both the opportunity and the confidence to delve deeper and extend beyond the realm of energy efficiency into the broader field of decarbonization.

The fruitful and productive exchange with my co-authors Werner, Diana, Christian, Marina, Liane, Josi, Chiara, Frederick, Anna-Lena, and Hannes, during which we each contributed our respective strengths and learned from one another, was an essential foundation for the success of this dissertation. Equally important were the conversations (especially during difficult times) and the sharing of ideas and visions with Chris, Rod, Igor, Thomas, Linda, Tom, Paul, Cindy, Diana, Noel, Sonja, Christoph, Patrik, Vanessa, Christian, Frieder, Anna-Lena, and the fantastic young individuals of the intern team SUG, who accompanied me on my journey. Thank you all!

For patience, unwavering support, particularly during the last two years when I often withdrew from various occasions to complete this work, I am deeply indebted to my partner, my family, and my friends near and far. Thank you for believing in me and forgiving my absences.

Lastly, I would like to express my gratitude not only to my colleagues at EEP, Fraunhofer, UNECE, IPEEC, the Export Initiative for Energy, EEFIG, and ECCI, but also to all those who posed challenging questions in conversations and around numerous presentations, both domestically and internationally. These inquiries prompted me to contemplate and view things from different perspectives. Likewise, I am thankful to all those who enabled me to comprehend the various layers of the overall picture/situation. One positive outcome of the COVID pandemic: it provided time and digital means to push through.

# Forewords

The world has changed constantly and drastically in recent decades. Just one indicator may prove that: I was born over 80 years ago. At that time, the world population was about 2.2-2.5 billion people. Only within these 80 years did the world population increase dramatically, exceeding the 8 billion mark in 2022.

This increase was not evenly distributed around the globe — on the contrary, the increase was and is mainly concentrated on the African continent and parts of Asia and parts of Latin and Central America. Hunger and underdevelopment are particularly concentrated in these regions of the world. There, economic growth is imperative. This growth requires energy, so that the prosperity gap can be broken down and the worldwide migration pressure can be reduced.

The highly developed countries have built their economic development process over years and decades on fossil fuels, on coal, oil and gas. The emissions associated with this energy consumption have taken a toll on people's quality of life. Willi Brandt captured this with the challenge: »Blue skies over the Ruhr are a social challenge and a goal of politics«. Appropriate air pollution control technologies were researched and made available. Economic development and environmental relief became achievable.

Energy efficiency and air pollution control challenged technologies only insofar as they created economic competitive advantages. The consequences of massive $CO_2$ emissions on the climate were not at the forefront of scientific research and development. The author has succeeded in changing this perspective so that he no longer declares the massive $CO_2$ emissions from industry to be "unavoidable" ceteris paribus. These emissions are the primary focus.

It is an obligatory task in all respects for highly developed nations to seek ways to drastically reduce all kinds of pollutants and to implement them. Thus, the focus of the present work is on the search for new technologies through which economic development processes can be realised without negative impacts on the climate, especially in developing countries. Research and investment, especially in the sun and wind as energy sources, meet the requirements for the technologies of the future. They are globalisable, they are fault-friendly and repairable, they can be used decentrally, they are labour-intensive. This globalisability of solutions is the task of developed countries in their climate policy, in view of the massive differences in prosperity in the world.

It is to be hoped that this very concrete, case-based work will be widely disseminated. Climate policy must be aware of the necessity that, in addition to a reduction of $CO_2$ emissions in the country itself, the contribution to a revolutionary transformation that is also successful globally, will be outlined by technology and behaviour.

PROFESSOR DR. KLAUS TÖPFER
*Member of the Advisory Board of the EEP and honorary Professor at the University of Tübingen, as well as former Executive Director of the United Nations Environment Programme (UNEP) and German Federal Minister for the Environment, Nature Conservation and Nuclear Safety*

Decarbonisation of industry is a major component of the societal development process towards climate neutrality. It is closely interwoven with relevant government regulations, with production costs and with social pressures towards decarbonisation that affect business decisions. Important factors in the decarbonisation process are company size, industry sector and energy intensity of production. Based on empirical results from various recent surveys in Germany, the importance of these factors is presented in many partial aspects and in overall perspectives. In Büttner's research, the complexity and confusion of the interrelationships is made clear in a convincing manner.

PROFESSOR DR.OEC.PUBL. DR. H.C. MULT. EBERHARD SCHAICH
*Economist and former Rector of the University of Tübingen*

The core motivation for the foundation of the Institute for Energy Efficiency in Production (EEP) was to create an institution that accompanies, empowers, and actively supports business, society and politics on the basis of figures, data and facts so that the energy transition in industry becomes possible. The present work embraces this idea and shows the aforementioned groups of actors from different perspectives how and under what conditions energy transition and (net) climate neutrality can be made possible for industry.

DR.-ING. E.H. HEINZ DÜRR

*Co-founder and inaugural Chairman of the Advisory Board of the EEP, philanthropist, former CEO and Chairman of the Supervisory Board of the Dürr Group, as well as CEO of Deutsche Bahn AG and AEG*

Climate neutrality can only be achieved with a significant increase in energy efficiency. This thesis builds on the surveys of the Energy Efficiency Index of German Industry conducted by the Institute for Energy Efficiency in Production at the University of Stuttgart. It clearly shows the important connection between energy efficiency and climate protection.

PROFESSOR DR.-ING. ALEXANDER SAUER

*Executive Director of the Institute for Energy Efficiency in Production (EEP) and the Fraunhofer Institute for Manufacturing Engineering and Automation IPA*

We face so many challenges to reach climate neutrality in our economies. Some of the most daunting challenges are in industry that must also remain competitive in their markets. This dissertation is a must read because it shows a clear way forward for Germany's manufacturing sector and beyond, and individual industrial enterprises to rise to the challenges and ensure a more sustainable future.

ROD JANSSEN

*Lead of the Industry Working Group of the Energy Efficiency Financial Institutions Group (EEFIG), Chairman of Energy Efficiency in Industrial Processes (EEIP) and Editor of Energy-in-Demand*

The realisation that our natural sinks, e.g., for nitrogen or $CO_2$, are exhausted, that biodiversity is severely threatened and that the global climate emergency must be combated, assigns companies and politicians a responsibility to find solutions. Manufacturing companies in particular have a very effective lever in their hands to achieve the urgently needed reductions. The analysis of this dissertation is an excellent help in pointing out practicable solutions, how industrial companies are or can become problem solvers for decarbonisation and a climate-neutral economy by acting correctly. There can be no more excuses.

DIETMAR HEXEL

*Advisory Board member of the EEP, former member of the Executive Board of the German Trade Union Federation (DGB)*

In the face of persistently high energy prices and the urgency of the climate crisis, companies in the industrial sector are challenged to rethink and adapt their manufacturing in order to remain sustainable. This dissertation offers a multi-perspective approach that makes it possible to shed light on the challenges at company level and to develop solutions for decarbonisation.

PROFESSOR DR.-ING. HUBERT WALTL

*Chairman of the Advisory Board of the EEP, former Chief Production Officer of AUDI AG.*

As an Energy & Climate Expert at international organizations such as IPEEC, UNDP, IEA, ADEME and LBNL, I have seen first-hand the importance of multilateral cooperation and increased energy efficiency in combating climate change. This dissertation illustrates how the industrial sector can contribute and identifies possible solutions to achieve the goal of climate neutrality.

BENOÎT LEBOT

*French Ministry of the Environment, former Executive Director of the International Partnership for Energy Efficiency Cooperation (ipeec) and energy & climate expert at UNDP, IEA, NREL and ADEME*

As a former member of the Scottish Parliament's Energy, Economy & Tourism Committee, I know first-hand the importance of thinking out of the box and engaging the industrial sector in addressing the energy and climate crises. Success or failure will be determined by how well we engage, enable, and empower stakeholders on the ground. While policies are shaped on a high level, it is the local governance that implements. Exchange of what works and what not across regions is hence essential. The results of this dissertation are an important contribution to the development of strategies that address the needs and harness the potentials of our regions and the global community.

PROFESSOR CHRISTOPHER HARVIE PHD

*University of Tübingen, founder of the Freudenstadt Symposium on European Regionalism and former Member of the Scottish Parliament, as well as its Energy, Economy and Tourism Committee (EET)*

Mr. Buettner's dissertation addresses a critical, and yet often overlooked, dimension of the green transition: bottlenecks and enablers for SMEs to decarbonize their operations at scale. Providing a systemic and honest analysis, it points to a large gap between stated climate ambitions at national level and the reality of many SMEs in Europe. It also offers a set of practical solutions, which, if adopted, can help improve the incentives for SMEs and help them come up with an optimal mix of decarbonization measures. I am pleased to see that the dissertation also builds on the practical work Mr. Buettner is undertaking in his capacity as Chair of the UNECE Expert Group on Energy Efficiency and hope the findings of his research will further feed into the work of the Group.

DR. DMITRY MARIYASIN
*Deputy Executive Secretary of the United Nations Economic Commission for Europe (UNECE), international economist and former resident representative of the United Nations Development Programme (UNDP) Armenia*

The ongoing energy transition and the need to address the climate crisis on our planetary home, Earth, will depend on our increasing awareness of our origins and our ability to make informed, scientifically grounded decisions that lead to positive outcomes in our lives.

The human capacity for reason and scientific inquiry, which has evolved over time, allows us to seek truth, understand causes, and identify opportunities. Through this, we have come to realize that after around 14 billion years — marked by Earth's revolutions around the sun, as time operates differently in the cosmos — we are the result of conscious transformation of cosmic energy into matter. The presence of numerous similar celestial bodies with rotating, luminous structures reinforces this understanding.

The energy radiating from our sun indirectly influences us by supplying energy through a quasi-retroactive primal radiation. This process led to the emergence of human life on Earth — a satellite of the sun —, which is gradually cooling over time. This natural cooling process contributes to geophysical phenomena such as earthquakes and volcanic activity, driven by vast, untapped heat reservoirs at the core.

Similarly, our planet's natural elements, including water and air, evolved as Earth cooled. Sunlight generates wind and warmth, nurturing various natural formations and contributing to the emergence of humans over billions of years. Humans created their "world" on the sun's satellite, populated it with life, and through the gift of reason, developed a consciousness distinct from that of animals. Yet, the rapidly approaching 10-billion population, driven by favourable conditions, is causing detrimental alterations to nature through births, machinery, and vehicles, including excessive $CO_2$ emissions. This has led to concerns and dissatisfaction, driving young researchers to seek solutions, revealing that material resources and money are insufficient.

Fortunately, our evolution does not just shape physical necessities. It also offers motivation for ethical behaviour and cooperation, fostering positive outcomes through lifelong learning.

With the aim of utilizing our innate talents and understanding the laws of nature, including physics, chemistry, gravity, etc., we endeavour to serve the pursuit of truth in a scientific manner. This will enable us to achieve outcomes that align with the pursuit of universal goodness, promoting comprehensive and sustainable change.

In this spirit, I extend my best wishes to Mr. Büttner for his research to pave the way and inspire others to follow similar paths. Witnessing these efforts and offering well-wishes for success brings me great joy, as a student entrepreneur engaged in philanthropy for already more than 25 years.

PROFESSOR H.C. DR. H.C. KARL SCHLECHT

*Co-Founder and Member of the Advisory Board of the EEP, founder of the Global Ethic Institute, inventor, philanthropist, 'Science Foundation of the Year' 2023 awardee (German University Foundation), and former CEO and Chairman of the Supervisory Board of the Putzmeister AG*

As someone hailing from the financial sector and advocating for a liberal economic policy, I am delighted by the insights offered in this dissertation. It distinctly reveals the absence of a universal solution for industrial decarbonization, a realization further underscored through our collaborative engagements in initiatives such as the 'Energy Efficiency Global Forum'. This forum, which facilitates concise and purpose-driven exchanges among decision-makers and thought leaders from diverse nations, reinforces the significance of tailoring strategies to address specific challenges and potentials of individual enterprises. Simultaneously, my commitment to promoting a liberal mindset compels me to emphasize the importance of granting businesses the autonomy to chart their unique paths toward achieving climate neutrality. This dissertation also underscores the presence of certain bottlenecks that must be eliminated for our shared objective to be attained. The insights garnered through our participation in events like the 'Energy Efficiency Global Forum' are indicative of the pressing need to ensure a conducive environment for focused discussions. This comprehensive work not only captivates the intellect but also equips policymakers with invaluable insights to guide their actions.

KLAUS BREIL

*Business Analyst, former Member of the German Parliament (Deutscher Bundestag) and Energy-Spokesperson of the FDP Parliamentary Group*

# 1 Introduction

## 1.1 A time of crises

**An ongoing poly-crisis has a firm grip on the lives and destinies of people, businesses, and economies. While these crises may take different forms and have varying degrees of intensity and impact in different regions of the world, they nevertheless affect us all in one way or another (Lawrence et al. 2022).**

**People's attention is often drawn to what is directly in front of them, so it is easy to lose sight of the bigger picture. However, this conundrum can be avoided by looking at the situation from different perspectives.**

**As many parts of this picture are in motion, it is not always easy to see the connections between them and to identify the parts that — if addressed — can change the overall dynamics and direction. For example, finding a way to address or even resolve one or more crises would subsequently influence the severity of others.**

**Even if one changes perspectives, one may not realise the magnitude of the components unless one looks beneath the surface because, like an iceberg, most of the mass that gives it its magnitude lies beneath what can easily be seen.**

One of these alluded crises is the climate crisis, another the energy crisis. The COVID-19 pandemic has taken the focus off the climate crisis and, likewise, the war in Ukraine has led to an energy crisis. The latter attached urgency to efforts to increase energy resilience, which in turn has an impact on the climate crisis, showing that the immediate challenges — as happens in many other aspects of life — are causing the medium and long-term challenges to be lost out of sight. Even if their consequences promise to be far more severe or irreversible. Finding the thread(s) that, if properly drawn, can untangle the complex web of interwoven crises and challenges is one of the great tasks of our time.

As many activists pointed out, climate change does not stop because of the COVID 19 pandemic, which has cost and changed the lives of many people since early 2020 and has rightly come into immediate focus (UN 2022; James et al. 2021). However, the pandemic has not only shown us how globally interconnected humanity has become and that we have practically nowhere to hide from crises, but also that when immediate threats are in view, countermeasures can be taken and solutions found — if people, science, businesses, and politics pull together. Conversely, the pandemic has also shown us how vulnerable our supply chains (dpa 2022; Hollinger et al. 2022) are and what turbulence a single ship blocking an artery of global freight traffic can cause (Kröger 2021; Hecking 2021).

At the heart of the problem are not only the supply chains of goods, but also of people, i.e. skilled workers who can help fill the gaps in the jobs where they are desperately needed (dpa 2022). Lean manufacturing and reliance on complex global supply chains have clearly become a risk in these crisis-ridden times.

The need for resilience has continued to grow since then, especially as the war in Ukraine highlighted how fragile our system really is. Skyrocketing energy prices, uncertain availabilities and increasing unaffordability are a major challenge for many. In addition, the rising number of severe weather disasters such as devastating hurricanes, floods and droughts have also shown us how vulnerable our energy system can be. Thermal power plants and nuclear power plants need cooling water, meaning that insufficient water levels force successive shutdowns. Moreover, water levels also affect inland navigation with goods and fuels on rivers, the power generation capacities of hydropower plants and pump storage power plants, and essentially also the drinking water supply (WMO 2022; Blume et al. 2022).

Increasing resilience means reducing dependence on factors that are beyond one's control. Ideally, those factors that are beyond one's control should be geographically within reach and/or diversified as well. This can concern the sourcing of energy as well as intermediate products.

Nevertheless, the energy crisis has had yet another effect. It gave perspective and lifted the metaphorical iceberg somewhat out of the water: With the looming gas emergency the issue of what happens if the gas demand can no longer be met gained public attention. Existing emergency plans implicitly list a sequence for rationing supply, according to which certain customers, among them households are particularly protected, effectively resulting in industry being cut-off first (Bücker 2022). Voices from the industry calling for a reverse sequence (Noé 2022) led to public outrage (Roider 2022). Zooming-in on the reasons why Karl-Ludwig Kley, chief of Eon's advisory board, may still have a point requires looking at the consequences of a gas supply shutdown for the industrial sector if appropriate gas saving efforts are not first made across the board, including by especially protected consumer groups. Above all, this rationing strategy would have a dramatic ripple effect on the economy (Noé 2022). The chemical industry, which produces basic materials for thousands of products manufactured in other sectors, relies on gas, notably for process heat. These basic materials are needed, for instance, for fertilisers, pharmaceuticals, beverages, glass, paper, steel, fibres, solvents, washing powder, and plastics (Käckenhoff et al. 2022). According to the German Economic Institute (IW), such a chain reaction would threaten 2,5 to 4 million jobs (Hennes 2022). The hiking prices alone caused many manufacturers to scale down their production and be on the verge of collapse, with further consequences for the supply chain (Specht et al. 2022). One of these is Nitrogen (N) manufacturer SPK Piesteritz (responsible for about 20 % of gas demand in Eastern Germany and one of only three manufactures of AdBlue) (Delhaes 2022), without whose Ammonia ($NH_3$) there would be no batteries, no carbonated drinks (Terpitz 2022), no vaccine ampoules, no chemical production and no Adblue that each modern diesel engine needs. The latter would have dramatic effects, as the transport of goods via trucks (e.g. to supermarkets) depends on Adblue and would thus be endangered (Delhaes 2022). The head of the NRW Federation of Business Associations, Arndt Kirchhoff, concluded in his assessment of the gas rationing sequence: »What good is it if the workers are sitting at home in the warmth and the jobs are gone?« (WDR 2022).

Even without supply bottlenecks for gas and electricity, high energy prices are driving industry, especially in Germany, into the "energy trap". As a result, they are scaling down domestic production, cancelling investments, shutting down parts of manufacturing, relocating the production of energy-intensive goods to other parts of the world or abandoning it altogether under the weight of the costs (Olk & Stratmann 2022; Specht et al. 2022). Despite its societal role as a key pillar of employment, supply of (elementary) goods and contribution to the gross domestic product, industry is often overlooked (except for five particularly energy-intensive sectors[1] that fall under the European ETS (European Commission 2022b)) when it comes to mitigating climate change and accelerating the pace of action to still be able to meet the goals of the Paris Climate Agreement.

## 1.2 The role of the industrial sector

As with the tip of an iceberg, the relevance of the industrial sector (beyond the energy-intensive sectors and associated supply chains) as both an issue and an essential part of the solution becomes visible when lifting it "out of the dark" and switching on the light in the black box:

In Germany, for instance, the industrial sector consumed 25 % of the country's energy and 45 % of its electricity, was responsible for 18.4 % of Germany's energy-related and

[1] In sequence of energy total energy consumption, name (sector code): Manufacture of chemicals and chemical products (20), Manufacture of basic metals (24), Manufacture of glass, ceramics, and other non-metallic mineral products (23), Manufacture of paper and paper products (17) and Manufacture of coke and refined petroleum products (19) (European Commission, 2022c, destatis, 2022a).

23.1 % of its overall greenhouse gas (GHG) emissions in 2019 (UBA 2021; UBA 2022a; Drosihn 2022; IEA, 2022). Although manufacturing (27 sub-sectors of industry) accounts for only 7.6 % of all companies in Germany (197,768 companies) (destatis 2022c; Eurostat 2022), it provides 17.7 % of all jobs (8.02 million) and 57.9 % of Germany's GDP by creating products worth EUR 2,011 billion, with a revenue of EUR 2,356 billion (destatis 2022c; destatis 2022d) (cf. *Figure 1*).

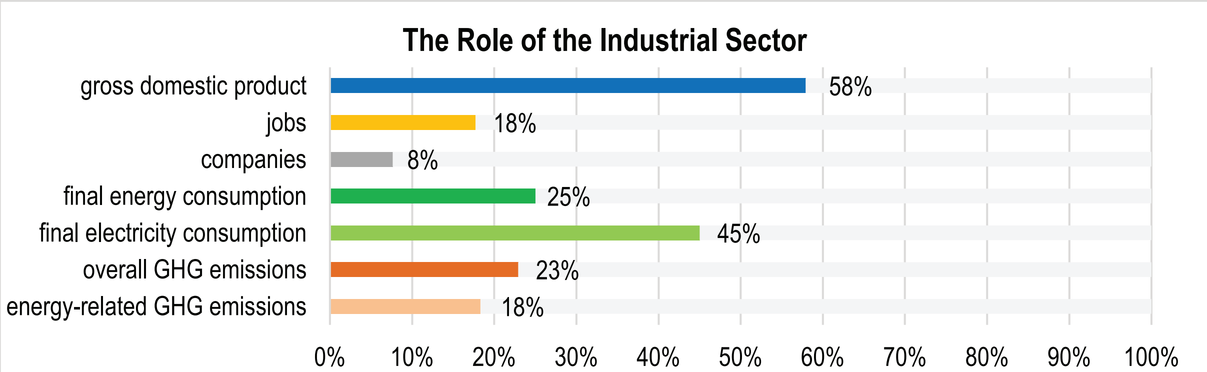



Figure 1. The Role of the Industrial Sector (in percent of total economy in Germany, 2019) (UBA 2021; UBA 2022a; Drosihn 2022; IEA 2022; destatis 2022b; destatis 2022c; destatis 2022d; Eurostat 2022)

Even though the industry has a large impact, this impact rests on many shoulders and not "only" a few large companies. As a matter of fact, the 5,300 large manufacturers[1] (European Commission 2003), make up "just" 2.7 %, and 15,282 medium-sized companies 7.7 %. The number of 52,282 small companies (26.4 %) and 124,904 micro

[1] Micro companies: Up to 9 employees and up to 2 million euros revenue.
Small companies: Up to 49 employees and up to 10 million euros revenue and not a micro company.
Medium-sized companies: Up to 249 employees and up to 50 million euros revenue and not a small company.
Large companies: Over 249 employees or over 50 million euros revenue (European Commission, 2003).

companies (63.1 %) highlight that micro-, small-, and medium-sized companies (MSMEs) play a significant role (cf. *Figure 2*, by employee size classes) and carry a particular burden in the poly-crisis: especially the smaller companies may not have (access to) dedicated and expert personnel to help address the energy-crisis through, for example, energy-saving measures. In contrast to large(r) companies, they are less likely to face international competition and public scrutiny and are exempt from certain regulations (e.g. the obligation to conduct energy audits (European Commission 2012) or to report on corporate social responsibility (CSR)(European Commission 2022a) and in some cases from the EU ETS (European Commission 2022c)). In addition to these four company sizes and different levels of energy-intensity, their distribution across 27 sub-sectors makes the industrial sector very diverse, so that one-size-fits-all approaches often will not work out.

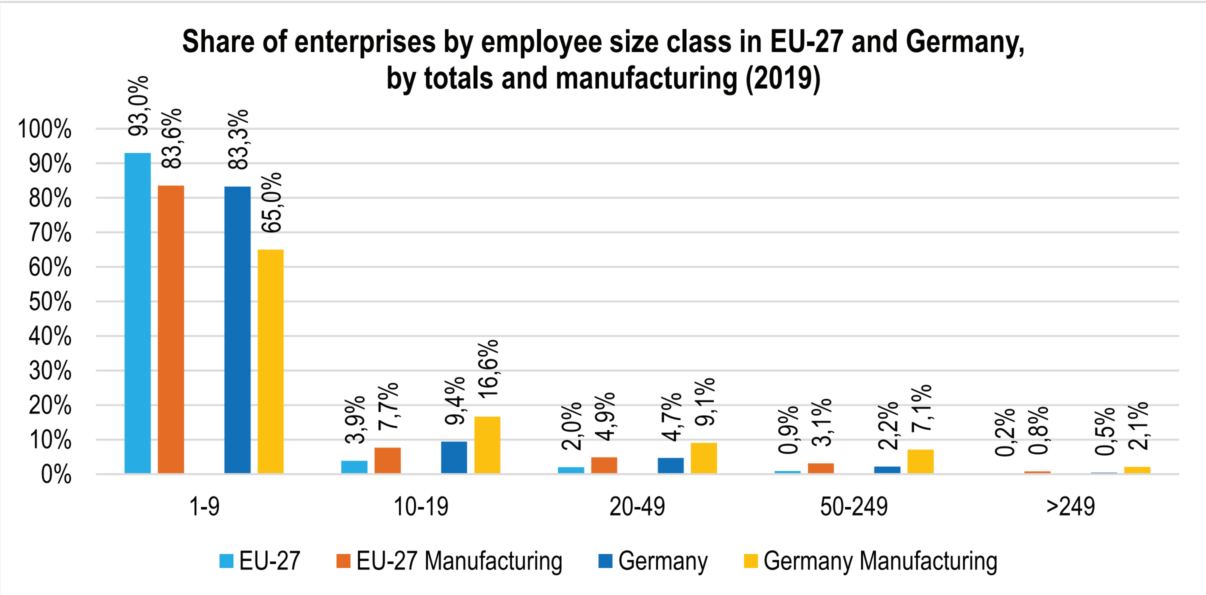



Figure 2. Share of enterprises by employee size class in EU-27 and Germany, by totals and manufacturing (2019) (Eurostat 2022)

In its press release on the 1st edition of the Energy Efficiency Index of German Industry (EEI) 2022, the Institute for Energy Efficiency in Production (EEP) points out that the majority of the approximately 850 manufacturing companies surveyed do not consider the use of waste heat to be of interest or worthwhile (EEP 2022). The EEP remarks that

»this is surprising because there is a high scientific-economic consensus for the potential of these instruments. However, they are apparently not being tapped by industry. This is tragic because these two measures can be particularly helpful in saving gas in a situation of gas shortage: More than 60 % of industrial energy demand is used for (process) heating and cooling and largely depends upon gas. The explanation for this could be a lack of information on potentials, procedures or a lack of appropriately qualified personnel.« (EEP 2022) In 2020, gas accounted for 31 % of industrial energy consumption, other fossil fuels, which are also affected by price increases and embargoes, accounted for another 32 % (mineral oil and coal, each half) (destatis 2022a). Despite intensive efforts, the electrification of all these processes will not be feasible in the short term, if at all, and even then the additional electricity demand cannot be met at a time when there are warnings of electricity shortages (Dürr 2022) and at the current pace of the energy transition (Zajonz & Wolff 2022). For the processes that cannot be electrified but could run on hydrogen, hydrogen is still too expensive and not available in relevant quantities for the foreseeable future (Dostert & Müller-Arnold 2022).

In order to reduce the ongoing pressure from high prices and supply insecurity, but also to reduce emissions from the industrial sector and avert a further worsening of the climate crisis, it therefore seems essential to take a closer look at the industrial sector and assess *how climate neutrality can be achieved for industry*. This is the motivation and shall be the focus of this dissertation.

## 1.3 Supply chains, levers and resulting research questions

As a starting point for this multi-perspective analysis, it is important to elaborate on why this is not only of relevance for the industrial sector, but is the foundation for achieving climate neutrality overall:

With the "sustainable product initiative" (European Commission 2022d) or the planned "resource passport for buildings" (Herz 2022), both the European Commission and the

German Federal Government have recognised that the impact of the industry's modus operandi has implications far beyond the sector itself. In most homes, offices, shops, and on the street, it will be difficult to find things that have never seen the inside of a manufactory or factory. Even plants and trees or their seeds and soil may have been grown and processed in manufactories and industrial plants.

Supply chain thinking is pivotal to realise the magnitude: The buildings and their components, all the household, consumer electronics and other products that can be found on the shelves, the food and drinks that can be bought, all the vehicles in the air, on water, on rails and roads, and the entire infrastructure already exist. Their embedded footprint already exists. Their recyclability, durability, resource and energy consumption, and greenhouse gas footprint during production and operation have already been determined. Upgrades, retrofits and replacements can only change this to a limited extent, if at all. In other words, with everything that is already there, one can try to make the most of it, use it efficiently, dispose of it sensibly and (where necessary) look for clean energy sources to power it. Therefore, it is all the more important to realise that it is necessary to start at the point where all this can still be influenced - at the drawing board.

In order to achieve net-zero greenhouse gas emissions, emissions, energy and resource consumption, as well as the circularity concept, need to be considered from the first stroke on the drawing board. Any delay in doing so inevitably leads to new "generations" of goods coming onto the market day after day that do not yet take this into account. Goods that often take years from the drawing board to the customer and usually even longer until they disappear from the supply. Goods that then require energy or resources and release emissions for weeks, months, years or even decades (e.g., ships, locomotives, buildings, energy generation or heating infrastructure), if not longer. Or goods that are not (easily) repairable, upgradable, recyclable, and then need to be replaced unnecessarily quickly. It is therefore necessary to focus on where such decisions are made.

In a way, following regulations can be reminiscent of having to do things at school that seem pointless, annoying or prevent one from doing what one actually wants to do. One reluctantly tries to fulfil the unpleasant duty with as little effort as possible or even shirk and evade it in the hope of not getting caught. A prominent real-world example is the diesel scandal (Hotten 2015).

The regulations that apply in Germany are largely issued by the European Union, the federal government and the 16 state governments. That is eighteen bodies that must then enforce and monitor compliance by the 23.2 million companies in the European Union, 2.6 million of which are in Germany alone (Eurostat 2022). For this reason, it is of great importance not only to enact regulations, but also to find ways to make the decision-makers in the companies, the product designers and everyone involved in the process, operation and production understand the "why" and show how it can also be in their interest. Convincing, encouraging, empowering, and accompanying these millions of companies on their way to net-zero would already be a big leap towards achieving the climate goals. Then policymakers could (and should) focus primarily on removing the obstacles on this path and closing the remaining gaps between companies' own ambitions and the climate targets set by society. Ideally in a way where the pursuit of a net-zero and circular economy becomes an intrinsic driver.

In addition to creating (1) an awareness that urgent action is needed (which has already largely been done in the context of the energy crisis), it is necessary to create (2) an understanding that every stakeholder (person, company, ...) has means to take action (and not only governments via targets, regulations and support programmes). Furthermore, there also needs to be (3) information about what measures are possible, as well as how they could be implemented and by whom. However, this knowledge is only of value if (4) decisions to act are made. Similar to New Year's resolutions, political goals and other decisions only have value if (5) they are persistently pursued and not delayed by bad weather or other challenges along the way, e.g. if the goal is to reach one's desired weight (Buettner et al. 2020). To stay with this metaphor, there may be a need for motivators, enablers, and facilitators to help achieve the goal set. One needs to know one's starting point, the weight, in order to fully understand the challenge ahead (i.e., as a company, one needs to know about energy consumption, emissions, etc.). Knowing a path (e.g., an intense cardio workout) does not necessarily mean that it is an effective path. Therefore, it also helps, especially at the beginning, to determine the personal constitution (i.e., strengths, weaknesses, "low hanging fruit"). Under the guidance of a "personal trainer" (i.e., facilitator, decarbonisation expert, ...), one can then configure a constellation of cardio training, weights, and nutritional changes (i.e., reduction, substitution and compensation, as well as on-site and off-site measures) that allows the goal (i.e., net zero) to be achieved in the most effective way. Once this goal is achieved, it must be maintained - as with the desired weight - which may require a changing mix of measures. As in this metaphor, having a sparring partner makes it easier to follow this path and overcome the challenges along the way.

Motivated by the current crises in combination with the notion that driving decarbonisation in the industrial sector will have a ripple effect on all other sectors and is needed to make the achievement of climate goals possible, *this dissertation aims to discover:*

*(1) what the actual situation and readiness for decarbonisation is,*

*(2) which preconditions have to be fulfilled to make it achievable,*

*(3) how stakeholders inside and outside companies can be made aware of the often hidden connections and the real relevance of the industrial sector for achieving the climate goals (without destroying the economy),*

*(4) how companies can be motivated to intrinsically wish to take action.*

*Furthermore, it aims to (5) develop tools and generate insights that enable them to configure an economic mix of measures that (6) is tailored to their individual context, so that companies can derive their decarbonisation roadmap from it. At the same time (7) it intends to provide policymakers, intermediaries, multipliers, financiers as well as the general public with a sound overview of how climate neutrality can become a reality and it intends to raise awareness that this change also depends on non-industrial actors (i.e. creating demand, providing framework conditions, qualified personnel, technical and* *strategic advice as well as financial mechanisms to make things that only pay off after some time, if at all financially, work).*

Uncovering missing dominoes, without which it will not work, is one aspect. In principle, many of the required technologies, many technology roadmaps and also access to finance are available as long as a company is financially viable. What is often missing is the decision within the company. This may be due to other priorities, or a lack of knowledge about how getting involved can help the company strengthen its resilience and competitiveness, especially in the long run, or simply because they do not know "how to do it". Similar to the waste heat example, it is often also a matter of uncovering and responding to "unknown unknowns" where companies do not perceive the savings potential in certain areas because they have not (yet) been coached to recognise them. As with building one's first house, one only knows what knowledge and support is needed when the knowledge gap becomes apparent — and that is when the task is visibly ahead and not much earlier, as will also be highlighted in several sections.

## 1.4 Outline of this dissertation

Following a multi-perspective approach, the individual chapters of this dissertation are divided into three parts. Combined, the seven chapters (2 – 8), referred to as articles, reports, papers, or documents, aim to lay out step by step *how climate neutrality can be achieved for industry* and thus provide an answer to the research question of this publication-based dissertation. As the target groups and methodological approaches differ in the individual chapters, details of these, as well as the respective research gaps, contributions to the field and literature reviews, are provided in the respective chapters where necessary.

As the terminology may sound interchangeable, it is first necessary to *create a common understanding* of what decarbonisation actually means (as, for example, the literal elimination of carbon atoms would mean the extinction of most life forms, as they are all partly made of and dependent on carbon). **Chapter 2** (Framing the ambition of carbon neutrality) defines carbon neutrality and how it differs from "other neutralities", and further outlines why establishing clarity on the target variable is essential. Together with a series of questions (subsequently addressed in **Chapters 3**, **4**, **5**, **6** and **8**), it explains the need to understand the »realities on the micro level« (Buettner 2020, p.3). It concludes that »understanding the [industry] sectors' actions, plans and ambitions […] is essential to shape suitable mechanisms, regulatory frameworks, infrastructure and local authorities' planning capacity to avoid bottlenecks and ensure the achievement of the goal on time« (Buettner 2020, p.5).

The second part picks up from this and aims at *setting the foundations for enabling decarbonisation*, taking a systems perspective. **Chapter 3** therefore takes up some of the issues raised in **Chapter 2** and focuses on *how German manufacturers react to the increasing societal pressure for decarbonisation*. Using quantitative data from the Energy Efficiency Index of the German Industry (EEI), the chapter examines which measures companies take to reduce their footprint, whether energy, resource and emissions footprints are taken into account, and whether and by when a net zero balance is aimed for. Based on the awareness that the manufacturing industry is very diverse, the results are analysed by company size, energy intensity class and manufacturing sector, and explained with examples from practice. It emerges from **Chapter 3**, in addition to the issues already raised in **Chapter 2**, that 2025 seems to be an important target year for many companies and that it depends on where the line is drawn and what companies are willing or able to do locally or what they need from the outside to achieve their goals. (Buettner et al. 2022b)

In light of the findings and questions raised in **Chapters 2** and **3**, further EEI surveys aimed at providing the empirical basis for answering these questions, e.g., what the targets for 2025 actually are and with what composition of measures these are planned to be achieved. **Chapter 4** takes a close look at these and finds that, on average, sixty per cent of the respective targets are to be achieved through measures on the manufacturers' premises. In combination with the somewhat surprising target of reducing the 2019 GHG emissions by more than 20 % by 2025, satisfying the legal, technical and capacity requirements (for the planned on-site measures and especially for the forty per cent of this target that is accounted for by off-site solutions) calls for *increasing the voltage and sequencing decarbonisation with green power and efficiency* (Buettner et al. 2023). Due to the unexpected ambition for 2025, which is roughly equivalent to a 50 % GHG reduction compared to the frequent policy base year (1990, base year of the Kyoto Protocol (UBA 2022b)) and only a few percentage points shy of the country's 2030 target (back then) (55 % (The Federal Government of Germany 2022)), the suspicion arose that companies might set ambitious short-term targets to tackle the challenge head-on (while governments often seem to increase their efforts towards the deadline). Another wave of the EEI was tasked with examining the industry's 2030 targets and confirmed that the average ambition of manufacturers participating in the EEI by then is "only" about 5 percentage points higher than in 2025. This poses a challenge for policymakers to significantly accelerate their efforts, as it appears to be less about motivating decarbonisation and more about removing the barriers that would enable companies to do so (or challenge them to do what they claim to be doing). To aid policymakers and facilitators in this process, **Chapter 4** attempts to estimate the amounts needed to achieve the 2025 targets in the different categories of measures.

Looking deeper into the company perspective, specifically the question of *how net-zero can be implemented in the manufacturing industry* is at the centre of **Chapters 5-8**. Building on other aspects of the same data as used in **Chapters 3** and **4**, **Chapter 5** concentrates on *what motivates companies to take the decision to decarbonise*, and how this could be used to motivate them to do so (Buettner et al. 2022a). Focussing initially on »identifying factors that potentially drive or motivate stakeholders« (Buettner et al. 2022a, p.3), the chapter identifies ten pressure points that appear to exert more or less subtle pressure on companies to take action, as well as a number of related motivators. An example from the automotive industry is used to qualitatively validate the observations. Finally, quantitative EEI data is used to investigate which three of seven (aggregated) factors motivate companies most to reduce their emissions and by how much. As alluded to in **Chapter 1.3**, the companies that are most motivated by government requirements are among those that set the least ambitious GHG reduction targets. This suggests that it might be worthwhile to find alternatives to address negative externalities of economic activity (on the environment) and to motivate (more) companies to decarbonise than (only) through Pigouvian taxes and regulations (Buettner et al. 2022a, Varian 1992).

Practical measures for decarbonisation are not only a question of motivation (cf. **Chapter 5**), but also a question of the decision-making determinants established in the companies. Anticipating different priorities among different types of manufacturing companies, **Chapter 6** is centred around finding out *what range of measures is best for one's business when determining one's ideal mix* (Buettner & König 2021). Building on the same quantitative sample as in **Chapter 5**, the chapter explores »which determinants play the largest role in composing a decarbonisation mix« (Buettner 2022, p.5), looking at the three most important of six decision determinants, which are again identified by considering sector, company size and energy intensity. It emerges that, on average, investment-related issues (costs per avoided tonne of $CO_2$-equivalents and the level of investment) and technical aspects are most often among the most important decision-making criteria. However, the data also shows that this is not true for all types of companies and that the ranking can change considerably if a company's second or third most important decision criterion is also taken into account.

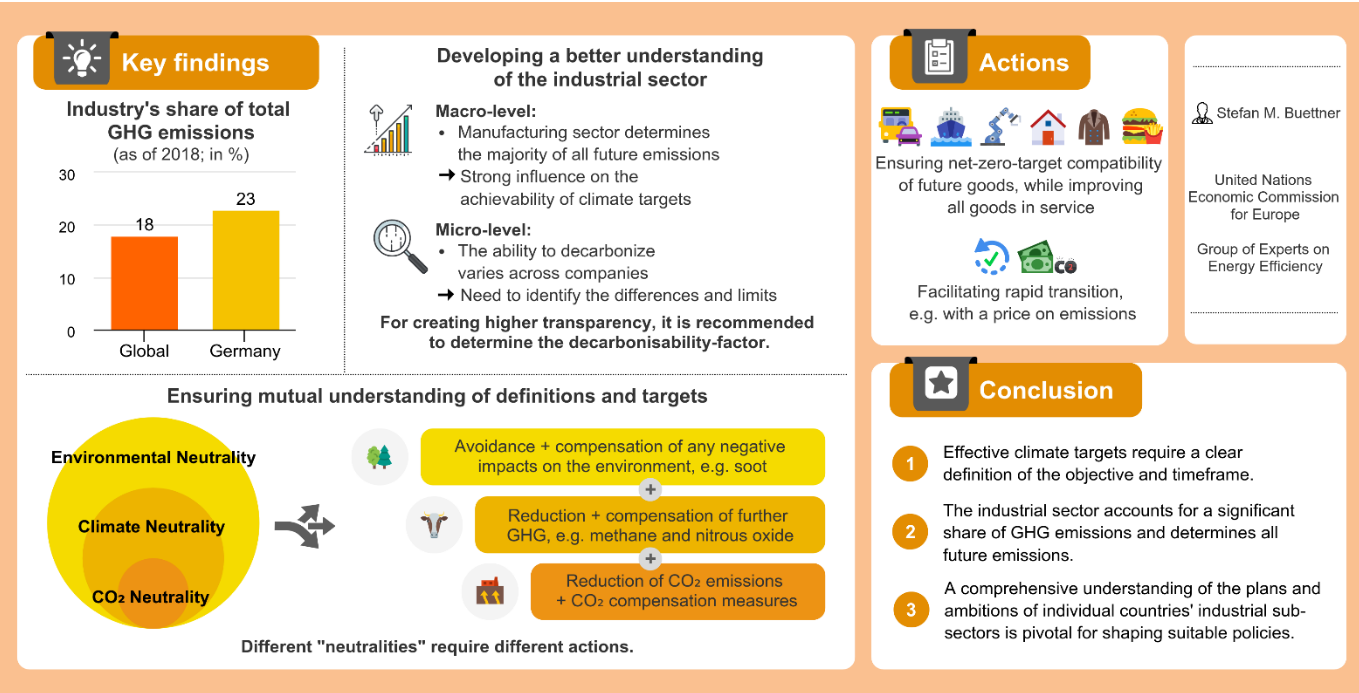
**Chapter 7** takes a step back and looks at the spectrum of measure options available to achieve net-zero emissions: reduction measures, substitution measures or compensatory measures. Focussing on six main types of measures, it illustrates *determinants for an economic assessment of industrial decarbonisation measures as an approach to reducing the greenhouse gas footprint in the manufacturing industry* (Buettner & Wang 2022). In doing so, it explains why a novel approach to calculating economic viability is needed to account for the difference between decarbonisation measures that serve a long-term goal, the often-ignored costs of inaction, and the impact of changing energy and emissions unit costs. It shows how measures that may appear to be the easiest and most logical choice in the short term can backfire in the medium to long term, especially in times when the desire for resilience is stronger. Apart from explaining the one-off and permanent impacts of six types of measures, **Chapter 7** highlights the impact of price changes on their performance and proposes a new economic efficiency calculation that facilitates the assessment of the economic performance of each measure at a specific point in time, e.g., for a milestone year on the way to net zero. A number of example scenarios are used to illustrate how an economic mix of measures can be put together and how, with the inclusion of other determinants such as motivation (cf. **Chapter 5**) and decision determinants (cf. **Chapter 6**), a scoring model can be created that proposes the company's ideal mix of measures, taking into account all the ingredients that are important to the company.

However, to determine an ideal mix, one needs to know where one stands, what is feasible, what one wants to optimise for, where to draw the line, what the ambition level is and likewise the motivation, as different decarbonisation measures can appeal to these motivators very differently. As explained in **Chapter 6**, decision priorities also have an impact on which measures are suitable and which are not. Many approaches illustrate individual measures for decarbonisation at the micro level (Bauer et al. 2022; Nurdiawati & Urban 2021; Cresko et al. 2015), describe pathways at the macro level (often only for energy-intensive industries)(Johnson et al. 2021; Rissman et al. 2020) or state that the above-mentioned factors, such as the target, need to be determined without explaining how this is done and what needs to be taken into account (South Pole 2021; Climate Neutral 2021; Fashion Cloud 2021; The Economist Applied 2020) **Chapter 8** brings all the components together and illustrates in a practical step-by-step approach *what foundational questions need answering to determine one's ideal decarbonisation strategy*, in other words, *one's roadmap to neutrality*. Building on the responses to seven questions, stakeholders will then be able to assess which general measures could be considered, which specific options might be of interest depending on their circumstances, and how they can build a mix of measures that is economically viable, including over time, using the approach presented in **Chapter 7**.

The concluding **Chapter 9** summarises and discusses the overall findings of the individual chapters of this dissertation. Finally, it derives implications for policy makers, companies and other stakeholders and provides an outlook on how climate neutrality in industry can be achieved.

# 2 Framing the ambition of carbon neutrality

**Abstract:**



(Published as: Buettner, Stefan M., 2020. Framing the ambition of carbon neutrality. *United Nations Economic Commission for Europe. Group of Experts on Energy Efficiency, Seventh Session. GEEE-7/2020/INF.2*. Geneva, Switzerland. Reprint with permission.) (Buettner 2020)

**Group of Experts on Energy Efficiency**
**Seventh session**
Geneva, 22 and 25 September 2020
Item 3 of the Annotated provisional agenda
**Task Force on Industrial Energy Efficiency**

# Framing the ambition of carbon neutrality

Mr. Stefan M. Buettner[1]

## I. Defining carbon neutrality

1. How to understand the terms 'decarbonization' and 'carbon neutrality'? It is not about removing carbon itself – it is the combination of carbon and oxygen (carbon-dioxide) which yields harmful consequences for the global climate. Carbon-dioxide ($CO_2$) accumulates in the atmosphere through natural and anthropogenic processes. In the atmosphere, $CO_2$ absorbs heat and thus causes the atmosphere to heat up.

2. There are, $CO_2$ aside, other substances which have a similar effect on the atmosphere, hence they are also regarded as advancing global warming, i.e. greenhouse gases (GHG) or $CO_2$-equivalents.

3. Does carbon neutrality include these emissions, as well? What does carbon neutrality mean? Do we aim for $CO_2$-neutrality? Is simply moving towards $CO_2$-neutrality sufficient for attaining the goals as agreed on in the Paris Climate Agreement? Or does this require including $CO_2$-equivalents? Does a full removal of GHG equal climate neutrality? And, what is the actual difference between climate neutrality and environmental neutrality?

4. Moreover, is 'neutrality', defined as absolute neutrality (no emissions remaining), or is 'net neutrality' the goal, defined as neutrality after summing up all positively and negatively contributing factors (remaining emissions are cancelled out through compensatory measures, i.e. planting trees or purchase of emission certificates)?

5. Conceptualizing this is essential in order to set climate goals and implement respective policies. If not properly defined, misconceptions will inherently lead to inefficient approaches and disputes during implementation. With regard to this, capabilities and characteristics of each actor – and especially on a macro level societal, geopolitical and strategical considerations of nation-states – need to be included before setting terms and recommendations.

6. Actions to attaining different levels of neutrality may be considered as follows:

(a) Carbon neutrality:
  (i) reducing $CO_2$ emissions;
  (ii) $CO_2$ compensation measures;

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(b) Climate neutrality:

(i) reduction and compensation of further GHG[2] with global-warming potential (GWP)[3] [4]: $CO_2$-equivalents;[5]

(ii) non-fluorinated: methane ($CH_4$), nitrous oxide ($N_2O$);

(iii) fluorinated: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride ($SF_6$),

nitrogen trifluoride ($NF_3$).

(c) Environmental neutrality:

(i) avoidance and compensation of the above and any other means negatively impacting on the environment and health (i.e. pesticides, nitrogen oxides ($NO_x$), soot, sulphur dioxide ($SO_2$), particulates, etc.).

## II. Necessity of establishing clarity on the target variable

7. How will decision makers be able to make good decisions if the issue to decide or act upon itself is not sufficiently clear: If for instance carbon neutrality is the proclaimed goal, is the intended goal neutralising all $CO_2$-emissions or does the goal extend to $CO_2$-equivalents as well, changing the actual goal to climate neutrality?

8. Clarity on the target variable is hence essential to make good decisions, the presence or absence of an '$CO_2$-e'-suffix changes the scope and corresponding strategy significantly. The challenge in this in particular is that usually – at least it should be like this – decision makers believe that the context is clear. Unambiguity therefore requires all stakeholders involved to be conscious of the clear definition(s) of the issue discussed, as well as having clear communication with one another.

9. The commonly used response to the question 'do you know what I mean' – 'yes I understand' emulates a perceived common understanding of the matter in question whilst in reality this means 'I believe I know what you mean' and can significantly harm, delay or prevent succeeding in achieving the (actually intended) goal set, respectively wasting time and resources. This calls for ensuring mutual understanding on targets and definitions rather than well intended assumptions (i.e. 'let us do something good for the environment' or in a personal context 'let us do something nice together' –> likelihood that something 'good' or 'nice' is considered to be something very different is high): hence, (order) clarification, where the involved parties define each element part of or excluded for target achievement is critical.

10. In context of this document: are $CO_2$-equivalents considered (hence GHG with the corresponding target of 'climate neutrality') or not?

11. Target-setting aside, measuring progress on the set target must be against statistics of the very same definition consistently and in the same manner. If it is not an absolute goal such as net-zero or incorporates milestones, the definition of base-figures is essential (i.e. certain percentage of reduction by 2030; this frequently is based on 1990 figures, but it cannot be assumed unless clearly stated). Less important in the long run, but critical during the starting period, is whether early milestones aim at, i.e., have strategies derived or contracts ready to be

[2] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Greenhouse_gas_(GHG)

[3] https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials

[4] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Global-warming_potential_(GWP)

[5] https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Carbon_dioxide_equivalent

tendered or the strategies approved, and the contracts awarded and signed. Here only absolute clarity will allow feasibility of schedules and successful progress. In practice, however, climate and environmental neutrality are often confused among another, as are carbon and climate neutrality.

## III. The hidden long-term relevance of industry

12. Noting fluctuations depending on country, industry accounted for approximately 18 percent of global GHG emissions in 2018, including energy, process and use-related emissions.[6] Depending on the set-up of manufacturing in a country the share of process emissions amongst total emissions varies. In Germany, industry accounted for around 23 percent of the country's GHG emissions, with one-third of these attributed to process-related emissions and two-thirds to energy-related emissions.[7] Looking at this from a status quo perspective, working on all sectors generating GHG emissions is an impediment and equally important. For the long-term perspective, however, it is the manufacturing sector that determines the majority of future emissions and, consequentially, whether or not carbon, climate, or environmental neutrality can be achieved.

13. Whilst it is necessary to improve 'the existing' across all sectors, decisions on the design, the sourcing and choice of materials, the lifetime energy consumption, the durability, as well as the energy and resources consumed during the manufacturing process are taken in those companies manufacturing future goods (i.e. ships, power-generating technologies, components for buildings). It is these determining the environmental performance.

14. As seen, regulative measures such as phasing out traditional light bulbs, can guide or accelerate process to longer lasting or more energy efficient goods. Similarly, in regions where a price on emissions is in place, there is a cost incentive encouraging decision reducing the footprint of manufacturing-related emissions.

15. Considering the long-lasting nature of many types of machinery, vehicles, building components, there is an urgency in encouraging and facilitating rapid transition. The products that are being designed now, will be manufactured in the future, and will in use for many years to come.

## IV. Carbon neutrality in industry

16. Working towards carbon (or climate) neutrality requires an effective assessment of the status quo. Awareness on the macro level is not sufficient in this instance as the manufacturing sector in particular is very diverse: company size determines, for instance, whether or not a dedicated person can take care of the issue, or whether the level of investment or cost per tonne of carbon emissions avoided is of higher relevance, the manufacturing sector determines through the specific mix of processes applied in that sector how emissions can be reduced and the energy intensity determines the associated cost lever.

17. In order to tailor fitting solutions understanding realities on the micro level, notably assessment of the topic and intentions to act on a company level, there is a necessity to understand:

(a) How effective are current policies considered to facilitate an increase in energy efficiency in industry?

(b) What measures, if any, are being taken by companies to reduce their carbon footprint?

[6] See UNFCCC_GHG_EMISSIONS_1990-2018_ANNEX1, by sector: 1.A.2 and 2 as share of GHG emissions without LULUCF

[7] See https://www.umweltbundesamt.de/daten/klima/treibhausgas-emissionen-in-deutschland#emissionsentwicklung-1990-bis-2018

(c) Are energy, resource and carbon footprint being considered during product development? In terms of the manufacturing process, or in terms of the whole life cycle? Which of these has the highest priority?

(d) Do companies aim at net-carbon or net-climate neutrality? If so, where do they stand in this effort. By when? If not, what is or are reasons for it?

(e) What factors motivate companies to reduce their GHG emissions?

(f) What GHG reduction do companies aim for within the next 5 years? How much of this do they associate with which type of measure?

(g) Which factors are most decisive in determining the aforementioned mix of measures?

(h) In what way does the COVID-19 pandemic affect companies energy efficiency and decarbonisation strategy?

18. On a policymaker level, the answers to these questions matter significantly, as they give an indication as to whether planned decarbonisation progress by industry is in line with the degree of progress intended by policymakers. Not only the progress itself matters, but also the method chosen: if, for instance, companies aim to decarbonise by largely switching to renewable electricity, this may lead to a demand overshoot: the increase in the supply of renewable electricity is not sufficiently high to satisfy the increase in demand for renewable electricity. Similarly, if a majority of measures is to take place on site, are there sufficient capacities among planning authorities, etc.

19. From a system perspective, it therefore makes sense (1) to reduce energy and resource consumption and then (2) to substitute with renewable sources, before (3) compensating what is left. From an infrastructure perspective, it is beneficial to aim for local substitution first (i.e. micro generation, such as photovoltaic, micro hydro, etc.). Not only does such sequence increase a company's resilience to supply and price shocks, but also places the ability and responsibility to act to companies rather the country. This is important as the general energy and (green) generation infrastructure undergoes at times long planning and building times, besides from being often unpopular. To increase transparency on a planning level, it makes sense to determine the 'decarbonisability-factor', the share of a company's emissions it is able to take care of locally, respectively the remaining share that needs to be taken care off 'by the system' (energy infrastructure and compensatory measures).

20. It should to be noted that the ability to decarbonise differs significantly between companies whose business model is based on releasing emissions (coal companies for example), to companies whose business model is by nature carbon negative (for example lumber). Between companies that release in majority process emissions, to companies whose emissions are solely energy-related. Between companies where the majority of emissions are under their direct control to those, often larger ones, that assemble pre-products without releasing a significant share of the product's total emissions (like car manufacturers).

21. Over the next months and in a collective effort, the 'Energy Efficiency Barometer of Industry' (www.eep.uni-stuttgart.de/eeei), aims to gather answers to the aforementioned questions from manufacturing companies across the UNECE region. Sufficient responses permitted, this undertaking will shed light on the current realities in manufacturing across all company sizes, all 27 manufacturing sectors and different energy intensities across the region, and ideally as many individual UNECE member countries as possible. Whilst technical aspects will be similar, other aspects influencing responses to the questions raised are likely to differ across countries.

## V. Conclusion

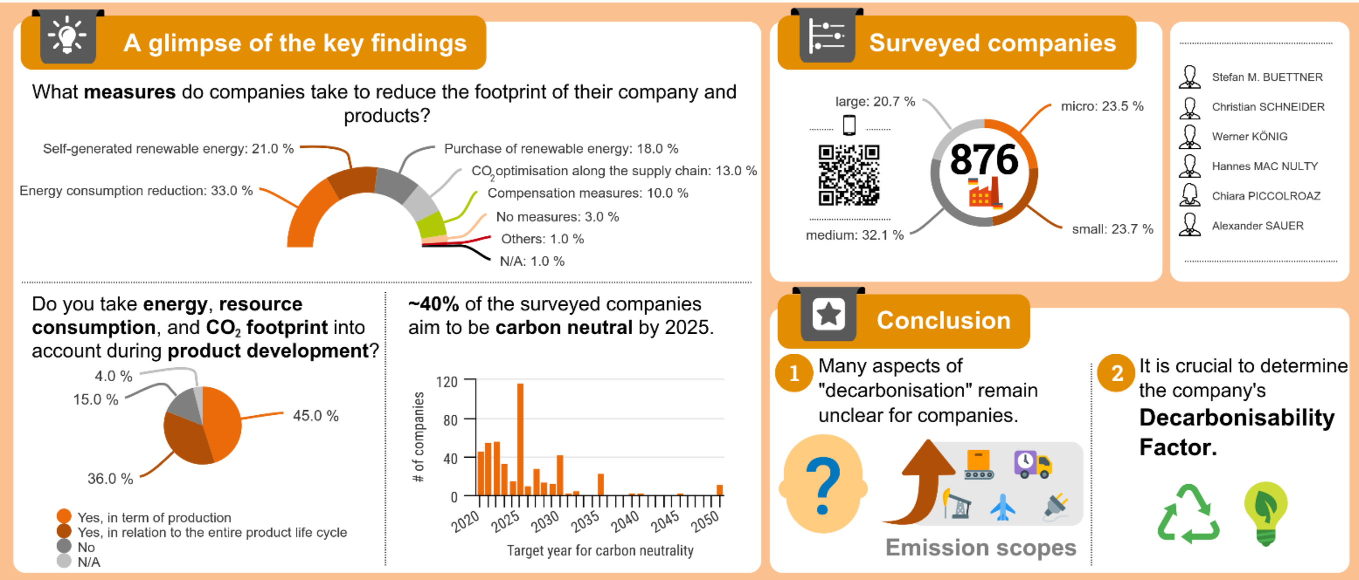
22. A clear definition and mutual understanding of the target variable, the goal aimed for and the associated timeframe, are a prerequisite to its achievement (for instance climate neutrality by 2050).

23. The industrial sector is varied in different dimensions. The sector has a pivotal role in enabling us to achieve the goal set.

24. Therefore, understanding the sectors' actions, plans and ambitions – as well as the differences across company size, subsector and energy intensity - is essential to shape, suitable support mechanisms, regulatory frameworks, infrastructure, and local authorities' planning capacity to avoid bottlenecks and ensure achieving the goal on time.

# 3 How do German manufacturers react to the increasing societal pressure for decarbonisation?

**Abstract:**




(Published as: Buettner, Stefan M.; Schneider, Christian; König, Werner; Mac Nulty, Hannes; Piccolroaz, Chiara; Sauer, Alexander, 2022. How do German manufacturers react to the increasing societal pressure for decarbonisation? *Applied Sciences*, **12**, 543. DOI: https://doi.org/10.3390/app12020543. Licence: CC BY 4.0) (Buettner et al. 2022b) *applied sciences*

MDPI

*Article*

# How Do German Manufacturers React to the Increasing Societal Pressure for Decarbonisation?

**Stefan M. Buettner [1,*], Christian Schneider [1], Werner König [2], Hannes Mac Nulty [3], Chiara Piccolroaz [1] and Alexander Sauer [1]**

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**Abstract:** From the perspective of manufacturing companies, the political, media and economic discourse on decarbonisation in the recent years manifests itself as an increasing social expectation of action. In Germany, in particular, this discourse is also being driven forward by powerful companies, respectively sectors, most notably the automotive industry. Against this background, the present paper examines how German manufacturing companies react to rising societal pressure and emerging policies. It examines which measures the companies have taken or plan to take to reduce their carbon footprint, which aspirations are associated with this and the structural characteristics (company size, energy intensity, and sector) by which these are influenced. A mix methods approach is applied, utilising data gathered from approx. 900 companies in context of the Energy Efficiency Index of German Industry (EEI), along with media research focusing on the announced decarbonisation plans and initiatives. We demonstrate that one-size-serves-all approaches are not suitable to decarbonise industry, as the situation and ambitions differ considerably depending on size, energy intensity and sector. Even though the levels of ambition and urgency are high, micro and energy intensive companies, in particular, are challenged. The present research uncovers a series of questions that call for attention to materialise the ambitions and address the challenges outlined.

**Keywords:** decarbonisation; carbon footprint; net-zero; resources; energy consumption; implementation; manufacturing; product carbon footprint; carbon neutrality

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**Citation:** Buettner, S.M.; Schneider, C.; König, W.; Mac Nulty, H.; Piccolroaz, C.; Sauer, A. How Do German Manufacturers React to the Increasing Societal Pressure for Decarbonisation? *Appl. Sci.* **2022**, *12*, 543. https://doi.org/10.3390/app12020543

Academic Editors: Stefan Lechtenböhmer, Max Åhman and Adrián Mota Babiloni

Received: 1 November 2021
Accepted: 28 December 2021
Published: 6 January 2022



## 1. Introduction

Facing the challenges to keep global warming below 1.5 °C by 2050, the so-called German "Climate Cabinet" negotiated a climate package that added sufficient new substance to existing agreements to get the opportunity to address the United Nations General Assembly in lieu of the UN Climate Action Summit in September 2019. Publicly challenged for its ambition and doubtful impact, the package finally passed in late 2019 under several conditions, including increasing the proposed $CO_2$-levy starting in January 2021 to 25 EUR per ton of $CO_2$-equivalents ($CO_2$-eq.) emitted [1–3].

Simultaneously, the UN Summit led to pledges by the business and financial sector, as well as regional and country players, to reach net-zero carbon (reducing carbon emissions and levelling residual carbon emissions through compensation) by 2050. A third of the global banking sector pledged to work to achieve the Paris Agreement goals, and companies with a capitalisation of 2 trillion euros united to commit to manage their companies to achieve climate targets [4,5].

In awareness of the relevance of both the climate package and the UN Climate Action Summit and their likely impact on the industrial sector, along with the frequent referrals by politics on the alleged position and situation of industry towards both the climate package requirements and decarbonisation, the Institute for Energy Efficiency in Production (EEP) chose to tailor its October/November 2019 data collection for the Energy Efficiency Index of German Industry (EEI), to capture the actual opinion of the German manufacturing industry on these issues [6] at the height of the discussion and public attention, and ahead of the United Nations World Climate Conference COP25 in Madrid. In this paper, which builds and extends on a conference paper presented at the ECEEE Industrial Efficiency 2020: Decarbonise Industry! Conference [7], we focus on the EEIs outcomes in relation to decarbonisation.

The importance of decarbonisation of manufacturing industries has been highlighted by scholars for several years [8,9]. Decarbonising industries is a complex societal problem and studies on this issue have been accumulating in recent years.

Labanca et al. [10] distinguish between three approaches to the study of industrial decarbonisation, namely energy system analysis (1), policy studies (2), and (3) sustainability transition research.

Energy system analysis (1) is about providing a technical understanding of what is feasible and technically required to achieve certain predefined goals and relating this to the sociotechnical context and policy requirements [10]. Scenario studies [11], technology potential studies [12], and studies on barriers or drivers for energy efficiency measures [13] are typical of this approach.

Policy studies (2) are devoted to developing and examining policy processes and instruments [10,14]. Characteristic for this field are, for example, studies on energy efficiency programmes [15] or policy pathways to net-zero emissions industries [16].

On the other hand, sustainability transition research (3) draws attention to conceptualising, explaining, and governing sociotechnical transitions towards sustainability [10,17]. In contrast to energy system analysis, sustainability research expands its perspective beyond technology diffusion to behavioural, institutional cultural changes. Typical for this strand of research is the assumption that decarbonisation is not a mere question of the availability of technology or individual choices. For Sovacool [18] (p. 372), for example, culture and its institutions are the “most surreptitious, yet powerful” barriers to renewable energy and energy efficiency. Similarly, König [19] emphasises the institutional and cultural context of decision-making in industrial organisations, whereas Rhodin and Thollander [20] underline the importance of corporate culture for the efficacy of measures within industrial enterprises.

Against this background, our study aims to contribute to the recent sustainability transition research. Labanca et al. [10] (p. 1) argue that current research approaches on decarbonisation are oftentimes too narrow, mostly because they rely on the assumption that energy supply and demand can be addressed exogenously and separately. Similarly, we assume that the aspirations industrial organisations have and the actions they take must not be considered as independent from their broader cultural and societal context.

To create a better understanding as to why the decarbonisation of the industrial sector is of particular relevance in avoiding climate change, it is helpful to observe Germany’s energy consumption and emission statistics. The share of industrial energy consumption (28.0%) is about as high as in the building sector (26.5%) and less than in the transport sector (30.6%) [21]. The industrial sector accounted for 18.4% of energy-related greenhouse gas emissions (GHG) in Germany, in 2019 [22]. Furthermore, considering process-related emissions, which make up about a third of industries’ overall greenhouse gas emissions, the percentage share rises to 23.1% of Germany’s GHG emissions, which is the second highest after the energy sector (31.9%) and more than the GHG emissions of the transport (20.2%) or buildings sector (15.2%) [23]. Unlike the latter two, the industrial sector decides on optimisations and investments on a daily basis, whereas the timespan of action for buildings and transport can be decades (i.e., heating systems, buildings, tractors, trucks, and ships). Furthermore, nearly everything leading to emissions in all sectors (except livestock) has been in a factory at one point; for instance, entrepreneurs decide upon how products are designed and produced, where the raw materials come from, and how products, components, and equipment perform and can be recycled—therefore, the industrial sector, in the long run, is the key to making net decarbonisation feasible by 2050.

Thus, this study focuses on the question of how manufacturing companies in Germany react to the increasing societal pressure for decarbonisation. Doing this, we analyse the situation from the companies' perspectives, in particular, by exploring what measures (if any) companies (plan to) undertake to tackle their carbon footprint and by when.

The findings of this study are of particular relevance to policymakers, as they underline that urgent policy action is needed to facilitate the pace of decarbonisation aspired by responding companies. It further presents valuable insights to companies, regarding where they are situated in contrast to their peers, as well as to facilitators and service providers, as these obtain a clearer view regarding the kind of support that might be needed by what type of company and when, and also to the general public that gains a better understanding of the actions, ambitions, needs, and complexities of the industrial sector.

The study showcases the differences across the various types of companies that call for approaches, other than "one size serves all" ones. By taking an all-round view on the findings, this study also uncovers a series of issues that call for further attention to support companies, service providers, and policymakers in successfully decarbonising the industrial sector in Germany and subsequently—due to also reducing the product carbon footprints of the produce of industry—the other sectors.

## 2. Methodology

This study builds on data gathered in the framework of the Energy Efficiency Index of German Industry (EEI). Introduced in 2013, in reaction to the lack of "targeted energy efficiency analysis" and "presented as an index for industry as a whole and especially the manufacturing sector" [24], EEI's methodology leans on the general approach of the German monthly economic indicator, the ifo-Index [24], and focuses on opinions, experiences, expectations, and intentions of entrepreneurs from across 27 sectors and different company sizes.

In 2017, around 540,000 manufacturing companies (178,000 of them in the 27 most relevant subsectors) employed 10.25 million people and created a revenue of almost 3.07 trillion euros [25] (p. 524). The data set examined in this paper contains answers of 915 companies and was gathered in October/November 2019—briefly after the September 2019 United Nations Climate Action Summit and the announcement of the German climate package.

Focussing on current issues at each of the semi-annual data collections, the 2nd data collection of the EEI in 2019 looked, in particular, at the position of the German manufacturing industry in respect to the German climate package and decarbonisation [6]. Among 28 questions in total, companies were asked to indicate the number of employees, energy consumption, revenue, and sector (with their largest share of revenue), to allow an analysis and cross-referencing of these parameters with current-topic question results. However, energy consumption and revenue in particular are considered confidential and were not provided by a significant number of respondents, explaining the different number of observations in the analysis to come.

The data collection was carried out using a mixed methods design, combining telephone and online surveys. Table 1 provides an overview of the sample by company size, as defined by the European Commission [26]. For the EEI samples, we purposely aim for an approximately even distribution across company sizes rather than following the actual size distribution of manufacturing companies in Germany [25] (p. 526), to allow us to make statements for all company sizes.

**Table 1.** Sample composition by company size (n = 876).

| Company Size | Number of Employees | Revenue | Observations | Percentage |
|---|---|---|---|---|
| Micro | 0–9 | ≤EUR 2 million | 206 | 23.5% |
| Small | 10–49 | >EUR 2 to ≤10 million | 208 | 23.7% |
| Medium | 50–249 | >EUR 10 to ≤50 million | 281 | 32.1% |
| Large | >249 | >EUR 50 million | 181 | 20.7% |

An even distribution across the relevant 27 manufacturing sectors (that represent 178,000 companies) was desired, but difficult to achieve. Therefore, several so-called core industries, from which at least 25 companies should participate, were defined in context of the telephone survey. These include sectors, such as mechanical engineering and automotive, which are considered to be very important for German industry. The sectoral analyses in this paper only feature sectors with, overall, at least 20 participating companies providing answers to the respective questions. Micro sectors' (with a total population (N) smaller than 10, N < 10) results are taken note of ('**'), when more than 50% of the sector participated in this study; similarly, the results of small sectors (N < 100) are taken note of ('*') when at least 15% of the sector participated. The sectors are coded according to NACE, the *'Nomenclature générale des activités économiques dans les Communautés Européennes'* (General Industrial Classification of Economic Activities within the European Communities), whose use is mandatory in the European Union and is in compliance with the global ISIC system (United Nations' International standard industrial classification of all economic activities) [27–29].

Responding companies are asked to indicate whether their responses are on behalf of their overall company or one specific site. Of the overall 915 observations, 686 refer to one specific site and 199 refer to multiple sites. Table 2 gives an indication of what percentage of the total number of companies in a sector participated. In very small sectors, such as the "crude petroleum and natural gas" sector (06), the percentage may appear to exceed 100%. In this case, 3 out of 7 responses refer to multiple sites while 4 refer to one specific site, leading to the assumption that all 4 companies in the sector responded—one by site and the other 3 by company.

As we assume that the position and intended action of companies towards the calls to decarbonise differ, depending on the energy intensity of a company, we computed the energy intensity for each company, where possible, and clustered these into five intensity classes. It could be argued that energy intensity is an inadequate measure as it cannot take into account the added value, and, therefore, the cost share of energy in relation to total costs should be applied instead. In theory, this would make sense. However, gaining access to this type of data would, in practice, be quite difficult to accomplish.

The energy intensity is calculated as the ratio between the energy used and the revenue of a company. The variable "energy use" contains information on the overall energy demand of a company (converted) in megawatthours (MWh), while the variable "revenue" provides information on the revenue of a company during the previous financial year in million euros. The results of this operation cover a wide range, which counts 688 cases and extends from 0.0001 to 10,000 watthours (Wh) consumed per euro of revenue (Wh/EUR) for this sample.

In order to classify the variable "energy intensity", corresponding values have been grouped into five classes, as illustrated in Table 3. The lower (higher) the class of variable energy intensity, the higher (lower) the energy productivity level of an industry. Energy efficiency is a key measure to increase energy productivity. Since only ten of the energy intensity observations fall into the fifth class, there are not enough cases ($n \geq 20$) to include this class in the analysis conducted on the EEP 2019 survey data. For this reason, the analysis in this paper will feature just four energy intensity classes.

**Table 2.** Sample composition by sector (n = 884).

| NACE Code | Sector | Total Population (N) | Observations (n) | Percentage n (N) |
|---|---|---|---|---|
| 05 ** | Mining of coal and lignite | 7 | 5 | 71.4% |
| 06 ** | Extraction of crude petroleum and natural gas | 4 | 7 | 175.0% |
| 08 | Other mining and quarrying | 1517 | 30 | 2.0% |
| 10 | Manufacture of food products | 21,498 | 29 | 0.1% |
| 11 | Manufacture of beverages | 2033 | 21 | 1.0% |
| 12 | Manufacture of tobacco products | 44 | 5 | 11.4% |
| 13 | Manufacture of textiles | 3643 | 21 | 0.5% |
| 14 | Manufacture of wearing apparel | 2625 | 10 | 0.3% |
| 15 | Manufacture of leather and related products | 1166 | 40 | 3.0% |
| 16 | Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials | 11,919 | 42 | 0.3% |
| 17 | Manufacture of paper and paper products | 1467 | 48 | 3.3% |
| 18 | Printing and reproduction of recorded media | 9832 | 32 | 0.4% |
| 19 * | Manufacture of coke and refined petroleum products | 84 | 13 | 15.5% |
| 20 | Manufacture of chemicals and chemical products | 3019 | 55 | 1.8% |
| 21 | Manufacture of basic pharmaceutical products and pharmaceutical preparations | 521 | 26 | 5.0% |
| 22 | Manufacture of rubber and plastic products | 6698 | 62 | 0.9% |
| 23 | Manufacture of other non-metallic mineral products | 8951 | 43 | 0.5% |
| 24 | Manufacture of basic metals | 2424 | 56 | 2.3% |
| 25 | Manufacture of fabricated metal products, except machinery and equipment | 40,338 | 70 | 0.2% |
| 26 | Manufacture of computer, electronic, and optical products | 6854 | 14 | 0.2% |
| 27 | Manufacture of electrical equipment | 5730 | 52 | 0.9% |
| 28 | Manufacture of machinery and equipment n.e.c. | 15,408 | 64 | 0.4% |
| 29 | Manufacture of motor vehicles, trailers, and semi-trailers | 2461 | 51 | 2.1% |
| 30 | Manufacture of other transport equipment | 1029 | 25 | 2.4% |
| 31 | Manufacture of furniture | 9615 | 35 | 0.4% |
| 32 | Other manufacturing | 19,096 | 24 | 0.1% |
| 99 | Other | | | |
| | **Total** | **177,983** | **884** | **0.5%** |

* small sector (N < 100) with at least 15% of total population (N) participating; ** micro sector (N < 10) with at least 50% of N participating.

**Table 3.** Sample composition by energy intensity (n = 688).

| Energy Intensity Class | Energy Intensity Interval | Observations | Percentage |
|---|---|---|---|
| Not energy intensive | 0 to <10 Wh/EUR | 150 | 21.8% |
| Less energy intensive | 10 to <100 Wh/EUR | 258 | 37.5% |
| Moderately energy intensive | 100 to <1000 Wh/EUR | 203 | 29.5% |
| Energy intensive | 1000 to <10,000 Wh/EUR | 67 | 9.7% |
| Very energy intensive | $\geq$10,000 Wh/EUR | 10 | 1.5% |

## 3. Results

### *3.1. How Do Companies React to the Rising Societal Pressure and Emerging Policies?*

German industry, as many others, suffered from a shortage of skilled personnel ahead of the COVID-19 pandemic, meaning the demand for them exceeds the supply, allowing, in most cases, young graduates, to choose where to start working. A McKinsey study has identified that sustainability has become a more important factor than salary or job security, and that similarly, according to a YouGov online poll, 68% deem sustainability action by their employer as important [30].

Unsurprisingly, companies increasingly state sustainability as a significant element of their corporate strategy to address this (e.g., Daimler and Henkel), but what does this mean? Is it a marketing activity, which, if uncovered, would have a negative impact on image and sales (i.e., 'greenwashing')? Or are there real intentions to take action? According to a member of the board of the Federal German Working Group for Environmentally Conscious Management (Baum), "family-run SMEs['] and start-ups['] environmental efforts are often more authentic than [..] Dax corporations['], because the owner family acts sustainably with an inner conviction" [30].

Those large companies, however, that pledged at the UN summit, have a longer history of corporate culture that is positive towards climate change measures and are often companies that customers recognise well, i.e., good corporate social responsibility matters a lot to their marketing strategy [4].

Many other companies made announcements or teamed up, such as the "entrepreneurs for future", comprised of over 2500 German SMEs that want to position themselves and make use of the arising chances as early movers, as well as "Leaders for Climate Action", that bring together a number of known brands [31].

Since the companies were surveyed, this momentum has steadily increased despite the COVID-19 pandemic, and several voices comment that industry is progressing quicker than policy makers. During the negotiations to form a new German Federal Government and ahead of COP26 in Glasgow, for instance, 69 of the largest German companies called the negotiating political parties for more concrete measures [32].

### *3.2. What Measures Do Companies Take to Tackle Their Carbon Footprint?*

Whilst pledges are already a reaction, they only work and do not backfire when real action follows. We therefore identified a number of practical measures that could be undertaken to reduce the carbon footprint of a company and their products.

#### 3.2.1. What Measures Do Companies Take to Reduce the Footprint of Their Company, Products and Supply Chain?

The "reduction of energy consumption through energy efficiency measures", as well as the "self-generation of renewable energies", can be considered as feasible internal measures, whilst the "purchase of renewable energies", "compensation measures", and a "$CO_2$ optimisation of the supply chain" are external measures. To allow responders to name additional measures, the option "others" was provided, as were "not known" or "no action". With just a 1% share of "others", it can be assumed that the range of options provided covered all the relevant answer options. As the measures provided are not excluding each other, the choice of multiple measures was provided to the 858 companies responding to this question, who on average selected two of them. The total number of choices made by the companies (n) is denoted as n′.

*The majority of measures chosen to reduce the carbon footprint are internal actions.*

Across all companies, 54% of the measures reported are <u>internal actions</u>, with 33% energy efficiency measures, and 21% self-generation of renewables. Looking at this from a **company size** perspective (cf. Figure 1a), the range of internal measures varies from 57% in large companies to 49% in micro companies, due to a larger share of efficiency measures in medium-sized and large companies (35%) in comparison to the smaller company sizes (32% and 30%). The higher emphasis on efficiency measures may be due to larger companies' increased means for dedicated personnel dealing with energy efficiency and related topics.

From a viewpoint of **energy intensity**, internal measures vary from 53% to 56%, with a gradual increase from non- (53%) to energy intensive companies (56%). With a share of 37%, the energy efficiency measures of energy intensive companies significantly outrank those of the other intensities (33%), potentially as a result of the energy management system obligation for (energy intensive) companies seeking to qualify for levy reliefs. Another reading is that energy intensive companies in particular have an interest in driving down their high energy costs, making up a much higher share of overall costs than in other companies and, hence, being in the focus of continuous optimisations of the cost structure. Similar to the company size review, the share for self-generation is fairly constant at around 20% across all energy intensity classes (cf. Figure 1b).

Reviewing the responses by **sector**, the situation differs completely and offers a large spread for internal measures, ranging from 42% ("manufacture of pharmaceutical products") to 66% ("beverage production"), underlining the different situations across the manufacturing sectors and the subsequent need for something other than "one-size-fits-all" policies.

The share of neither energy efficiency measures, nor self-generation follow this pattern in a linear or parallel way. On the contrary, it fluctuates largely from 24% ("other vehicle construction" and "production of textiles") to 43% ("manufacture of other goods") for energy efficiency measures. Even though only 13 companies of the "coke and refined petroleum" sector responded, they represent 15% of 84 companies in this small sector [25] (p. 524), and, therefore, their 42% should be noted. This allows us to confirm the hypothesis previously made on energy intensity: the levy relief affects the cost of energy, but not the amount of emissions, which in the "coke and refinery" sector stems mainly from non-electric sources. For self-generation of renewables, shares fluctuate from 12% for that very sector (noting the 11% of the 5 responding "coal mining sector" companies that represent 71% of the sector [25] (p. 524))—confirming the assumption regarding the source of energy—and the "manufacture of furniture" to 33% ("beverage production"). For the latter, as well as the "production of textiles"' sector (30%), the share of companies deciding to generate their own renewable energy is about a third higher than in the other ones that, with one exception ("printed products"), do not exceed 23% (cf. Figure 1c).

*How do companies differ when it comes to external forms of intervention to reduce their carbon footprint?*

Looking at the external forms of intervention to reduce the carbon footprint, the purchase of renewable energy (18%) outranks the $CO_2$ optimisation of the supply chain (13%) and compensation measures (10%). No measures are undertaken by just 3% of the companies in that sample.

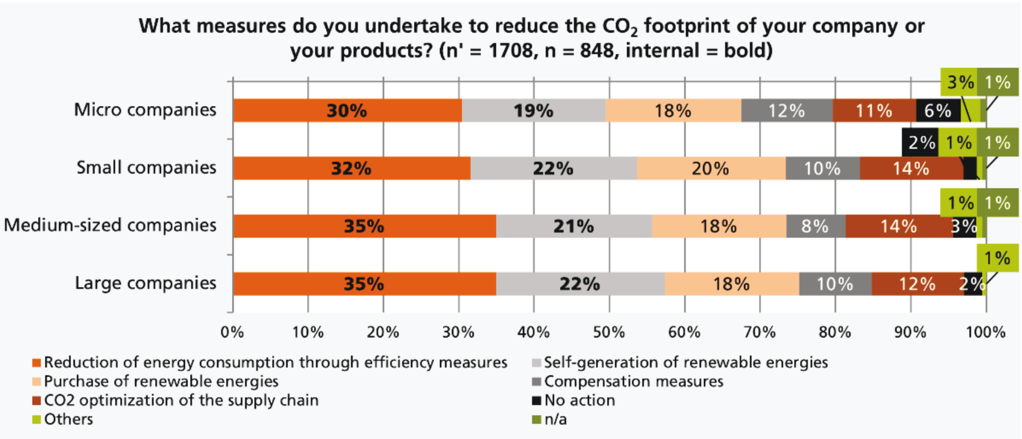
Figure 1a illustrates just marginal deviations, when looking at the purchase of green energy and compensation measures from a **company size** viewpoint. This said, for compensation measures, micro companies lead the board (12%), leaving medium sized companies (8%) behind. The data indicates that the measured $CO_2$ optimisation of the supply chain does not depend so much on company size; deviating only marginally, it is chosen more often by small and medium-sized (14%) than by large (12%) and micro companies (11%). The degree of inaction is largest with micro companies (6%) but hardly visible for small companies (2%), indicating that, amongst smaller companies, the micro ones may need the most support regarding the reduction of their footprint (cf. Figure 1a).

The self-generation of renewables is fairly similar when looking at **energy intensity** that only the energy intensive companies generate to a slightly lesser degree than the others. Only small differences occur looking at the degree to which compensation measures are chosen; for non-energy intensive and moderately energy intensive companies (11%) it is slightly greater than for less energy intensive and energy intensive companies (9%). For non- and less energy intensive companies, comparatively low costs and corporate social responsibility considerations may be motivators; for energy intensive companies it may be difficult to reduce their carbon footprint by optimising their supply chains, as it is in the nature of energy intensive companies that the majority of emissions occur on site. Therefore, it is not surprising that this share increases by 50%, with decreasing energy intensity from 10% to 15% (cf. Figure 1b).

Again, the variability is higher when looking at the **sectors**. However, the purchase of renewable energy only fluctuates between 15% and 22%, with two outliers, "manufacture of glass and ceramics" (10%) and "manufacture of other goods" (26%). Compensation measures, however, significantly vary from 5% ("food products" and "other goods") to 19% ("other vehicle construction", followed by "other mining and quarrying", i.e., extraction of stone and earth, and the "non-metallic mineral products" sector, i.e., glassware and ceramics)—"coal mining" would rank first at 22%, again pointing to more energy intensive sectors with difficulties to decarbonise through other means. Externalisation of decarbonisation efforts to the supply chain also deviates significantly: from 5% ("printing and media reproduction" and "other goods", followed by again "glassware and ceramics", "beverage production", as well as "extraction of stone and earth") to 19% ("pharmaceutical products", followed by "food products"). Here, however, there is a broad "midfield" ranging from 8% to 15%. It is striking that there are a few sectors with nearly twice the average percentage of inaction, all between 6% ("rubber and plastics"), and 11% ("furniture"), with "pharmaceutical products" in-between. All of these are sectors, for which reducing the footprint is challenging as either the share of non-electric energy is much higher, or emissions are released due to the nature of the process (cf. Figure 1c).

### 3.2.2. Do Companies Take Energy and Resource Consumption, and $CO_2$ Footprint into Account When Developing New Products?

Energy and resource consumption, as well as the $CO_2$ footprint of new products (in their production and use), largely determine the long-term energy and resource needs and emissions for the industrial sector. Beyond this, they also largely impact on the footprint of the sector or location in which these products are used, as well as the transport, housing, and energy sector. Therefore, it is crucial to explore how the manufacturing sector deals with this responsibility.

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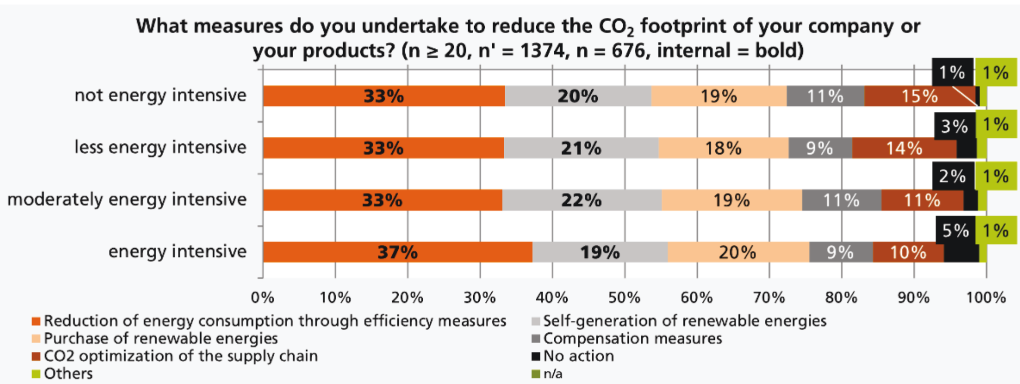


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**Figure 1.** *Cont.*

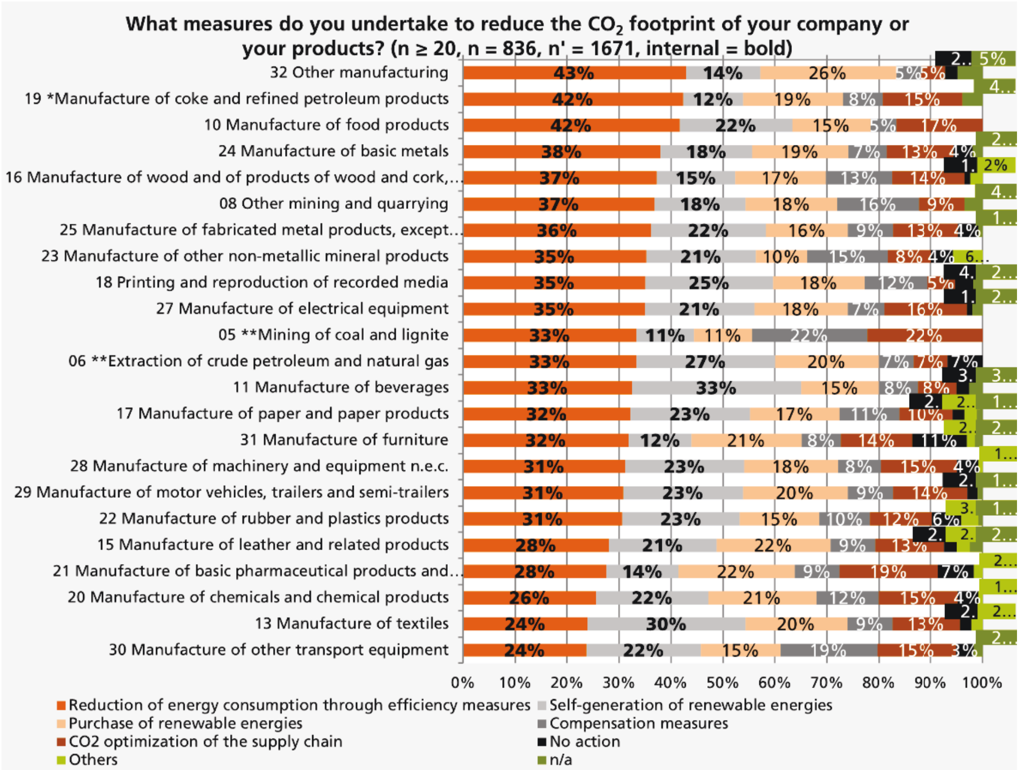


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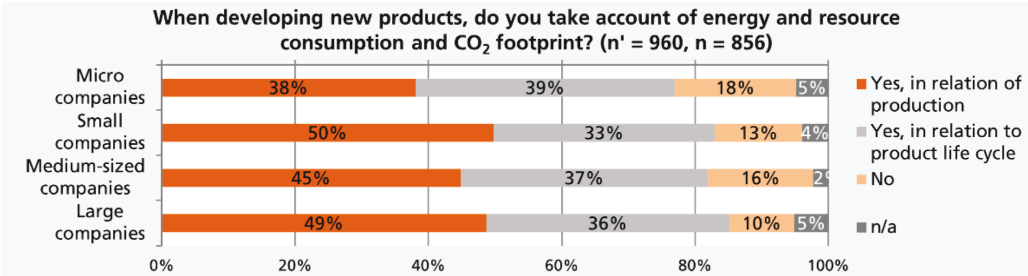
**Figure 1.** (**a**) Measures undertaken to reduce the $CO_2$ footprint of a company or products, by company size; (**b**) measures undertaken to reduce the $CO_2$ footprint of company or products, by energy intensity; and (**c**) measures undertaken to reduce the $CO_2$ footprint of company or products, by sector.

Nearly half of the 856 companies (45%) responding to this question indicated that they consider these factors in shaping their production process. Of the 36% taking into account the full product life cycle, only a third also looks into the production process, and only a quarter does so vice versa. Intuition would have suggested that those who look into the life cycle do, to a large extent, consider the production itself as well. This identifies a potential weak point in the wording of the question, where some of the 36% of companies may have considered the options as mutually exclusive and others may have not, which can find support in a low rate of 12% of companies providing 2 answers and calls for further analysis. That said, only 15% considered neither option.

Looking at the **company size** (cf. Figure 2a), a significant share of large and small companies exceed (49/50%) the average of 45% of companies taking production into consideration, whilst the opposite is the case for micro companies (38%), possibly due to the limitations they face with the machinery they possess and have in use longer than larger companies because of investment costs. The same applies in relation to not considering either factor (18%), with 13% and 10% for small and large companies. In relation to the overall lifetime of products, the situation switches around with micro companies being ahead of the average (39%)—potentially due to the nature and complexity of the product, e.g., a gasket versus goods whose use leads to energy consumption but is equally possible due to a decision by principle by the owner of micro companies.

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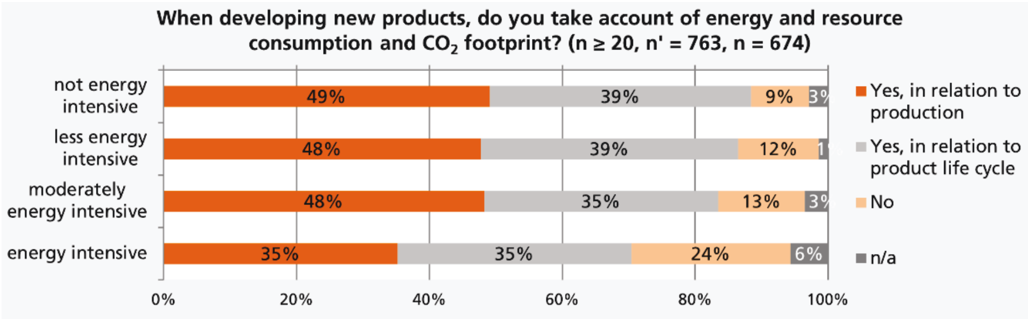


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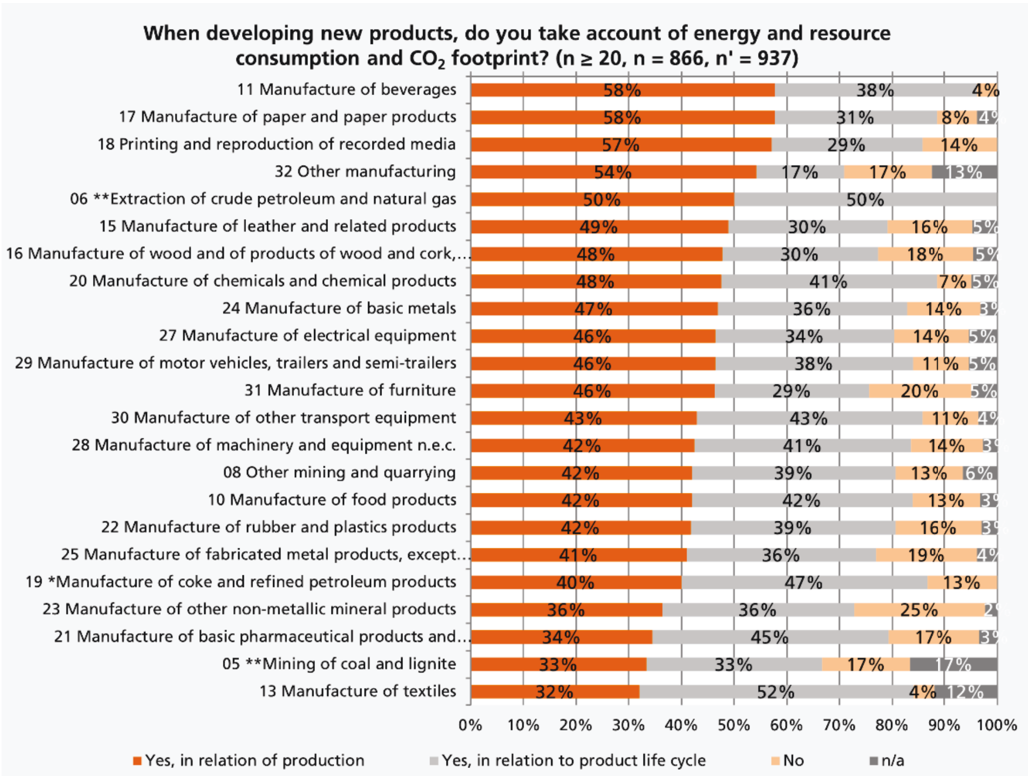



(**c**)

**Figure 2.** (**a**) Consideration of energy/resource consumption and footprint in product development, by company size; (**b**) consideration of energy/resource consumption and footprint in product development, by energy intensity; and (**c**) consideration of energy/resource consumption and footprint in product development, by sector.

Among all except the **energy intensive** companies (35%), a consideration of energy, resources, and $CO_2$ footprint takes place in nearly half of the companies (48–49%), whereas the not and less energy intensive companies (39%) consider the product life cycle only moderately more often than moderately and energy intensive companies (35%). The share of companies not taking account of the associated energy and resource consumption, as well as the $CO_2$ footprint when developing new products increases nearly threefold from not energy intensive (9%) to energy intensive companies (24%), again pointing to process and technical limitations in doing so (cf. Figure 2b).

"Beverage" and "paper and paper products" **sectors**, (58%), as well as "printed matter and reproduction of media" (57%) and "other goods" sectors (54%) well exceed the average in relation to a consideration of the production process of newly designed products, whereas "textiles" (32%), "pharmaceutics", and "glassware and ceramics" sectors (36%) fall significantly short. The entire life cycle, however, plays an above average role in the "textiles" (52%) and "pharmaceutics" sectors (45%), both sectors whose product portfolio is typically worn or consumed rather than used in an emitting manner. The life-time performance is of least relevance in the "other goods" sector (cf. Figure 2c).

The share of companies taking no consideration is by far the highest in the "glassware and ceramics" sector (25%)—understandable as, once the product exists, it rarely emits anything and can often easily be recycled. On the other hand, the lowest share of companies not considering the performance can be found in the "beverage" and "textiles" sectors (4%), followed by the "chemical" (7%) and "paper and paper products" sectors (8%) (cf. Figure 2c).

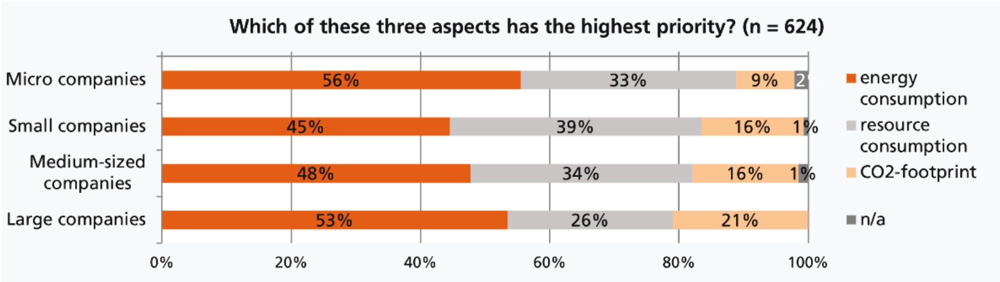
Having assessed the consideration of environmentally relevant factors in shaping new products in principle, it is important to establish which one is assigned with the highest priority.

#### 3.2.3. If Considered, Which of the Three Aspects Has the Highest Priority?

Half the companies follow the path of efficiency first, as an energy consumption reduction subsequently leads to a smaller carbon footprint. Resource consumption has the highest priority for a third of the companies, whereas the footprint itself is the leading factor in only 16% of the cases, perhaps as saving costs is the primary driver so far.

Among micro companies (56%), the priority of energy consumption reduction is highest, whereas it is the lowest for small companies (45%). Resource consumption, however, plays a significant role in small companies (39%) and a much smaller one in large companies (26%)—possibly, as many small companies manufacture products with a higher likelihood of scrap and waste, whereas large(r) companies often "just" combine the specific parts they have ordered from their supply chain. As large companies are more visible and often—if also energy intensive—falling into the European emission trading system (EU ETS) [33], the share of companies prioritising the $CO_2$ footprint is highest in that group (21%), and, for the same, reason lowest for micro companies (9%) (cf. Figure 3a).

For non-energy intensive companies, energy consumption has the highest priority (54%). This decreases with increasing **energy intensity** to 48%, whilst the priority of resource consumption increases with increasing energy intensity from 33% to 36%—for the more energy intensive companies it may be easier to reduce the amount of resources than the amount of energy needed for a new product, as significant reductions in energy demand would require a complete redesign of the way they are manufacturing their product, i.e., the transformation in the steel industry towards hydrogen instead of coke as agent. The priority of the carbon footprint is similarly low across intensities, deviating from 13% (not energy intensive) to 16% (moderately energy intensive), possibly as both energy and resource consumption directly impact on the $CO_2$ footprint and promise to reduce costs, whilst primarily looking at the footprint does not necessarily do so (e.g., switching to green energy) (cf. Figure 3b).

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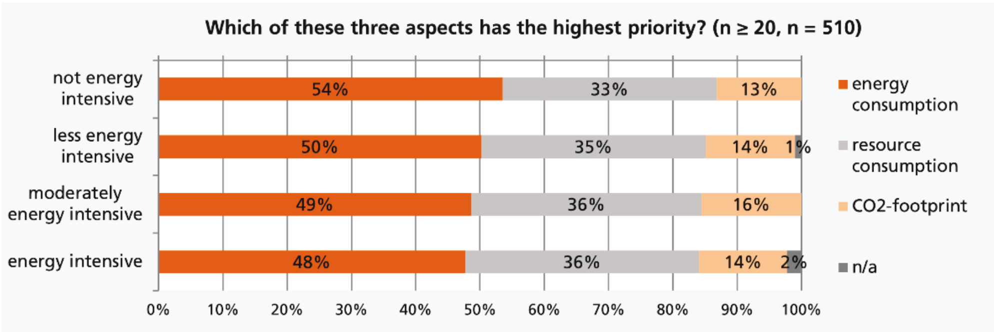


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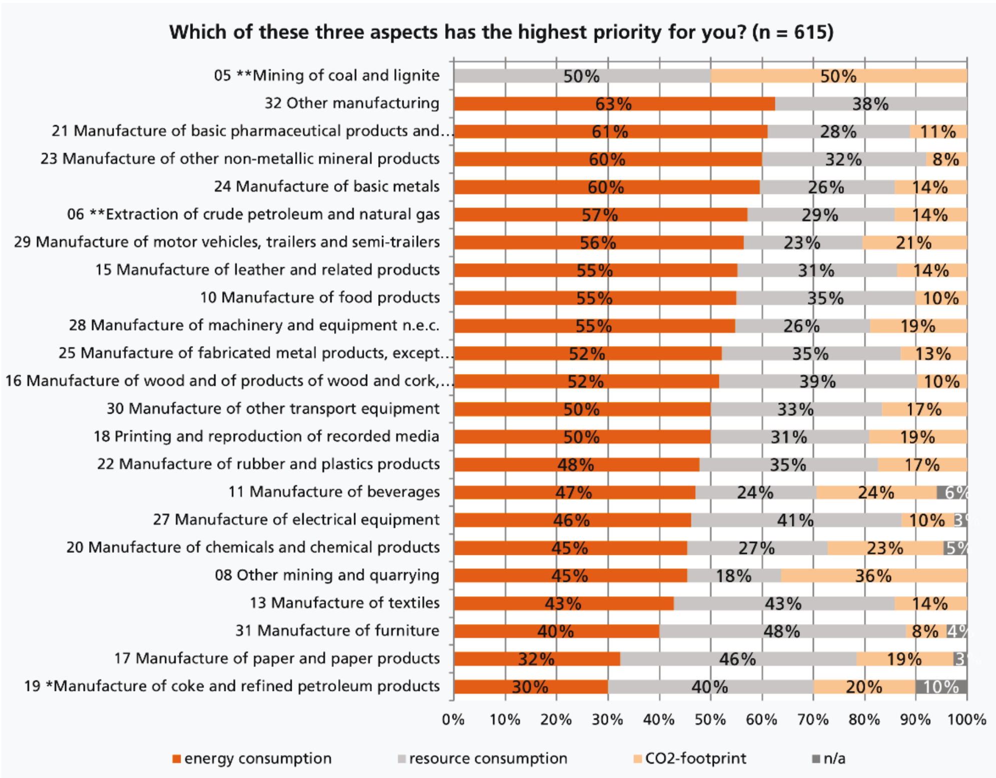



(**c**)

**Figure 3.** (**a**) Energy and resource and footprint—which factor has highest priority, by company size; (**b**) energy and resource and footprint—which factor has highest priority, by energy intensity; and (**c**) energy and resource and footprint—which factor has highest priority, by sector.

In respect to **sectors**, energy consumption plays the biggest role, by far, in the "glassware and ceramics" and "metal production and processing" sectors (60%), and is least often regarded as the highest priority by the "paper and paper products" sector (32%), followed by the "furniture" sector (40%), where, in return, resource consumption (46/48%)

is most often of the highest relevance, and least often in the "extraction of stone and earth" sector (18%). All this is understandable due to the nature of the products manufactured in these sectors. The carbon footprint is by far most often named aspect of the highest relevance in the aforementioned sector (36%), followed by the "chemical" sector (23%)—possibly as both cannot do much about resource and energy consumption without a larger transformation—and least often in the "glassware and ceramics" and "furniture" sectors (8%), followed by the "wood/wood products" sector (10%) (cf. Figure 3c).

### *3.3. How Do German Manufacturers React to the Increasing Societal Pressure for Decarbonisation?*

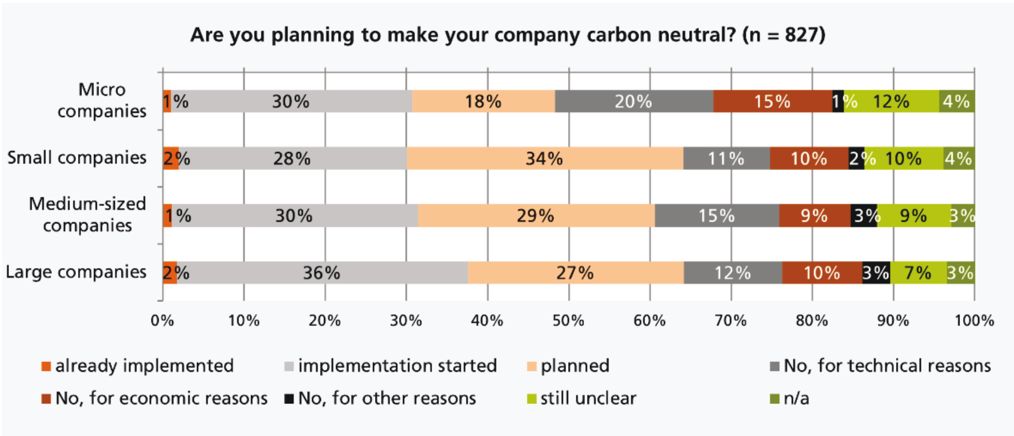
Having gained a better understanding of the measures intended and those put in place to reduce companies' carbon footprint, and about their priorities regarding the development of new products and manufacturing processes for them, the big question remaining is how far companies are actually willing to go.

#### Are Companies Planning to Become Net Carbon Neutral?

In addition to the small number of big companies that pledged to become net carbon neutral, there is a large proportion of the sample that has similar intentions. Nearly 60% of companies either plan (27%), have started (31%), or concluded (1%) the implementation to reach the state of net-zero carbon. The prefix "net" is of particular importance, as the ability to fully decarbonise is limited to a few cases, such as forestry's, but, at present, impossible for most manufacturing sectors. A total of 28% of companies therefore state that they are not pursuing that road, due to technical (15%), economic (11%), or other reasons (2%). Once carbon has a price across all sectors and company sizes, and is not, as at present, only affecting larger and simultaneously energy-intensive companies via the EU ETS, the share of economic reasons may shrink. Depending on the level of the carbon price, a point may be reached at which process redesigns become an option. The price levels at which process redesigns become an option, however, remain to be further researched.

From a **company size** perspective, the ambition to fully decarbonise is higher than average in large (65%) and small (64%) companies, and significantly below average for micro companies (49%), possibly because these may have the greatest difficulties in assessing how to do it (without changing the better part of their machinery). This assumption is underlined by looking more closely at the fairly similar share of companies who have started the implementation across all sectors; here, only the large companies are ahead by 6% points. When it comes to planned action, small companies are greatly above average (34%) and micro companies are significantly below average (18%). It is those companies that have the highest rate of unknowns (12%), in contrast to large companies (7%) that have largely made their decision. Economic reasons are, as alluded to above, a larger issue for micro companies (15%), as are technical reasons (20%), keeping them at a distance from becoming net carbon neutral. To some extent, the latter also applies to above average- to medium-sized companies (15%) (cf. Figure 4a).

For **energy intensity**, the share of companies aiming towards carbon neutrality is unsurprisingly highest amongst the non-energy intensive companies (68%), with moderately (65%) and less energy intensive companies (64%) close behind. As expected, energy intensive companies less often strive towards net carbon neutrality; however, nearly the majority (49%) does strive towards this goal. Looking more closely at the data, provides a similar picture: energy intensive companies (24%) lag 10% points behind in implementing measures towards carbon neutrality, and 6–9% points in planned action (22%). Technical reasons keep energy intensive companies away from carbon neutrality, 2.4 times more often (24%) than non-energy intensive companies (10%), confirming the assumption made earlier when looking at the development of new products. Similarly, economic reasons are the prohibitive factor for 16% of energy intensive companies, which is twice as many as for non-energy intensive companies (8%), understandable due to the great transformation and costs involved in many cases. The share of undecided companies is highest among less energy intensive companies (10%), and on a lower level for the other intensity classes (6–7%) (cf. Figure 4b).

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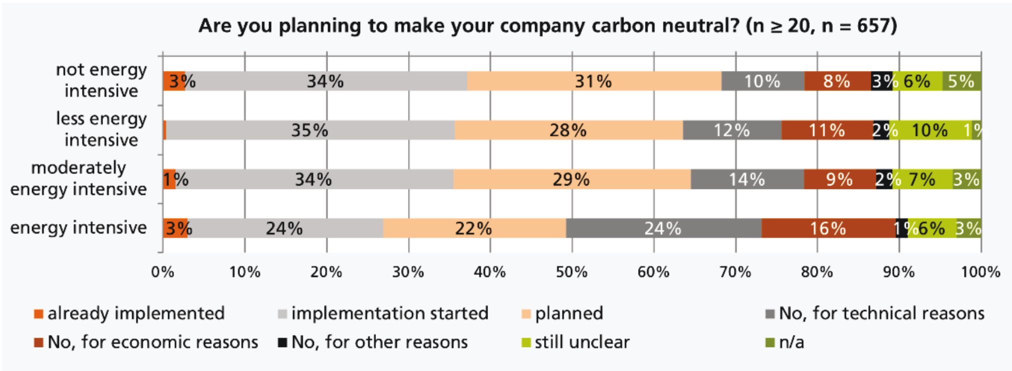


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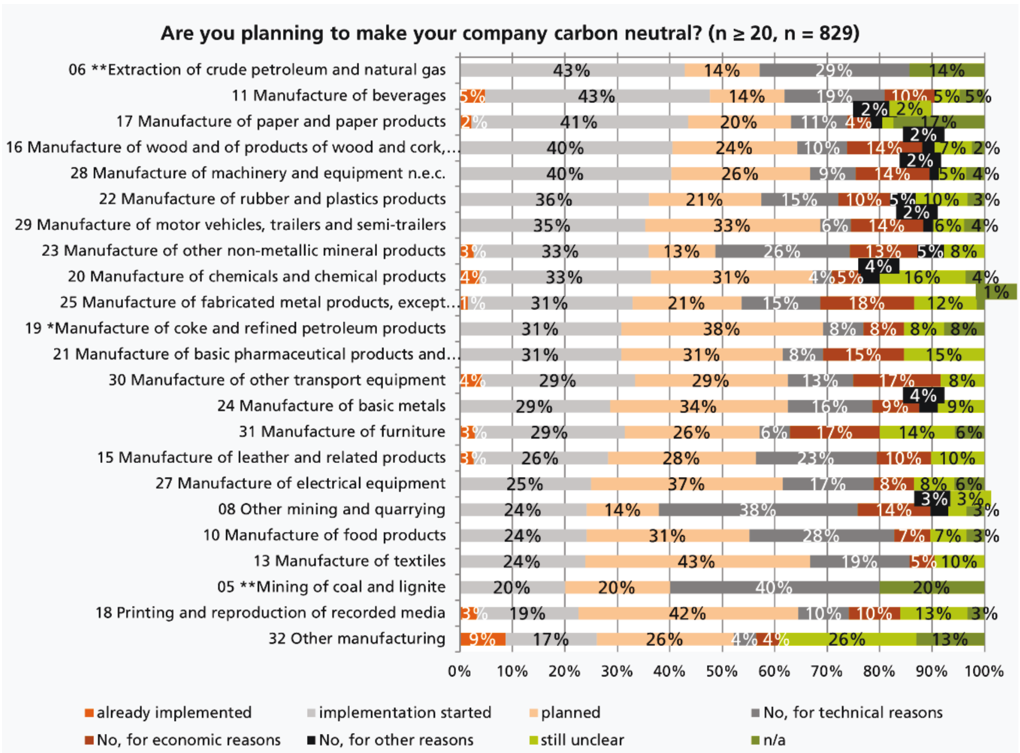


(**c**)

**Figure 4.** (**a**) Plans to become net zero carbon, by company size; (**b**) plans to become net zero carbon, by energy intensity; and (**c**) plans to become net-zero carbon, by sector.

The highest share of companies aiming to decarbonise can be found in the "motor vehicles" **sector** (69%), followed by the "chemical", "mechanical engineering", and "textiles" sectors (67%), and another eight sectors above average, leaving the "extraction of stone and earths" far below (38%), followed by the "glass and ceramics" (49%) and "other manufacturing" (52%) sectors. This, as previously assumed, is due to their limited ability to decarbonise. We face nearly the inverted picture, looking at those who choose not to fully decarbonise, the only difference being that "other manufacturing" presents the lowest share of companies not decarbonising (9%). Simultaneously having the highest share of "still unclear" by a factor of two (25%), reflects the prefix ("other") of this apparently very inhomogeneous sector. Looking at the numbers with closer attention to progress, the "beverages" (43%), "paper and paper product" (41%), as well as the "wood and wood products" and "mechanical engineering" (40% each) sectors are ahead of all the others, whereas "other manufacturing" (17%) and "printing and media reproduction" (19%) fall behind. The latter, however, nearly leads the board (42%) when considering planned action, together with the "textiles" (43%) and "electrical equipment" (37%) sectors, whilst "glassware and ceramics" (13%) and "extraction of stone and earths" (14%) are falling short, together with the "beverages" (14%) sector. Economic reasons provide the biggest challenge to companies in the "fabricated metals", "furniture", and "other vehicles" sectors (18/17%). In line with the previous assessments, technical reasons are most often the reason for the "extraction of stone and earths" sector (38%) to not plan for carbon neutrality, followed by the "food products" (28%), "glassware and ceramics" (26%), and "leather" (23%) sectors, who have all in common that changing the way their goods are manufactured is either not yet possible or requires a bigger changeover in processes and equipment (cf. Figure 4c).

### *3.4. Decarbonisation: Yes! But When?*

With the carbon countdown running and frequent statements that faster action is required, some companies' announcements of a 2050 target date, or 2040 (after coal-fired power plants have closed in 2038), appear to fall out of time and may allow us to distinguish between ambitious and marketing pledges, following the statement made by Bosch, mid-2019, that becoming net carbon neutral by 2020 "can be done. Here and Now" [34]. We therefore decided to incorporate the question by when the net-zero carbon state is aimed to be achieved, giving legislators a clear picture of what the private sector's level of ambition is, but also what support action (e.g., the provision of sufficient renewables) is needed. EEIs first data collection (2020) aims to help quantify the latter.

Of the 489 companies that aim to reach net carbon neutrality, two thirds have this goal for 2025 already, surpassing 90% by 2030 and 96% by 2035. This calls on policy makers to shape a series of five-year plans to facilitate this, rather than a strategy for 2050 with an interim stop in 2030, as it appears that more than half the intended decarbonisation action until 2050 is scheduled for the next five years! (cf. Figure 5). Only one company aims to meet the goal later than 2050.

Looking at the ambition per **company size**, 71% of micro companies that strive for carbon neutrality plan to have reached this goal by 2025 (or earlier), 93% 5 years later, and 97% by 2035. Fairly similar for medium-sized companies, the percentage figures are 70%, 90%, and 98% for these milestones, whereas small companies aim a slightly lower, with 66%, 85%, and 94% of companies planning to achieve decarbonisation by these dates. Of the large companies participating in this question, this is 61% by 2025, 94% by 2030, and 99% by 2035.

From an **energy intensity** perspective, 64% of the non-energy intensive companies plan to have reached net carbon neutrality by 2025, 88% by 2030, and 96% by 2035; the ambition rises looking at less energy intensive companies with targets of 68%, and 92% and 98% of them having succeeded by then. Moderately energy intensive companies aim for 74%, 93%, and 99% decarbonisation by the target years. Only energy intensive companies fall back to the level of non-energy intensive companies: 64% in 2025, 90% in 2030, and 97% 2035.

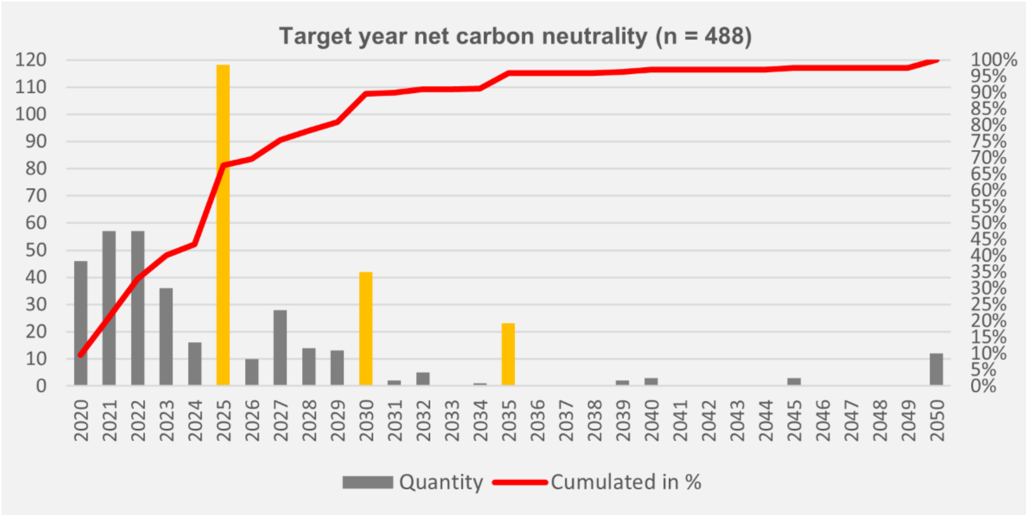


**Figure 5.** By when do companies plan to reach net carbon neutrality?

Looking at the ten **sectors** comprised of at least 20 companies aiming to become net carbon neutral by a specific target date, the "motor vehicle" and "wood and wood products" sectors (80%) are ahead for the first milestone in 2025, with the "chemical industry" (56%), "basic metals", and "machinery and equipment" (59% each) falling behind. By 2030, all participating companies of the "motor vehicle" sector plan to have achieved the goal, with 96% of the "wood" and "paper" sectors close behind, and 81% of the "rubber and plastics" sector following below the average for that milestone. By 2035, "leather", "electrical equipment", and "paper and paper products" will have caught up to the automotive sector and, thus, have reached carbon neutrality, whilst the "chemical" sector will have achieved 91%.

Whether the 489 companies are representative of the level of ambition of their peers, and whether they will succeed in the time planned, is a different question. So are the challenges in their path.

## 4. Discussion

The ambitions described by the automotive industry in terms of their decarbonisation timeline and intended measures fall in line with, for instance, Daimler and Volkswagen pushing the decarbonisation agenda, with suppliers, such as Bosch and Continental, having to follow [35]. Whilst the data indicates that companies push the responsibility for decarbonisation down the supply chain more often (13%) than being prepared to compensate emissions (10%), the factor "company size" does not play the big role expected. That said, suppliers from the SME sector may face greater problems satisfying such requests, as most of them are reported to not be ready for this transformation. For one, this is because of the small margins and expensive replacement of machinery, but also because they are mostly not in a position to demand higher remuneration, unless being a unique specialist. Others have not recognised the state of affairs or do not yet dare to bet on a particular technology in which they want to invest [35]. According to Müller [36], only one in five SME has taken measures to decarbonise themselves; it is a higher share in our sample, but the reading is similar. Identifying their optimal mix of measures to reduce costs and emissions is even more complex than in the case of efficiency optimisation alone.

If the decarbonisation of the industrial sector moves ahead at the pace suggested by the EEI data, investments need to double, and bottlenecks will soon become a problem: IG Metall approximates the need for 12,000 additional wind turbines to provide for a transition of the German steel industry alone to convert to hydrogen [37]. Avoiding process emissions, which make up, for example, for approximately 30% of emissions in the chemical, steel, and cement industry, will require a drastic increase in renewable generation [38]. As this is scarce, it becomes evident that doing whatever is possible through a more efficient use of energy and self-generation (internal measures)—as half the companies in the sample indicate doing—is a prerequisite to achieve overall decarbonisation. Implementing all this on-site and within the indicated timeframe will require a greater number of skilled personnel being able to identify and implement, and suppliers to deliver efficiency and microgeneration equipment. Particularly smaller SMEs require help, the distinct composition of which differs between sectors. If successful, this activity, however, promises a gradual decoupling from uncertain energy and emission charges, as well as from potential energy supply shocks whilst increasing energy productivity.

While, at present, the ownership structure and corporate culture largely determines the degree of ambition (e.g., Bosch is owned by Bosch Foundation), the Climate Action Summit in 2019 paved the way for an increasing number of investors considering investment in fossil business models a "stranded investment", with a known due date [4,5]. This means that in future, more and more shareholder-controlled companies are likely to decide for decarbonisation.

Having addressed the research gap of current approaches on decarbonisation as being too narrow [10], by taking interdependencies and specifics of the diverse industrial demand side into consideration, as well as the broader cultural and societal context across the previous pages, this work uncovers a series of questions and issues.

### *4.1. Where Is the Line Drawn? The Question of Scope*

Having a better insight into companies' intentions and means they intend to apply to decarbonise, it remains unclear what companies actually consider as "decarbonisation", and where the line is drawn—is it their estates? Is it including (scope 1) or excluding their mobile assets (e.g., trucks, vans, and cars) or also the materials they use? The indirect emissions from the generation of the purchased energy (scope 2)? Or all indirect emissions, beginning-to-end of the value chain (scope 3) [39]?

This question of scope cannot be answered at this point. From an operational point of view, it appears that for such an analysis of intended action, it is better to be able to draw a clear line as to where one company's responsibility for emissions ends and another's begins. In an article for the Financial Times, Alecta chief executive Magnus Billing puts it like this: "The reporting of Scope 3 data will remain plagued by uncertainty for the foreseeable future" [40].

### *4.2. Why Decarbonise? What Is the Range of Factors That Influence the Decision?*

Similarly, it remains unclear what set of triggers leads companies to decide on decarbonising their operations in the first place. The understanding of which factors, besides regulation and carbon tax, play a role in the decision to decarbonise, is essential to tailor schemes and services appealing to these trigger points. Of similar relevance is the (relative) weighting of the individual factors.

### *4.3. How Do Companies Prioritise? How Do They Identify Their Ideal Mix?*

Motivation and scope aside, how do companies prioritise different options that come with direct costs, these being clustered as interventions reducing their energy demand, on-site generation of green energy, purchase of green energy, and compensation measures? Is it the level of investment, the cost of carbon saved per EUR, technical aspects, experience in the type of intervention, access to skilled personnel, or other factors, such as environmental considerations and image, for instance via visible interventions—or is it a mix of them? How do they identify a mix of measures that is ideal for them, such as saving most emissions and preparing for the carbon tax [41]?

Drawing on the supply chain, similar to the question of Scope 3, we consider an external measure, similar to minimum requirements in tendering services (e.g., ISO 9001 to certify quality management procedures).

### 4.4. Are Companies Able to Decarbonise?

Asking whether companies are planning to become net-zero carbon and by when, does not answer the question of whether they are able to decarbonise at all and to what extent. Christian Stöcker [42] nicely summarises that there are six different types of companies with different means to decarbonise from carbon negative ones, such as forest enterprises (cat. 6), to those whose business model builds on carbon, such as coal mines (cat. 1). Companies in the other four categories have differing means to decarbonise: those whose products emit $CO_2$, such as, the automotive industry that could switch to e-vehicles (cat. 2), companies whose business models currently lead to emissions but do not necessarily have to, such as, logistics (cat. 3), and category 4—including most companies—comprises those who depend on cat. 2 and cat. 3. And finally, those who claim to be carbon neutral (cat. 5)—many of these may only achieve this with compensation schemes [42,43].

One could argue that manufacturing sectors can easily be tagged with one of these categories. However, is this really the case, or does it depend on their individual business case? Tesla, for example, can be considered as automotive, but their products do not emit $CO_2$ during operation if green electricity is used. Putting it differently, the six categories are where companies begin by sectoral default and—through the choices they make and the mix of measures they apply—they have different means and ambitions to move towards category 5 or 6.

### 4.5. What Is the Companies' Individual "Decarbonisability Factor"?

Tagging a company to one of these six decarbonisation categories therefore proves difficult from the outside, and is more something that arises from an internal assessment of "decarbonisability". *Decarbonisability* describes what percentage of decarbonisation (emission reduction) can be achieved on site, through (1) the reduction of consumption and choice of materials, and, in a second step, through on-site generation, flexibility, and buffer storage means, i.e., internal measures. Identifying this *Decarbonisability Factor* is of relevance to assess the weight imposed on the system to permit a full net decarbonisation of the economy. The problem: externalisation—someone else will take care of it. These emissions still remaining need to be compensated outside the factory premises through sustainable generation or compensation measures. However, considering the large number of companies aiming to become net zero carbon by 2025, combined with the policy goal striving for a coupling of energy sectors towards electricity as a main source, will quickly lead to a run on the easiest decarbonisation option, the green electricity on the market. Whilst this market noted a 42.6% record share of renewable electricity in 2019, the industry sector alone accounted for 45.7% of the overall electricity consumption [44,45]. Considering that the increase in new renewable energy installations has plummeted in 2019 [46], due to public concerns and new transmission lines struggling with the same issues, the demand will overshoot supply and eventually drive up their prices; the story is the same for domestic compensation projects—finding ones with a reliable effect may become increasingly difficult. The effect is decarbonisation leakage to other parts of the world (similar to emissions leakage, the effect happens elsewhere), and it is to be questioned what this does to the country's emissions balance sheet. Therefore, it is crucial to determine the decarbonisability factor, to allow an aggregation of the required amount of green energy and to assess by how much it overshoots what is available on the market, and, hence, to inform legislators who still have to find a solution to end the green generation grid lock and generate acceptance in society.

### 4.6. Are All Companies Willing to Become Net-Zero Carbon? Those Who Are Not, Are They Not Willing at All, or Just Unwilling to Go That Far?

We must not forget about the third of the companies that does not strive towards net carbon neutrality. For these, it is a question of whether they cannot, or they choose not to do so. For both options, it still remains to be explored how close to their decarbonisability factor they want to come and how high that factor is.

*4.7. Do Companies Really Strive for Carbon Neutrality or Do They Mean Climate Neutrality (or Vice Versa)?*

The policy goal of the European Union is reaching climate neutrality [47]. The measuring unit to achieve this goal is reaching a net-neutrality of $CO_2$-equivalents. As, according to Buettner [48], the suffix "equivalents" becomes easily lost in the practical use and conversations, it is an impediment to create a common understanding and clarity of the actual goal, as, otherwise, actions are taken that would not have been needed to reach carbon neutrality, and, more severely, actions that are critical to reach climate neutrality are not taken (i.e., addressing methane emissions).

## 5. Conclusions

This study has analysed the demand-side perspective of decarbonisation in German industry. Overall, the analysis has shown that despite ambitious reduction targets, companies in German industry face difficulties that vary significantly from company to company, making industrial decarbonisation multi-layered and complex.

This applies, in particular, across structural characteristics (i.e., company size, energy intensity, and sector). Especially micro-companies and energy-intensive companies are challenged. However, this is also the case for companies whose processes can only be decarbonised by substantial interventions into core processes and the way the products are being created.

Gaining clarity on what the actual status quo, the system boundaries, and the dimensions of the goal are, is equally important to make a decision regarding which factors and motivators determine the mix of measures chosen to pursue the goal set. Understanding this and also the actual means that a company has to cut carbon emissions on-site, will allow for the determination of the decarbonisation factor, and give an indication of what energy generation and transmission infrastructure as well as compensatory means are needed.

Understanding what triggers companies to make the decision to decarbonise is as relevant to tailor fitting policies and providing the environment for concrete action (i.e., planning permissions and transmission lines) as knowing what type of decarbonisation action companies intend to undertake by roughly when.

The conclusion of this study is not only that previous research has paid too little attention to the voice of the demand side, but also that a "one-size-serves-all" approach to decarbonising German industry is not efficient. Instead, policymakers and researchers should work more closely with industry to identify and to address their challenges and needs. Taking this approach will allow industry to fully work towards fulfilling the pledges that individual companies made and continue to make.

Having gained an improved insight into companies' intentions and means for decarbonisation, some questions nevertheless remain unanswered and should be addressed by further research.

As the number of companies taking the decision to decarbonise steadily increases and, from the authors' perspective, should continue to do so, it is of high relevance that this further research is undertaken in the near future and on a broad empirical basis to adequately consider the broad bandwidth of German manufacturing companies.

*An Outlook: Answers and Transferability of Findings*

Whilst all these questions arising from the data discussed remain unanswered for the moment, subsequent iterations of the Energy Efficiency Index in 2020, 2021, and 2022 (will) provide the basis to find an answer for many of these questions, in regards to German companies and lead to a number of forthcoming publications currently in preparation.

In this paper, we focused on data from companies manufacturing in Germany. Whilst the sector coding and technologies available differ only slightly, between industrialised countries (i.e., the theoretical decarbonisability factor for a company), the general stance towards climate questions and approaches, and, hence, towards decarbonisation, greatly differs.

It is in the nature of scientific studies that their results reveal limitations or open up new questions. As the EEI only captures the perspective of German manufacturing companies, the results reflect the institutional and cultural background of Germany. Comparative or cross-national studies may shed light on how manufacturing enterprises act towards decarbonisation, depending on their different contexts. Therefore, upcoming data collections of the Energy Efficiency Barometer of Industry (#EEBarometer) are of particular interest.

Whatever the decarbonisation choice and mix is, the combination of measures resulting will be quite individual based on individual priorities, goals, financial means, and realities. Therefore, each puzzle differs. Let's start puzzling.

**Author Contributions:** Conceptualisation, S.M.B.; methodology, S.M.B., C.S. and W.K.; formal analysis, S.M.B., C.S. and C.P.; investigation, S.M.B. and C.S.; data curation, C.S., C.P. and S.M.B.; writing—original draft preparation, S.M.B., W.K. and C.P.; writing—review and editing, S.M.B., W.K., C.S., C.P., H.M.N. and A.S.; visualisation, S.M.B.; supervision, S.M.B.; project administration, S.M.B.; funding acquisition, S.M.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** The article processing charge was funded by the Deutsche Forschungsgemeinschaft (DFG) in the funding programme Open Access Publishing.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy issues.

**Acknowledgments:** The underlying research in form of the Energy Efficiency Index of German Industry (EEI, #EEBarometer) would not have been possible without the continuous support of the Karl-Schlecht-Foundation and the Heinz und Heide Dürr Foundation, as well as the 915 companies participating and the network of partners of the EEI, as well as those reviewing and supporting in progress of developing this paper and the EEI data collection process, notably Josefine Döpp and the team of student researchers. In Germany, evidence is collected each April/May and October/November (www.eep.uni-stuttgart.de/eei); the #EEBarometer runs all year round in 9 further languages across 88 countries (www.eep.uni-stuttgart.de/eeei). All conclusions, errors, or oversights are solely the responsibility of the authors.

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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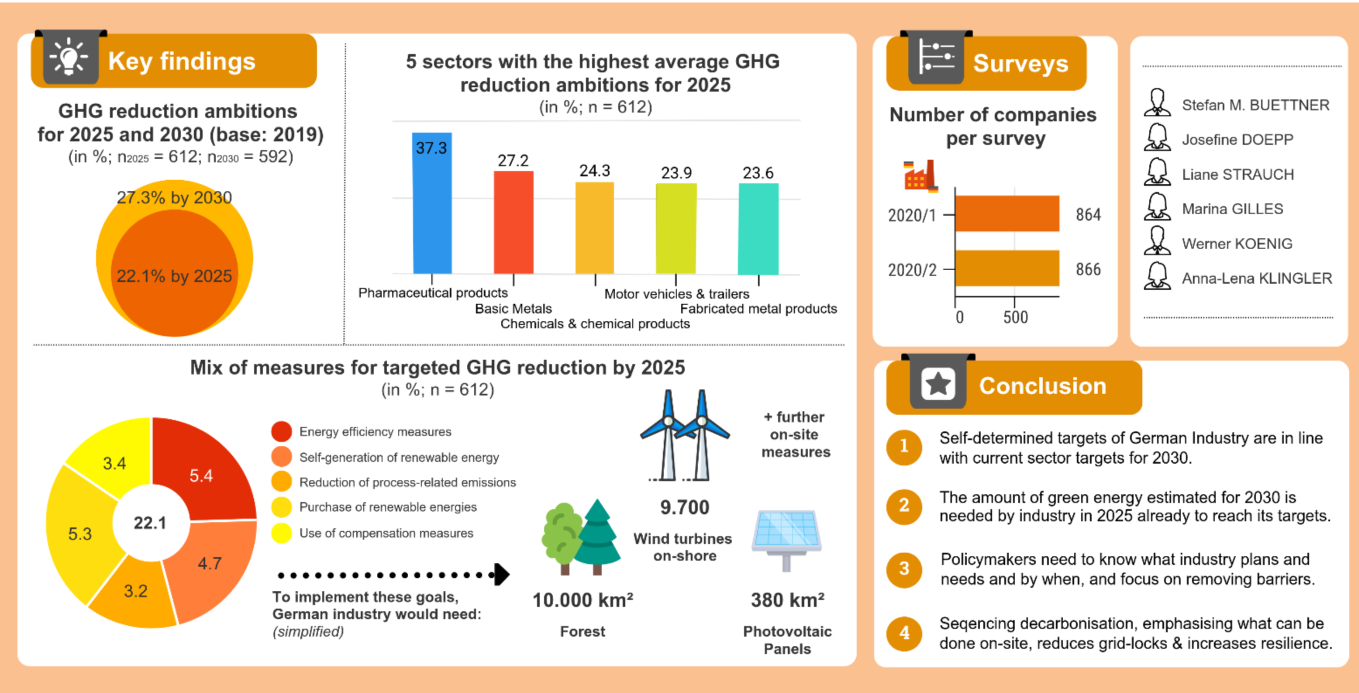
# 4 Increasing the voltage — sequencing decarbonisation with green power & efficiency

**Abstract:**




(Published as: Buettner, Stefan M.; Döpp, Josefine; Strauch, Liane; König, Werner; Klingler, Anna-Lena, 2023. Increasing the voltage - sequencing decarbonisation with green power & efficiency. *Preprints*, **2023020495**. DOI: https://doi.org/10.20944/preprints202302.0495.v1. Licence: CC BY 4.0) (Buettner et al. 2023)

 doi:10.20944/preprints202302.0495.v1



*Article*

# Increasing the Voltage – Sequencing Decarbonisation With Green Power & Efficiency

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**Abstract:** The quickest and easiest way to avoid greenhouse gas (GHG) emissions is to purchase renewable electricity and offset the remaining emissions. However, the industrial sector's electricity needs already exceed renewable electricity generation. Moreover, electricity accounts for only one third of the industry's energy needs. Simultaneously, the advance of sectoral coupling and the decarbonisation of industrial processes, as well as the desire to rapidly decrease dependence on fossil fuels, are creating significant additional demand for renewable energy. Neither existing nor planned generation and transmission infrastructure will suffice to meet the expected short-term demand. Based on survey data from the German Industry Energy Efficiency Index, this article therefore examines the share of GHG savings that companies intend to achieve on- and off-site. Understanding how much additional generation and transmission capacity is needed by the industry to decarbonise and by when is crucial to identify and address the extent of excess demand. On average, companies plan to avoid 22 % of their 2019 emissions by 2025 and 27 % by 2030, primarily through on-site measures. In combination with the extrapolation of the entire industry's needs for off-site capacity, the data calls for a rapid expansion of planning authority and green generation capacities.

**Keywords:** decarbonisation; energy supply security; energy demand; energy systems; industry; capacity planning

## 1. Introduction

### *1.1 Background*

Over the past few years, an increasing number of countries and non-state actors, such as local authorities, cities, financial institutions and companies have declared their intention to eliminate their carbon ($CO_2$) or even Greenhouse Gas (GHG) footprint to an extent at which they have reached "net-zero", a state where remaining, respectively unavoidable emissions are balanced out with means of compensation or removal [1-4]. Back in 2015, numerous initiatives formed on all levels to coincide with the Paris Climate Agreement [5]. More than 2000 companies, for instance, allied in the Science Based Target Initiative (SBTi) to strive for the 1.5° C goal [2]. Simultaneously, the European Commission launched the Horizon 2020 funding Programme. Among other projects, the programme enabled the creation of the NetZeroCities (NZC) initiative to assist cities in their transformation to climate neutrality [6] and, more recently, also the Covenant of Companies for Climate and Energy (CCCE) "seeking to help European companies to transition to the net zero economy"[7].

For the process of decarbonisation, a variety of measures can be applied to achieve the goal set (i.e. net-zero GHG emissions = climate neutrality). Decarbonisation strategies are quite individual in their composition, as they largely depend on the specific circumstances, decision criteria, the envisaged scope and timelines, as well as the underlying motivation. Furthermore, they also often depend on geographical aspects [8].

The types of measures at hand can be divided in three major categories: Reduction measures (energy efficiency, resource and material efficiency, process emission reduction), substitution measures (self-generation or purchase of renewable energies) and compensatory measures (emission allowances, certified emission reductions (CERs), climate protection projects; Carbon Capture, Storage and Use (CCUS), as well as, Direct Air Carbon Capture and Storage (DACCS))[9].

Buettner and Wang [9] (pp. 5-10, 14-15) assess each category of measures in respect to their one-off, and ongoing effects, both in relation to economic (investment and operational costs), energy-related (effect on energy-demand, need to acquire energy from external sources), and emission-related matters (effect on emissions output). They come to the conclusion that, in the short-term, *it only appears* quickest, easiest and cheapest to focus on the purchase of clean energy and compensate all remaining emissions [9](p. 12). Recent data from the 2021/2022 winter survey of the Energy Efficiency Index of German Industry (EEI)[10] indicates that 78 % of manufacturing companies want to decarbonise their Scope 2 emissions (in-direct emissions from the energy purchased). Moreover, 77 % of companies want to address their Scope 1 emissions (direct emissions arising from their vehicles and activities on their premises, energy- and process related) and 75 % also want to address their Scope 3 emissions (in-direct emissions of the up- and downstream supply chains)[11]. Considering that, if each part of the supply chain addressed its Scope 1 and 2 emissions, there would be hardly any Scope 3 emissions left, and given the large risk of double counting of emissions [11], this article is focussing on Scope 1 and 2 emissions only. As the EEI data points out, not merely more companies are opting for a Scope 2 emission reduction, but they are also more advanced in the implementation process. However, one must also acknowledge the industry's overall electricity and energy demand in conjunction with Germany's green/clean energy generation capacities [12], as well as the current price hikes [13,14]. In addition, supply uncertainties [15] along with warnings of a potential gas rationing [16-23] and of electricity demand overshoots in the industrial centres [24] make it quite clear that simply switching to another energy tariff might be easier said than done. What would be the price and how would it impact companies' resilience?

For several years, the primary path pursed in context of the energy transition was the integration of power sectors, meaning the gradual electrification of all energy-users and their supply with green (or clean) energy [25]. Where not feasibly, power-to-x (P2X) should not only be applied to store electricity but also, for instance, to convert it into hydrogen, allowing one to substitute natural gas needs [25-27]. Nonetheless, the issue with this proposition is that with each conversion there are conversion losses [28], making the clean substitute fuel much pricier and less efficient than the status quo – on top of an insufficient renewable electricity generation capacity.

To put this in context, in 2019, the German Industry consumed about 35 % of its energy in the form of natural gas, 10 % in coal and 6 % in oil products. Combined about 1.5 times as much as the industry's electricity consumption (34 %). Nevertheless, already back then, industry accounted for 45 % of Germany's final electricity demand (as well as for 35 % of Natural gas, 4 % of Oil products and 88 % of Coal, peat and oil shale consumption) [12]. Another obstacle is that each source of energy has its "sweet spot", which refers to a purpose for which it is the most effective energy carrier [28]. For example, if one compares E10 fuel to standard fuel, the amount needed to cover a distance of 100km is usually higher due to the difference in the calorific values of the fuels (as ethanol provides a bit less energy than pure petroleum)[29]. Similar to this, depending on the type of process and the temperature needed, a combustion may achieve the desired outcome with less energy input (or the other way around). If one uses a P2X gas or hydrogen, the energy balance may be even worse (due to the conversion losses in its creation from green electricity), which is why, at present, electricity that could otherwise not be fed into the grid

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and would be lost is the "best energy source" for P2X gas or hydrogen. This example underlines that there is no easy solution to decarbonising the industry's energy needs, particularly considering that about two thirds of it are process heat (and cold) [30].
The expansion of renewable energy generation is much behind schedule and far away from (i.e.) providing 80 % of Germany's electricity via renewable sources in 2030 [31,32]. An important reason for this situation is that it takes on average 6 – 8 years for a wind turbine to go online from planning to energy generation, due to bureaucratic planning rules and processes as well as capacity issues. Additionally, disputes with individuals and initiatives, long-lasting court cases and similar obstacles contribute to the much too slow progress on expanding the capacity and number of transmission lines and interconnectors [32]. Apart from increasing capacity, the latter expansion would also increase the robustness, resilience and effectiveness of the overall grid and avoid surplus generation from being wasted and surplus loads from being shed. Essentially, these efforts have the potential to also lower spot market prices as demands could be served easier and with less barriers.

### *1.2 Are the forecasted needs realistic?*

Another issue concerns how the required energy, notably the electricity baseline, is actually determined and on what basis. If the 2019 configuration was to serve as a baseline, increasing efficiency measures would reduce the overall electricity demand and therefore automatically lead to an increase of the share of renewable energy in the mix. However, if one intends to simultaneously switch substantial parts from the transport sector (share of electricity in 2019: 2 % [12]) to for instance 15 million electric vehicles, the electricity needs for the transport sector would increase fivefold (from 12 to approx. 60 Terawatt hours TWh [33]) and could already eat up much of the energy efficiency savings across all sectors. If, at the same time, heat pumps were replacing gas, oil and coal based heating systems, the electricity demand would grow by another 10 % (from 270 to 298 TWh) [33]. EWI estimates that the electricity needs of industry would grow by 21 % (from 218 TWh to 263 TWh) and the envisaged electrolyser capacity (10 GW to produce 20 $TWh_{th}$ Hydrogen) for 2030 would require about 29 $TWh_{el}$ [33](p. 5).

In late 2019, the chemical industry giant BASF estimated that decarbonisation of operations at their German Ludwigshafen site via electrification would probably triple its annual electricity demand (6.4 TWh), which already represents 1 % of Germanys overall electricity demand [34]. The chemical industry overall would need four times as much electricity as before [35]. In 2020, BASF announced the assessment of the $CO_2$-footprint of all its sales products [36]. Moreover, in2022 it first participated in tenders for offshore windfarms to support its goal of switching its 2021 power needs to fully renewable electricity by 2030, allowing them to reduce their GHG footprint by 25 % by 2030 [37]. Next, BASF started construction of the "first demonstration plant for large-scale electrically heated steam cracker furnaces" that would allow it to reduce the emissions of one of the most energy-intensive processes (and foundation of many basic chemicals) by about 90 % [38]. Nevertheless, this emission reduction would come at the cost of additional electricity needs (as indicated). Not all close to 200.000 manufactures pace ahead with this speed, but what would happen if this was the case? Even though BASF is a large company in one of the most energy intensive sectors [30], there is also the steel industry, which estimates that about 12,000 wind turbines would be necessary to generate sufficient electricity to produce hydrogen for green steel [39,40]. Also, further companies in this and other sectors, i.e., ArcelorMittal (steel), Covestro (chemicals), Opterra (cement), are taking a lead to ensure "their" green power needs en route to net zero emissions are served [41-43].

Assessing the required additional renewable energy capacities to switch from fossil fuels to renewables is one thing, another to switch it to the right form (i.e. gas to electricity) and yet another to decarbonise process-related emissions. The latter may require a completely different process technology that by itself may emit less, but could need different amounts of energy. Therefore, assessing the required clean energy needs gets harder layer

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by layer. It is thus essential to gain an understanding of how much renewable energies are actually needed, where, and roughly when to sync the capacity planning with the decarbonisation progress.

These roadmaps, however, do not necessarily reflect what is actually planned by energy consumers, where, and by when. Considering the industry accounts for nearly half of Germany's 2019 electricity consumption, this article therefore proposes that an estimation of short to medium-term renewable energy demands should be made on the basis of what companies plan to do (cf. the 78 % of manufacturers that are planning to decarbonise their energy-demand). To illustrate and facilitate such an estimation, this article will analyse data from about 850 manufacturing companies, after the beginning of the COVID-19 pandemic in 2020 and explain (1) what share of their 2019 greenhouse gas (GHG) emissions companies aim to decarbonise by 2025 and (2) by which means. Further, it will introduce (3) the concept of the "decarbonisability-factor", (4) showcase what additional savings ambitions are envisaged for 2030 and (5) explain what implications arise from this for policymakers, financiers, the energy-sector as well as for society. Hence, the article will also (6) provide an estimation of the impact and associated needs if companies were to implement their 2025 ambitions as indicated in the EEI and, (7) lastly, it will provide a mechanism that could ease the energy system and decarbonisation capacity planning in respect to the industrial sector and thus "increase the voltage – through sequencing decarbonisation with green power and energy efficiency".

## 2. Materials and Methods - Methodology

The observations and ideas presented in this article originate from a combination of quantitative and qualitative data. The qualitative elements are drawn from professional interactions with manufacturing companies in Germany in the context of decarbonisation. In conjunction with professional press and work on committees, they highlight potential weaknesses and oversights concerning energy efficiency and decarbonisation, as well as companies' resiliency in the energy- and climate crisis. The assumptions arising from this were then consecutively tested within the framework of the Energy Efficiency Index of German Industry (EEI). The EEI was introduced in 2013 and focuses on views, needs, opinions, observations and experiences of all kinds (size, sector, energy intensity) of manufacturing companies in Germany [44].

The EEI data this article draws from is comprised of 864 observations gathered in May 2020 [45], which was in-midst of the first wave of the COVID-19 pandemic in Germany, and 866 observations gathered in November 2020 [46].

Each of the EEI's semi-annual data collections has a specific focus on selected current issues. The 1st and 2nd data collection in 2020 looked at a series of issues around the topics of decarbonisation and energy, notably in regard of Germany's climate and energy goals [32]. In total, around 20 questions were posed to participants of the EEI. They survey requested information on, for instance, their sector, revenue, number of employees and energy consumption, but also on a half-dozen thematic questions, such as the intended GHG reduction goals for 2025 and 2030, as well as on with which proportions of measures they aim to achieve these self-determined goals. The data collection was carried out using a mixed methods approach, combining online (7 %) and telephone surveys (93 %). Achieving an even distribution across the 27 manufacturing sectors that represent 198,000 companies was desired, but difficult to achieve. 'Core industries'[1] were defined to aid focusing the telephone survey. The target was to recruit at least 24 companies per core industry for participation. The automotive sector and the machinery & equipment sector are two of a

1 [1] 'Core industries' are the eleven sectors that have most economic weight in Germany (NACE code in brakets, sorted by Code): leather- (15), wood & cork- (16), paper- (17), chemical- (20) rubber & plastics- (22), non-metallic minerals- (23), basic metals- (24), fabricated metals- (25), electrical equipment- (27), machinery & equipment- (28) and motor vehicle (29) industries.

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total of eleven core sectors of the German industry. For the sectoral analyses in this paper, only sectors are taken into account in which at least 20 companies provided answers to the respective question(s) [44] (p. 4).

**Table 1**. Sample composition by sector ( $n_{2020/1}$ = 864, $n_{2020/2}$ = 866 )

| NACE Code | Sector | Total population (N) | Observations (n) | | Percentage n (N) | |
|---|---|---|---|---|---|---|
| | | | 2020/1 | 2020/2 | 2020/1 | 2020/2 |
| 05 ** | Mining of coal and lignite | ~ | 8 | 4 | ~ | ~ |
| 06 ** | Extraction of crude petroleum and natural gas | 5 | 13 | 11 | 260.00% | 220.00% |
| 08 | Other mining and quarrying | 1,438 | 12 | 13 | 0.83% | 0.90% |
| 10 | Manufacture of food products | 26,897 | 31 | 27 | 0.12% | 0.10% |
| 11 | Manufacture of beverages | 2,435 | 19 | 16 | 0.78% | 0.66% |
| 12 | Manufacture of tobacco products | 62 | 8 | 7 | 12.90% | 11.29% |
| 13 | Manufacture of textiles | 4,637 | 18 | 19 | 0.39% | 0.41% |
| 14 | Manufacture of wearing apparel | 3,306 | 14 | 11 | 0.42% | 0.33% |
| 15 | Manufacture of leather and related products | 1,371 | 34 | 32 | 2.48% | 2.33% |
| 16 | Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials | 12,944 | 39 | 49 | 0.30% | 0.38% |
| 17 | Manufacture of paper and paper products | 1,558 | 53 | 36 | 3.40% | 2.31% |
| 18 | Printing and reproduction of recorded media | 10,986 | 24 | 27 | 0.22% | 0.25% |
| 19 | Manufacture of coke and refined petroleum products | 89 | 13 | 13 | 14.61% | 14.61% |
| 20 | Manufacture of chemicals and chemical products | 3,280 | 48 | 52 | 1.46% | 1.58% |
| 21 | Manufacture of basic pharmaceutical products and pharmaceutical preparations | 554 | 26 | 31 | 4.69% | 5.60% |
| 22 | Manufacture of rubber and plastic products | 7,090 | 64 | 54 | 0.90% | 0.76% |
| 23 | Manufacture of other non-metallic mineral products | 9,908 | 44 | 44 | 0.44% | 0.44% |
| 24 | Manufacture of basic metals | 2,374 | 42 | 41 | 1.77% | 1.73% |
| 25 | Manufacture of fabricated metal products, except machinery and equipment | 44,106 | 64 | 75 | 0.15% | 0.17% |
| 26 | Manufacture of computer, electronic and optical products | 7,935 | 21 | 23 | 0.26% | 0.29% |
| 27 | Manufacture of electrical equipment | 6,036 | 67 | 56 | 1.11% | 0.93% |
| 28 | Manufacture of machinery and equipment n.e.c. | 15,964 | 72 | 74 | 0.45% | 0.46% |
| 29 | Manufacture of motor vehicles, trailers and semi-trailers | 2,769 | 49 | 60 | 1.77% | 2.17% |
| 30 | Manufacture of other transport equipment | 1,276 | 15 | 24 | 1.18% | 1.88% |
| 31 | Manufacture of furniture | 10,826 | 29 | 24 | 0.27% | 0.22% |
| 32 | Other manufacturing | 19,985 | 30 | 38 | 0.15% | 0.19% |
| 99 | Other | | 7 | 5 | | |
| | Total | 197,831 | 864 | 866 | 0.44% | 0.44% |

* small sector (10 ≤ N < 100) with at least 15% of total population (N) participating; ** micro sector (N < 10) with at least 50% of N participating, ~ figures not disclosed in official statistic due to small sector size and associated confidentiality issues.

**Table 1** depicts what percentage of a sector's total population (number of companies) participated. The percentage may seem to be greater than 100 % in very small sectors, such the "crude petroleum and natural gas" sector (06). In this case, all 13 responses refer to specific sites instead of each representing an entire company.

The results of micro sectors (N < 10) are considered ('**') if more than 50 % of the sector participated in this study, while the results of small sectors (10 ≤ N < 100) are taken into account ('*') if at least 15% of the sector participated [44] (p. 4).

## 3. Results

The wish to take decarbonisation actions has increased considerable since 2019 [44]. The reasons why stakeholders are pursuing decarbonisation efforts are plentiful: increasing emission pricing, skyrocketing energy prices following the war in Ukraine, as well as severe weather events that threaten both the resilience and the output of the energy system. Along with other shocks, such as disrupted or vulnerable supply chains, they further feed the desire to increase the resilience of a company. [9,47]. Decreasing dependence on these risk factors or diversifying risks can help reduce pressure on either a systems level (i.e., energy generation and grid infrastructure, origin of fuels) or on an individual level (i.e., reducing the demand, circularity thinking, local sourcing, self-generation of energy, energy storage)[9] (pp. 12-15). Since decarbonisation roadmaps are based on an initial assessment of the status quo and shape the path to achieve a certain outcome at a certain point in time, they are (a) often linear in their growth plan. Moreover, they (b) may lose their predictive power if some foundational factors change, demonstrating the difficulty of forecasting on the basis of past development patterns (i.e., technology disruption or fundamental change of process technology), and they are (c) dependent on the appropriate framework conditions being in place to facilitate the transformation (i.e., planning permission, legal framework, time from decision to going operational). Nevertheless, despite the value of technology roadmaps and system scenarios, what the end users actually plan to do, where, and by when, as well as what they may need to "pull it off" or which possibly marginal bottleneck is in the way of achieving this goal remains a black box. Hence, this article aims to assist in turning on the light in this black box.

Based on data of the 2nd Energy Efficiency Index of German Industry, Buettner et al. [44] found that already in late 2019, ahead of the COVID-19 pandemic, the war and the energy crisis, there was a strong ambition to pursue the path of decarbonisation. Nearly 60 % of the participating companies (of all sizes, sectors and energy-intensities) indicated to work towards net-zero emissions (p. 13). Of these, about two thirds indicated that they target achieving net-zero by 2025 (about a third of these in 2025 alone), which is equivalent to about 40 % of all participating companies. Further target year peaks were found for the semi-decades 2030, 2035, 2040, 2045 and 2050 (pp. 15-16). Simultaneously, the concern rose that this desire would most likely be cooled off by insufficient capacities in various areas needed for the implementation of companies' plans. Alerted by this situation, the first iteration of the Energy Efficiency Index of German Industry in 2020 (EEI) was tasked to establish:

a) Whether industry indeed structures decarbonisation in 5-year plans (or in short-term plans "to get it over with"),
b) what motives companies to decarbonise,
c) on which basis they take their decarbonisation decisions and most importantly,
d) by how much they plan to reduce their Greenhouse Gas emissions by 2025 and
e) by which means (in respect to 2019 as the last full business year, which today often serves as base year, given that it was the last "normal" year before the pandemic and the war hit).

In consideration of the research question, this article will focus on addressing (a), (d) and (e). (b) and (c) are addressed in detail by Buettner et. al [48] and Buettner and König [49].

*3.1 What are companies' ambitions for this decade?*

As the industry is very diverse there cannot be a one-size-serves-all approach [44]. The range of possible interventions in different areas is vast and quite likely much broader than in other parts of the economy [9]. Sometimes commonalities can be found across company size, sometimes in respect to the level of energy-intensity, or most intuitively in respect of the sector. Therefore, this section zooms in on these perspectives, while also providing insights on the overall average outcome of the sample. A drop in ambition levels compared to the 2nd data set of EEI in 2019 was expected, primarily because of the impact of the COVID-19 pandemic, but also because of the difference between asking for a net-zero year and asking for a specific GHG reduction level (distinguishing between marketing goal and estimate by when what can be achieved).

3.1.1 What is the bandwidth of ambitions?

The largest differences can be observed when looking at the targets of sectors from which sufficient amounts of companies participated in this question. It stands out, that the wood, cork (16) and furniture (31) industries set the least ambitious targets, while many companies of the pharmaceutical industry (21) and the basic metals industry (24) set more ambitious targets. Nonetheless, the spread of companies' goals is also the widest in these sectors (cf. **Figure 1**).

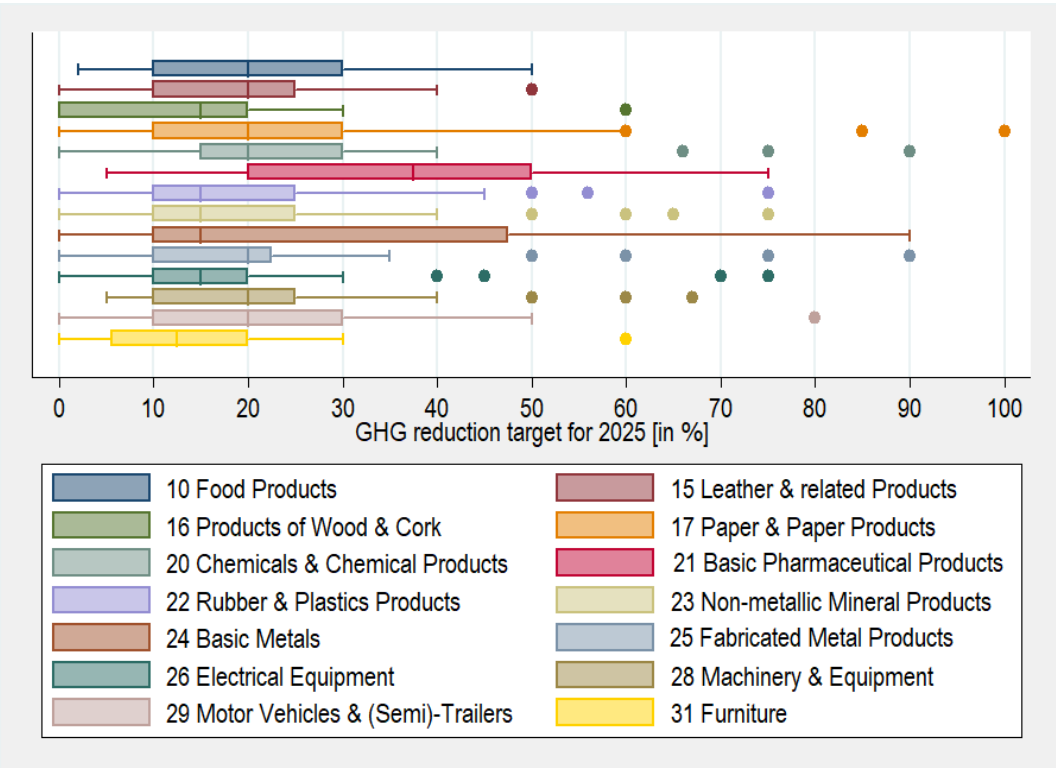


**Figure 1.** GHG reduction target for 2025 [in %], by sector ( n ≥ 20 )

Due to the increasing pressures imposed on the supply-chain to also "do their part" and reduce the embedded emission footprint of pre-products [8] (pp. 11-12), it is not surprising that the more ambitious half of companies, set themselves more ambitious goals (cf. **Figure 1**, area to the right of/ above the median). Specifically, the upper whisker of the basic metals industry is 15 %-points higher. However, the less ambitious half of all companies is nearly on the same level. This dynamic holds true to some extent (unless otherwise stated) for most dimensions showcased so far, meaning that most differences can be

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seen among the more ambitious halves of companies in their respective dimensions (above the median).

Buettner et al. further analyse how the GHG reduction ambitions vary depending on what primarily motivates a company and based on which determinants the decarbonisation mix is decided upon [8,48].

The question that arises (and which was mentioned earlier) is whether companies have, in principle, picked up their pace in pursuing decarbonisation, which would be reflected in a steadily growing decarbonisation goal. Thus, one must observe whether the growth rate of ambition increases further or flattens after meeting the short-term goals. To facilitate answering this question, the 2nd iteration of the EEI in 2020 asked for companies' GHG reduction targets for 2030. Even though panel data would have been preferred to get the answers for both dates from the same (set of) companies, the situation should be sufficiently homogenous to permit the comparison within their sub-categories.

### 3.1.2 How do the targets for 2025 and 2030 differ?

Looking at **Table 2**, the data confirms the assumption that average GHG reduction goals of companies differ considerably depending on their sector. Only sectors with at least 20 companies responding to this question in both data collections are listed in the table to limit random outcomes. Although the data sets are not equivalent to panel data, the share of returning participants was about 38 % in both data collections. With a 22.1 % reduction, the sample's average overall GHG savings ambition for the year 2025 appears quite considerable. However, looking at the sample's goal for 2030, one can observe that within the "first" half of the 2020s (2021-2025), companies aim to achieve an average of 4.4 % GHG savings per year, but for the second half of the 2020s (2026-2030) the additional ambition only amounts to another 1.1 % GHG savings per year.

**Table 2.** GHG reduction ambitions 2025-2030, by sector ( n ≥ 20), base 2019

| | 2019 | 2025 | 2030 | 2025-2030 | $n_{2025}$ | $n_{2030}$ |
|---|---|---|---|---|---|---|
| 27 - Manufacture of electrical equipment | 0 | 18.9% | 23.0% | 4.1% | 37 | 22 |
| 17 - Manufacture of paper and paper products | 0 | 23.6% | 23.3% | -0.3% | 36 | 21 |
| 20 - Manufacture of chemicals and chemical products | 0 | **24.3%** | 24.1% | -0.2% | 38 | 26 |
| 28 - Manufacture of machinery and equipment | 0 | 20.7% | 25.4% | 4.7% | 56 | 37 |
| 23 - Manufacture of non-metallic mineral products | 0 | 21.7% | 26.1% | 4.4% | 33 | 20 |
| 25 - Manufacture of fabricated metal products | 0 | 23.0% | 26.4% | 3.4% | 44 | 37 |
| 24 - Manufacture of basic metals | 0 | **27.2%** | 28.7% | 1.5% | 32 | 20 |
| 06 - Extraction of crude oil and natural gas | 0 | 22.5% | 32.5% | 10.0% | 8 | 8 |
| 29 - Manufacture of motor vehicles & (semi-)trailers | 0 | 23.9% | **32.5%** | **8.6%** | 39 | 29 |
| 22 - Manufacture of rubber and plastic products | 0 | 18.9% | **36.6%** | **17.7%** | 45 | 25 |
| **Overall** | **0%** | **22.1%** | **27.3%** | **5.3%** | 612 | 592 |

This highlights two possible explanations: Companies either want to address the issue heads-on and then put it on the back burner or their planning horizon does not permit them to estimate precise percentage goals for a year further ahead in time. Furthermore, there are also substantial differences on a sectoral basis. The goals of the rubber & plastics, automotive and oil & natural gas industries increase substantially for the second half of the decade. Perhaps this divergence is due to the timespan required for sophisticated changes in process technology and for arising benefits to kick-in. On the other end of the spectrum, the ambitions of the pulp & paper, chemical and basic metals sectors remain on roughly the same levels also for 2030. One possible explanation for the latter point is that all three sectors are among the most energy intensive ones, depending largely on gas.

Subsequently, they may require a sufficient and reliable supply of hydrogen to achieve higher GHG savings. As for these sectors, the biggest gains appear to be only feasible via green hydrogen. For all sectors listed (apart from rubber & plastics), it is true that the growth of their decarbonisation ambitions appears to follow a limited growth function.

While, from a political perspective, it may be challenging to imagine how an almost 5 % GHG reduction per year could be at all feasible, from a company viewpoint such a target figure is not unheard-of: The Science-based Target Initiative reported, for instance, that 338 companies in their analysis "collectively reduced their annual emissions by 25% between 2015 and 2019 – a difference of 302 million tonnes, which is equivalent to the annual emissions of 78 coal-fired power plants. This is true leadership and differs markedly from the global trend: over the same five-year period, global emissions from energy and industrial processes increased by around 3.4%."[50]

*3.2 What mix of measures do companies plan to apply to achieve their 2025 goals?*

To serve the overall goal of this article – to assess what is needed by when and by whom – this section is factoring in the mix of measures with which companies would like to achieve their GHG reduction targets for 2025.

Buettner and Wang [9] illustrate in detail the merits of different measure types for decarbonisation. These can, in principle, be sorted into two dimensions:

1. What the measures "do": reduction measures save energy, resources and process emissions; substitution measures replace fossil energy sources with renewable energy sources; compensation measures do not avoid the emission but prevent them either from causing harm or compensate their effect by alternative means.
2. Where the measures "take place": Measures that can be implemented on-site (energy efficiency measures, self-generation of renewables or process decarbonisation) give the company more control and also address the desire for resilience from hikes in energy, resource and emission price. Off-site measures refer to the purchase of renewable energy and any type of off-site compensation. Off-site measures have in common that the company depends on someone else in respect to availability and prices. They cement the status quo in terms of resiliency or, in terms of compensation, increase dependence on a steady stream of viable compensation projects at a potentially increasing price and also the risk of bad press [51].

**Figure 2** highlights how the 22.1 % average savings ambition is disaggregated by measure type. It emerges that at the time of the data collection, companies embraced the notion of "efficiency first" (5.4 % percentage points of goal), yet this was closely followed by the notion "purchase of renewable energy" (5.3 %) and "self-generation of renewable energy" (4.7 %). This illustrates that renewable energy is supposed to contribute 10 % points overall to achieving the target. Considering that process decarbonisation can be quite complex and does not necessarily lead to energy savings, it is not surprising that a slightly higher proportion is attributed to compensatory measures (3.4 % vs. 3.2 %). In summary, companies intend to achieve on average 60 % of their targets through measures implemented on site (highlighted bold in **Figure 2**).

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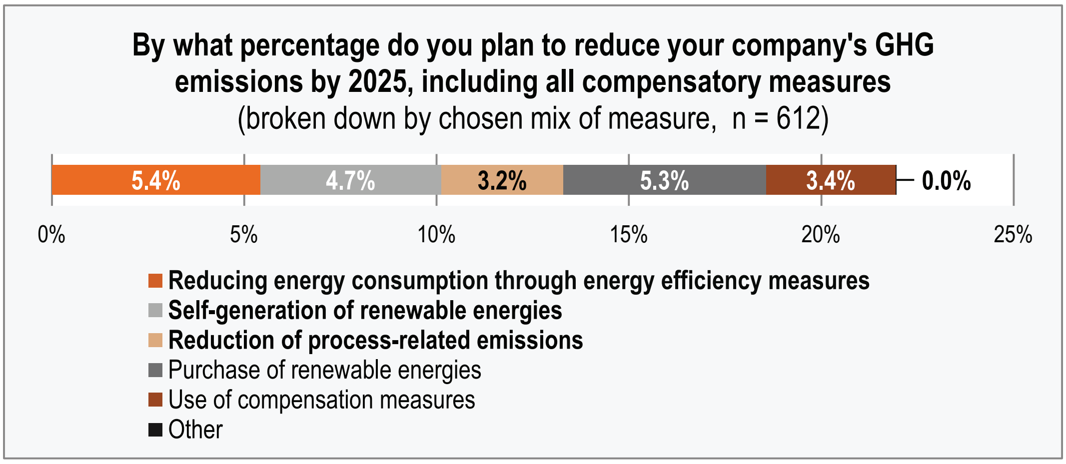


**Figure 2.** GHG reduction target for 2025, broken down by measure option [in %]

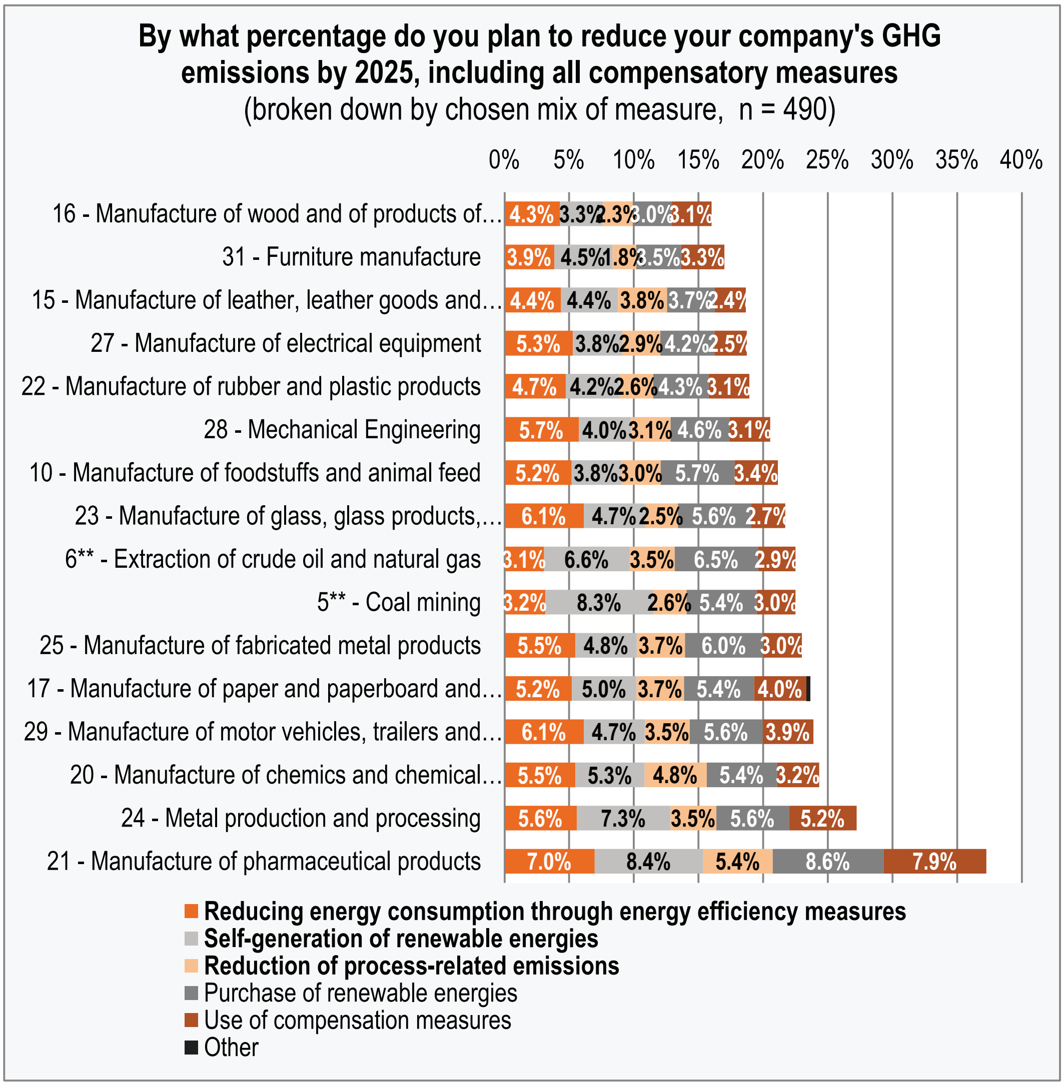


**Figure 3.** GHG reduction target for 2025, broken down by measure option [in %], by sector (n ≥ 20)

Irrespective of a company's sector, the average proportion of intended on-site measures is between 55 – 67 % of the company's envisaged goal (cf. **Figure 3.** GHG reduction target for 2025, broken down by measure option [in %], by sector (n ≥ 20). However, depending on the specifics of the sectors, the proportions may differ. For instance, the role of energy efficiency measures is smaller in the oil & gas as well as the mining sector, while renewable energy sources play a much larger role there. This is quite likely due to the type of machinery and vehicles used and due to the savings, that can be achieved via these activities in terms of emissions.

*3.3 Putting industry's GHG saving goals in political context*

The previous sections have provided insights on the spread and the average GHG reduction ambition. They also highlighted in general terms with which overall types of measures companies aim to achieve their goals. From other studies, we have learnt that the set goals are not unrealistic to achieve from a company perspective [2,50]. What we have not yet established is what these 22.1 % and 27.3 % targets actually mean. While using a recent "normal" business year (often 2019) as a basis makes sense from a business perspective, political targets usually refer back to another base year, 1990 [52].

In order to compare political and industry targets, it is necessary to identify the amount of GHG emissions the companies in the sample emitted in 2019. For the moment we take the simplifying assumption that the sample is fairly representative of the industrial sector in Germany. In 2019, the German industry emitted circa 187 million tonnes of $CO_2$-equivalents. In 1990, the industry's emissions where at 284 million tonnes [53]. If the percentage goals for 2025 and 2030 were to be applied, the 187 million tonnes emitted in 2019 would be reduced by 22.1 / 27.3 %, which corresponds to 41 / 51 million tonnes (cf. **Table 3**). Subtracting these reductions from the 2019 emission leads to the remaining emissions for 2025 and 2030 respectively. The prospected 2025 and 2030 emissions then allow one to determine the targeted percentage reductions compared to the common policy base year of 1990. It is remarkable that this percentage is almost on the same level as Germany's overall emission reduction target for 2030 at the time of data collection, which was - 55 %[54]. Nevertheless, the goal has since been increased to 65 % [32]. If this goal was applied across the board, it would lead to a reduction down to 99 million tonnes by 2030. However, as of mid-2021, the sector targets under the climate protection act list 140 million tonnes of remaining emissions as the target for the industrial sector. In other words, if the industry reached its self-determined targets for 2030, it would already meet Germany's current sector targets for 2030 (cf. **Table 3**).

**Table 3.** Converting Industry targets from 2019 to 1990 base year

| $CO_2$-equivalents (in million tonnes) | 1990 | 2019 | 2025 | 2030 |
|---|---|---|---|---|
| Absolute & Policy Target Emissions for Industry | 284 | 187 | | 140 |
| Absolute if measures are implemented as planned | | | 146 | 136 |
| Absolute savings of planned measures | +97 | 0 | -41 | -51 |
| %-change compared to 2019 | 52 % | 0 | -22.1 % | -27.3 % |
| %-change compared to 1990 | 0 | -34 % | -49 % | -52 % |
| Political Target (overall) | | | | -65 % |

The implications from this are considerable for two reasons: Firstly, numerous articles and studies have highlighted that the climate change targets will be difficult to meet at the current pace of action [32]. With the goals determined, industry sets a strong-self-determined signal. Accordingly, policymakers should focus on ensuring that the industry is able to fully reach its targets. Such a course of action would necessitate policymaker to engage with industry to identify potential prohibitors and to clear the path – in contrast to prescriptive efforts to push industry to "try harder". The second reason is much more concerning. In **section 3.1.2.** we have established that industry plans to accomplish 80 %

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of its decarbonisation efforts (contributing to the figures presented in **Table 3**) within the first half of the decade, which means by 2025. However, the problem is that due to the difficulties explained in **section 1**, the average planning time, building and commissioning times for generation infrastructure as well as wind parks is beyond a half decade. Accordingly nothing that is not already in the pipeline will be ready by 2025, unless planning processes, capacities, etc. are improved in the immediate future [32]. To get a better understanding of how and where potential shortages might appear, it is necessary to apply the simplified procedure used to estimate the overall saving ambitions (cf. **Table 3**) on the subdivision of the savings targets as well.

In this regard, it is important to note that some measures can (only) impact energy-consumption and energy-related emissions. Conversely, other types of emissions can only be tackled with process decarbonisation, CCUS or compensatory projects. Offsetting GHG emissions is the only measure that can compensate for any type of emission (however it cannot prevent emissions). As a result, a proportion of the emissions is energy-related and can only be addressed through the described means, and another proportion are process-related emissions. While the process-related proportion can be quite different across sectors, applying the general ratio, valid for industry as a whole, will be sufficient for the simplified estimation: Of the 187 million tonnes of GHG emissions of industry, two thirds are energy-related and one third is process related. According to destatis, industry's total final energy consumption (energetic) in 2019 was 3336 Petajoule (PJ), which is equivalent to 926.67 Terawatt hours (TWh). In the same year, industry's energy-related GHG emissions were at 125 million tonnes [55]. Dividing the emissions by the energy consumed leads to the industry's average emission factor of 0.1349 tonnes GHG emissions per TWh energy consumption. If this factor is applied to the energy-related decarbonisation-measures (energy-efficiency, renewable energy), one finds the approximate amount of energy-generation / savings needed to meet the proclaimed 2025 savings goal. It has to be noted that with each step taken in this estimation process the deviation from reality may increase. Particularly in context of final energy consumption, comparatively small deviations across data sources can lead to a substantial change of the emission factor. Executing the operation suggests the need for 138 TWh in renewable energy capacity (not necessarily electricity), and 65 TWh in savings from energy efficiency measures. While keeping in mind that companies may wish to make use of a broad range of renewable energies, the estimated amounts are converted into on-shore wind turbines and photovoltaic panels for illustrative purposes. A modern wind turbine can generate 5-10 GWh per year. Using 7.5 GWh as factor, this translates into 9.700 wind turbines. For an average photovoltaic panel, the annual electricity generation is about 0.17 MWh/m² [56] and a forest stores approximately 6 tonnes of GHG emissions per hectare per year [57], leading to the figures in **Table 4.**

**Table 4.** Impact estimation of 2025 Saving Targets

| Measure | in % | in Mio t $CO_2$-eq. | in TWh | ca. equivalent to |
|---|---|---|---|---|
| Energy Efficiency | 5.4 % | 10.2 | ~75 | |
| Self-generation of renewable energies | 4.7 % | 8.8 | ~65 | 380 km² photovoltaic |
| Reduction of process emissions | 3.2 % | 6.0 | | |
| Purchase of renewable energy | 5.3 % | 9.9 | ~73 | 9.700 wind turbines |
| Compensation | 3.4 % | 6.3 | | 10.000 km² forest |
| Other | 0.1 % | 0.0 | | |
| Estimated total GHG savings Industry | 22.1 % | 41 | ~138/~75 | |

 doi:10.20944/preprints202302.0495.v1



The EWI estimates that meeting the wind energy growth targets and the ambition of serving 80% of electricity demand in 2030 with renewable sources will require on average 5.8 wind turbines going online per day between 2023-2029 [33]. Between 2010-2021, on average 3.5 wind turbines went online per day [32]. If the estimated 9.700 wind turbines to meet industry's target were to be installed within five years (from the point of the data collection in 2020), 5.3. turbines would need to go online per day. The EWI estimates additional electricity needs for industry of 45 TWh. To produce 20 TWh of green hydrogen for industry, it estimates that a further 29 TWh of electricity from renewable energy sources is required [33]. Putting EWI's depiction of the goals set out in the coalition agreement in the context of our estimate shows that the additional green energy needs of industry estimated by the EEI for 2025 would be on par with EWI's numbers – however: only if all energy efficiency measures are applied, the 138 TWh are reduced to about half and if it all happens within half the time. This is as the needs estimated by EEI are for 2025 and EWIs for 2030.

## 4 Discussion and Conclusion

As underlined before, the estimations provided in the previous section suffer from a number of limitations due to the simplifications and assumptions, which had to be made along the way. To improve the estimate, the following steps promise to increase its accuracy: (a) Firstly, one defines the proportion of a sector's energy consumption compared to the industry as a whole and expresses this ratio as a weighting factor to be applied to each individual observation. (b) Secondly, one expresses the ratio of MSMEs in each sector with a weighting factor and applies them on the goals set (as preliminary data shows relevant differences in ambition levels depending on company size).

However, even if the figures provided are off by up to 50 %, the forecasted generation capacities are quite likely not sufficient and, more importantly, come too late.

In order to reduce suffering from such supply risks, companies are well advised to undertake those measures, which are within their "control" – the on-site measures. Particularly, the common saying that the best unit of energy is the one not used holds true in this context. The more efficient end users become, the more impact each additional wind turbine, each photovoltaics or solar thermal energy panel will have. Moreover, planning permissions and shortages in installers, equipment and energy experts all take their toll and constitute a potential, often a real, bottleneck in companies' resilience and net-zero plans. This dynamic further underscores the importance of efficiency, if not in general then in terms of the timeline (and the cost increases over time).

Given the risks and obstacles to companies' resilience and net-zero plans, it would be beneficial to determine each company's decarbonisability factor [44]. The latter describes the proportion of emission reduction that cannot be satisfied through on-site measures for technical and space reasons, instead requiring off-site means. Awareness of decarbonisability factors would equip policymakers with a certain degree of plannability in terms of required capacity growths (similar to a shopping list in some way).

To improve the accuracy of transformation plans, policymakers should further complement their estimations, basing them not only on technology roadmaps but also on bottom-up information to gain an actual understanding of what exactly is needed when by whom. This can either be done in a survey format, such as the EEI, provided a more precise estimation approach, or a full data collection, similar to a census. For the latter, each company would be asked to fill-in a confidential online-questionnaire providing company-size, sector, federal state, composition and amount of energy use (for larger companies also energy- and process-related emissions). Further one would enquire how the company intends to contribute to the country's GHG target (in % by 2030). Information on the scopes in which the company pursues emission reductions, how advanced the company is in its decarbonisation and where it needs help can further make such tool serve as a two-way facilitator. Firstly, policymakers acquire a better understanding of the required infrastructure and the progress towards decarbonisation. Secondly, companies have a chance to indicate what they need to help achieve the societal climate goals. Policymakers can then address these with specific measures.

To improve the accuracy of the estimates in this article and to benefit from the additional viewpoint, it would be valuable to complement the present analysis, which focuses on industry sectors, with the perspective of different energy intensities and company sizes. With sufficient participation, the questionnaire could be useful to assess from a demand-side perspective what is needed, when, by whom and where. To master the climate and energy crisis successfully, all stakeholders, particularly policymakers, but also companies need to "up their game" and quickly push ahead with decarbonisation. Particularly through the application of energy efficiency measures and the parallel expansion of self-generation capacities.

**Author Contributions:** Conceptualization, S.M.B.; methodology, L.S., J.D., S.M.B. and W.K.; validation, L.S. and S.M.B.; formal analysis, L.S., S.M.B., J.D.; investigation, J.D. and S.M.B.; data curation, L.S., J.D., and. S.M.B.; writing—original draft preparation, S.M.B. and J.D.; writing—review and editing, S.M.B., M.G., J.D., L.S., W.K., A.-L.K.; visualization, S.M.B., J.D., L.S.; project administration, S.M.B.; funding acquisition, S.M.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** The article processing charge was funded by the German Research Foundation (DFG) grant "Open Access Publication Funding / 2023-2024 / University of Stuttgart" (512689491).

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy issues.

The underlying research in form of the Energy Efficiency Index of German Industry (EEI, #EEIndex) would not have been possible without the continuous support of the Karl-Schlecht-Foundation and the Heinz und Heide Dürr Foundation, as well as the about 850 companies participating, and those reviewing this paper, particularly Ali Kara. All conclusions, errors or oversights are solely the responsibility of the authors.

**Conflicts of Interest:** The authors declare no conflict of interest.

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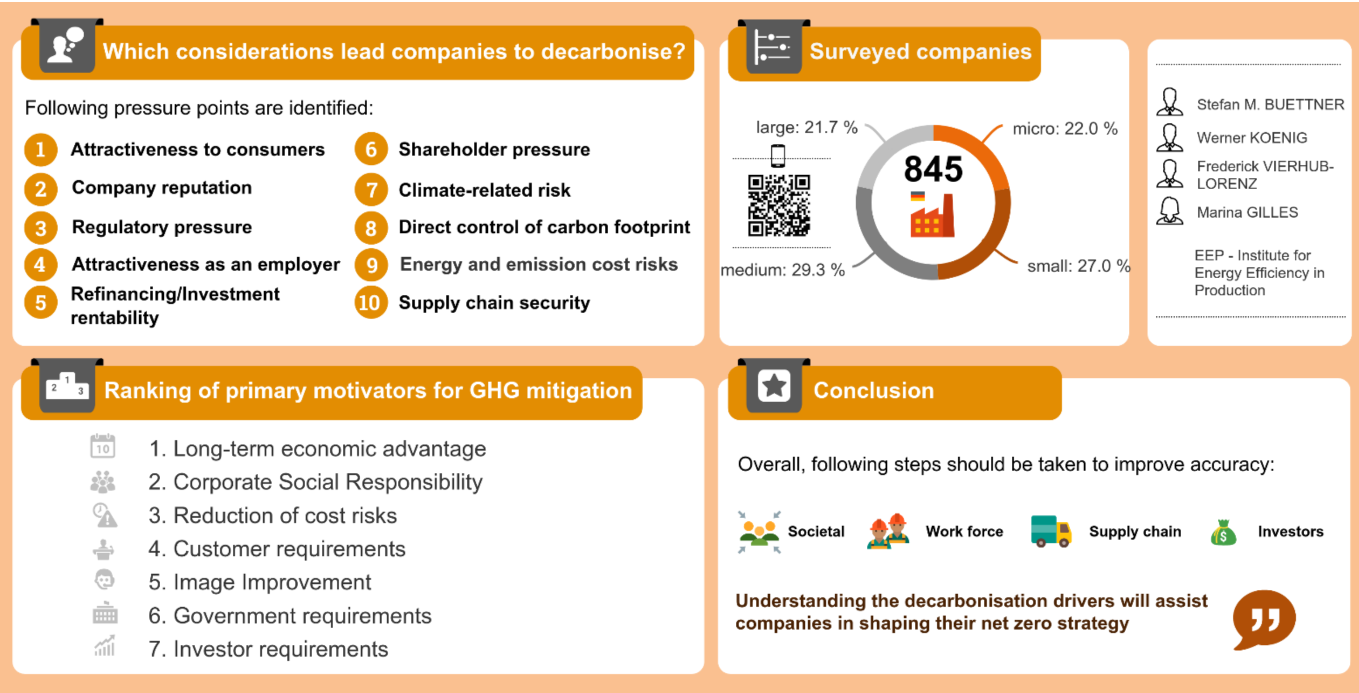
# 5 What motivates companies to take the decision to decarbonise?

**Abstract:**




(Published as: Buettner, Stefan M.; König, Werner; Vierhub-Lorenz, Frederick; Gilles, Marina, 2022. What Motivates Companies to Take the Decision to Decarbonise? *Preprints*, **2022100395**. DOI: https://doi.org/10.20944/preprints202210.0395.v2. Licence: CC BY 4.0) (Buettner et al. 2022a)

*Article*

# What Motivates Companies to Take the Decision to Decarbonise?

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† This paper is an extended, adapted and fully revised version of our paper 'Looking behind decarbonisation' published in the Proceedings of the 2021 ECEEE Summer Study, digital, 7–11 June 2021; pp. 345–354.

**Abstract:** Already more than 140 countries consider or have pledged to reach net-zero emission targets by 2050 or earlier and the share of global emissions falling into an emission pricing scheme has steeply increased over the past three years. Even where there are no direct implications for industry (yet), there is a series of subtle pressure points driving an increasing number of companies across the globe to work towards climate neutrality and pledging ambitious emission reduction goals. This article sheds light on the pressure points, the subtle triggers, the underlying considerations as well as the hoped-for benefits for industrial companies from achieving net-zero emissions. The observations and ideas presented in this paper are derived from quantitative data obtained via the Energy Efficiency Index of German Industry (EEI) and qualitative data. Not only societal, work force, supply chain and investor expectations play a large role, but also many strategic considerations which have the potential to make the company more resilient and profitable, particularly in time of crisis. Those companies that do not move towards decarbonisation, on the other hand, may face a costly late-mover disadvantage. This piece uncovers subtle interconnections, helping stakeholders from industry and beyond to grasp opportunities and challenges ahead.

**Keywords:** decarb-efficiency; decarbonisation; industrial energy saving; cost effectiveness; strategic decision-making; climate neutrality; net-zero; drivers; motivators; resilience

## 1. Introduction

### *1.1. Background*

Even though the COVID-19 pandemic has put many aspects of life on hold across the world, this has not been the case for climate change. Whilst the emission level initially shrank in 2020, this positive effect of the pandemic was hardly measurable: The pandemic had an impact on what has been directly emitted, but not on the speed of the damage already in motion in terms of particles per million in the atmosphere [1]. Instead, another record high in emission levels was reported recently [2-3]. If large parts of the economy must be rebuilt after the pandemic 'anyway', this opportunity to iron out shortcomings of the pre-pandemic configuration should be used more than has been the case so far. This consideration not only relates to the outdated or missing infrastructure, insufficient security and resilience in energy supply, lacking digitalisation in learning, work-place, administration and processes, as well as the robustness of supply chains, but also to the chance to incorporate environmental and resilience considerations into the vast recovery programmes of, for instance, the European Union and the United States [4-5]. With this, tightened interim climate goals of EU and others [6] and warnings of climate scientists, social expectations are also rising in several dimensions despite the pandemic [7]. The most recent report of the Intergovernmental Panel on Climate Change (IPCC) puts it quite clearly: "Urgent action [is] required to deal with increasing risks" [8]. The war in Ukraine and the resulting drastic increase in energy prices, concerns about (energy supply) security, and disrupted global supply chains and markets add another dimension. On the one hand side, this unleashed, notably in Europe, rapid policy action to decrease dependency from fossil energy sources, including even more ambitious goals for energy efficiency and renewable energies, as well as for immediate demand reductions, on the other hand this policy action also promises measures to ease and support reaching these goals [9, 10].

Undoubtedly, a lot needs to be done. However, one of the main findings of the Energy Efficiency Watch Survey EEW4 [11] is, that the levels of energy efficiency improvements continue to be disappointing. This is partly because the question of "Why" to decarbonise remains unanswered for respective stakeholders and is not linked to issues of job and competitive impacts of energy efficiency. This is even more a shame, as those issues are considered to be of highest importance for a majority of stakeholders throughout the EU27, as the survey observes. It thus becomes clear, that the objective of decarbonisation and becoming more energy efficient largely depends on a public narrative, that underlines benefits and cost-saving-advantages in contrast to pure regulation forcing stakeholders to do so. Identifying *factors that potentially drive or motivate stakeholders* hence becomes *vital to plot this new narrative* [11].

### *1.2. What is known on drivers and motivators and what are limitations?*

A bulk of existing literature examines the drivers, motivators and barriers to the adoption of more climate friendly or carbon-emission-reducing technologies and measures; however, they all differ in the way to do so. Sousa Jabbour et al. [12] review literature on the subject and conclude that the most cited factors include primarily political/regulatory and governance measures while technological and market factors are less frequently mentioned. A similar literature review study by Biresselioglu et al. [13] identify drivers (barriers and motivators) affecting European energy transition from different levels of decision-making. They find that motivators to decarbonise prevail at higher levels of decision-making (policymakers and international energy providers) and are more neglected at lower, individual levels. Other studies examine actual drivers by applying business surveys and empirical methods. In a study of 2007, Okereke [14] identifies motivations such as financial gain, credibility, fiduciary duty, risk guidance and ethical considerations. In contrast, drivers include energy prices, changes in the market, regulations and directives, investor demands, and technological change. A third category – barriers – refers to the lack of a strong policy framework, uncertainty about government action and uncertainty about the market. Palsson and Kovács [15], Wong and Shahidi [16] and Boiral et al. [17] evaluate why companies from different sectors (transport, construction, manufacturing) and different countries (Sweden, Australia and Canada) reduce their production-related emissions and what the key determinants of those - internal and external – drivers are. They conclude that company strategy (internal) outweighs stakeholder pressure (external) [15], that more stringent standards and rewards (rather external) in combination with respective organisational culture (internal) outweigh fear of penalty (external) [16] and that firms committed to tackling climate change have better financial performance. Economic motivation is not key for a commitment to reduce greenhouse gas (GHG) emissions though, which is more influenced by environmental and social concerns (internal) [17].

The literature thus mainly identifies two determining factors that lead to the decision of companies to become climate friendlier: drivers and motivators (barriers are rather hindering factors and thus not relevant for the research question to be addressed). Okereke [14] (p. 479) defines motivators as factors which "arise more or less directly from the raison d'être of business to maximise profit […;] motivational factors on their

 doi:10.20944/preprints202210.0395.v2



own are capable of inciting corporations to undertake carbon management actions." Drivers on the other hand are defined as "the factors that have the potential to 'force' corporations to take climate response action even when they would not have ordinarily wanted to do so". However, having identified two overarching determinants, it remains unclear what specific factors fall into these categories for the different sectors of an economy.

Other studies are focusing on motivations that lead to increased Corporate Sustainability (CS) [18] or how (low-cost) business models can profit from increased CS [19]. They identify normative motives such as ecological and social responsibility as the main motivators for increased CS, followed by reputation as well as cost- and risk- management. Shareholder, political and social pressure are ranked least important. Benefits from increasing CS can reach from creating implicit contracts that prevent harmful claims against a company and the ability to transfer risk to suppliers, to helping improve leadership by motivating management and employees. These studies are however limited to the matter of corporate sustainability in general, and thus are not explicitly linked to the current topic of decarbonisation.

### *1.3. Identifying factors that potentially drive or motivate stakeholders to plot a new narrative*

Hence, building and extending on a conference paper presented at the European Council for an Energy Efficient Economy's digital summer study 2021 [20], this article aims at filling the abovementioned gaps by identifying specific factors leading manufacturing industries to decarbonise that can be pooled under the overarching determinants described as drivers and motivators.

The role of the industrial sector is understudied given its significance as it accounts for 28.0 % of final energy consumption, 18.4 % of energy-related emissions and 23.1 % of Germanys overall greenhouse gas emission (GHG) in 2019 [21-23]. Moreover, it essentially determines how future products and components for all other sectors are designed, sourced, and manufactured, as well as how they perform [24] (p.2). Thus, for the identification of factors that drive or motivate stakeholders to decarbonise, it makes sense to take a closer look at the manufacturing industry, specifically how manufacturers operate, decide and act.

Several research questions arise from these considerations and will serve as framework for this article: (1) Why do companies in the industrial/manufacturing sector pledge to decarbonise, (2) what is the range of factors that potentially influence their decision to do so? (3) And is it really environmental consciousness or something else that motivates them?

Doing so, the research ambition is to help gain a better understanding of how to communicate decarbonisation and the multiple benefits arising from it to companies and the respective stakeholders, so that they deliberately choose to adopt appropriate measures.

Understanding what the drivers and motivators, the external pressures as well as internal ambitions are, may facilitate the *plotting of a new narrative* triggering successful decarbonisation and the tailoring of fitting policies that appeal to these factors. Additionally, it may help the development of support schemes that expedite decarbonisation of the industrial sector – without harming the sector's competitiveness or even existence.

A strong and convincing narrative that both breaks the ice from the entrepreneurial perspective by triggering the intrinsic wish to decarbonise (internal ambition) and enables external stakeholders to undertake effective measures to trigger this wish in others (external pressures) is of utmost importance. Such a narrative is especially significant con-

 doi:10.20944/preprints202210.0395.v2



sidering the noticeable but far too limited (and often also narrow) uptake of decarbonisation action, the increasing insecurities in energy and material supply, as well as energy and emission prices.

Identifying effective triggers is hence necessary to make use of the general principles of doing business – the strive to maximise profit. The latter is the difference between income (revenue) and expenditure (costs), with every internal or external action or decision having a positive or negative influence on it. For this reason, companies seek to reflect these variables in a profit function, which aims to identify the decision constellation where the difference between the revenue and cost functions (which reflect the variety of costs and associated revenues arising for each given set of decisions), and thereby the profit, is at its highest (positive) point [25] (pp. 23-26). Since the framework conditions are constantly changing due to internal or external decisions, this constellation leading to the maximum profit is a snapshot and requires a continuous optimisation of the profit function.

The state (or other actors) may intervene in this 'natural' striving for the maximisation of profit when an entrepreneurial action appears problematic or harmful to society by changing the framework conditions [25] (pp. 432-439). This change can either be achieved by the promise of increased/decreased revenue (shifting the revenue function) and/or of increased/decreased cost, risk or hardship (shifting the cost function). Ideally, such an intervention leads to congruence between the behaviour of the company necessary for an optimised profit function and the behaviour that is socially and ecologically desirable or necessary. If this succeeds, the adjustment of behaviour is an intrinsically desired reaction to changed framework conditions; if this fails, it can lead to measures being perceived and encountered as extrinsically 'motivated'. In the latter case, implementation may be reluctant, if it happens at all, resulting in poorer results and demanding more control efforts. To avoid unnecessary control efforts, the goal should therefore be to identify those factors that lead to self-motivated (intrinsically motivated) measures towards the socially desired action.

In this context, the question is: Which ingredient(s) can help shift companies' profit function towards the societally desired and agreed outcome corridor of averting climate disaster and achieving climate neutrality, in which both, business ambitions and the societal desires are met? The ingredient(s) leading to such shift and their individual shifting-intensity (how big of a shift one specific ingredient triggers) may differ significantly from company to company.

To ensure broad applicability of the findings and to identify differences between company types, it is essential to equip the analysis with a quantitative element that assesses weight and ranking order of key motivators across company sizes, industrial sectors, and energy intensities. This data was gathered by the Institute for Energy Efficiency in Production (EEP) in context of its spring 2020 data collection for the Energy Efficiency Index of German Industry (EEI) [26].

Findings will hence not only inform policymakers and the general public but also allow companies to reflect upon the points made in their internal deliberations on whether to decarbonise and how to shape their own decarbonisation strategy.

In order to provide an appropriate basis for the analysis, this article commences by constructing a framework, establishing and explaining the categories of motivators and drivers (Section 3.1-3.2). This framework is then applied to a qualitative case study focusing on the automotive industry (Section 3.3), specifically Bosch, and quantitatively tested across the manufacturing industry (Section 3.4). The quantitative part of the analysis relies on the results of the energy efficiency index of the German industry to examine what *actually* motivates German manufacturing companies to decarbonise, addressing differences in motivating factors depending on company size, sector, energy intensity, supply chain position and decision determinants. After a brief discussion (Section 4), this

 doi:10.20944/preprints202210.0395.v2



article concludes (Section 5) that motivators generally have the highest motivational relevance in the decision to reduce one's GHG emissions, while external drivers rank by and large below the motivators. Moreover, the results show that positive motivators lead to higher ambition levels than negative (external) drivers. Thus, policy measures that trigger an intrinsic reaction by strengthening the motivators would positively impact ambition levels and probably generate better outcomes than policies applying external pressure.

## 2. Methodology

As mentioned, the observations and ideas presented in this article are derived from a combination of quantitative and qualitative data. The study builds on observations made during professional interactions with manufacturing companies in Germany concerning energy efficiency and decarbonisation, as well as on media articles about this topic, particularly announcements of climate pledges. The arising assumptions on why companies choose to decarbonise and the range of factors that influence this decision were then tested in the framework of the Energy Efficiency Index of German Industry (EEI). The latter aims to assess the assumed and anecdotally observed drivers and motivators influencing corporate decisions towards decarbonisation.

In reaction to the lack of "targeted energy efficiency analysis" [27], the EEI was introduced in 2013 "as an index for industry as a whole and especially the manufacturing sector". It focuses on intentions, expectations, experiences, opinions, and observations of entrepreneurs from companies of all sizes, energy intensities and across 27 manufacturing sectors. The methodology of the EEI is modelled after the German monthly economic indicator, the ifo-Index [27].

A total of around 674,000 manufacturing companies in Germany created a revenue of nearly 3.43 trillion euros in 2019, employing around 11.61 million people; 198,000 of these companies belong to the most relevant subsectors that EEI focuses on [28].

The EEI data this paper is referring to is comprised of 864 observations gathered in May 2020, which was in-midst of the first wave of the COVID-19 pandemic in Germany, as well as half a year after the September 2019 United Nations Climate Action Summit and the announcement of the much-criticised German climate package [29-30].

Each of EEI's semi-annual data collections has a specific focus on selected current issues. The 1st data collection in 2020 looked predominantly at motivation, prioritisation and intended action of the German manufacturing industry in respect to decarbonisation and in light of the plan of a European Green Deal, aiming at climate neutrality by 2050, announced by the European Commission on 11 December 2019 [26,31].

Among the 18 questions posed to participants of EEI in total, companies were asked to indicate their sector (the one with the largest share of their revenue), revenue, energy consumption and number of employees. This enables cross-referencing and analysis of current-topic questions by these parameters. However, since revenue and energy consumption are often considered confidential, a significant number of respondents chose not to provide these figures or not to respond to some of the other questions asked. Therefore, the number of observations varies between the different EEI questions analysed below.

The data collection was carried out using a mixed methods approach, combining online (7 %) and telephone surveys (93 %). **Table 1** provides an overview of the sample by company size (as defined by the European Commission [32]). Instead of following the actual size distribution of manufacturing enterprises in Germany [28], we aim for an approximately even distribution across company sizes for the EEI's samples. As explained by Buettner et al [33] (pp. 3-4), this allows us to make statements on all company sizes.

**Table 1.** Sample composition by company size (n = 845)

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| Company size | Number of Employees | Revenue in million EUR | Total population (N) | Observations (n) | Percentage of Sample |
|---|---|---|---|---|---|
| Micro | 0-9 | ≤ 2 | 124,904 | 186 | 22.0 % |
| Small | 10-49 | > 2 to ≤ 10 | 52,282 | 228 | 27.0 % |
| Medium | 50-249 | > 10 to ≤ 50 | 15,282 | 248 | 29.3 % |
| Large | >249 | > 50 | 5,300 | 183 | 21.7 % |
| Total | | | 197,768 | 845 | 100.0 % |

Although difficult to achieve, desired was an even distribution across the 27 manufacturing sectors, representing 198,000 companies. Therefore, 'core industries'[1] were defined for the telephone survey, each of which should have at least 24 companies participating. Automotive industries and mechanical engineering are two of the eleven sectors of high importance for German industry. For sectoral considerations in this paper, only sectors are taken into account in which at least 20 companies provide answers to the respective question(s) [33] (p. 4).

Results of micro sectors (N < 10) are considered ('**') if more than 50 % of the sector participated in this study; results of small sectors (10 ≤ N < 100) are taken into account ('*') if at least 15% of the sector participated [33] (p. 4).

The sectors themselves are coded according to the '*Klassifikation der Wirtschaftszweige 2008'*, which is the German implementation of the *Nomenclature générale des activités économiques dans les Communautés Européennes'* (engl.: General Industrial Classification of Economic Activities within the European Communities), NACE, whose use is mandatory in the European Union and in compliance with the *United Nations' International standard industrial classification of all economic activities*, ISIC [33-36]. Three participants selected other sectors than those in focus and are hence excluded from further analysis, four further observations are considered manufacturing but were not able to self-assign to one of the sectors. These four are considered in the general, but not in the sector-specific analysis, reducing the sample size to 861.

As part of the questionnaire, companies were asked to indicate whether their responses refer to one specific site or to their entire company. Of the 861 observations remaining, 659 refer to multiple sites (the whole company) and 199 to one specific site, 3 remain undeclared. **Table 2** depicts what percentage of a sector's total population (number of companies) participated. The percentage may seem to be greater than 100 % in very small sectors, such the "crude petroleum and natural gas" sector (06). In this case, all 13 responses refer to one specific site; the same is the case for 6 out of 8 observations of the "mining of coal and lignite" sector (05), leading to the assumption that the majority (n(N) ≥ 50 %) of companies in both sectors participated and thus allowing for the inclusion of their results in the analysis.

**Table 2.** Sample composition by sector (n=864)

| NACE Code | Sector | Total population (N) | Observations (n) | Percentage n (N) |
|---|---|---|---|---|
| 05 ** | Mining of coal and lignite | ~ | 8 | ~ |
| 06 ** | Extraction of crude petroleum and natural gas | 5 | 13 | 260.0% |
| 08 | Other mining and quarrying | 1,438 | 12 | 0.8% |
| 10 | Manufacture of food products | 26,897 | 31 | 0.1% |
| 11 | Manufacture of beverages | 2,435 | 19 | 0.8% |

1 [1] 'Core industries' are the eleven sectors that have most economic weight in Germany (NACE code in brakets, sorted by Code): leather- (15), wood & cork- (16), paper- (17), chemical- (20) rubber & plastics- (22), non-metallic minerals- (23), basic metals- (24), fabricated metals- (25), electrical equipment- (27), machinery & equipment- (28) and motor vehicle (29) industries.

 doi:10.20944/preprints202210.0395.v2



| | | | | |
|---|---|---|---|---|
| 12 | Manufacture of tobacco products | 62 | 8 | 12.9% |
| 13 | Manufacture of textiles | 4,637 | 18 | 0.4% |
| 14 | Manufacture of wearing apparel | 3,306 | 14 | 0.4% |
| 15 | Manufacture of leather and related products | 1,371 | 34 | 2.5% |
| 16 | Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials | 12,944 | 39 | 0.3% |
| 17 | Manufacture of paper and paper products | 1,558 | 53 | 3.4% |
| 18 | Printing and reproduction of recorded media | 10,986 | 24 | 0.2% |
| 19 | Manufacture of coke and refined petroleum products | 89 | 13 | 14.6% |
| 20 | Manufacture of chemicals and chemical products | 3,280 | 48 | 1.5% |
| 21 | Manufacture of basic pharmaceutical products and pharmaceutical preparations | 554 | 26 | 4.7% |
| 22 | Manufacture of rubber and plastic products | 7,090 | 64 | 0.9% |
| 23 | Manufacture of other non-metallic mineral products | 9,908 | 44 | 0.4% |
| 24 | Manufacture of basic metals | 2,374 | 42 | 1.8% |
| 25 | Manufacture of fabricated metal products, except machinery and equipment | 44,106 | 64 | 0.1% |
| 26 | Manufacture of computer, electronic and optical products | 7,935 | 21 | 0.3% |
| 27 | Manufacture of electrical equipment | 6,036 | 67 | 1.1% |
| 28 | Manufacture of machinery and equipment n.e.c. | 15,964 | 72 | 0.5% |
| 29 | Manufacture of motor vehicles, trailers and semi-trailers | 2,769 | 49 | 1.8% |
| 30 | Manufacture of other transport equipment | 1,276 | 15 | 1.2% |
| 31 | Manufacture of furniture | 10,826 | 29 | 0.3% |
| 32 | Other manufacturing | 19,985 | 30 | 0.2% |
| 99 | Other | | 7 | |
| | Total | 197,831 | 864 | 0.4% |

* small sector (10 ≤ N < 100) with at least 15% of total population (N) participating; ** micro sector (N < 10) with at least 50% of N participating, ~ figures not disclosed in official statistic due to small sector size and associated confidentiality issues.

Assuming that both stance and envisaged action of a company in respect to decarbonisation activities differ depending on its energy intensity, the latter was computed for each company (if possible), and clustered into five intensity classes (not-, less-, moderately-, energy-intensive, very energy-intensive) [33] (p. 4).

The ratio between energy used and revenue of a company is used to calculate the "energy intensity" variable. The variable "energy use" contains information about the total energy demand of a company (converted) in MWh, while the "revenue" contains information about the revenue of a company in the previous fiscal year in million euros [33]. The results of this operation span a wide range. The 656 cases range from 0.0111 to more than 10,000 Watthours consumed per euro (Wh/EUR) for this sample.

**Table 3** displays the distribution of observations across the five energy intensity classes. The lower a company's energy intensity class, the higher its energy productivity, and vice versa. A key measure for raising energy productivity is increasing energy efficiency [33]. As only twenty of the energy intensity observations fall into the fifth class, there are just enough cases (n ≥ 20) to include this class in the analysis of the EEP 2020/1 survey data. If the figure falls below 20 observations in an analysis, only the lower four energy-intensity classes remain.

**Table 3.** Sample composition by energy intensity (n = 656)

| Energy Intensity Class | Energy Intensity Interval | Observations | Percentage |
|---|---|---|---|
| not energy intensive | 0 to < 10 Wh/EUR | 151 | 23.0 % |
| less energy intensive | 10 to < 100 Wh/EUR | 243 | 37.0 % |
| moderately energy intensive | 100 to < 1,000 Wh/EUR | 198 | 30.2 % |
| energy intensive | 1,000 to < 10,000 Wh/EUR | 44 | 6.7 % |
| very energy intensive | ≥ 10,000 Wh/EUR | 20 | 3.1 % |
| Total | | 656 | 100.0 % |

## 3. Results

### *3.1. Why decarbonise: What factors influence the decision to decarbonise?*

The number of companies pledging to comply with the Paris climate goals is steadily increasing, as are those that announce climate, carbon neutrality or net-zero goals for diverse target years. What set of triggers leads these companies to take the decision to decarbonise in the first place? As pointed out by Buettner et al [33] (p.17), "the understanding [..] which factors, besides regulation and carbon tax, play a role in the decision to decarbonise, is essential to tailor schemes and services appealing to these trigger points. Of similar relevance is the (relative) weighting of the individual factors."

To address this question, this article aims to identify drivers and motivators that potentially influence such decisions. As explained in the literature review, drivers can be understood as mainly external pressure points that indirectly trigger, sometimes even force companies to take action. Motivators on the other hand are rather defined as internal considerations which can reach from purely business orientated profit maximising/business survival issues to more abstract value-based determinants that are not as trivial to identify. Experiencing pressure (may it result from a driver or motivator) on a specific point can positively or negatively affect an underlying need, core value or ethic of either the person in charge or what the person in charge is measured by. However, since the publication of the relevant literature by scholars such as Okereke [14] on drivers and motivators, more than a decade has passed in which economic conditions, environmental considerations, as well as business culture have changed, necessitating a re-examination.

Recent announcements to become climate neutral (or carbon neutral) may initially be perceived as if environmental consciousness was the dominating motivation, but actually serve other underlying needs, intentions, values or strategies or result out of external pressure. Thus, establishing what these underlying factors are nowadays will help to (a) understand how companies which have not yet come forward with decarbonisation plans can be triggered to do so, and (b) inform supporting bodies on how and where they can help best.

In summary, understanding the underlying needs, values and considerations, as well as external pressures allows to tailor subsequent activities to trigger an effective reaction that is satisfying the needs of the company, as well as to reach the societally desired outcomes, ideally in a win-win manner. Unleashing such 'change through anticipative steering' (#CTAS) [37] hence builds on identifying pressure points (drivers) and subtle triggers (motivators).

### *3.2. What are the pressure points, the negative (external) drivers?*

Having discussed the relevance of understanding the underlying pressure point(s) for triggering effective reactions, this section will present and explain the nine most significant negative (external) drivers:

(a) Being **able to sell one's products** is perhaps the core need of any company. Whilst the question of how these products came into existence was rarely focused on in the past, **public and regulatory scrutiny** direct more and more attention to this aspect now and hence urge manufacturers to follow suit. While the spotlight was predominantly on sweatshops and child labour [38] in the late 20$^{th}$ century, fair trade aspects [39] have moved into focus in the early 21$^{st}$ century. In recent years, however, the focus has gradually shifted towards environmental aspects, such as local pollution caused in harvesting natural resources, for example lithium [40] (crucially important for batteries and e-mobility), deforestation of rainforest to create space for soy [41], or rapeseed being planted for biofuels instead of eatable crops [42].

(b) Not only do these direct causalities constitute pressure points that are potentially very **harmful to a company's reputation** and success - increasingly, also **indirect factors** are **becoming a cause of concern**. The multi-facetted German brand SIEMENS was hit by a PR-disaster in early 2020 in context of its activities as supplier of railway signals. Whilst in other circumstances this would have been good news considering railways are seen as a comparably environmentally friendly mode of transport, SIEMENS faced calls for boycott as these signals were to manoeuvre trains to a new coal mine in Australia that was much debated from an environmental perspective [43-44].

(c) The EU commission's proposal for a new **supply chain regulation** makes the manufacturer legally and financially responsible for what happens (or not) in its supply-chain, wherever it begins, adding a significant need for caution on top of the PR (and sales) perspective [45]. This proposed EU directive is reaching further than the German one, that comes into force in 2023 already [45-46]. However, respecting these requirements is not an easy undertaking considering how fragmented and multi-layered supply chains have become in the past decades. This applies similarly to the measures envisaged by the EU's sustainable products initiative, for which "product-specific information requirements will ensure consumers know the environmental impacts of their purchases" thanks to "Digital Product Passports" facilitating repairs, recycling and the tracking of relevant substances along the supply chain [47]. A pragmatic approach, which implies only checking the directly preceding and succeeding supply chain actors and contractually binding these to the same regulatory standards, may work as long as these companies are themselves falling under the regulation (geographically).

(d) Unsurprisingly, all these points also have an impact on the **attractiveness of a company as an employer**. Whilst unemployment rose in general due to the COVID-19 pandemic, many thousand positions remain vacant in German manufacturing. From an academic viewpoint, open positions exceeding applicants is called 'employee's market'. This gives applicants and employees a stronger position as they constitute a 'scarce good' during periods and in sectors with a shortage of skilled personnel [48]. In an environment where skilled applicants can choose with whom to sign a contract, the preferences and expectations of new recruits and the existing workforce matter more than usual to a company if it wants to attract new personnel and retain existing employees. According to a McKinsey study, the sustainability (ethos) of a future employer has a higher importance to – in most cases – young graduates than starting salary or job security, similarly, a YouGov online poll found that, of existing workforce, 68 % consider sustainability efforts of their employer as important [49-50].

(e) From a **re-financing perspective**, pressure is also on the rise, particularly for companies in shareholder-ownership. Around the 2019 UN Climate Summit in New York, investors clarified their position in relation to divestment and complying with the goals set out in the Paris Climate Agreement [51]. Similarly, in his 2021 "Letter to Shareholders", Larry Finkman – chairman of Blackrock – announced the commitment to climate issues including temperature alignment goals in Blackrock's investment portfolios [52]. This position is not ideologically driven – it follows the general notion that (long-term) investors have a responsibility for the assets they have been trusted with, meaning they cannot justify investing these into **business models** that have a known **expiry date**

 doi:10.20944/preprints202210.0395.v2



(i.e., coal power plants in countries that have announced to phase out coal). The thinking behind is that investments with an outdated or no-longer working business model will lose in value or become a so-called stranded investments (which means their value drops towards zero) – and therefore are toxic to (continue to) knowingly invest in.

(f) Initial investments aside, shareholders do have a say on the strategy and approaches taken by companies. Once the share of investors following the aforementioned ethos or ideologically supporting climate action reaches the **majority of shares**, strategy changes and climate goals can be put in place against the will of the company leadership. A recent example is the US oil company EXXON, where a coalition of activist investors was successful in electing at least two climate-friendly directors to the board of the energy behemoth [53].

(g) Further, in late 2020, investors have sent a letter to Europe's largest companies warning them to disclose **climate related risks**, as these can significantly impact a company's success [54]. In 2019, for instance, BASF faced significant problems regarding their production since the water level of the Rhine River was too low to allow goods to be transported via barges [55]. This situation at present, in the summer of 2022, is even more severe causing difficulties in the supply (and the associated transport cost) of raw materials and fuels, the low water levels, are not sufficient to cool nuclear and coal power stations and operate hydro power hence leading to reduced energy generation and subsequently energy cost increases or involuntary shutdowns [56, 57]. Similarly, in the food industry, droughts can have a severe impact on (the price of) crops needed for products. Moreover, for companies requiring significant amounts of water, i.e., for paint shops and battery plants, water usage curfews may negatively impact their output.

(h) With globalisation, focusing on core strengths and specialisation, many companies have outsourced parts of their production, leading – in some sectors – to a **low vertical range of manufacture** among the so-called Original Equipment Manufacturers (OEMs). This means that components are – at large – only assembled, painted, tested and wrapped for delivery to the end customer. Consequently, only very **little of the emission footprint** of the product actually lies **within the direct control** of OEMs. In the automotive industry, for example, the direct emission footprint of a car manufacturer for a car sold to the customer, can be as low as 5 % of the total carbon footprint (of which the painting process causes the majority) [58-60]. Whilst outsourcing and specialisation has in general been advantageous (in terms of economies of scale, focusing on core strengths and comparative cost advantages), it can now become a burden when a company aims to identify its Scope 3 emissions[2] or its product carbon footprint[3]. Even more so if it wants to reduce these footprints. This is a severe issue as, according to McKinsey, "only 2 percent of companies have visibility into their supply base beyond the second tier" [63] and according to the 2nd iteration of the Energy Efficiency Index of German Industry in 2021, 75 % of participating companies plan to decarbonise their Scope 3 emissions, 70 % even strive to be able to offer products with a net-zero footprint, leading to already 38 % of companies already adding emission-footprint related requirements to their contracts with suppliers to achieve this goal. Among the companies aiming for a net-zero product carbon footprint (PCF) it is nearly every second one that does impose such requirements (45 %), twice as many as among companies that do not aim for a net zero PCF (21 %). [64].

(i) Therefore, not only **rising energy prices** [65], but also **increasing emission charges** [66] present an economic incentive for companies to take action to reduce cost risks and regain competitiveness through energy efficiency and decarbonisation

2 [2] Scope 3 emissions are indirect emissions of the up- and downstream supply chains (excluding indirect emissions arising from the generation of energy purchased, which are Scope 2) [61], as well as for instance commute, waste and business travel.

3 [3] The Product Carbon Footprint (PCF) "represents the sum of all carbon dioxide emissions (measured in $CO_2$) and greenhouse gas emissions (measured in $CO_2$-equivalents, $CO_2$-eq) caused directly and indirectly by [..] a product [..] over a defined period of time or over its life cycle." [62].

 doi:10.20944/preprints202210.0395.v2



measures. This is especially the case when lower emission intensity or even net zero PCF is desired by either the company itself, its downstream supply chain/clients or legislators.

(j) Other, non-climate related pressure points such as the **futureproofing** of the business model and product portfolio, as well as a general **supply chain security** have become an increasing cause of concern:

At times broken lines of supply during the pandemic and cases such as the cargo ship *Ever Given* being stuck and blocking off the Suez Canal [67-68] had serious **ripple effects** on the global flow of goods. The war in Ukraine, the effects of the Shanghai lockdown [69] and ongoing supply shortages in several industries [70] underlines that the turmoil caused by the initial wave of the pandemic and the *Ever Given* were not just unfortunate one-off turbulences but are something a business should better be prepared for (for instance by diversifying supply, increasing the 'buffer-storage' of required goods and materials, and buying local). This preparedness extends both to price and general availability of energy, goods and resources. The less of these are needed (due to efficiency gains, local sourcing, and circularity efforts), the lower the exposure in absolute terms.

In brief, there are ten negative (external) pressure point, which are of relevance in the decision-making process on whether to decarbonise. Namely, these pressure points are (a) the ability to sell one's product, (b) company reputation, (c) supply chain regulation, (d) attractiveness as an employer, (e) re-financing perspective, (f) shareholder pressure, (g) climate-related risks, (h) direct control over one's carbon footprint, along with (i) energy- and emission cost risks and (j) supply chain security. However, the precise impact of each of these negative (external) drivers depends on the political, economic and societal circumstances and setting of a company.

### *3.3. What are the assumed motivations, strategic considerations and benefits?*

After having established the points pressure is applied to – the (negative) external drivers – in the previous section (3.2.), this section switches perspective and analyses possible motivations, (strategic) considerations and assumed benefits of an early mover that announced ambitious and short-term goals before it became a trend to do so.

The announcement of Bosch on 9 May 2019 to become carbon neutral by 2020 [71] appeared to come out of the blue – ahead of the European Parliament elections (23-26 May 2019) with a land slide gain in support for the Greens, the UN's New York climate summit (23 September 2019) with climate pledges and packages from many stakeholders, as well as the peak of attention for Fridays for Future so far and the European Green Deal (11 December 2019) [31]. According to the press announcement, this commitment secured Bosch the "earliest carbon neutrality of any global industrial enterprise" [71].

With "Bosch's carbon-neutral initiative [which at that time was] unprecedented in scope and timeframe" [71], the company – that is owned by the charitable Robert Bosch Foundation, and hence bound to its values – succeeded in **displaying leadership** in an issue of increasing global and societal relevance after climate scientists called for urgent action (08 October 2018) [72].

#### 3.3.1 Taking initiative and leadership in climate action has several effects

While such an action does come with risks, as is the case for most early adopters, it also awards the **first mover advantage**, the 'pole-position' in all benefits associated. It allows one to shape the narrative and to have the near exclusive benefit of the arising publicity, with the possibility of associating such a move with the company's name or one of its products if it proves to be an innovative pioneer (in context of this article: a decarbonisation frontrunner). In this way, Sony's Walkman became the generic name for mobile cassette players, "to google" a common expression for searching for something in an internet search engine, a Hoover a synonym for a vacuum cleaner or a Xerox for a photocopier [73,74]. These are just a few examples of many. However, it is not necessarly enough to be the first, but to set a new standard, i.e., to be the first to do it so well - or in such an innovative way. Apple, for example, was not the first to offer smartphones with touchscreens, but set the standard with its incomparable "simplicity", which has become synonymous with the brand [75]. This is where successful communication at an early stage is crucial:

What is known as **near-exclusive PR** describes the situation where the first mover will have a period of unparted attention, and anyone who follows second and third only receives lower levels of attention (if sticking to the same media formats).

When taking a far-reaching step as a first or early adopter, one achieves several things: firstly, being **on top of the game** and daring to address challenges head-on; secondly, giving the impression of striving for **innovative approaches** and **future-proofing** the business. Especially the latter point relates to the fact that the innovativeness of one company **imposes significant pressure on all immediate competitors**. For Bosch, being a globally active supplier to (in large parts) the automotive industry, future-proofing appears to be of high strategic importance in the midst of a disrupted automotive sector. No manufacturer wants to share the fate of Nokia, which lost its spot as world market leader for mobile phones and vanished from the market within only a few years when it missed the shift towards touchscreen-operated smart phones [76].

As mentioned before, there is scarcity of skilled personnel; according to the Ifo-Institute, every second company is affected with the outlook of further worsening [77]. In light of the McKinsey study and the YouGov poll referred to earlier [49], it appears crucial to appear climate conscious, innovative, socially responsible and future-proof to **attract skilled personnel or graduates** [50] – and being able to do this <u>earlier</u> than competitors make this aspect also a motivator

Apart from sector disruptions, peer- and recruiting pressure, pressure imposed by customers can play a large role. Besides end-customers, these are large original equipment manufacturers and brands that have a tremendous market power. This power allows them to basically determine the standards and specifications for parts that are later used to assemble the end-product. It is needless to say that – unless it is a very specific niche-product – such market power also comes along with significant price pressure (for instance milk prices secured by large supermarket chains). Such **supply-chain pressure** is increasingly applied by car manufacturers on their supply chain in respect of the environmental performance of pre-products: Daimler, Volkswagen and others push the decarbonisation agenda and suppliers, such as Bosch and Continental have to fall in line if they are not already acting proactively [78]. The associated motivation is to be 'ahead of the game' so that when such pressures are being imposed one's company is not hit unprepared, illustrating how thin the line between drivers and motivator is.

The supply chain aspect, in combination with client expectations [and regulatory requirements] makes the situation particularly complex in, for instance, the automotive industry.

### 3.3.2 Example: The impact of interdependencies on decarbonisation in the automotive sector

Following the Diesel scandal, many manufacturers and suppliers both pledged climate goals and a shift of their model range more and more towards non-combustion engine driven vehicles. The vulnerable point of combustion engine driven vehicles is that they (mostly) run on fossil fuels and emit – especially diesel engines – harmful particulates and fine dust. Conversely, for electric vehicles the weak point is the limited distance that can be traversed with one charge, in combination with the much longer 'refilling' time and the availability of charging stations. The larger the battery the longer the range – assuming an already optimized drive train and consumers.

However, batteries require comparatively large quantities of lithium, the mining of which can also be quite harmful to the environment [40]. The environmental damage done by the mining activities to acquire Lithium (or other rare earths and raw materials) is unquestionably an issue, irrespective of the decarbonisation efforts on one own's direct carbon footprint (this is on-site emissions, Scope 1) and choice of energy sources (these are indirect emissions associated with energy purchased, Scope 2), which are exclusively under one's control [61], thus leading to public criticism [79].

A viable solution to address this was the announcement by, for instance, Volkswagen that their first mass market electric vehicle ID.3 will have a footprint of **(net) zero carbon at the point of handover** [80]. To understand the scope and implications of this announcement, it is necessary to understand the nowadays low production depth and the subsequently vast range of suppliers and sub-suppliers. This means, that except for design, testing, assembly, and painting, few production steps take place at site of the vehicle manufacturer. In aggregate, this may be around 15 % of the vehicle's total production footprint (two thirds of these energy-related scope 2 emissions, one third process related scope 1 emissions [60]). Since, in turn, around 85 % of the footprint are emitted by the supply chain [58] (p.6), manufacturers have a strong interest not to carry the 'net zero' costs (alone). Whilst they may initially achieve such net-zero footprint through compensation, there is a strong financial incentive for manufacturers to pass the responsibility down to the supply chain as much as possible (as it is in fact done by Volkswagen via contractual requirements and certified climate protection projects [80]). The same applies to the suppliers, and subsequently their suppliers until the beginning of the chain.

While large suppliers – such as Bosch – have taken the step to decarbonise their operations proactively, many others, smaller companies, and competitors have not done so – not yet. This is an issue we will get back to. Smaller suppliers are faced with the triple issue that (a) they may not have the capacity, knowledge, and assets to take the decarbonisation decision easily, (b) they cannot be certain that their product range will survive the disruption of the sector and (c) they cannot take action as long as it remains undefined what changes to the product range (and hence production machinery and associated processes) are desired by their clients resulting from this disruption [78,81].

Therefore, as pointed out by Buettner et al [33] (pp.16-17), particularly small companies and energy intensive companies, which have a large footprint due to their processes, need assistance.

The European Emission Trading System ETS only applies to what happens within the European Union (in some particularly emission-intensive sectors and energy generation) and, furthermore, has exemptions in place for some sectors to avoid them from leaving Europe due to their emission intensity which would also cause 'carbon leakage', meaning the emissions remain but happen elsewhere [82]. The German national emission price on the embodied carbon emissions of other primary energy sources, which are not covered by ETS already, only applies to companies' manufacturing sites in Germany. A European Carbon Border Tax/Adjustment may never come, due to the concerns of the World Trade Association and other countries [83].

However, the question remains why suppliers from outside Germany, respectively outside the European Union, may still have to undertake steps towards emission reductions?

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 November 2022 doi:10.20944/preprints202210.0395.v2



1. According to World Bank, the number of countries and regions working on or having implemented a carbon pricing scheme has risen to 22,3 % of global GHG emissions in 2020. This is about 8 % more than in 2019 [84] and the world's largest emitter, China, has also announced that it considers introducing some sort of carbon pricing [85], which it has launched in the meantime. Whether we are on a way to a global price for carbon, as called for by US climate envoy John Kerry [86], or whether there will be a carbon border tax scheme between countries with such a scheme and those without is a different question, but not of relevance here. Similarly, having a scheme in place does not automatically lead to having a noticeable effect, which was the case for the EU ETS before its reform in 2017 [87]. In September 2022, the global carbon pricing initiatives represent 23.11°% of global GHG emissions [84].
2. Particularly for companies in countries or regions, where societal and legal expectations for tackling climate change and reducing emissions are high, it may be quite disadvantageous and costly not to conform. In particular, the company's image might be harmed and there may be boycotts if it does not apply high standards even outside its stricter home region. The example of Siemens's railway signals alludes to this dynamic. The German supply chain law and the European supply chain regulation in development further tighten the options to deviate [45,46,88].
3. There are a number of precedents that underline that a tough standard in one market of a critical size can lead to a general adoption of that standard even if it is not required elsewhere. This is the case as pursuing different standards at the same time would (a) contradict the principles of the economies of scale in terms of costs of production, acquiring parts, etc. and (b) it may only work for a limited period of time to sell a product of a lesser standard. Nevertheless, the validity of the latter point largely depends on the product in question. A prominent example has been the strict environmental standards on combustion engines imposed by the State of California (ca. 80 million people) that then became the quasi-standard for the United States as a whole (ca. 330 million people) [89]. Later, this phenomenon became known as the "California effect" [90].
4. Due to globalised supply chains, however, requirements of the client (car manufacturers in this example) may be the ultimate reason to act – irrespective of the country one is manufacturing in. Unless being supplier of a very specialised or of a niche product, the client company determines what it purchases and to what terms. The supplier will have to comply if it does not want to be replaced by a 'more willing' competitor. The longer a supplier waits to take action, the harder it may become to pass costs of the transition on via its product price.

Thus, irrespective of whether OEMs or regulators define a quasi (global) standard only legally binding in some geographies, there is little chance for suppliers (that wish to remain suppliers) not to pursue decarbonisation. This holds true even in cases where carbon pricing or adjustment schemes may not (directly) affect one's manufacturing if the company at the top end of the chain decides on (net) carbon or climate neutrality of their product at the point of handover.

A question that should be monitored is to what extent the supply industry is supported in such a transition or "merely" forced to act. On the one hand, **supportive approaches** such as decarbonisation networks in the supply chain and capacity building programmes can accelerate the process and thus shorten the period in which car manufacturers have to take on the burden of offsetting the remaining emissions. On the other hand, changing **requirements in** progressively renewed **supply contracts** can force a reduction of the GHG emissions embedded in upstream products. While this would lead to the same outcome for the car manufacturer as in the previous case, it would also be left up to the supplier to decide how and whether to achieve this, including the corresponding consequences. The approach taken can have a significant impact on the speed and ability of supply chains to decarbonise, as well as on the survival of indigenous suppliers.

The points made largely and generally apply to many different sectors, even though this example focuses on the automotive industry – the more globalised, the more present in daily life the product is, the more the points made are likely to apply. The results of the second data collection of the Energy Efficiency Index of German Industry (EEI) 2021 [64] show sectoral patterns regarding the paths followed as well as a connection between what is experienced and what is done: 60 % of the participating companies in the computer and electronics industry (sector 26) make requirements in supply contracts and 64 % of them stated that they are confronted with requirements in supply contracts (across all companies: 38/32 %). Of the manufacturers of metal products (sector 25), 39 % work with their suppliers through decarbonisation networks and 42 % of them report that their customers do the same with them (across all companies: 26/ 22 %).

Most companies depend on loans or investments made available by banks or (long-term) investors to fund the set-up or change of operations, if not the operations in general. As indicated with the pressure points (see section 3.2), **remaining attractive to investors,** which increasingly abandon non-futureproof business models, is a critical factor for companies. 100 banks and long-term investors managing approximately 4 trillion dollars of assets voluntarily subscribed to the 'energy efficiency financing principles of G20 participating countries', its associated bank statement, and UNEPs Principles for Responsible Investment around the World Climate Conference 2015 in Paris (COP21). The share of global investors who place a high(er) **emphasis on sustainability aspects in financing requests has increased significantly** since then [91-92]. Two legislative frameworks of the European Union put further pressure – but also offer opportunities – on the issue of access to funding: The so-called EU taxonomy regulation (EU)2020/852 is meant to aide identifying sustainable activities and thus to help financing sustainable growth within the European green deal [93]. The non-financial reporting directive 2014/95/EU "require[s] large companies to publish regular reports on the social and environmental impacts of their activities" [94]. Even though strictly speaking of a non-financial nature, company sustainability/energy managers consider their Corporate Social Responsibility reports (CSR) more than an obligatory exercise. In fact, managers of two companies interviewed in 2020 consider CSR reports as essential means to present their pledges and associated activities to remain investable. Wang and Buettner [95] describe further how sustainability key performance indicators (KPIs) within CSR reports can become a motivating vehicle for sustainable transformation of businesses.

### 3.3.3 Economic rationality: The perhaps strongest and most immediate motivation

Bosch [71] explained they would invest 2 billion Euros by 2030 to become carbon neutral by 2020. Nonetheless, it would essentially only cost them 1 billion Euros due to the savings achieved through energy efficiency and other interventions reducing costs.

To manage a full net carbon neutrality by 2020 – in Bosch' case within 20 months – a number of phases need to run in parallel. After a full assessment of the status quo in terms of emissions and means to structurally avoid them, it is necessary to swiftly change all sources of energy (economically) feasible to sustainable sources and offset the remaining emissions through the purchase of carbon credits. This is significant as technical interventions, such as energy efficiency measures, local self-generation of renewable energy and means to buffer store surplus energy must first be thoroughly planned, then approved by the authorities and finally be built/installed, tested and brought online. Consequently, over time, energy use will be successively more efficient and the amount of energy generated locally will increase in a manner which means that less sustainable energy needs to be purchased-in and/or less emission certificates will be required. In summary, while neutrality is achieved almost instantly, the way it is achieved will gradually change and become cheaper. Specifically, efficiency upgrades will have paid off at one point and the cost savings of energy generated on-site will exceed the investment and maintenance costs. The higher energy and/or emission prices are the quicker this will be the case.

Instead of (exclusively) paying others for energy supply and security, companies have the chance of **vertical internalisation**, meaning that they can get a number of these steps into their balance sheet envelope. For example, the costs of generation, procurement, transmission, and the margin that energy suppliers would otherwise have received can be internalised.

As described, the *easiest* means to expedite decarbonisation is **switching the energy tariff** to a green (or blue) energy tariff and to **compensate/offset remaining emissions –** at least it appears that way. In fact, the trick is in the detail and the overall picture, making it only supposedly simple: In 2019 about 43 % of German electricity came from renewable sources, but the industrial sector alone accounts for about 46 % of German electricity consumption [96,97]. Therefore, even without sectoral coupling (electrification), e-mobility and decarbonisation of industrial processes through green hydrogen, the demand for sustainable electricity will quickly exceed the supply. Roughly estimated based on EEI data [26], the additional renewable energy demand of industry by 2025 would be equivalent with a 25 % increase of renewable energy generation compared to 2019 if companies are (able to) decarbonise their operations as indicated in the survey [98]. Typically, a demand overshoot at least leads to sharp price increases (see for instance the price peak when the Texan energy system collapsed in early 2021) or even to no sustainable energy tariffs being accessible to new clients for the time being [99]. Additionally, as the market for renewable energy is swiped empty in such scenario, the GHG footprint of the standard tariff of everyone else will worsen leading to a societal zero-sum game as long as no substantial additional renewable generation is put in place, either on-site or attached to the grid.

Similarly, the number of and price charged by decent compensation schemes or certificates will increase in a situation of demand overshoot. Further, the risk that chosen schemes backfire increases as one needs to thoroughly assess how the compensation is done to avoid negative PR over questionable or even fraudulent compensation measures. For instance, burning down rainforest to make space to plant new trees, ensuring that planted trees will never be chopped down, or ensuring certificates are correctly computed [100] and newly protected forests were actually endangered [101].

Particularly (a) the steep increase of the European ETS price (from around 25 EUR per tonne of $CO_2$-equivalent in October 2020 to around 75 EUR in September 2022 [102]) since the EU raised its climate-protection ambitions for 2030 from a 40 % to 55 % emission reduction compared to 1990, (b) the introduction of the German emission price in January 2021, as well as reports that (c) ETS may become a playball to speculators encourage to take decisive 'counter measures' [103]. Thus, building one's decarbonisation strategy only on these supposedly simple measures may backfire in terms of cost, availability, or PR risks.

Therefore, timely action – be it through early acquisition and long-term contracts and/or through local efficiency upgrades and self-generation – constitutes an **early disconnect from increasing cost and supply shocks** and allows companies to gain control over energy and emission related risks & costs.

The outcome of these actions is a **reduction of payments to 'others'** in terms of the general cost of energy. The more of the decarbonisation activities are taking place locally or are secured through long-term contracts (including options and futures), the more this applies. Furthermore, the higher emission- or energy prices are, the higher the costs of inaction would be and the quicker countermeasures that were undertaken pay off.

Instead of buying emission certificates, investing into external compensation schemes, or paying for ETS or other emission price schemes outright, **setting up one's own compensation scheme** could be an interesting option for manufacturers of some types of products. Specifically, it has the potential to internalise functions and thus disconnect from price, PR, and availability shocks. This could be similar to the approach taken in energy efficiency obligation schemes, where energy providers need to ensure to save a certain percentage of their annual energy sold in the form of energy efficiency activities [104]. An example would be scrappage schemes where customers are asked to provide the specifications of their current fridge, to get a substantial rebate on a more energy efficient fridge acquired through the shop of the energy provider. In this case, the energy provider can claim the energy consumption difference for a typical use case as energy efficiency saving in context of its energy efficiency obligation. Typically, a provider would have a small range of replacement products on offer, allowing them to secure bulk-purchase prices and hence reduce the acquisition costs and the net cost of their scrappage scheme. Although it might be farfetched to transfer this idea to manufacturers and it would require thorough compliance-checks to count as compensation measure, self-initiated scrappage schemes using their own range of products could potentially save on emissions. Moreover, such schemes could lead to an increase end-use energy efficiency, have lower costs than external solutions and be beneficial for one owns economies of scale. For other types of products, it may be feasible to use them in external aid-based compensation projects and gain good press from doing so.

As described, optimising the energy consumption, internalising value creation, and generating energy on-site – in summary local decarbonisation action – not only saves money and builds resilience against external shocks, it also leads to **improved energy productivity, as well as increased competitiveness and resilience**.

Having successfully found a route to become, i.e., (net) carbon neutral comes along with much knowledge gained on the options, but also aspects that went well and those one would do differently. In the language of human resources, the company will have gained specific human capital. While a decarbonisation approach evolves even after net carbon neutrality is reached, there is the option to make use of the capacity built to **get paid for showing others** how to replicate becoming carbon neutral (as Bosch now does via Bosch Climate Solutions).

To conclude section 3.3, what most strategy-related announcements have in common is that **the timing matters**. So why did Bosch choose to announce their goal to become net zero carbon by 2020 at this point, why at all and what might have been the motivations behind such a decision? Whilst the real motivations are only known to those who took the decision, there are a series of indications that *might* have played a role, that are *likely* to have played a role and that Bosch *declared* have played a role.

On 23 May 2019, exactly two weeks after the carbon neutrality pledge, it was announced that Bosch was being fined 90 million Euros for its involvement in the *Diesel scandal* [105]. Before being fined there was an investigation by the relevant authorities, which usually takes months if not years. Even if it was not yet known by Bosch at the time, when and what fine they would be faced with, it is rather likely that they knew something was coming in the near future. This allowed them to pre-emptively take the bull by the horns, meaning they were able to make a move before the bad news became publicly known. As numerous examples by other companies involved showcase, the sequence of events makes a huge psychological and PR difference: those that are found guilty and who promised to do better are not appearing as genuine as those who have promised better before they were found guilty [106].

What is known, and also visible here, is that it is often strong exogenic factors or incidents that drive or trigger organisational change [107]. The Diesel scandal *may* have played a strong role for Bosch, as probably have many of the other factors described. Similarly, Volkswagen, with its dozen brands, would have probably not taken the most drastic choice of all large manufacturers towards e-mobility and zero carbon vehicles (at the point of handover) [108] without having been at the centre of the scandal [106]. How-

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ever, whether these measures were put in place to pre-empt external pressures from unfolding their full weight or to reduce upcoming pressure early on can ultimately only be answered by those who were involved.

Driver of such organisational change, i.e., declaring to become climate or carbon neutral, can be one single or a combination of triggers. What has been uncovered in the analysis thus far is a set of pressure points and possible triggers, derived from findings of various disciplines, observations, anecdotal first-hand experience and news articles.

The following section is therefore taking a closer look at what companies are ready to disclose with regard to what actually motivates them most to reduce their greenhouse gas footprint.

*3.4. Why decarbonise? What motivates companies most to decarbonise?*

In the framework of the first iteration of the Energy Efficiency Index of German Industry (EEI) in 2020 [26], companies were presented with seven potential factors leading to a decarbonisation decision. These are derived from what has been discussed in chapter three so far, as it was necessary to limit the answer options to facilitate the telephone-based market research component: customer requirements, investor requirements, government requirements, image improvement (for instance attraction of skilled workers, or displaying leadership role), corporate social responsibility (CSR), long-term economic advantages and reduction of cost risks. Some of those factors can be classified as (external) drivers, such as customer-, government- and investor requirements and cost risks. Other are rather classified as motivators, such as long-term economic advantages, image improvements and corporate social responsibility. Companies were asked to indicate which (up to) 3 factors motivate their company *most* to reduce their greenhouse gas emissions.

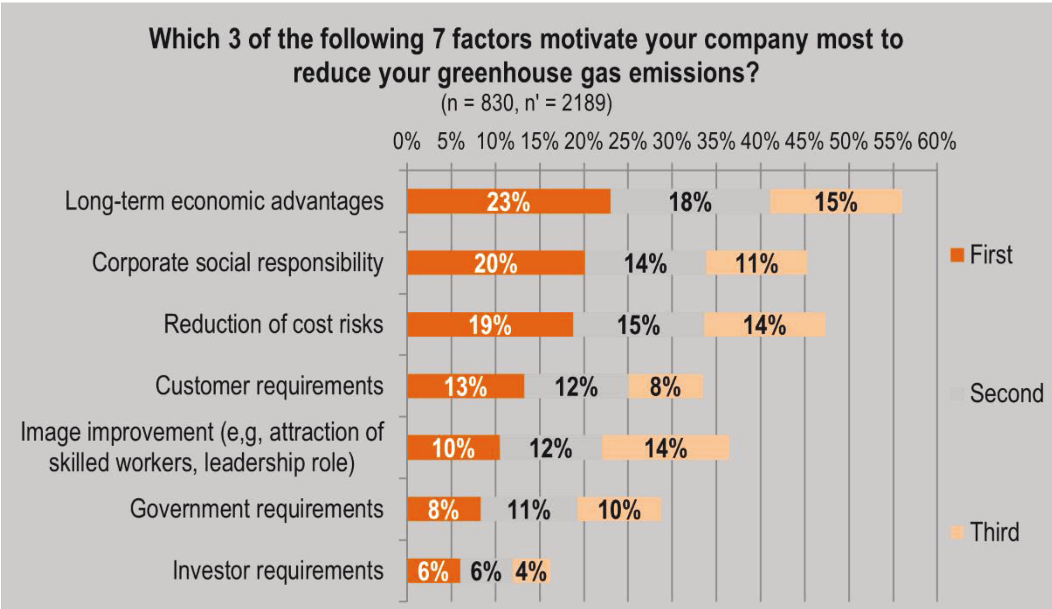


**Figure 1**: Top 3 motivators for Greenhousegas (GHG) reduction decisions, overall sample (n = 830) [26]

More than half (56%) of participating companies state that **long-term economic advantages** are among their top 3 motivators to reduce their greenhouse gas (GHG) emissions, while for nearly one-fourth (23 %) of them it is even their primary motivator (cf. **Figure 1**). Looking at the overall sample, no other motivator is indicated by companies as often as their first, second or third priority. Additionally, many (not all) measures reducing emissions are accompanied by an increase in efficiency, a decrease of ongoing

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costs, as well as reduced emission costs. These side-effects influence the overall production costs and subsequently competitiveness. In terms of hard financial factors but also soft factors (i.e., surfing on the sustainability wave), decarbonising promises a company long-term economic benefits. These hard factors are also those leading to a **reduction of cost risks, which was the first priority for 19% of participating companies**. A reduced demand of energy delivered to the company from outside and reduced emissions both help to lessen the impact of emission and energy prices (and concerns about their availability). Therefore, it is not surprising that the reduction of cost risks is among the top 3 motivators to decarbonise by nearly every second company 48 %. That said, another factor is a primary motivator for more companies: **corporate social responsibility (CSR)**. Counting to the 'soft factors', CSR represented the first priority for 20% of participating companies. Moreover, the fact that 45 % of companies list CSR among their top 3 motivators underlines that taking (and displaying) responsibility already plays a significant role in the industrial sector. However, how genuine this is in comparison to those who are economically or resilience-driven can only be judged if the measures *actually* taken are compared in their impact on decarbonisation rather than targets announced only.

Even though **customer requirements** rank as the fourth most frequently chosen primary motivator, there is a substantial gap between it and the first three primary motivators (13 % vs. 19-23 %). When taking the top 3 motivators in aggregate (33 %), it even falls behind **image improvement** (36 %). What is interesting about comparing these two is that while the percentage of companies considering customer requirements as a top 3 motivator increases (third priority 8 %, second priority 12 % and first priority 13 %), it decreases for those considering image improvement a top 3 motivator. This *could* suggest that the image impact of decarbonisation efforts is a relevant consideration but not often the primary one. Given that the percentage figure for third priority is only as high / slightly higher with the motivation of long-term economic advantages (15 %) and reduction of cost risks (14 %), this assumption finds some support in the data. For customer requirements, this *could* indicate that if a company decarbonises to please its customer [109], they are more likely to do so if image improvement is higher up in their motivational priorities.

**Government requirements** are a motivator for less than a third of companies (29 %), suggesting that almost all other factors are stronger triggers for a company to increase its decarbonisation efforts. Similarly, **investor requirements** are a top motivator only for few companies (16 %). Nonetheless, this may look different for companies that have a high dependency on (long-term) investors. If one distinguishes between business loans (i.e., from a commercial bank) and long-term investments, the significance of investor requirements might be higher for larger companies that are not in private ownership and those that have higher capital needs. In fact, a deeper look into the data suggests this is to some extent the case for medium-sized companies (19 %), for whom investor requirements are primary motivator 50 % more often (9 % compared to 6 % on average). In light of the increasing popularity of ESG (Environmental, Social, and Governance) investments over the past years in combination with companies' desire to remain investable or increased direct pressure from shareholders it is likely that these figures would be higher if the same question was asked today; the same most likely also applies for the reduction of cost risks during the current energy crisis. According to recent studies of the Federation of German Industries (BDI) and the German Economic Institute (IW), the crisis also leads to postponing investments into the ecological transition, which is tragic, as the less companies invest into decarbonising their operations, the more they are hit by increasing emission and energy prices [110].

From a general viewpoint, the motivators such as economic benefits described earlier therefore have the highest motivational relevance in the decision to reduce one's greenhouse gas emissions. Purely external drivers in contrary are ranked almost consistently below these motivators. This is essentially in line with the findings of earlier presented literature that internal motivation outweighs external pressure [15-17]. Further,

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this suggests that aiming to successfully trigger intrinsic action might lead to at least higher motivation and potentially even better outcomes than applying external 'force'. However, the results of this study differ from Boiral et al. [17] in that long-term economic advantages were found to be the most significant motivator rather than being less important than environmental and social concerns (except for micro companies). Additionally, in comparison to previous studies, the reduction of cost risks was discovered to be of higher significance than image improvement (reputation).

As the industrial sector is very diverse, it makes sense to explore how this analysis differs when looking at it from a company-size (Section 3.4.1), a supplier-state (Section 3.4.2), an energy-intensity (Section 3.4.3), and a sectoral (Section 3.4.4) viewpoint, as well as depending on company's primary decision determinants (Section 3.4.5). Before doing so, considering different dependencies and underlying strategies in the choice of priorities as suggested in Sections 3.1-3.3, it makes sense to also assess how the company's GHG reduction ambitions differ, depending on their primary decarbonisation motivator.

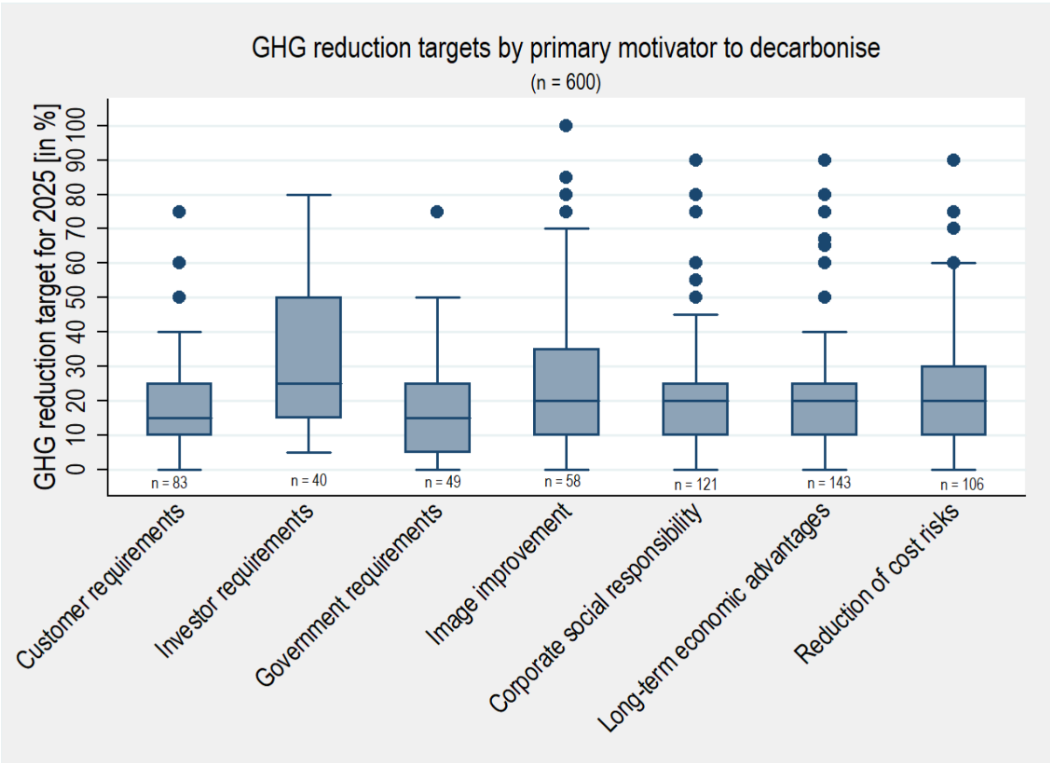


**Figure 2**: GHG reduction targets by primary motivator to decarbonise (n = 600) [26]

Only a small proportion of companies (16 %) have declared investor requirements as one of the top motivators in May 2020. Nevertheless, for those attributing such requirements as their primary motivator to decarbonise (6 %), the associated level of ambition is substantially higher than with any other primary motivator, including all quartiles and whiskers **(cf. Figure 2)**. Given (a) conversations with entrepreneurs who stated that remaining investable is critical to the survival of the business, (b) the increasing trend to preferentially invest in funds that carry a green or sustainable label, and (c) the new EU taxonomy, the number of companies motivated by investor requirements may have increased significantly since the data was collected.

The data further illustrates that the more ambitious half of companies, which is primarily motivated to decarbonise by image considerations, is also significantly more ambitious in relation to its GHG reduction goal than the average. Considering the ever-increasing skills gap due to demographics and a shift in the type of skills needed, it could very well be that 'being more attractive' to applicants than competitors in terms of ambitions could explain to some extent the above-average goals of this group of companies. On the flip side, doubts have been voiced concerning the honesty of targets, particularly when they appeared to be image-driven (i.e., greenwashing) [111].

Similarly, but to a slightly lesser extent, the more ambitious half of companies, whose primary motivator to decarbonise is the reduction of cost risks, have also targeted GHG goals that are significantly above average. In the current situation, the war in Ukraine, the resulting increase in energy costs, the security of supply issues, and the high emission cost combine to a particular challenge. Consequently, there is a chance that both the weight and the level of the motivator of reducing cost risks is increasing further. In particular, resilience against price and supply shocks can be increased by a 'sustainable' decrease of the emission footprint along with boosting on-site decarbonisation efforts, such as energy efficiency and self-generation of renewable energies [112].

In contrast, companies that are primarily motivated to decarbonise because of customer requirements show a below-average level of ambition. It cannot be distinguished whether the responding companies consider a customer or the company they supply to as the end client. The data cannot confirm whether these companies set their target to show just enough ambition to maintain the contractual relationship with their customers or to be able to sell their products, but these could be considerations of these companies. Provided this assumption is correct, there is a high likelihood that the level of ambition set by these companies would rise if the question was asked again today. The Energy Efficiency Index of German Industry found in early 2022 that 7 out of 10 manufacturing companies plan work to be able to sell their products with a net-zero emission footprint. Nearly half of these 70 % stated that they impose or will impose requirements on their supply chain to fall in line and reduce their emissions to achieve this goal [64].

The lowest level of ambition is found in companies whose primary motivator to decarbonise are government requirements. As all other motivators contribute to maintaining a successful business model (keeping clients and investors happy, being attractive to the outside and new recruits, looking caring and ensuring long-term profitability whilst reducing any risks), it appears that external demands, which limit the company's freedom without contributing to its business goal, are catered for like a check box exercise: The company does just enough to meet the requirements. In other words, it appears that there is only a willingness to do more for motivators promising a benefit for the company. Accordingly, for motivators which are about not being penalised, companies are more likely to do just as much as necessary.

Therefore, the key takeaway from **Figure 2** is that positive drivers appear to lead to higher ambition. Consequently, strategies to motivate companies to decarbonise or set ambitious goals should refrain from building on regulatory requirements and instead focus more on motivators and market tools. **Policy measures that *indirectly* impact any of these could hence have a stronger effect on ambition levels than imposing *direct* requirements.**

In light of this, holding companies accountable to actually achieve their goals is a whole other issue, but that is to be analysed elsewhere.

86 While **Figure 2** illustrated the envisaged GHG emission reduction ambitions of participating manufacturers in general in consideration of their respective primary motivator, the box plot figures in the following subsections allow a deeper view, showcasing how ambitions vary depending on company size, supplier state, energy intensity, sector and primary decision factor. Even though on these levels the sample size is still considerable, caution has to be applied and results should be considered as indications only. For this reason, the analyses of these figures are limited to highlighting the most striking differences between the categories shown.

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3.4.1 Company size perspective on primary motivators for GHG reduction decisions

Switching to a company size viewpoint (cf. **Table 4**) makes clear that role and weight of the motivating factors differ across company sizes:

**Table 4**: Primary motivators for GHG reduction decisions, by company size (n = 817) [26]

| | micro company | small company | medium-sized company | large company | total |
|---|---|---|---|---|---|
| Long-term economic advantages | 22% | 21% | 20% | 29% | 23% |
| Corporate social responsibility | 25% | 15% | 19% | 24% | 20% |
| Reduction of cost risks | 21% | 19% | 17% | 19% | 19% |
| Customer requirements | 14% | 14% | 12% | 13% | 13% |
| Image improvement | 10% | 15% | 12% | 4% | 11% |
| Government requirements | 6% | 10% | 10% | 7% | 8% |
| Investor requirements | 3% | 6% | 9% | 5% | 6% |
| Observations | 174 | 222 | 246 | 175 | 817 |

Whereas long-term economic advantages are the most frequently chosen primary motivator in general, this is not the case for all company sizes. Taking responsibility – possibly due to a high share of locally embedded and family-owned companies – is the most frequently chosen primary motivator for micro companies (25 %), followed by economic advantages (22 %) and cost risks (21 %). Small companies are the only company size where cost risks are second most often chosen (19 %). For them, the image factor is the primary driver much more frequently (15 %) than for medium-sized (12 %), micro (10 %) or large companies (4 %). On the other hand, CSR is by far the least frequently chosen primary motivator for small companies (15 %). While medium-sized companies are closest to the average distribution, large companies stand out with a significantly higher share of companies nominating long-term economic advantages as primary motivator (29 %) and a significantly lower share choosing image considerations as the primary driver (4 %) at the time of data collection.

Looking at GHG reduction targets from a company size perspective (cf. **Figure 3**), considerable differences can be observed. Medium-sized companies that consider customer requirements their primary motivator set considerably higher GHG reduction targets than companies of other sizes. This could be a result of larger companies already introducing strict requirements by which particularly medium-sized companies are affected or anticipate they will be affected (cf. automotive industry in Section 3.3.2). While micro companies who are mainly motivated by government requirements indicate considerably lower than average GHG reduction targets, the opposite is the case for large(r) companies. One possible explanation is that regulatory policy often focuses on large(r) companies, while most micro-enterprises may not be sufficiently affected to envisage higher GHG targets. Many small and micro companies who consider image improvement their primary motivator set substantially higher GHG reduction targets than other companies. It is possible that difficulties in attracting staff (especially competing with larger companies) and/or the desire to appear as an environmentally conscious company locally could explain the higher targets of the more ambitious half of small and micro-companies. While many medium-sized companies who are primarily motivated by the reduction of cost risks set higher GHG reduction targets than the other companies, the opposite is the case for micro companies. Micro-enterprises often do not have the necessary expertise on energy and decarbonisation aspects unless the company is energy intensive. Therefore, either the share of energy costs is not high enough or there is a lack of awareness of the possible negative consequences of inaction (especially if charges increase).

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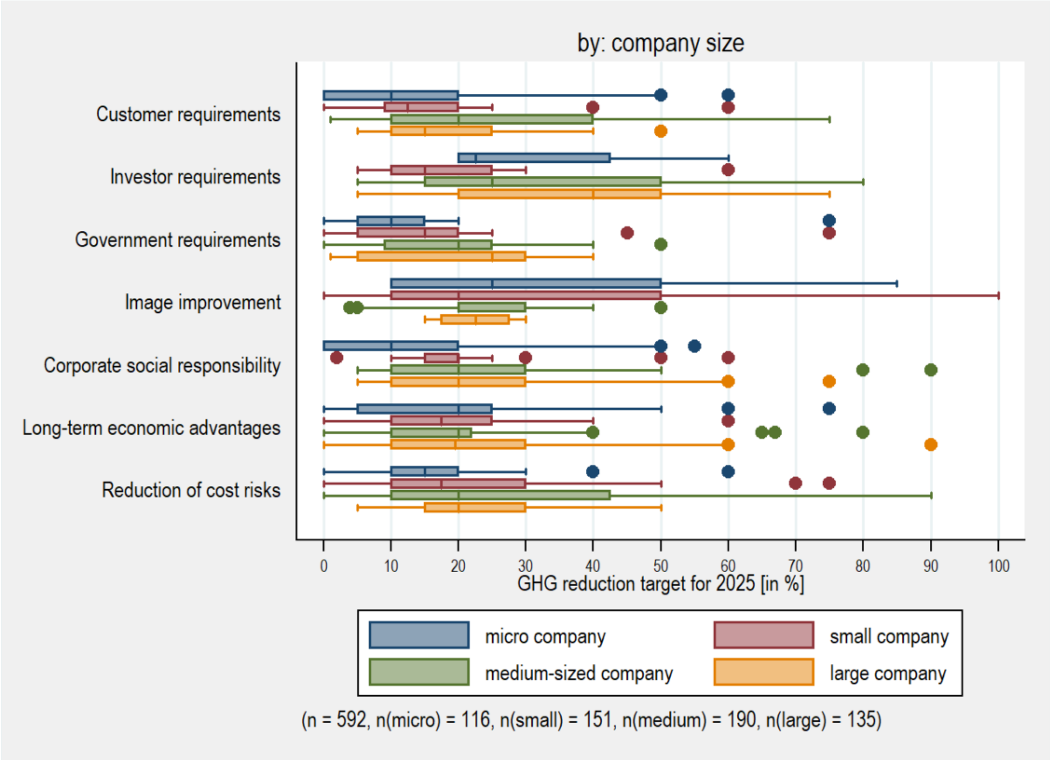


**Figure 3**: GHG reduction targets by primary motivator to decarbonise (n = 592), by company size [26]

3.4.2 Supplier perspective on primary motivators for GHG reduction decisions

It appears that those companies at the end of the supply chain, meaning those companies that are not suppliers of other companies (cf. **Table 5**) are considerably more often motivated by long-term economic factors (26 %) and by CSR aspects (23 %) than the average and than companies considering themselves mainly as suppliers. Being at the top end of the supply chain could allow more degrees of freedom for decisions based on principle and entrepreneurial foresight. At the same time, large companies that fall into this category are more likely to fall under the EU CSR directive and thus under the CSR reporting obligation [95]. It remains to be checked whether, in the case of suppliers, customer requirements deviate in importance from the average when looking at the secondary or tertiary motivator. Regarding primary motivators, with 14 % such a deviation is – somewhat surprisingly – hardly visible.

**Table 5:** Primary motivators for GHG reduction decisions, by supplier status (n = 821) [26]

| | Do you consider your company primarily as supplier to other companies? | | |
|---|---|---|---|
| | **Yes** | **No** | **Total** |
| Long-term economic advantages | 21% | 26% | 23% |
| Corporate social responsibility | 19% | 23% | 20% |
| Reduction of cost risks | 19% | 18% | 19% |
| Customer requirements | 14% | 12% | 13% |
| Image improvement | 12% | 8% | 11% |
| Government requirements | 9% | 9% | 9% |
| Investor requirements | 7% | 5% | 6% |
| Observations | 564 | 257 | 821 |

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Whether a company is predominantly a supplier to other companies appears to lead to the biggest differences in level of ambition if 'investor requirements' are the primary motivator (cf. **Figure 4**). In the face of increasing demands on the upstream supply chain, this can be an attempt to pre-empt or meet them and thus protect the company's value or remain investable and secure the financial resources to fund implementation (see section 3.2 and section 3.3.2). That suppliers set more ambitious goals if they are primarily motivated by 'customer requirements' or 'image improvement' appears more intuitive (cf. requirements in supply contracts, being in the 'good books', etc). As suppliers are, in consequence of their state as supplier, involuntary risk-takers (dependent of what their client may or may not want of them) a bigger spread of GHG reduction ambition level when it comes to 'reduction of cost risks' as primary motivator appears understandable.

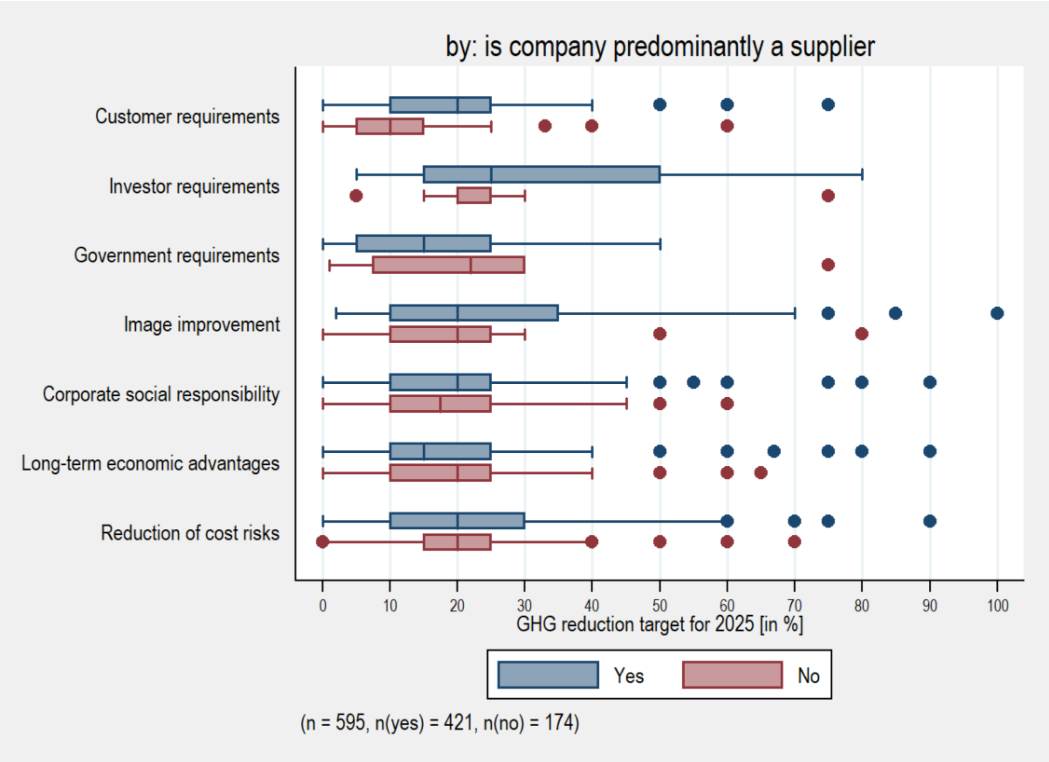


**Figure 4**: GHG reduction targets by primary motivator to decarbonise (n = 595), by supplier state [26]

3.4.3 Energy intensity perspective on primary motivators for GHG reduction decisions

**Table 6:** Primary motivators for GHG reduction decisions, by energy intensity (n = 622) [26]

| | not energy intensive | less energy intensive | moderately energy intensive | energy intensive | Total |
|---|---|---|---|---|---|
| Long-term economic advantages | 22% | 19% | 24% | 23% | 22% |
| Reduction of cost risks | 19% | 20% | 19% | 30% | 20% |
| Corporate social responsibility | 16% | 23% | 17% | 23% | 20% |
| Customer requirements | 16% | 15% | 14% | 2% | 14% |
| Image improvement | 10% | 9% | 11% | 14% | 10% |
| Government requirements | 9% | 9% | 7% | 7% | 8% |
| Investor requirements | 7% | 6% | 8% | 2% | 7% |
| Observations | 149 | 235 | 194 | 44 | 622 |

Taking a brief look at the primary motivators from an energy intensity viewpoint (cf. **Table 6**), the reduction of cost risks significantly sticks out, selected by 30 % of energy

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intensive companies, understandably as energy intensity often goes along with carbon intensity and a high associated footprint as well as associated costs. Long-term economic advantages are most often the primary motivator (24 %) of moderately energy-intensive companies. For energy-intensive companies, customer or investor requirements are a significantly less important motivator (2 % each) than for other energy intensities. Conversely, image plays a higher role (14 %) than on average.

When it comes to the level of ambition (cf. **Figure 5**) it strikes out that if 'investor requirements' are primary motivator then particularly not energy intensive companies set above average ambitions. Perhaps this is because it is comparatively easy for (many of) them to reduce the majority of their emissions by switching their source of fuel allowing them to drastically reduce emissions. If 'customer requirements', or 'image improvement' are primary motivators, many of these companies tend to set more ambitious targets the more energy intensive they are. This finding seems logical, as energy consumption is more visible and better known, which tends to increase (implicit external) demands for decarbonisation measures. Since energy and emission costs are more significant on companies' balance sheets the more energy-intensive they are, it stands to reason that ambitions increase with energy intensity if companies are primarily motivated by 'long-term economic benefits'. The same applies, with the exception of moderately energy intensive companies, regarding the 'reduction of cost risks'. The opposite appears to be the case with 'CSR', but possibly with the limitation that larger companies are required to have CSR reporting in place, which influences their ambitions.

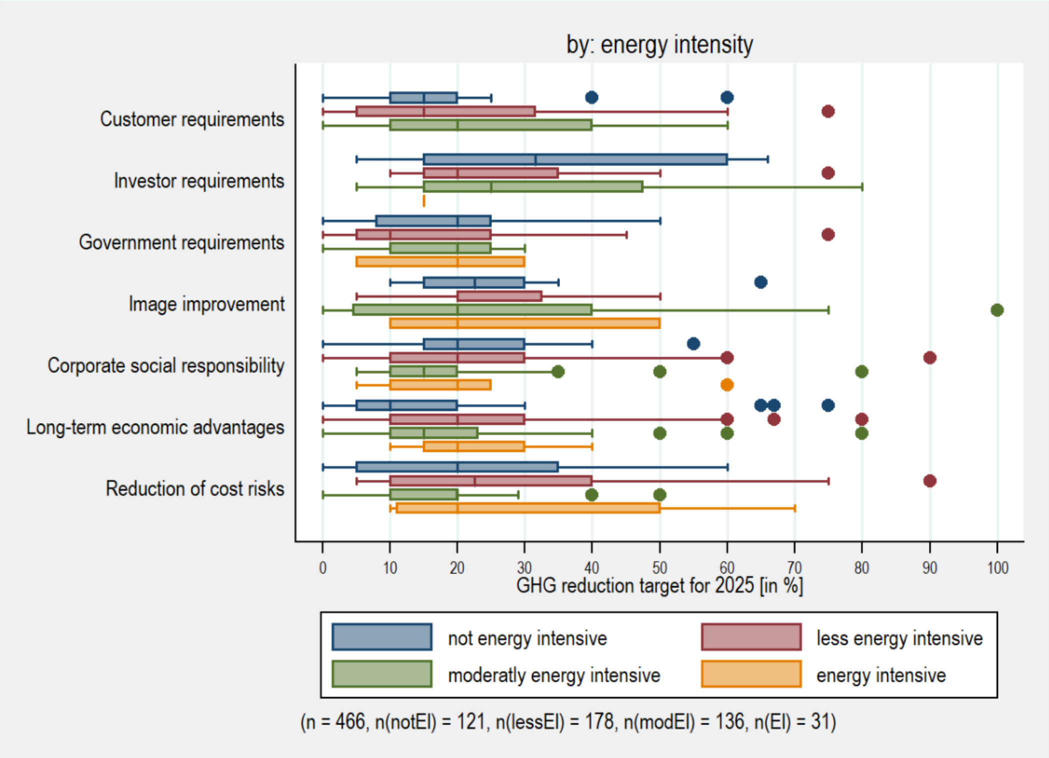


**Figure 5**: GHG reduction targets by primary motivator to decarbonise (n = 466), by energy intensity [26]

3.4.4 Sectoral perspective on primary motivators for GHG reduction decisions

As can be expected, from a sectoral viewpoint, the situation deviates significantly for primary industry motivators and requires a more in-depth analysis to allow qualified statements.

 doi:10.20944/preprints202210.0395.v2



**Table 7** underlines that the significance of a primary motivator is nowhere as varied as when one distinguishes the companies by sector, with a difference of up to 35 percentage points between sectors. These large differences between sectors highlight the importance of a sectoral approach to decarbonisation, especially for policy measures: While 'long-term economic advantages' are primary motivator for 43 % of companies in the computer & electronics industry (26), the same motivator is named a primary one only by 10 % of companies in the leather industry (15). Potentially there is a link to the energy-intensity of the product range, as well as investment intensity for changing over the production machinery, that could explain the difference. On the flip side 'CSR' and 'customer requirements' are primary motivators most often for the leather industry (15; 35 % and 26 %), which suggest a high customer sensitivity to the way products are being created by this sector. The 'reduction of cost risks' is most often a primary motivator for the automotive industry (29), which is not surprising considering points made in section 3 so far. As oil and gas are responsible for large parts of energy-related emissions, it is not unexpected that 'image' is the most frequent primary motivator (23 %) for decarbonisation in this industry (06) and 'government requirements' most frequent for companies in the coal mining industry (05; 25 %). The fact that the chemical industry (20) is quite emission intensive and faces more difficulties in decarbonising their core processes possibly explains why 'investor requirements' are most often a primary motivator in this sector (13 %), combined with an above average rate for both 'reduction of cost risks' (24 %) and 'long-term economic advantages' (24 %).

**Table 7:** Primary motivators for GHG reduction decisions, by sector (n = 729, n(sector) ≥ 20 or **)

| Primary motivation, by sector (n = 729, n ≥ 20 or **, *) | Long-term economic advantages | Corporate social responsibility | Reduction of cost risks | Customer requirements | Image improvement | Government requirements | Investor requirements | Observations |
|---|---|---|---|---|---|---|---|---|
| 26 Manufacture of computer, electronic and optical products | **43%** | 19% | 14% | **0%** | 14% | 5% | 5% | 21 |
| 10 Manufacture of food products | 32% | 23% | 13% | 19% | 10% | **3%** | **0%** | 31 |
| 22 Manufacture of rubber and plastic products | 32% | 19% | 14% | 13% | 10% | 5% | 8% | 63 |
| 16 Manufacture of wood & of products of wood & cork, except furniture; manufacture of articles of straw and plaiting materials | 31% | 23% | 13% | 15% | **3%** | 13% | 3% | 39 |
| 06 ** Extraction of crude petroleum and natural gas | 31% | 15% | **8%** | 15% | **23%** | **0%** | 8% | 13 |
| 17 Manufacture of paper and paper products | 28% | 18% | **10%** | 24% | 10% | 8% | 2% | 50 |
| 05 ** Mining of coal and lignite | 25% | **0%** | 25% | 13% | 13% | **25%** | 0% | 8 |
| 20 Manufacture of chemicals and chemical products | 24% | **7%** | 24% | 13% | 13% | 4% | **13%** | 45 |
| 24 Manufacture of basic metals | 23% | 25% | 28% | 8% | 10% | 5% | 3% | 40 |
| 28 Manufacture of machinery and equipment n.e.c. | 21% | 21% | 20% | 14% | 11% | 6% | 6% | 70 |
| 32 Other manufacturing | 21% | 21% | 21% | 10% | 10% | 10% | 7% | 29 |
| 31 Manufacture of furniture | 21% | 21% | **10%** | 14% | **21%** | 10% | 3% | 29 |
| 21 Manufacture of basic pharmaceutical products and pharmaceutical preparations | 20% | 12% | 20% | 16% | 12% | 8% | 12% | 25 |
| 23 Manufacture of other non-metallic mineral products | 20% | 34% | 20% | 7% | 7% | 7% | 5% | 41 |
| 25 Manufacture of fabricated metal products, except machinery and equipment | 19% | 22% | 22% | 16% | **3%** | 9% | 9% | 58 |
| 27 Manufacture of electrical equipment | 19% | 22% | 17% | 6% | 14% | **16%** | 6% | 64 |
| 18 Printing and reproduction of recorded media | 17% | 26% | 26% | 13% | 9% | 9% | 0% | 23 |
| 29 Manufacture of motor vehicles, trailers and semi-trailers | 16% | 12% | **33%** | 12% | 8% | 12% | 6% | 49 |
| 15 Manufacture of leather and related products | **10%** | **35%** | 10% | **26%** | 6% | 6% | 6% | 31 |
| Total | 23% | 21% | 19% | 13% | 10% | 8% | 6% | 729 |

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As underlined, the number of companies per sub-category shrink substantially the deeper one drills into details. This particularly applies for the sectoral perspective, which is why only the four sectors with most participating companies in this question are showcased for illustrative purposes (cf. **Figure 6**). The largest differences in level of ambition are found where 'investor requirements' or 'CSR' are primary motivator. What sticks out is that both the ambition level and spread are closest across sectors when it comes to 'long-term economic advantages' desire that understandably all companies have in common as it 'makes economic sense'. The pressures perceived by the automotive industry (29, cf. section 3.3.2) may explain their substantially higher average and range of GHG reduction ambitions. That ambition levels vary largely underlining that triggers stimulating to achieve higher targets can be very sector-sensitive. This point showcases the need for tailored approaches building on the pressure points, interdependencies and motivators highlighted in sections 3.1-3.3.

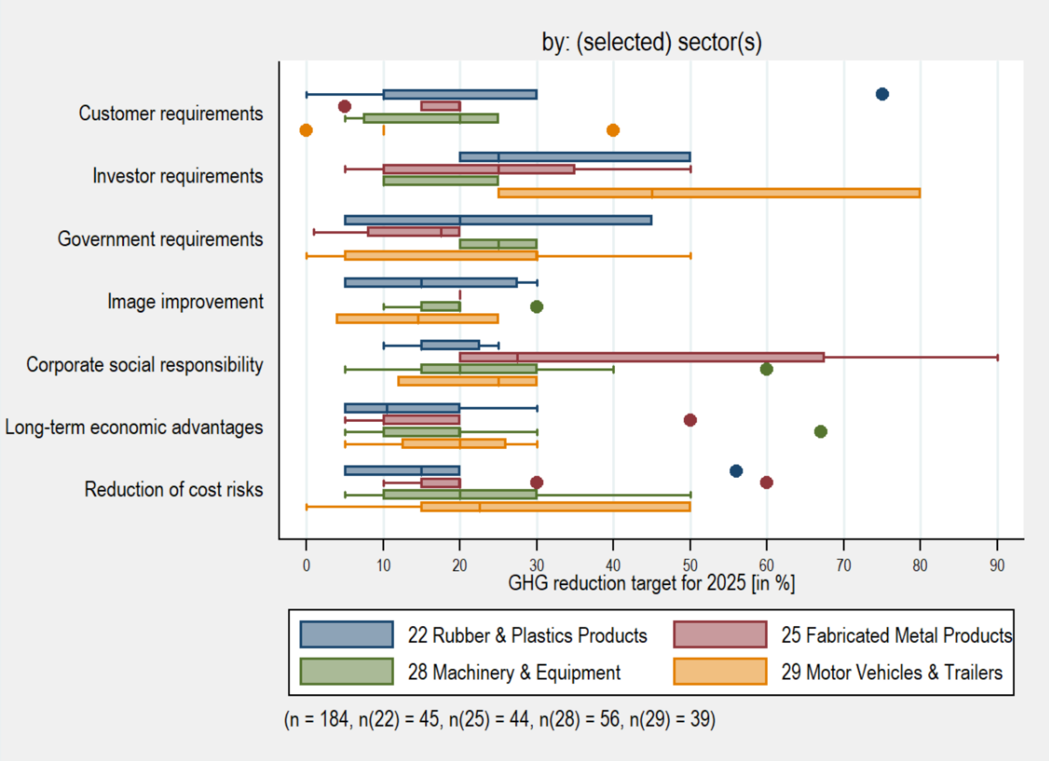


**Figure 6**: GHG reduction targets by primary motivator to decarbonise (n = 184), by sector [26]

3.4.5 Decision determinant perspective on primary motivators for GHG reduction decisions

In the EEI questionnaire [26], companies were also asked based on which primary decision criterion they take their decarbonisation decisions, which is analysed in its own right by Buettner and König [113].**Table 8** illustrates that primary motivators to decarbonise differ considerably, depending on which primary decision determinant a company uses to guide its decisions. Confirming what intuition would suggest, the 'long-term economic advantages' are most often the primary motivator for those that decide primarily based on 'expected increases in productivity'. In turn, the opposite is the case for those driven by the desire to avoid costs, which often suggest an ad-hoc and not a strategic approach. Where 'implementation competence' is the primary determinant, CSR considerations are least often a primary motivator (14 %); when the decision determinant is encompassing economic considerations, the 'reduction of costs risks' is more often a primary motivator than for other decision determinants. Furthermore, where

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'implementation competence' is the primary decision determinant, both 'customer requirements' (17 %) and 'image improvements' (16 %) are more often primary motivators than elsewhere. Interestingly, 'image improvements' are less often the primary motivator for those companies whose primary decision determinant is positive image effects. They are most often primarily motivated by 'long-term economic advantages' (23 %) and least often by 'investor requirements' (2 %). At the same time, while this group is primarily motivated by 'government requirements' more often (11 %) than all other determinant groups, they are overall least often motivated by 'investor requirements' (2 %).

**Table 8:** Primary motivators for GHG reduction decisions, by primary decision-making criterion (n = 822)

| | Please indicate which 3 of the following 6 points are the most decisive in determining your decarbonisation mix? | | | | | | |
|---|---|---|---|---|---|---|---|
| | Level of investment | Cost per avoided tonne of $CO_2$-eq. | Expected increase in productivity | Technical aspects | Implementation competence | Image effect through visible measures | Total |
| Long-term economic advantages | 23% | 18% | 31% | 20% | 24% | 23% | 23% |
| Corporate social responsibility | 18% | 21% | 19% | 23% | 14% | 22% | 20% |
| Reduction of cost risks | 21% | 21% | 20% | 19% | 16% | 15% | 19% |
| Customer requirements | 15% | 12% | 10% | 14% | 17% | 15% | 13% |
| Image improvement | 8% | 10% | 6% | 11% | 16% | 12% | 10% |
| Government requirements | 7% | 8% | 8% | 7% | 7% | 11% | 8% |
| Investor requirements | 7% | 10% | 6% | 5% | 5% | 2% | 6% |
| Observations | 149 | 164 | 124 | 134 | 94 | 110 | 822 |

A more substantial assessment of the connections between decision determinants, motivators, and the rationale behind, including assessment of the GHG reduction levels targeted would necessitate a more in depth and more sophisticated statistical analysis and is thus an area for further research.

While the general assumption that companies of one sector respond to the question of primary motivator and ambition level quite differently depending on whether they are a supplier appears to hold true, the sample size is too small at this level of detail to safely confirm.

## 4. Discussion

The decarbonisation of industrial organisations can be considered a far-reaching project of institutionalisation driven by political actors, professional actors, social movements, the general public, as well as industrial organisations themselves. As institutional theorists claim, organisations require legitimacy to survive and thrive in their social environment [114,115]. The access to resources (from material resources such as capital or orders to non-material resources such as reputation or work force) therefore depends on whether the actions of industrial organisations are perceived as proper and appropriate by their environment.

Considering the contemporary discourse on decarbonisation, the pressure on organisations to achieve and maintain legitimacy will hardly decrease. On the contrary, due to regulatory measures (e.g., carbon pricing), normative elements (e.g., increasing professionalisation, guidelines, best practices) and cultural-cognitive aspects (e.g., public opinion, peer-pressure), combined with the inevitable interdependencies between manufacturing organisations, actions to decarbonise are simply actions to survive in the long run for industrial organisations [116].

Buchenau points out that "many companies have realised the need to manufacture sustainably too late" [78]. According to Wolfgang Hahn, managing director of ECG Energy consulting, "most of smaller and medium sized companies still underestimate what the increasingly called-for climate neutrality and carbon certification actually means for their company" and that "increasing pressure from supply chain, politics and society calls for urgent action to secure one's own future" as a business [78]. Therefore, the opportunity costs of inaction are high. In the current environment of potential energy scarcity, security and price concerns, this statement may hold true even more. These circumstances and the question of how best to act [24] in light of the situation commends a rethink of economic viability calculations. The latter would lead to investment decisions being taken differently and, consequently, would underline why it makes even more sense now to prioritise on-site measures to decarbonise [112]. In other words, the 'pain' felt by companies in many respects may, under the current circumstances (cf. section 3.1), risk putting decarbonisation efforts on the back burner. However, if it is successfully highlighted how decarbonising their operations can ease companies' 'pains', it may even reassure and fortify their decarbonisation determination. Nevertheless, this is only the case if it is perceived as helping them in their core ambition to be a successful business – not if it appears as yet another regulatory burden in a time when business survival is hard enough.

By communicating the opportunity cost of inaction and supporting decarbonisation measures, companies' profit function may be shifted so that their business interest and thereby their motivations are in alignment with societal needs.

Therefor this article focussed on identifying aspects that may help stimulate an intrinsic action in companies (from inside or outside) which then triggers them to take decarbonisation action.

## 5. Conclusions

This article has endeavoured to answer the question of which underlying factors motivate companies in Germany's industrial sector to take the decision to decarbonise. In order to provide an appropriate basis for analysis, this article commenced with a review of the literature, establishing and explaining the categories of motivators and drivers. On the one side, motivators were defined as stemming directly from the business's key objective of maximising profit, including factors like image and future-proofing. On the other side, drivers were defined as external factors forcing businesses on a course of action they would not have naturally taken, including factors like government regulations and shareholder pressure. Subsequently, the qualitative case study examined Bosch to illustrate the different pressure points as well as the effect of interdependencies in the automotive sector. Particular attention was given to the strategic considerations behind the decision to decarbonise, such as preventive measures in the face of the Diesel Scandal or pre-emptive measures regarding expected supply chain pressures. To check and substantiate the findings of the case study, the quantitative part of the analysis relied on the results of the energy efficiency index of the German industry to find out what actually motivates German manufacturing companies to decarbonise. The quantitative analysis also highlighted differences in motivating factors depending on company size, sector, energy intensity, supply chain position and companies' determinants for decision-making. Contrary to previous studies, this article found that long-term economic advantages are the top motivating factor and that the reduction of cost risks is of higher significance than image improvement – even ahead of the current war in Ukraine and associated price peaks and uncertainties.

The analysis has shown that societal, workforce, supply chain and investor expectations play a large role when companies make a decision to decarbonise. Nevertheless,

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a large number of strategic considerations are also significant since they have the potential to make the business more resilient and profitable. Experience from the past, as well as the analysis of economic aspects and rare goods in the context of decarbonisation allude to the fact that companies not moving towards decarbonisation, may face a costly late-mover disadvantage. In general, motivators were found to have the highest motivational relevance in the decision to reduce one's GHG emissions, while external drivers are by and large ranked below the motivators. Moreover, the results regarding the factor priorities were examined in light of the companies' GHG emission reduction targets, showing that positive motivators lead to higher ambition levels than negative (external) drivers. Thus, policy measures that trigger an intrinsic reaction by strengthening the motivators would positively impact ambition levels and probably generate better outcomes than policies applying external pressure.

*An Outlook: answers and transferability of findings*

If the intrinsic reaction to decarbonise is triggered, it is however crucial to ensure that decarbonisation strategies are shaped and implemented in an effective manner. For this, there are a few questions that remain to be answered:

- Are companies sufficiently aware of their energy and process-related footprints?
- While it was already analysed which factors play the largest role in deciding which option to go for among feasible options? Are there further aspects that need to be considered to determine one's ideal mix?
- In general, what role will other means of non-fossil energy (i.e., nuclear) and other means of tackling unavoidable emissions (i.e., carbon capture, storage and utilisation) play in reaching reach net-zero?

Whilst all these new questions arising from the issues and data discussed remain unanswered for the moment, further data from the first iteration and new data from the second iteration of the Energy Efficiency Index in 2020 provide the basis for answers to many of these questions for German companies. In this paper, we focused predominantly on high-level data and evidence from companies manufacturing in Germany.

Whereas the sector coding and available technologies differ only little between industrialised countries, the general stance towards climate questions and approaches and hence towards decarbonisation may differ significantly. Cross-country analyses, based on identical questions asked in quantitative fieldwork – the technical foundation for this is laid -, would provide a relevant puzzle piece to shape overarching decarbonisation policies and strategies for industry.

**Author Contributions:** Conceptualization, S.M.B.; methodology, S.M.B. and W.K.; formal analysis, S.M.B.; investigation, S.M.B., F.V.L. and M.G.; data curation, S.M.B.; writing—original draft preparation, S.M.B., F.V.L., M.G. and W.K.; writing—review and editing, S.M.B., M.G., F.V.L. and W.K.; visualization, S.M.B.; supervision, S.M.B.; project administration, S.M.B.; funding acquisition, S.M.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** The article processing charge was funded by the Deutsche Forschungsgemeinschaft (DFG) in the funding programme Open Access Publishing.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy issues.

 doi:10.20944/preprints202210.0395.v2



**Acknowledgments:** The underlying research in the form of the Energy Efficiency Index of German Industry (EEI, #EEIndex) would not have been possible without the continuous support of the Karl-Schlecht-Foundation and the Heinz und Heide Dürr Foundation, as well as the companies participating and the network of partners of the EEI, including those reviewing and supporting in progress of developing this paper and the EEI data collection process, notably Matthias Belak, Claudia Ricci, Josefine Döpp, Anabel Reichle, Lukas Bebensee, Anastasia Wittmann, Thomas Renaldy, and Prof. Gilbert E. Metcalf, the decarbonisation team and the team of student researchers. In Germany, evidence is usually collected each April/May and October/November (www.eep.uni-stuttgart.de/eei; accessed on 02 October 2022); the #EEBarometer runs all year round in nine further languages across 88 countries (www.eep.uni-stuttgart.de/eeei; accessed on 02 October 2022). The summarised results and recordings of briefings on the results can also be found there. All conclusions, errors, or oversights are solely the responsibility of the authors.

**Conflicts of Interest:** The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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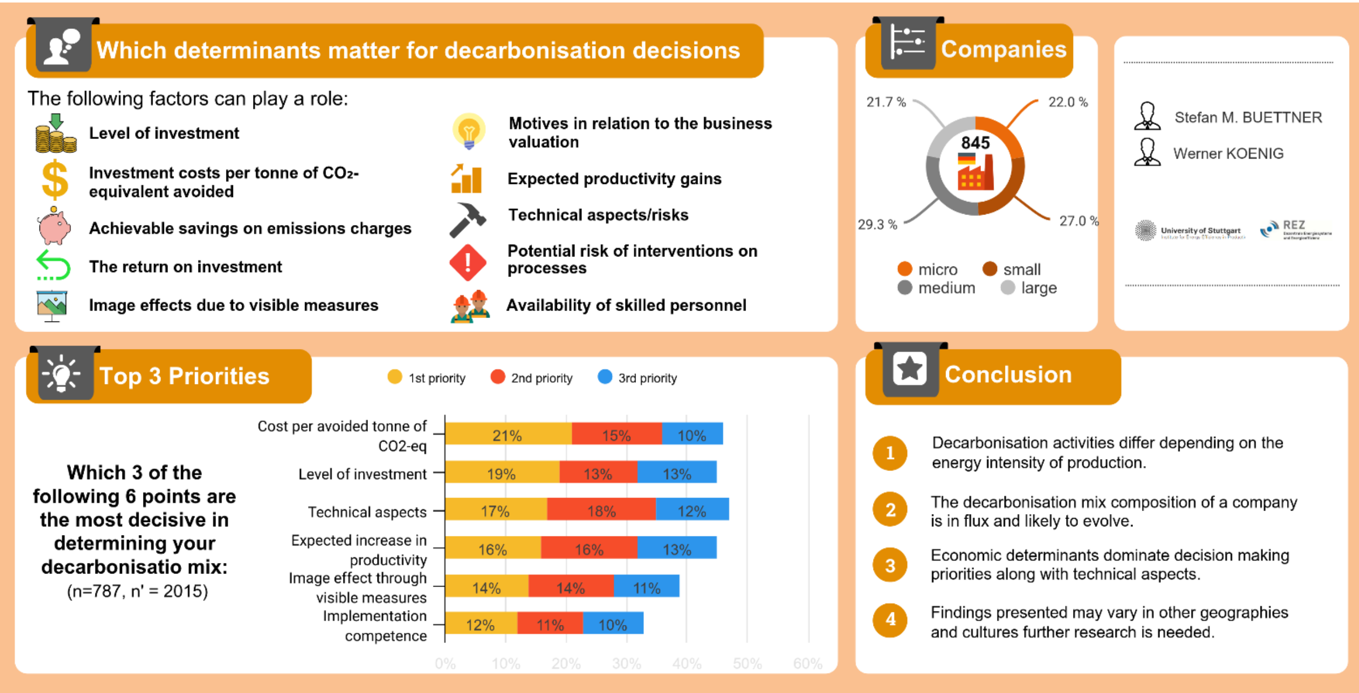
# 6 Determining the ideal mix — (finding out) what range of measures is best for one‘s business?

**Abstract:**




(Published as: Buettner, Stefan M.; König, Werner, 2021. Determining the ideal mix — (finding out) what range of measures is best for one’s business. In: American Council for An Energy-Efficient Economy, ed. ACEEE Summer Study, 13–15 July 2021. digital; Washington D.C., USA. Reprint with permission) (Buettner & König 2021)

# Determining the ideal mix – (finding out) what range of measures is best for one‘s business?

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**ABSTRACT**

Many companies of various sizes have pledged to decarbonise. As many different routes could be taken, how do they identify their ideal mix of measures? What baseline information is needed and what strategic priorities do they need to get clarity on by the management board to be able to determine the mix? Motivation and scope aside, how do companies prioritise diverse options that come with direct costs, these being clustered as measures reducing their energy demand, on-site generation of clean energy, purchase of green energy, and compensation measures? Is it the level of investment, the cost per tonne of carbon saved, technical aspects, experience in the type of intervention or access to skilled personnel, or is it other factors such as environmental considerations and image aka visible interventions – or is it a mix of them? How do companies identify a mix of measures that is ideal for them, such as saving most emissions and preparing for a potential and increasing price on carbon? This paper builds on survey data gathered from 861 manufacturing companies operating in Germany and confirms a significant divergence between company sizes as well as energy intensities. Whilst cost-factors unsurprisingly have the highest relevance in determining the choice of measures, other factors appear quite close; irrespective of company size about 60% of intended measures are of an on-site nature.

## Introduction

At the New York Climate Summit in September 2019, it not only was the governments raising their ambition on their climate plans and targets but also many ‘non-state actors’ pledged and made their statements. Among these were many actors from financial markets along with numerous global enterprises (FT 2019). Their pledges, as well as the raised ambitions in combination with the growing pressure of civil society in several regions, have since led to a continuous surge of companies developing targets for themselves. Some of them by determination, some due to investor, customer, or supply chain pressure. The recently escalating price on $CO_2$, predominantly in Europe, also increases the financial pressure on companies, as acting becomes increasingly economic in comparison with non-acting and the arising monetary climate risks and emission costs (Buettner, Wang, and Schneider 2021).

Making the decision to decarbonise goes along with the motivation to identify a mix of measures that is ideal for a company. Such a mix cannot be taken off the shelf, as each company’s situation varies, even if the difference appears marginal. Marginal or not, it may severely impact the ‘decarbonisation efficiency’ which will be defined later.

Assessing the status, the marginal differences, the underlying motivation as well as the strategic considerations is something that needs to be decided upon as a pre-requisite which will be discussed at length in a forthcoming publication (Buettner and Koenig 2021a) and hence only be briefly touched upon in this paper.

The focus of this paper is to study how companies determine their ideal mix of decarbonisation measures based on strategic priorities, current situations, and motivations, as well as their target level and deadline. At the core of identifying a mix stands the question of what determinant(s) the measures at hand are ranked against and which of the determinants are most decisive in weighting the different decarbonisation options.

The *Energy Efficiency Index of German Industry EEI* of the Institute for Energy Efficiency in Production (EEP) gathered information from 861 manufacturing companies in May 2020, supporting this paper by providing an empirical answer to the question (EEP 2020).

Understanding which determinant(s) matter(s) the most in entrepreneurial decision-making concerning decarbonisation allows tailoring fitting policies appealing to these priorities, and also aide equipment- and service providers to shape their portfolio and to uncover differences between sectors, sizes, or energy intensities. It will also be explored whether the level of ambition or supplier status has an influence.

Lastly, although an identical survey in ten languages is currently handed out to manufacturing companies in numerous countries[1], the data collected from manufacturers in Germany shall be the basis of this analysis.

## Methodology

Ideas, analyses, and conclusions presented in this paper are based on empirical data as well as the experiences gained working with manufacturing companies in Germany and with dedicated international working groups on energy efficiency and decarbonisation issues, such as the Energy Efficiency Financial Institutions Group (EEFIG) of European Commission and the UNEP Finance Initiative. These experiences are further complemented by observations stemming from newspaper articles along with press releases on the topic matter.

The hypotheses arising from professional work and general observations as well as the question of what aspects are most decisive in determining a company's decarbonisation mix are then quantitatively assessed within the framework of the Energy Efficiency Index of German Industry (EEI).

First implemented in 2013, EEI's objective is to study the intentions, expectations, experiences, and opinions of entrepreneurs from companies of all sizes, -energy intensities, and across 27 manufacturing sectors on matters of relevance to energy efficiency. Furthermore, it aims to inform businesses, science, policy- and lawmakers, as well as the public on basis of the arising findings. The focus has since widened to include aspects of relevance for a gradual decarbonisation of the industrial sectors. EEI has been made available in multiple languages and has dedicated versions for eleven additional countries referred to as the 'Energy Efficiency Barometer of Industry' (#EEBarometer). EEI is modelled after the general methodology of Germany's monthly economic indicator, the ifo-Index (Mandel and Sauer 2014).

This paper builds on data EEI gathered in May 2020, in-midst of the initial wave of the COVID-19-pandemic, and only a few months after a series of events that gave energy, climate, and decarbonisation considerations additional momentum: the wave of support for Green parties at the European Parliament elections and movements such as Fridays for Future, Scientists for Future and Entrepreneurs for Future, the tightened German climate package and the September

[1] Emerging from *Energy Efficiency Financial Institutions Group*'s (www.eefig.eu) data working group in 2015, the *Energy Efficiency Barometer of Industry* (www.eep.uni-stuttgart.de/eeei) is gathering evidence from manufacturing industries in 12 dedicated country versions in addition to five international versions and thus reaches native speakers in 88 countries. EEBarometer is reporting to the Industrial Energy Efficiency Task Force of the United Nations Economic Comission for Europe (UNECE) as part of its action plan and to other national and international bodies.

2019 United Nations Climate Action summit, and lastly the announcement of a European Green Deal to reach climate neutrality by the European Commission on 11 December 2019. The data set comprises 864 observations (European Commission 2019, EEP 2020, Brunsden 2019).

The semi-annual data collections of EEI always comprise a section, in which a specific focus on selected current issues is highlighted. For the first data collection in 2020, the focal point was aimed at motivation, prioritisation, and intended actions of the German manufacturing industry in respect to decarbonisation.

Companies were asked to answer 18 questions. Apart from the selected thematic- and index-associated questions, companies were asked to indicate their sector (with the largest share of their revenue), revenue, energy consumption, and number of employees. These are the foundation to cross-reference and analyse outcomes of current issue questions across these categories. As revenue and energy consumption are often considered confidential a significant number of respondents chose not to provide these figures or not to respond to some of the other questions asked. The number of observations, therefore, varies in the analysis to come.

Table 1: sample composition by company size (n=845)

| Company size | Number of employees | Revenue | Observations | Percentage |
|---|---|---|---|---|
| micro | 0-9 | < 2 mio. EUR | 186 | 22.0 % |
| small | 10-49 | 2 to < 10 mio. EUR | 228 | 27.0 % |
| medium | 50-249 | 10 to < 50 mio. EUR | 248 | 29.3 % |
| large | >249 | ≥ 50 mio. EUR | 183 | 21.7 % |

The data collection was carried out in a mixed-methods design, combining online (7 %) and telephone surveys (93 %). Table 1 provides an overview of the sample by company size (as defined by European Commission 2003). We purposely aim for an approximately even distribution across company sizes in EEI's samples rather than mirroring the actual size distribution of manufacturing companies in Germany (Destatis 2019, 526). This is to allow us to compare across and make statements for all company sizes.

Even though desired, it is difficult to achieve an even distribution of responses from across the 27 manufacturing sectors which represent 178,000 companies. 'Core industries' that are of high relevance to German industry were therefore defined for the telephone survey aiming for at least 24 responding companies. Among these were for instance automotive industries and mechanical engineering. Wherever a sectoral view is taken, only those sectors with at least 20 responding companies for the respective question are considered.

Even though the sectors are defined according to the '*Klassifikation der Wirtschaftszweige 2008*', they are compatible to the United Nations' *International standard industrial classification of all economic activities*, ISIC. (Destatis 2008, Eurostat 2020).

Assuming that position, priorities, and envisaged action in respect to decarbonisation activities differ depending on the energy intensity of production, energy intensity was computed for each company where sufficient data was provided. The variable 'energy intensity' is calculated as the ratio between the energy used and the revenue of a company. The variable 'energy use' contains information on the overall energy demand of a company (converted) in megawatt-hours (MWh). The variable 'revenue' provides information on companies' revenue for the previous financial year in million euros (1.2 million USD) (Buettner et al. 2020).

The 656 results of this operation span across a wide range, from 0.0111 to over 10,000 watthours (Wh) consumed per euro of revenue (Wh/EUR) for this sample.

To classify energy intensity, values have been grouped into five classes as illustrated in Table 2. The lower the class of the variable energy intensity, the higher the energy productivity level of a company – and vice versa. Energy efficiency is an essential measure to increase energy productivity. As only 20 of the energy intensity observations fall into the fifth class, there are just enough cases ($n \geq 20$) to include this class in the analysis conducted. In whatever analysis the figure drops beneath 20 observations, only the lower four energy intensity classes remain. Each of the energy intensity classes cut across a broad spectrum of sectors making it difficult to tag a sector with a specific energy intensity level. The share of energy intensive companies however is high in i.e. the building material, chemical, glass, paper, non-iron metal and steel industries.

Table 3: sample composition by energy intensity (n=656)

| Energy intensity class | Energy intensity interval | Observations | Percentage |
|---|---|---|---|
| not energy intensive | 0 to <10 Wh/EUR | 151 | 23.0 % |
| less energy intensive | 10 to <100 Wh/EUR | 243 | 37.0 % |
| moderately energy intensive | 100 to <1,000 Wh/EUR | 198 | 30.2 % |
| energy intensive | 1,000 to <10,000 Wh/EUR | 44 | 6.7 % |
| very energy intensive | ≥10,000 Wh/EUR | 20 | 3.1 % |

## Results

At the beginning of determining an ideal mix is the question: an ideal mix for what? Therefore, it is essential for a company's executive management to take a clear position (i.e. defining goal and due date) and assess the status quo. This is, for instance, to establish a common understanding of the target dimension (i.e. climate neutrality) as well as how it is defined. How ambitious the goal shall be within this target dimension and by when it shall be reached is as important as defining system barriers for this goal, i.e. limited to ones' manufacturing sites and the sources of energy acquired (Scope 1+2, WRI 2021). Understanding the current situation in terms of energy and emission footprints, actions feasible or already undertaken is as essential as having a clear definition of the target dimension, -level, and -date: only when starting point and finish line are known, a 'decarb efficient' strategy can be derived.

Being trigger to the decision to act in the first place, the underlying motivation and needs play a major role as they largely influence the choice of options. If public image is the major driver, measures that particularly contribute to a positive image or are easily noticed would have to be prioritised over measures that do not, given similar outcomes.

Only once all other environmental factors, starting points, finish lines and system barriers are identified, and all technically feasible intervention options are on the table, an ideal mix can be derived. 'Decarb efficiency' can only be reached, if such a (decarbonisation) mix is comprised in a way that allows reaching (the) decarbonisation (goal) in the most effective manner. Similar to energy efficiency, which is defined as achieving the same output with less energy put in – a more efficient use of energy - , 'decarb efficiency' considers the efficiency and effectiveness (of the set of measures applied) in reaching a set outcome, i.e. net decarbonisation. It is benchmarked against the starting point of the decarbonisation process; this is the emissions footprint and energy consumption within the chosen system barriers. Ingredients of such packages can positively or negatively influence the effect of each other and thus the overall effect of the package. Whilst it is tempting to define decarbonisation efficiency only against the speed or against the budget required to reach decarbonisation, it is sensible to define it as the aggregate economic performance forecasted against one or two pre-determined milestone dates.

The automotive supplier Bosch (2019) for example set a short ‘net zero’ target of fewer than two years (2020) but calculated spendings also against total costs and savings achieved by 2030. This means that their expenditures to achieve net-zero which initially cost them EUR 2bn (USD 2.44bn), will have cost them ‘only’ EUR 1bn (USD 1.22bn) in 2030. Considering emission prices (on electricity) climbed much faster than was foreseeable at the time and with additional emission charges (on other sources of energy) introduced by the German Government in early 2021 and considerations by the European Commission to do so across the union the net costs are likely to be much below EUR 1bn or even lead to a surplus compared to a scenario of inaction. The price of the European emission trading scheme ETS rose from EUR 5 per tonne of $CO_2$-equivalent in 2017, to EUR 25 in late 2020. The tightened climate goals since caused it to rise to EUR 53 within 6 months; the German system on emissions not covered by EU ETS starts at EUR 25 and increases annually, first by EUR 5, then by EUR 10 until 2026. (DEHSt 2020).

Net zero can be achieved straightforwardly by purchasing green energy and paying for compensation for all remaining emissions. Since both (as of now) require continuous additional spending, they are not the most economical way to decarbonise an industry in the medium- to long term. Therefore, the decarbonisation mix composition is in flux and likely to evolve: Bosch (2019) reached a speedy net zero state with the easy measures described, however simultaneously launched a longer-term process to optimise energy use and increase on-site generation of energy. This component of intertemporal optimisation is further explored by Buettner, Wang, and Schneider (2021) and hence not the focus of this paper.

**1. Which determinants play the largest role in composing a decarbonisation mix?**

Key to a company’s ‘decarb efficiency’, thus their ideal mix, is choosing wisely what measures must be prioritised or ranked by and which of these determinants considered for the ranking are most decisive. Is it the level of investment or the investment costs per tonne of $CO_2$-equivalent avoided? Or is it the achievable savings on emissions charges, respectively reduction of (external) cost risks as a whole, the return on investment, or image effects due to visible measures or motives in relation to the business valuation, expected productivity gains, or technical aspects/risks, such as the complexity of a measure or its severity? Or is it the potential risk of how interventions may interfere or disrupt core or peripheral processes, the availability of or access to personnel that can implement possible measures?

This question is the focus of this analysis and will be assessed from different points of view. For ease of the analysis, these determinants have been grouped into six categories, as illustrated in Figure 1. Companies have been asked to rank up to three priorities (Prio 1, 2 and 3).

As can be seen, there is no dominating determinant. This means that companies are heterogeneous regarding their primary determinant for the decision of their decarbonisation mix. What is however visible is an almost linear decrease between the different shown determinants: The cost per avoided tonne of $CO_2$-equivalent is the most decisive factor for 21 % of companies. Not much less, 19 % of companies mention the level of investment required to reduce emissions as their most decisive determinant. Technical aspects (e.g. complexity/difficulty/technical compatibility of the measure) are marginally more often chosen as the main priority (17 %) than expected increases in (general) productivity. Measures related to soft factors, such as image effect (14 %) or one’s competence (12 %) are down at the bottom of the primary priority list.

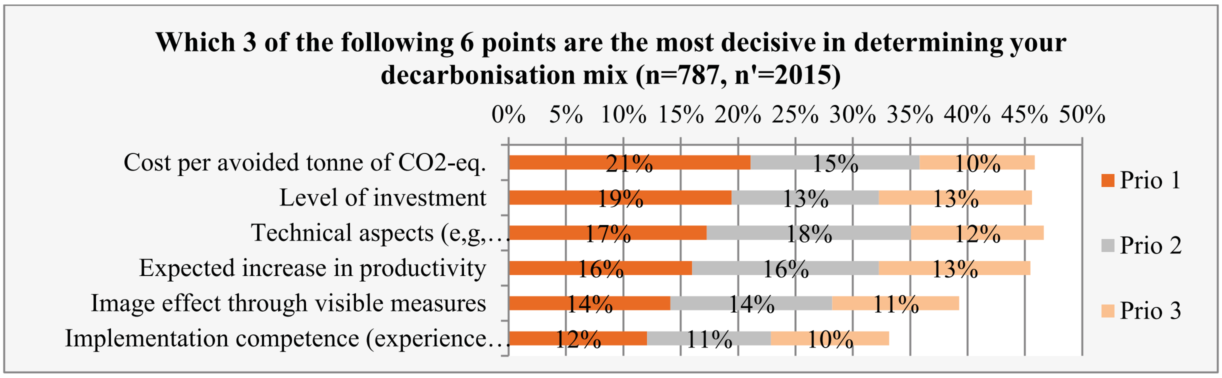


Figure 1. Measures most decisive in determining the decarbonisation mix composition. *Source:* EEP 2020.

Looking at the secondary priority, the picture changes and technical aspects (18 %) are chosen most frequently. This is not surprising as whatever is implemented needs to fit in the existing setup and must not cause production risks during the implementation or operation phase. Productivity increases (16 %) are coming second with investment and image aspects following.

As for the tertiary priority, the preferences are almost evenly distributed. Not all of the 787 companies provided secondary or tertiary priorities.

However, looking at the aggregate of all three priorities, technical aspects are a decisive determinant for most companies (47 %), closely followed by investment aspects (46/45 %) and productivity expectations (45 %) that are all chosen nearly equally often. Even though falling behind them, nearly 40 % of companies stating image considerations within their top three determinants for their decarbonisation mix composition underlines the increasing relevance for companies to pay attention to their outside perception. Considering that there is a shortage of skilled personnel on the job market and both young graduates and the existing workforce pay increasing attention to the (future) employers' stance towards climate-related issues, it is not surprising that hoped for image effects of decarbonisation activities are a priority when four out of ten companies determine the composition of their decarbonisation mix (Scheppe, Sommer, and Specht 2021; Scheppe and Steinharter 2019).

These findings, which are based on the overall sample, may look very different when the data is dissected by either company sizes, energy intensities, or manufacturing sectors. The underlying motivation to decarbonise may as much have an influence as whether a company is supplier to other companies or not, as the decarbonisation pressure imposed on supply chains significantly increased over the past months.

### 2. Does company size have an influence on the prioritisation according to which the decarbonisation mix is determined?

Surprisingly, the emission avoidance costs per tonne are most often cited as the first priority by micro companies (24 %, cf Figure 2.1). Considering decarbonisation activities often go along with significant investments, one would have thought that the absolute level of investment required (16 %) would rank higher than the relative avoidance costs. Instead, it is ranked third, just slightly above the image effects (15 %) and productivity increase (14 %); technical aspects, however, are the most important determinant for 22 % of companies. Technical aspects are not only the most frequently chosen secondary priority (20 %) but also the most important determinant overall, named as a priority by one out of two micro companies. In contrast, implementation competence is a priority for less than a quarter of companies in determining their decarbonisation mix. This may be a consequence of companies thoroughly assessing technical aspects, where too complex solutions that would require specific competencies are ruled out already. Another reason might be that micro companies often do not have in-house personnel specialised in energy and footprint matters and are therefore used to hire-in external expertise leading three-quarters of them not to consider this as a priority in determining the composition of their decarbonisation mix.

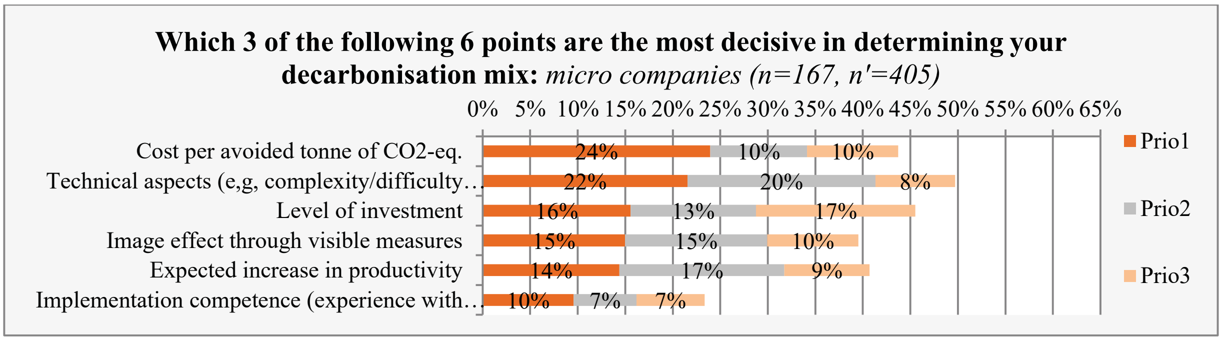


Figure 2.1. Measures most decisive in determining the decarbonisation mix composition. By size: micro companies
*Source:* EEP 2020.

The situation differs quite a lot looking at small companies (cf Figure 2.2). In contrast to the sample average, level of investment is considered the first priority by most small companies (19 %). Relative avoidance costs (18 %), technical aspects (18 %) and expected productivity increases (17 %) are nearly as frequently named first priority. As for micro companies, technical aspects are the leading secondary priority (18 %). Expected productivity increases are not only an important secondary priority but also the determinant that was named a priority most often by small companies (49 %).

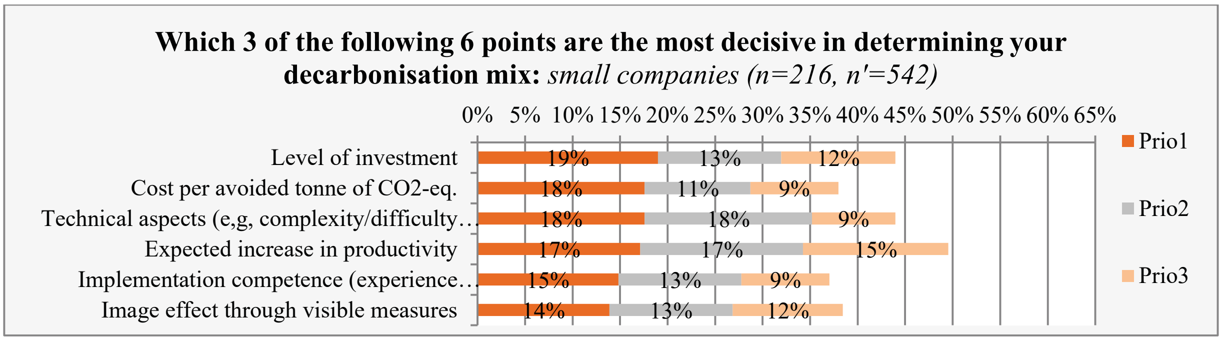


Figure 2.2. Measures most decisive in determining the decarbonisation mix composition. By size: small companies
*Source:* EEP 2020.

Relative avoidance costs are not only first priority (22 %), but also second (20 %) and third (20 %) for medium-sized companies (cf Figure 2.3) and thus a priority to many more companies than the other determinants. A possible explanation could be that such companies are large enough to manage bigger investments and have the necessary expertise, and at the same time not yet a too large degree of complexity of their operations allowing them to attach such priority to the relative costs. On the other hand, it may also be that medium-sized companies, many of which are among the so-called 'hidden champions' in Germany with a high share of exports and international competition, are consequentually vulnerable to market- and hence price pressure, as much as to pressure to decarbonise from their downstream supply chain. Whilst the level of investment is the first priority (19 %) for nearly every third medium-sized company, in aggregate technical aspects, productivity expectations and image are considered a priority more often (48/47 %). Implementation competence is least often a priority for medium-sized companies, possibly as the relevant expertise can be hired-in if need-be.

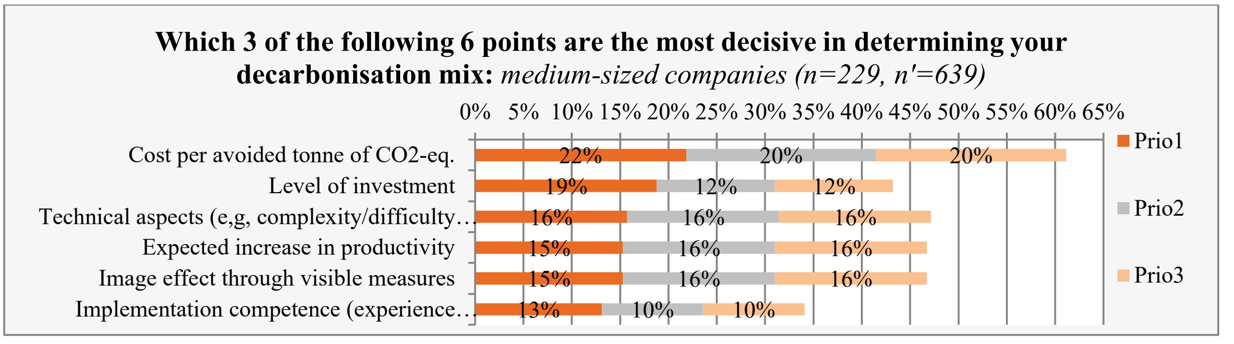


Figure 2.3. Measures most decisive in determining the decarbonisation mix composition. By size: medium-sized companies *Source:* EEP 2020.

For large companies (cf Figure 2.4), level of investment (24 %) and relative avoidance costs (23 %) are almost equally often the first priority. Other determinants are named the first priority much less often. Here, too, technical aspects are the most frequent secondary priority (18 %) and almost as often of overall priority (48 %) as absolute (49 %) and relative (50 %) costs.

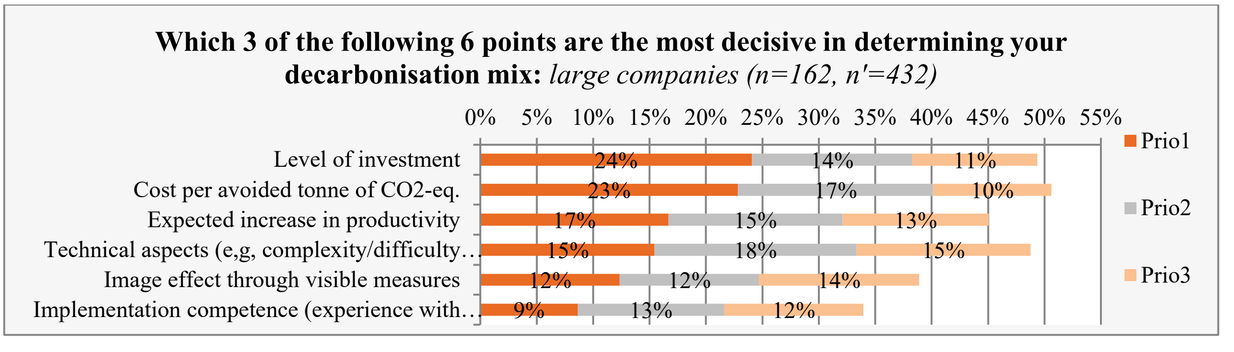


Figure 2.4. Measures most decisive in determining the decarbonisation mix composition. By size: large companies *Source:* EEP 2020.

Looking across company sizes, the priority companies attach to the six determinants assessed differ quite significantly: Taking a closer comparative look per determinant, the cost per avoided tonne of $CO_2$-equivalent is much beyond average (46 %) a priority for medium-sized companies (62 %), and much below average for small companies (38 %), likely for one of the reasons described. Whilst most important to large companies (49 %), the spread is much smaller for the level of investment (45 % +/-4 % points). This may be the case as absolute costs often can be attached to the question of whether one can afford the expenditure, whereas relative costs can be attached to the question of which measure is the most economic one to decarbonise with.

Technical aspects, most important to micro companies (50 %), have a similar spread (47 % +/- 3 % points). Expected productivity increases (45 %) are least often a priority to micro companies (40 %) and most often to small companies (49 %). Whilst image considerations are in general a priority to 39 % of companies of most sizes, this is a priority to 47 % of medium-sized companies, perhaps due to the mentioned exposition both regionally and on the world market. While larger companies attach an average priority to the implementation competency (33 %), this is more important to smaller companies (37 %) and is, likely due to one of the reasons discussed before, only a priority to a quarter of micro companies (24 %).

3. **Does energy intensity have an influence on the prioritisation according to which the decarbonisation mix is determined?**

Energy intensity often comes along with a higher amount of energy-related emissions. Energy-intensive processes are also often among those with an above-average share of process emissions. Therefore, it is worth exploring whether energy intensity influences the determination of the decarbonisation mix composition.

For non-energy-intensive companies (cf Figure 3.1), the level of investment is a key priority, not only as the first one (22 %) but also overall (57 %). Productivity increase expectations are of priority to every second company (50 %). As energy-related emissions often are the main cause of emissions under direct control (scope 1+2) of not energy-intensive companies, tackling these is at the centre. At the same time, the proportional share of the energy cost of their total costs is low. Saving a proportionally high share of energy therefore does not have an as big effect on total cost as it would for more energy-intensive companies. This may explain why the absolute level of investment has been chosen as a priority that often. This is a bit counter-intuitive as one could also have assumed, that relative avoidance costs would have played a more dominant role in not energy-intensive companies. That said, there may not be many different approaches to structurally reduce the energy-related footprint, most of which are capital intensive, hence the focus on the level of investment.

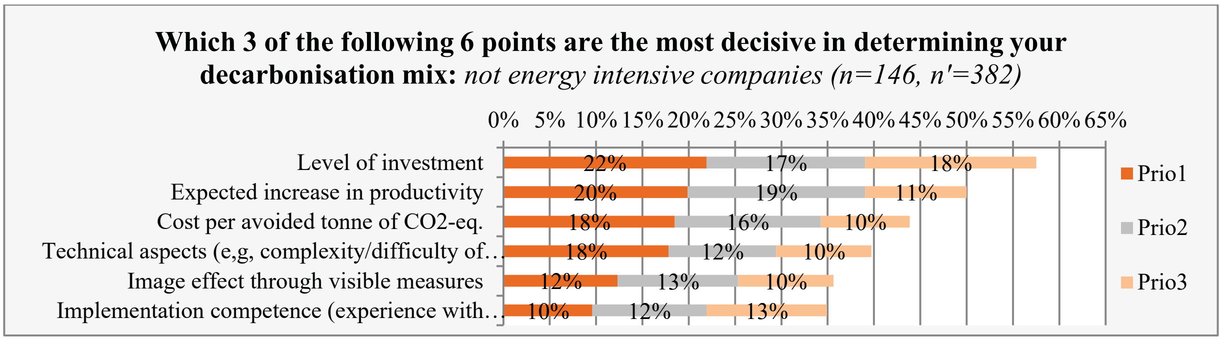


Figure 3.1. Measures most decisive in determining the decarbonisation mix composition. By energy intensity: not energy intensive companies. *Source:* EEP 2020.

It is the less energy-intensive companies (cf Figure 3.2) for which the relative avoidance costs are of the highest importance, both as a first priority (22 %) and overall (48 %). Technical aspects are however most often named second priority (20 %) coming in a close second in overall priority (47 %). This underlines that as soon as energy plays a larger role, technical aspects do so, too, when determining the composition of a company's decarbonisation mix.

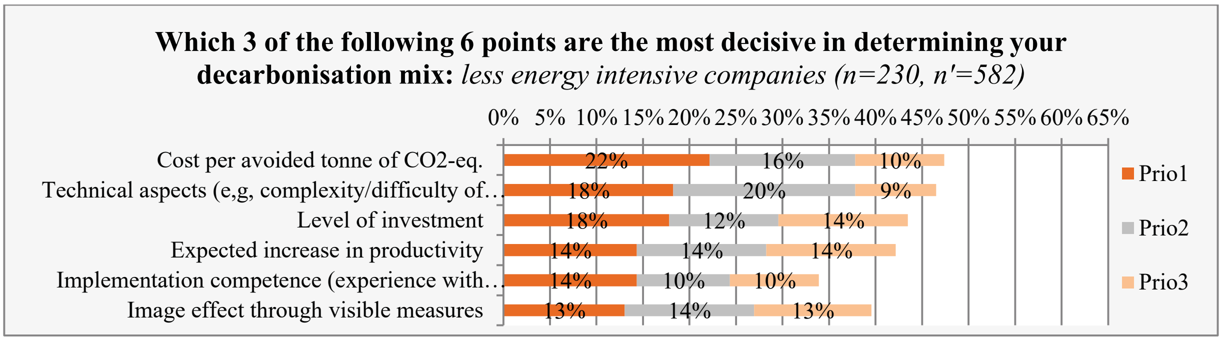


Figure 3.2. Measures most decisive in determining the decarbonisation mix composition. By energy intensity: less energy intensive companies. *Source:* EEP 2020.

Looking at moderately energy-intensive companies (cf Figure 3.3), the situation is very different: Whilst relative avoidance costs are, with a margin, most frequently mentioned as the first priority (20 %), followed by other economic aspects, technical aspects are not only the second priority chosen by most companies (19 %) but also a decisive aspect for more than half of all moderately energy-intensive companies (52 %). This may be the case as from experience energy- and process emissions are increasingly difficult to address the more energy-intensive a company is. From experience, the more energy intensive a company is the more important is addressing the process technology when decarbonising, the less energy intensive a company is the more cross cutting technologies, often 'low hanging fruit' are in focus. The process technology chosen has a large influence on process emissions arising from the process. Overall, expected productivity increases are a priority for more companies (49 %) than relative costs (46 %).

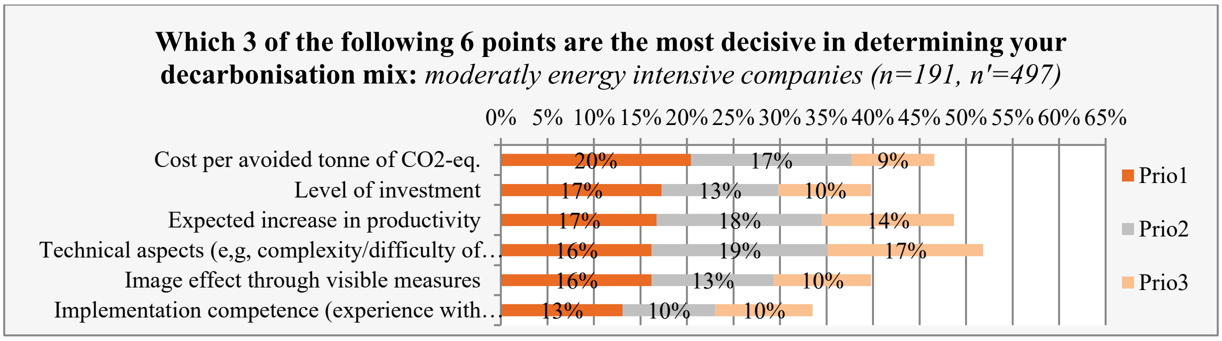


Figure 3.3. Measures most decisive in determining the decarbonisation mix composition. By energy intensity: moderately energy intensive companies. *Source:* EEP 2020.

Even though the sample group of the energy-intensive companies (cf Figure 3.4) is much smaller, these companies are deemed to represent the general group. Technical aspects are by far the most decisive aspect (24 %), followed by productivity gains (20 %). Energy and emission costs are significant cost factors because many energy-intensive companies are obliged to participate in the European emissions trading scheme (ETS). Therefore, a reduction of these costs has a large impact on the energy productivity of companies and their margins; being an important part of the core process, improvements can, but must not, lead to an overall productivity increase. As heavy emitters publicly 'stand out of the crowd', it is not surprising that image considerations are by far the most often chosen secondary priority (27 %). These are indicated as a priority by every secondenergy-intensive company responding to this question (49 %). As many on-site decarbonisation options, such as energy efficiency measures or reducing process emissions cut deep into the core operations, required investments are likely to be high. Therefore, it is not surprising that being a first priority (17 %), the level of investment is much less often defined as a priority in general (27 %) than the relative avoidance costs (39 %) or put differently which of the expensive interventions provide the lowest costs per avoided tonne of $CO_2$-equivalent.

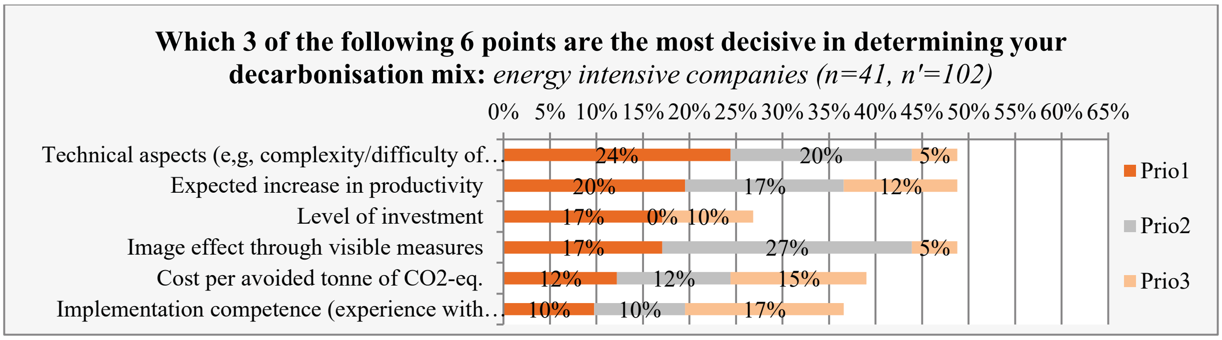


Figure 3.4. Measures most decisive in determining the decarbonisation mix composition. By energy intensity: energy intensive companies. *Source:* EEP 2020.

Across all energy intensity classes, relative costs are, however, categorised as priority least frequently by energy-intensive companies (39 %) while around 45 % of companies belonging to the other intensity classes set this aspect as a priority (average: 46 %). Confirming the assumptions made, the level of investment is mentioned as a priority most often by not energy-intensive companies (57 %). That share gradually declines across company sizes and is lowest for energy-intensive ones (27 %, average: 45 %). Technical aspects are a priority most often to moderately energy-intensive companies (52 %) and least to non-energy-intensive companies (40 %, average: 47 %). Expected productivity increases are, overall, of equally high importance (49/50 %) to companies of almost all energy intensity classes, except for less energy-intensive companies (42 %, average: 45 %). The statement that energy intensity has an impact on the weight of image considerations in determining the decarbonisation mix is enhanced by the observation that the number of companies considering this aspect as a priority is increasing with increasing energy intensity: this comprises 35 % of non-energy-intensive companies, 40 % of less- and medium energy-intensive companies, and 49 % of energy-intensive companies. The implementation competence is a fairly relevant determinant across the energy intensity levels (around 33 %). Only non-energy-intensive companies (35 %) and energy-intensive ones (37 %) suggest it as a priority more often.

4. **Is being a supplier influencing how companies prioritise the composition of their decarbonisation mix?**

Whilst the role of relative avoidance costs is chosen equally often as the first priority (21 %, cf Figure 4A-B), this differs for the role of the level of investment and technical aspects. For the non-suppliers, they are fairly equal (19 %), whereas, for suppliers, the level of investment (20 %) is more often a priority than technical aspects (17 %). This may be due to the weight of supply chain pressure on margins and the emission footprint. Where productivity increases are of similar relevance (16/17 %), image is less important to suppliers (13 % vs. 15 %), whereas implementation competence is more (13 % vs. 10 %). Only looking at the overall priorities the differences are more significant: Where productivity increases and costs per avoided tonne of $CO_2$-equivalent are the determinants most often named priority by suppliers (47 %) and investment levels, as well as technical aspects not far behind (45/46 %), for companies that are not predominantly suppliers, technical aspects are the determinant named a priority most often by a margin (50 %). This may be as the share of micro and large companies being a supplier is considerably larger and for those technical aspects have a higher relevance than for the other company sizes. Also the second most frequently named determinant, level of investment (47 %), is chosen considerably more often than relative costs (43 %), productivity expectations, as well as image considerations (both 41 %). Implementation competency appears to be more (often) important to suppliers (35 vs. 30 %). While supplier state appears to have a clear influence on the composition of the decarbonisation mix, it is diffuse why. This is, however, understandable as the heterogeneity of companies in this dimension is far bigger than from a company size or energy intensity viewpoint.

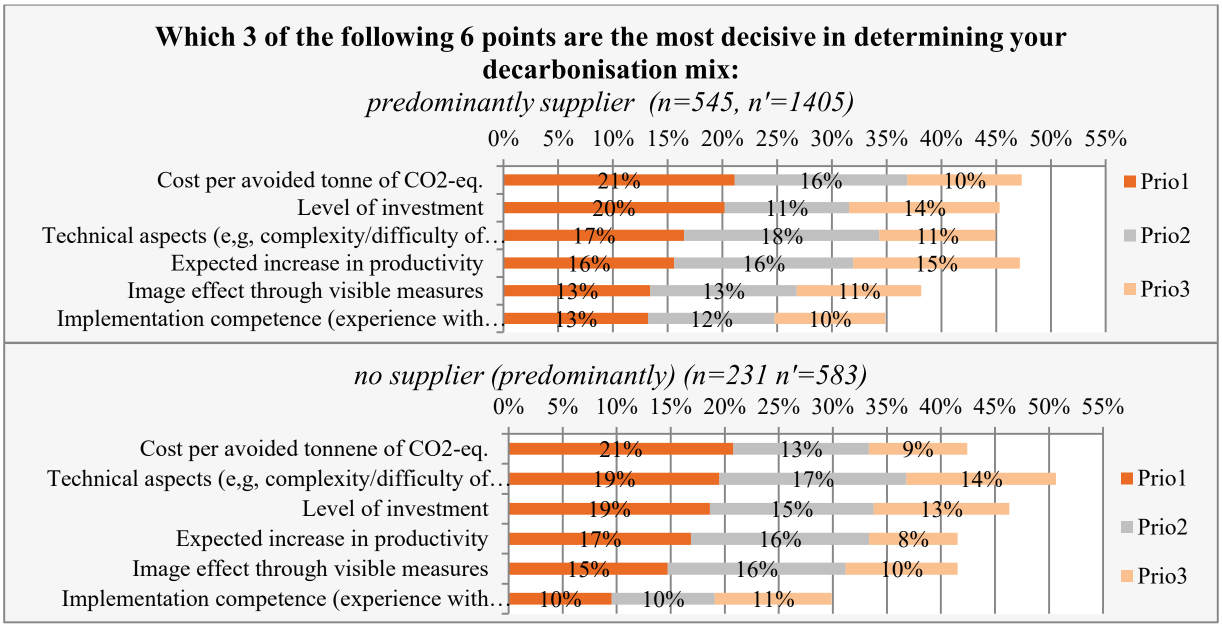


Figure 4A-B. Measures most decisive in determining the decarbonisation mix composition. By supplier state. *Source:* EEP 2020.

### 5. What influence has the motivation to decarbonise on the priorities in relation to the composition of the decarbonisation mix?

The motivation to decarbonise is thoroughly analysed by Buettner and Koenig (2021b). In brief, for those companies that decarbonise predominantly because of government requirements, technical aspects are the priority (48 %), followed by relative avoidance costs (47 %) and productivity expectations (46 %).

Not surprisingly, for companies whose primary motivation is long-term economic advantages, productivity expectations are named by far most often a decisive determinant

(55 %), followed by technical aspects and level of investment (both 46 %). Relative avoidance cost plays a role for much fewer of these than of all companies (37 vs. 46 %).

For those companies where customer requirements are the driving motivation to decarbonise, the level of investment (51 %) is most frequently mentioned as a determinant, with productivity increases close behind (48 %). This could be as these companies aim to fulfil what their clients expect with least capital expenditure weighing on their margins, and the highest productivity increases gained in doing so.

Looking at companies whose primary motivation to decarbonise is image improvement (cf Figure 5), image surprisingly is neither more nor less often named a priority than in the overall sample (39 %). On the contrary, relative avoidance costs and technical aspects (both 48 %) are most often declared as a decisive determinant. This leads to the reading that it matters most which technically feasible measures allow to reach the decarbonisation goal cheapest; their individually visible actions appear to be less weighty less than the image gain from achieving the goal itself.

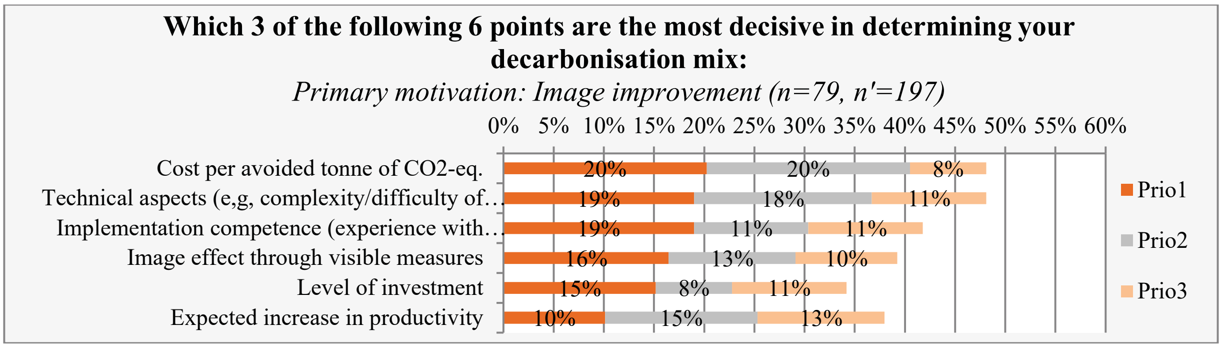


Figure 5. Measures most decisive in determining the decarbonisation mix composition. By primary motivation: image improvement. *Source:* EEP 2020.

More intuitive is that companies aiming at a reduction of cost risks much more often name the relative avoidance costs (56 %) and level of investment (49 %) than the other determinants. With 32 %, image consequently plays a role less often for these companies.

Where investor requirements are driving motivator to act, all economic and technical determinants are considered decisive by roughly every second company of that group, with productivity increases being chosen most often (55 %) and relative avoidance cost second most often (51 %). This follows intuition as investors care for achieving targets in the most economic manner (therefore the relative costs) but also look for a continuous improvement of productivity.

For companies being motivated to decarbonise following their corporate social responsibility (CSR), image considerations are a decisive determinant as often as relative avoidance costs (both 49 %). This follows the notion of the saying ‘do good and talk about it’, particularly as the emission reduction ambition and goals aimed at by these companies are not higher than average. Instead, they are lower than the ones of the average company and considerably lower than the ones of those being motivated to decarbonise by their investors, to reduce cost risks or to improve their image (EEP 2020). Whether CSR is lip service in terms of its environmental component cannot be judged adequately in the context of this paper.

Overall, relative avoidance costs are most often called decisive by companies whose decarbonisation motivation is the reduction of cost risks (56 %) and least by those looking for long-term benefits (37 %), the level of investment most by those companies being motivated by customer requirements (51 %) and least by those striving for image improvement (34 %). Expected productivity increases are most often a determinant for those with either a long-term expectation or following investor requirements (both 55 %). As described, image effects are most often the decisive factor in the CSR context (49 %), however least for those motivated by investor requirements (29 %). The competence to implement stands out as a decisive factor for companies motivated by image improvement considerations (41 %).

6. **Is there a link between the sector and the determinants according to which the decarbonisation mix is composed?**

As it would go too far to look at each of the 27 manufacturing sectors within the context of this paper, we will briefly highlight some sectors where the results appear to be most striking: except for implementation competence, each of the determinants is the most often chosen decisive determinant in at least one of the sectors with a sufficient participation rate for this analysis.

Image effects through visible measures are most often a primary determinant for companies in the pharmaceutical (29 %) and not surprisingly in overall priority for those in the 'manufacture of coke and refined petroleum products' industry (59 %). Image consideration is, by a margin, least often labelled as a critical determinant in the chemical industry (23 %).

Whereas implementation competency is most often the primary determinant in the 'printing and reproduction of recorded media' sector (23 %), it is the 'manufacture of food products' sector in overall priority (50 %). With 16 %, least companies attach importance to this in the 'manufacture of coke and refined petroleum products' sector.

The expected increase in productivity is the dominating determinant in a number of sectors, but from a cross-sectoral viewpoint, it is most often primary determinant for the food industry (33 %), however closely followed by the chemical industry (30 %), where it is also of highest overall priority (57 %). Productivity increases are least often a critical determinant for the composition of the decarbonisation mix in the 'printing and reproduction of recorded media' sector (23 %).

Technical aspects are by far the most often primary determinant in the 'other manufacturing' sector (32 %) that also leads from an overall viewpoint (64 %), closely followed by the leather industry (62 %). Technical aspects appear to be of least concern in prioritising decarbonisation options to the (extraction of) oil and gas industry (23 %) where there is not much flexibility on the technically feasible options at hand.

The level of investment is awarded by far with the highest primary priority in the 'printing and recorded media' sector (45 %), more than fifty percent higher than the next one. However, overall the 'manufacture of coke and refined petroleum' sector attaches the highest overall priority to the level of investment (59 %), with the fabricated metals sector close behind (57 %). For the 'other manufacturing' sector it is of least relevance with a distance (24 %).

The cost per avoided tonne of $CO_2$-equivalent is primary determinant by far most often for companies in the 'manufacture of computer, electronic and optical products', 'coke and refined petroleum' and 'extraction of crude petroleum and natural gas sectors (45 %, 42 %, and 38 %). However overall priority of relative avoidance costs is highest in the 'manufacture of motor vehicles, trailers and semi-trailers' sector (64 %), closely followed by the computer and electronics industry (60 %). Least often but still on a high level, this determinant is considered a key priority in the 'printing and reproduction of recorded media', followed by the 'manufacture of food' sector (32/33 %).

## Discussion and Conclusion

While the average viewpoint indicated that relative avoidance costs, level of investment, technical aspects, and expected productivity increases are a decisive determinant for nearly the same and high share of companies (around 45 %), the multidimensional analysis has shown that this homogeneity vanishes when looking closer and that every view point we looked from has its justification. Even though taken in consideration indirectly, the state of the economy, stimulus or support programmes (that i.e. serve to reduce absolute or relative costs of a measure) are external factors that can also have a significant impact on the composition of the mix.

This means that there cannot be a standard package of measures to suit all needs and perspectives. Instead, the focus ought to be devising a procedure according to which an ‘ideal’ mix of measures can be devised. The determinants to which decarbonisation options are prioritised and weighted are an important part of this decision process, however only a part.

What these decarbonisation options are, which ones are applicable in which context, serving which goal and in which timeframe, however, are issues that call for closer separate analysis and build on strategic considerations and a thorough status quo assessment (cf. Buettner and Koenig 2021a).

Doubtlessly, many decarbonisation mix ingredients, and hence the ‘ideal mix’ by itself are also affected by variable energy and emission prices, respectively acquisition risks, so any strategy ought to consider temporal effects (Buettner, Schneider, and Wang 2021).

What is clear though, is that the challenge ahead is large, as are the opportunities within. On average the 861 companies participating in this sample aim to reduce their greenhousegas emissions by 22 % by 2025 (base: 2019), which is equivalent to a 49 % reduction compared to 1990, the international base year in climate issues. Even though the specific decarbonisation mix remains to be determined, companies have stated that they envisage tackling, irrespective of company size, 60 % of these emissions through measures on-site (6 % through energy efficiency, 3 % via a reduction of process related emissions, 5 % through on-site generation and storage) and the remaining 40 % through purchase of green energy (5 %) and compensatory measures (3 %) (EEP 2020).

Whether and in what way the findings presented apply in other geographies and cultures remains to be seen. Potentially the data currently gathered by the ‘EEBarometer’ can shed light upon this question.

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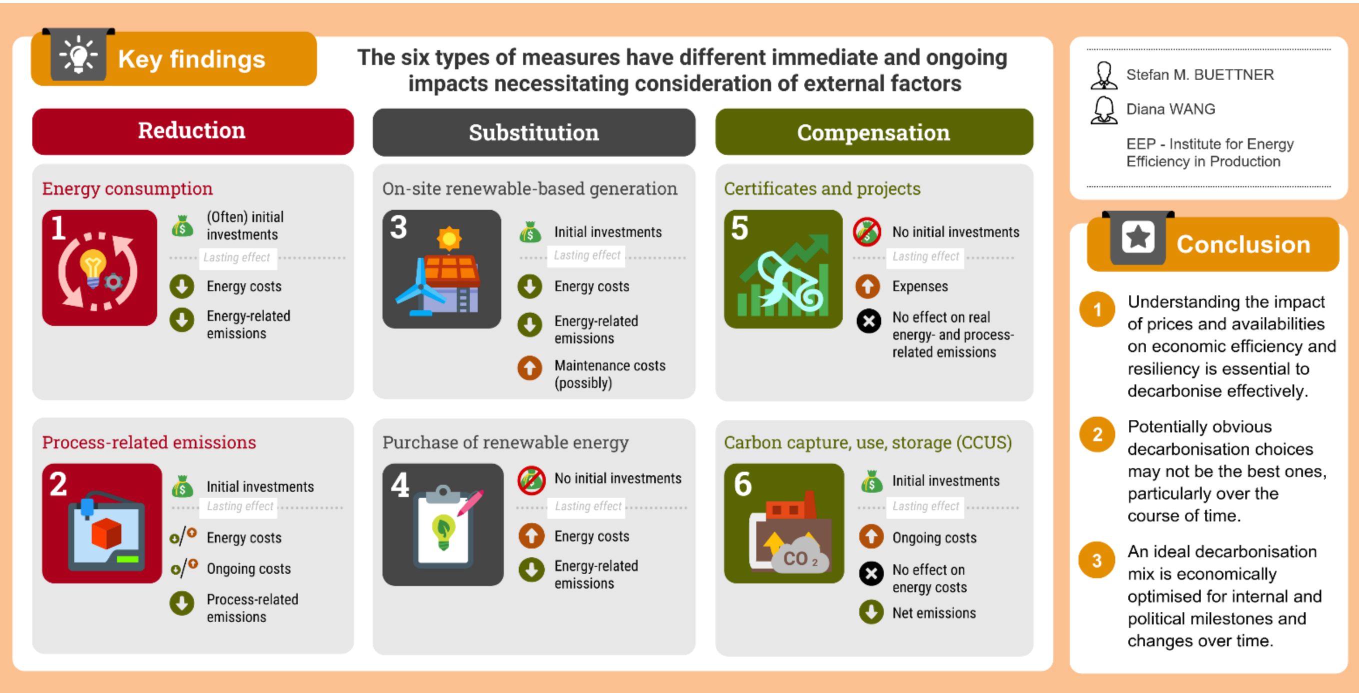
# 7 An approach to reducing the greenhouse gas footprint in the manufacturing industry: Determinants for an economic assessment of industrial decarbonisation measures

**Abstract:**




(Published as: Buettner, Stefan M.; Wang, Diana, 2022. *An approach to reducing the greenhouse gas footprint in the manufacturing industry: Determinants for an economic assessment of industrial decarbonisation measures*. University of Stuttgart: Stuttgart, Germany. DOI: https://doi.org/10.18419/opus-12615) (Buettner & Wang 2022)

*Report*

# An approach to reducing the greenhouse gas footprint in the manufacturing industry:

## Determinants for an economic assessment of industrial decarbonisation measures

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**Abstract:** A reduction of the greenhouse gas footprint towards net zero emissions can be achieved with the help of a wide variety of measures. There are three principal approaches (categories): first, reducing greenhouse gases by adjusting the way business is done (efficiency and processes); second, substituting what business is done with (sources of energy and material); and third, offsetting the greenhouse gases emitted.

Some measures seem simple and obvious, while others appear complex and demanding. The decisive factor is the respective impact on economic efficiency. Therefore, the authors have identified six types of measures that differ in terms of the impact of investment and operating costs on energy and emission costs.

In this report, the authors evaluate these types of measures from an economic perspective and address the limitations and advantages and disadvantages of the different types of measures in terms of emerging needs for action and consequences. Since, for example, on-site measures are often more sensible and also the increase or introduction of emission prices in many countries can have significant cost implications (and subsequently affect global supply chains), an adjustment of the traditional approach to economic valuation seems necessary.

On this basis, a novel economic valuation approach for decarbonisation measures is proposed. The approach, illustrated by calculation examples and extensions to dynamically rank, score, and adjust to changing circumstance over time, facilitates an optimal selection of measures to support companies in achieving and sustaining their greenhouse gas reduction goals while maintaining economic efficiency.

**Keywords:** economic viability, opportunity costs, decarbonisation, economic assessment, net-zero emissions, energy efficiency, renewable energy, emission compensation, industry, decarbonisation measures

**Disclaimer**: This is an update, adaptation and extension of S. M. Büttner, D. Wang, C. Schneider, "Der Weg zur Klimaneutralität - Bausteine einer neuen Methodik zur Bestimmung eines wirtschaftlichen Maßnahmenmix" [1] to the international context, and in such the foundation of ECE/ENERGY/GE.6/2021/3 [2] and GEEE-8/2021/INF.2 [3].

# 1. Introduction

## 1.1 Clarity in terminology and its meaning, as well as targets is essential

The foundation for finding an economic mix of measures to achieve net zero is, on the one hand, clarity about the point in time by which this target should be achieved and, on the other hand, about whether there are ideational or structural limitations on the available instruments [4]. Moreover, it is particularly significant to establish absolute clarity about the terminologies and ensure a mutual understanding of these among all actors involved in the process [5]. A certain state (e.g., Scope 3 carbon neutrality) can be achieved however efficiently - this efficiency is worthless if the required outcome is a different one (e.g., Scope 1+2 climate neutrality). One would have tackled aspects unnecessary for the goal (here: extending to Scope 3 emissions) and, at the same time, neglected to address other aspects that would have been necessary for achieving the goal (here: addressing greenhouse gases apart from $CO_2$, such as methane). This also applies to net zero goals and the way to achieve them. The following example represents no rarity and underlines an insufficient clarity: in late 2020, the *New York Times* reported that Japan's new government has set itself the goal of *carbon* neutrality. At the same time, the *Reuters* reports that Japan is now striving for *climate* neutrality, showing a discrepancy in reported target dimensions [6,7].

Possibly decisive in this frequent confusion is that greenhouse gases (GHG, including $CO_2$ itself), whose mitigation make *climate* neutrality reachable, are measured in the unit "$CO_2$ equivalents". The suffix "-eq" for "equivalents" ($CO_2$-eq) is then quickly lost in common usage, resulting in "just" $CO_2$ with the corresponding $CO_2$ neutrality as target dimension [5].

Actual and complete neutrality - be it $CO_2$-, climate-, or environmental neutrality (cf**. Figure 1**) – is hardly achievable. In most cases it can only be achieved regarding the 'bottom line', this is 'net-zero'.

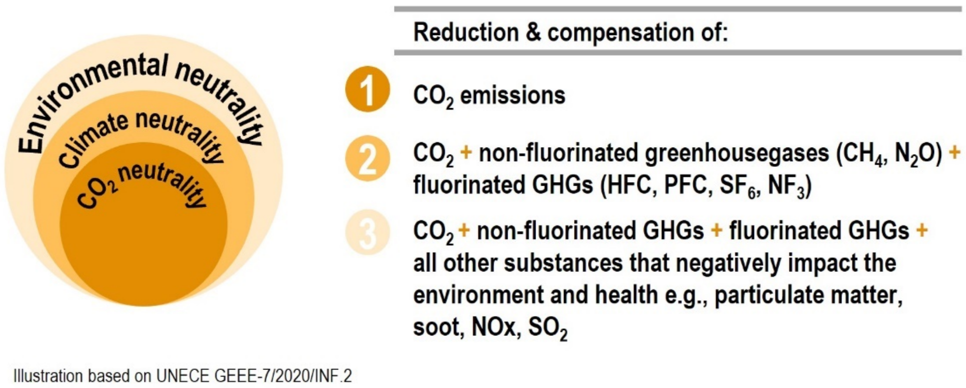


*Figure 1. Defining different neutralities and what is needed to achieve them* [5]

The situation is not much different when it comes to identifying the emissions footprint. Which emissions count, and which ones do not? Is climate neutrality defined as achieving net-zero greenhouse gas (GHG) emissions based on local emissions from one's site and the purchase of energy from climate-neutral sources? Or does the GHG footprint also include emissions emitted by employees on the way to their workplace, by business travel and by logistics, such as transporting materials to the factory and the finished products to their customers? Does climate neutrality mean the end product itself has a "net zero greenhouse gas emissions" footprint at the "point of handover" to the end customer - i.e., a full decarbonisation including the upstream and downstream supply chain? Or would climate neutrality be only achieved if all lifetime emissions (including disassembly and recycling) of a product are included in the calculations?

How stakeholders define their 'system boundaries' for decarbonisation activities also determines which "Scope" or which elements of this "Scope" they work towards. Scope 1+2 are often aspects under direct control of companies, Scope 3 are indirect emissions and often more difficult to capture and address (cf. **Figure 2**) [8].

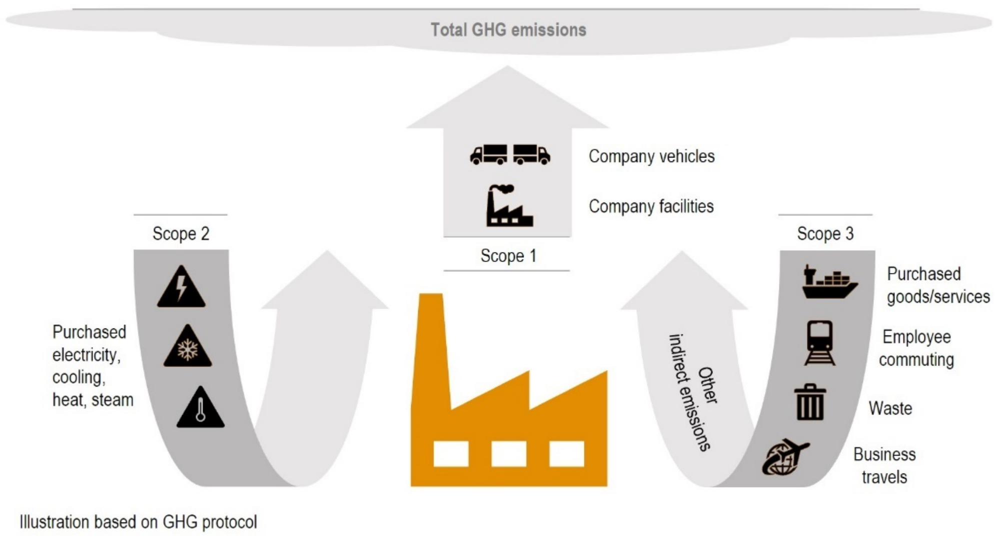


*Figure 2. Carbon footprint assessment Scopes based on the GHG protocol* [8]

Legislative initiatives by the European Union and individual member states (e.g., supply chain regulation and sustainable product initiative) [9,10] as well as announcements by car manufacturers and suppliers indicate a trend towards climate neutrality at the "point of hand-over" in this part of the world. The point of handover refers to the time when the end customer receives the product or places the item into their shopping cart after paying at the checkout [11].

Therefore, as target dimension, target scope and how they are understood can also vary across the world, across stakeholders and often within individual stakeholders, a common understanding needs to be established initially, and a clear (minimal) objective must be determined, considering one's values and external factors before proceeding further [12].

In addition, there are other relevant definitions for which a common understanding among decision-makers is mandatory, among others: energy-related emissions and process-related emissions. On the one hand, energy-related emissions occur when primary energy (raw fuels) is converted into a secondary energy carrier e.g., electricity, which can for example then be used to power a LED bulb that produces 800 lumens of brightness with consuming energy at a rate of 5 Watts per hour. On the other hand, process emissions emerge during the production process, such as by-products of chemical reactions or livestock breeding (e.g., methane emission from cattle).

## 1.2 Awareness of own emission footprint, requirements and regulations

Determining energy-related emissions is simple if data on the consumption per energy source and its composition (electricity mix) are available, which can be multiplied by the corresponding "emission factor" [13,14].[1] Conversely, it is much more challenging to determine process-related emissions. Firstly, there is a risk of misunderstanding: process-related emissions are often misunderstood as the energy-related emissions of a process. Secondly, actual process-related emissions are more difficult to measure (accurately) and, apart from sectors with large amounts of process emissions, may be hardly noticeable or not known to exist. Conversely, companies that have to report (and pay for) their process-related emissions are more likely to also know the energy-related footprint of their activities for two reasons: First, energy-related emissions should be comparatively easy for them to determine and, second, in the case of electricity, they are often already factored into the price of energy charged by energy suppliers and hence a noticeable cost-driver [15]

It is also indispensable to be familiar with (where applicable) the national- [16], the European- [17], or other regional emission pricing systems and whether the applicable pricing system explicitly includes all greenhouse gas emissions ($CO_2$ equivalents) or only $CO_2$. It is

[1] Some chambers of commerce offer calculators to determine $CO_2$-costs for energy related emissions, i.e. IHK $CO_2$-Calculator [14].

also important to know whether it applies to both energy and process-related emissions, or only to energy-related emissions, or whether this depends on the industrial sector.[2]

## 1.3 Three categories of measures to address the emissions footprint

In the following, we address emissions that are primarily under the direct control of decision-makers in the company. To address these, three principal categories of decarbonisation measures are defined:

- Reduction of greenhouse gases by adapting *how* one does business (efficiency and processes)
- Substitution of *what* one does business with (energy sources and materials)
- Offsetting the greenhouse gases emitted.

Substitution can be seen as an “upstream” emissions mitigation (preventing emissions from occurring), while offsetting can be seen as “downstream”.

Based on this definition, we performed a combined consideration of economic and energy aspects. Since both long-term effect and dependence on external factors are taken into account, these categories of decarbonisation measures are suitable as indicator categories for corporate management on the path to climate neutrality [18,19].

## 1.4 Why a novel approach is needed for decarbonisation: Gap, Relevance and Methodology

Which measures are actually implemented depends on a number of aspects. In particular, spatial, technical or strategic aspects can lead to a pre-selection or exclusion of some possible measures. After this pre-selection, in the vast majority of cases the financial aspects are in the foreground, such as the question within which period of time the measure will pay off.

In practice, measures are often only implemented if they pay off in a short period of time, usually no more than 3 years. In view of unclear planning horizons, economic cycles and product cycles, this is understandable. Nevertheless, it can still lead to some (very) worthwhile measures being excluded from the outset or to measures that are worthwhile in the short-term turning out to be a cost or resilience risk in the medium to long term.

Regarding production, on the *micro level* the time in which one will probably be able to produce a product with this equipment is defined more by the product cycles (cf. mobile phones, computer chips) than by the technical durability of the production equipment, and the risks mentioned might be overlooked in this micro perspective.
However, this is different for measures on the *meso- or macro level*. With few exceptions, decarbonisation targets are set for the medium to long term and exceed the 3-year time horizon, which is usually applied. Nonetheless, in many cases the “traditional” payback time methodology is still applied, although it would be economically more efficient to optimise for the year of the (intermediate) target (taking into account the sometimes shorter “useful lives” of some components and plants).
Above all, the many crises that mark our time show that there can be noticeable consequences if the costs of non-action, availability barriers and price risks for energy and possibly emission prices are not taken into account.

Since the established procedures do not address these aspects sufficiently, this report focuses on providing decision-makers in companies, service providers, financiers of politics, but also households with a methodology/an approach that addresses the shortcomings described and that they can use to determine their optimal mix of measures. The latter must make economic sense for their objectives, regardless of which country they are in, what the energy prices are there or whether there are emission levies.

[2] i.e., in the German *National Emissions Trading System* [16] all sources of energy which lead to $CO_2$-Emissions and are not falling under EU ETS jurisdiction are considered. The EU Emissions Trading System EU ETS [17] covers $CO_2$ from electricity & heat generation, energy-intensive industry sectors and commercial aviation within the European Economic Area, $N_2O$ & fluorinated GHGs.

To this end, the report first provides an insight into the importance of definitions in order to avoid misunderstandings. Then it elaborates on the impact of the three main types of measures and their subcategories, before further explaining how external effects can have a massive positive or negative impact. Taking these factors into account, a new calculation system that takes the above aspects into account is developed and presented.

Finally, an outlook is given on how this can be embedded in the wider decision-making context and how it can be simplified and dynamically adapted to constantly changing circumstances through digital measures, resulting in the optimal mix of measures for each chosen point in time.

# 2. Six types of measures and their impact

The three basic categories need to be further subdivided and then evaluated in terms of their *general* impact to allow derivations for the determination of an economic mix of measures. For each type of measure, both the *one-off economic effect* and the *permanent economic effect* are assessed, as well as whether it has a direct *impact on emissions*.

## 2.1 Reduction

The category “reduction” includes types of measures that - regardless of the energy source - lead to a reduction in emissions. This can be achieved in various ways:

**Measure type 1: Reduction of energy consumption**

The (final) energy consumption can be reduced through a variety of selective (i.e., increasing the energy efficiency of a paint shop) or systemic measures (i.e., increasing efficiency of the compressed air system or energy management system) without negatively affecting the production quantity or quality. With these measures, known as energy efficiency measures, the desired result is achieved with less energy input, meaning that more value is obtained from one unit of energy.

*Economic one-off effect:* The implementation of energy efficiency measures requires various one-off interventions, depending on the type of measure: in most cases, these are *one-off investments* for the purchase of more efficient products, machinery and equipment and, if necessary, for their selection and installation. However, *organisational* and *awareness-raising measures* (e.g., switching off lamps or appliances that are not needed) and the *optimised use of existing control systems* (e.g., heating control) can also achieve relevant savings *without investing* in hardware. This activity can increase energy efficiency as well as uncover and eliminate energy wastage. Nevertheless, one-off time resources or external support are required. If monitoring is desired, additional costs are incurred for mobile or stationary measuring devices, for example, thermal imaging cameras, which can use artificial intelligence to automatically detect and report leaks in compressed air systems at comparatively low cost [20].

*Lasting effect:* The lasting effect of type 1 measures (reduction of energy consumption) is that the amount of energy required for a unit of output, i.e., ongoing energy costs, falls permanently to a lower level. This also increases energy productivity (revenue generated per unit of energy used). The higher the energy cost share of a product, the greater the positive impact of energy efficiency improvements on energy productivity and competitiveness. The energy costs saved could, for example, be used to reduce the end-customer price, refinance investments, increase the profit margin, create or maintain jobs, or a combination of these measures.
It should be noted that systemic optimisation often involves measures that go beyond the energetic 1:1 optimisation of the initial state. For example, the installation of brightness sensors that switch the lighting on and off independently depending on the incidence of light or also regulate the power independently so that the brightness is always maintained at a certain level, taking into account the brightness of natural light. If a higher brightness (lumens per square metre) is selected when light sources are replaced, for example to improve working conditions or (work) safety, or if larger or additional equipment is purchased, some of the

savings are eaten up again. This is called the *rebound effect* [21], which however is not subject of this study.

*Conclusion*: Reducing the amount of energy required to achieve a certain output not only leads to *lower ongoing energy costs* but also a *reduction in ongoing (energy-related) emissions* to the same extent (unless the energy source is already emission-free).

**Measure type 2: Reduction of process-related emissions**

Reducing process-related emissions is often only possible through a fundamental adjustment of the production process itself, a change in the form of energy required for the process, or a combination of these measures. An example of this can be found in steel production, where iron ore and coke are traditionally combined at high temperatures. The cast iron created in this reaction through incorporation of carbon atoms (C) from the coke is, in a further step, injected with oxygen ($O_2$) to remove the carbon (C) in the form of $CO_2$ and obtain steel [22]. This result can also be achieved by other means, e.g., via the electric arc process or by using (clean) hydrogen e.g., for the direct reduction process, leading to lower emissions caused by the process. In essence, it is about achieving the same result through a different chemical reaction that releases less methane, carbon dioxide or other greenhouse gases. In the case of organic compounds, other factors play a role, too. In livestock farming, for example, adapting the feed can lead to better digestion and consequently lower methane emissions. In addition to chemical reactions, the production approach can also lead to emission savings. For instance, instead of lathes that remove material from the workpiece (and thereby potentially waste it), additive processes such as 3D printing and/or lightweight construction techniques can be used which fulfil the same requirements for the end product (e.g., stability) with a completely different approach and lower (energy and) material input.

*Economic one-off effect:* Significant *one-off investments* are required to avoid structurally induced process emissions through process adaptation (as all machines for this process have to be replaced at once). In addition to the investments themselves, there are also the production losses during the conversion and retooling process, i.e., lost margins and fixed costs nevertheless incurred. Therefore, such modifications make sense when major maintenance is due anyway, machines need to be replaced, or a new building is planned.

*Lasting effect:* Compared to the original process, the emissions released per output decrease, but the effect on energy- and other ongoing costs depends on the alternative production technique chosen. In fact, it can also happen that the energy input per product increases. Particularly but not exclusively in the chemical industry, it is important to weigh up carefully what effect a changeover will have on emissions and on energy requirements and costs, i.e., how much electricity and/or hydrogen is needed additionally, at what cost, with what embodied emission footprint, to avoid how many process- and energy-related emissions.
The boundary between an actual reduction in process emissions and the energy-related emissions from a process (e.g., from burning gas) is very thin. This applies in particular to process (and infrastructure) modifications that enable a switch to clean energy sources. An example of this is the electrically heated steam cracker furnace, which could enable the chemical industry to switch its most energy-intensive and complex process, which produces chemicals for many products, to another fuel (clean electricity) [23].

*Conclusion:* A change in process engineering and/or process technology *leads to a reduction of ongoing (process-related) emissions*. How this affects the *ongoing energy costs depends on the production technology chosen*. They can remain unaffected, decrease, but also increase.

**Further reduction-related measure types:**

Not discussed in detail, but also falling into this category, are *emission reductions* through a reduction of the scrap rate and a more efficient use of the material or the use of waste products, offcuts, or other leftovers. These material and resource efficiency measures also lead to ongoing cost savings, as less raw material is needed, or several/more things can be produced with the same amount of raw material. However, these savings in ongoing costs do *not necessarily* lead to *energy cost savings* (i.e., less off-cut does not lead to less energy used as the energy use per product output is not affected. Yet, less off-cut means less material and therefore less energy is needed to produce and transport the material. Depending on whether this material is produced on-site or by someone else off-site, these savings are either Scope 1/2 savings or Scope 3 savings, which are not considered in this report.

## 2.2 Substitution

"Substitution" includes those measures in which one energy source is replaced by another energy source of similar value. Value refers to both the "calorific value", which can vary across fuels (i.e., for a litre of petrol depending on its octane figure and whether it is bio-based or fossil-based), and the effectiveness of the substitute in achieving the desired outcome (i.e., the quantities – and associated calorific values – needed to reach a certain temperature). Conversion losses can also play a role (e.g., converting clean electricity into hydrogen instead of directly using the electricity, or heat radiation that is not used).

**Measure type 3: Substitution with self-generated renewable energies**

There are many ways to self-generate (or recover) energy. The main forms are hydropower, wind power, geothermal energy, solar energy (for electricity or heat) and bioenergy (biogas/biomass) [24]. Forms of heat recovery, such as heat pumps or waste heat conversion, are on the borderline of energy efficiency measures.

*Economic one-off effect*: *One-off investments* are required to explore which type of energy generation is possible at the site, as well as for the *acquisition*, *construction & commissioning of the technology itself*. While some renewable energy sources guarantee a continuous energy supply (e.g., geothermal energy), this fluctuates for most other energy sources. If the generation coincides with the time of energy demand, everything is fine. However, in most applications, a suitable energy storage system (e.g., thermal, electrical, mechanical or chemical [25]) is required to ensure a continuous energy supply or the smoothing of peak loads, and - or alternatively - a flexible external energy supply to cover potential gaps. Instead of or in addition to the one-off investment in an energy storage system, it is also possible to check which energy consumption could be automatically throttled or switched off (or the energy source changed) without any problems during periods of insufficient generation. The Kopernikus Project "SynErgie" explores means to facilitate the development and implementation of energy adaptive production technologies and approaches in industry. It builds on nine different forms of energy demand flexibilisation, originally described by Grassl and Reinhart [26](p. 130), that can be considered, including virtual storage, but these are not discussed in further detail here [27].

*Lasting effect:* Although there are additional ongoing maintenance costs apart from biogas, and possible charges for the use/diversion/discharge of water, the ongoing costs for on-site energy generation are - in most cases - very low or even zero in relative terms.

*Conclusion:* The construction of an energy generation plant on one's own premises requires in most cases an accompanying storage and/or flexibilisation approach and *reduces the ongoing energy-related emissions* and the *ongoing energy costs* (in most cases) to almost zero.

**Measure type 4: Substitution through the purchase of renewable energies**

Instead of generating renewable energies oneself, they can also be sourced from outside. This can be done, for example, via district heating networks, biomass/biogas plants and in the form of gases or electricity from sustainable energy sources (see above).

*Economic one-off effect:* In most cases, no one-off investments are required for the purchase of renewable energies. In some cases, connection fees may apply (e.g., for connection to a district heating network).

*Lasting effect:* The price for a kilowatt hour (kWh) of renewable energy in "green electricity tariffs" is currently often still higher than a kWh in a "standard tariff", as energy providers often add a surcharge to the otherwise increasingly competitive price in order to finance the expansion of renewable generation facilities. Indeed, technological advances and other effects (e.g., social value, emission price schemes that make fossil generation more expensive) mean that energy generation from renewable sources is increasingly competitive or more competitive than conventional energy generation. Nonetheless, it will still take time before these competitive plants account for the largest share of renewable energy generation and thus are more competitive on average. Moreover, the geographical location has a large impact on the cost competitiveness (i.e., differing solar radiation, strength of wind, tidal range, geology)[28,29]. Therefore, the ongoing energy costs may even increase a bit in some cases.

*Conclusion:* The purchase of renewable energies, especially in electrical form, is easy, as it often only requires switching to an appropriate tariff. However, the *ongoing energy costs* (often) *increase* and availability is still more limited than conventional generation, which can also have an impact (i.e., excess demand can drive unit price or limit access to such a tariff). At the same time, the *ongoing energy-related emissions are reduced* to near zero (in most cases).

**Further measure types to substitute fossil energy carriers:**

Participation in (external) energy generation plants is a mixed form, which - apart from the location outside the own premises - differs from local self-generation mainly because the energy is first fed into the public energy grid, and expenses are incurred for this. More and more large and energy-intensive companies, such as BASF [30] or ArcelorMittal [31] are investing into “their own” wind farms to gradually be able to cover their energy needs from sustainable sources. However, in contrast to measure type 3, these are not located on their factory’s premises. The (co-)ownership of the generation infrastructure leads to *one-off and maintenance costs*, but the *ongoing energy costs drop* to almost zero.
Another special form is power purchase agreements (PPAs). In contrast to energy tariffs, which are based on the price per unit, PPAs comprise a long-term contractual agreement on certain energy quantities for a fixed price. This provides security for both the energy supplier (secure revenue at a fixed price) and the customer (guaranteed access and usually no price risks). Unsurprisingly, according to the wind energy association WindEurope [32], corporate wind energy PPAs have become quite popular among large energy users, as also shown by the announcements of Covestro [33], or the cement company OPTERRA [34].
While in PPAs long-term agreements are made and the source of energy (i.e., the wind farm) is sometimes built just to serve one specific customer, there is *no co-ownership or direct investment* by the customer, so *ongoing energy costs continue*.
Both mixed forms result in *ongoing energy-related emissions approaching zero* and are not discussed in further detail here.

The substitution of materials can also reduce emissions, especially with regard to the product-related footprint. This is the case, for example, with the addition of recovered paper in paper production, of scrap metals in iron, steel and copper production, or recycled plastic in many products made of synthetic fibres and materials, such as clothing.

The substitution by less $CO_2$-containing energy sources (e.g., coal by gas), mentioned in other approaches in this context, is not addressed in this report. From the authors’ point of view, this can only be a transitional solution.

## 2.3 Compensation

Compensation refers to those voluntary and involuntary measures that aim to offset the effects of energy- or process-related emissions, but do not prevent the emissions themselves.

**Measure type 5: Compensation through certificates or projects**

Two types of measures can be distinguished: firstly, the purchase of emission allowances. For example, if a state or a company emits less than the emission allowances allocated to it or purchased by it allow, it can sell on the surplus allowances. Manufacturers of electric vehicles, for example, have been able to generate considerable revenue with this in the past [35]. Secondly, climate protection projects can lead to emission reductions and get issued emission reduction certificates, which can be used to offset one’s own surplus GHG emissions, through emission reductions somewhere else and not at one’s own location.

*Economic one-off effect:* Although the purchase of certificates is made selectively or a project is financed on a one-off basis, it is not a one-off economic effect in the context of this publication, as it needs to be repeated continuously to offset emissions as they arise (i.e., if a company emits 100 tonnes of $CO_2$-eq. per year, then it needs to find projects to finance each year to offset the new 100 tonnes of emissions). However, one-off search costs may be incurred for the identification and due diligence of suitable projects. These costs take the form of staff hours or direct cost (i.e., for service providers, consultants or subscriptions to platforms) – both are 'transaction costs' that need to be taken into account in the overall financial assessment.

*Lasting effect:* Energy-related and process-related emissions continue to occur as a result of ongoing economic activity. Offsetting these emissions is therefore an ongoing additional expense.

*Conclusion*: The ongoing energy costs and the *emitted emissions* remain unchanged, but the emissions are *offset elsewhere*. This incurs additional ongoing costs, which could increase if the availability of suitable compensation options is scarce.

This only applies to measures where emissions reductions are certified for the entire lifetime and permanence is assumed without further ongoing costs (e.g., financing the planting of a tree). The other form of climate protection projects, where a one-off investment and ongoing costs are incurred in return for generating annual emission reduction certificates (e.g., building a wind farm), is not considered in this example. In contrast to the one-off example, such a multi-year project can offer predictability, initially high but in the long-run lower costs per tonne of offset emissions, and instead of search-costs for suitable projects there are maintenance, operating and certification costs.

**Measure type 6: Compensation through storage, binding & use**

Another form of compensation (which is not permitted everywhere, however [36]) is the capture and storage of emissions as they arise (carbon capture and storage, CCS) [37] or their further processing and use as raw material elsewhere (carbon capture and utilisation, CCU), for example in the chemical or building materials industry [38]. The amount of $CO_2$ permanently stored (CCS) or used (CCU) reduces the GHG emission balance of the company, and thus decreases the amount of GHG that needs to be addressed by measure types 1-5 (as achieving zero emissions is not feasible with CCS/CCU alone).

*Economic one-off effect*: So far, there are only a few installations. Considering the often still experimental nature of the facilities, significant one-off investments are to be expected and there is still little, but increasingly more, information on the predicted one-off- and ongoing costs [39]. Moreover, these largely depend on how and where the emissions are to be stored (i.e., on-site or in depleted oil wells), how much needs to be stored (as this contributes to operational expenditure (OPEX) and equipment limitations), the type of storage medium, and how the emissions are captured and transported there (i.e., pipeline or ship).

*Lasting effect*: Energy is needed to operate a CCS/CCU plant, which means that *additional ongoing energy costs* will be incurred. In the case of CCS, additional ongoing (transport and) storage costs might arise.

*Conclusion:* Current emissions are not avoided, but they are reduced and prevented from causing harm. If they are used in a converted form as a substitute elsewhere, they can reduce emissions there. The *ongoing energy costs* from the actual economic activity remain *unchanged*. Nevertheless, the factory may incur *additional ongoing energy/operating/transport/storage* costs for the CCS/CCU plant, which in the case of CCU can be partially offset by additional ongoing revenues. Typically, CCU/CCS is a solution for hard-to-abate sectors (i.e. chemical and petrochemical industries, iron and steel and cement)[40,41] and fossil energy generation (i.e., gas and coal-fired power plants)[42,43].

**Further measure types to offset emissions:**

In addition to the two types of measure types described, there is a separate category of approaches: Carbon Dioxide Removal (CDR) or Negative Emission Technologies (NETs). In contrast to approaches that avoid or reduce *fossil* GHG emissions, carbon-negative approaches actively remove emissions from the atmosphere, which means that they permanently store *atmospheric* or *biogenic* carbon dioxide. The International Energy Agency distinguishes between nature-based solutions (e.g., afforestation, reforestation), enhanced natural processes (e.g., storing emissions in the soil, enhanced weathering, or ocean fertilisation) and technological solutions (e.g., bioenergy with carbon capture and storage (BECCS) or direct air capture and carbon storage (DACCS))[44].

All these solutions have the potential to remove emissions but come with *additional one-off and often also energy- and other ongoing costs*, e.g., for maintenance or general transaction costs.

## 2.4 Reference Scenario: Do not act

Although non-action means that "neutrality" in any form (carbon-, climate-, environmental- ) is not a goal, it is necessary to mention it in terms of opportunity costs – i.e., the costs of the action alternative/non-action.

*Economic one-off effect*: There are no investments.

*Lasting effect:* In countries and regions where there is an emissions price on energy- and/or process-related emissions, the ongoing costs will increase by the amount of the current emissions multiplied by the price of the respective emission type. This is not the case in countries and regions *without* emission charges on energy- and/or process-related emissions. However, if a company manufactures in a country/region without emission levies, but carbon border adjustments (CBAM) are in place in the country/region to which the company wants to export its products, the situation changes [45,46]. An emissions levy *may* be charged per exported product unit, which is based on the product carbon footprint (PCF) and aligned with the emissions price of the target market [47]. Such additional ongoing costs may also be incurred – regardless of whether emission prices or CBAMs are in place- if customers insist on the delivery of products with a reduced or net-zero product PCF [48].
The nature/extent of the immediate economic effects of inaction – apart from progressive climate change and its effect on the general and immediate local weather, ecosystem, etc. – mainly depends on where the emitter is located geographically, and what rules apply there.

*Conclusion:* Although *neither emissions nor ongoing energy costs are reduced*, depending on the location, noticeable *additional ongoing costs can be incurred* for the emissions released. Depending on the pricing model, these costs per unit of emissions can vary. If these revenues flow to state actors and are used for climate protection projects, at least a part of the emissions is offset – but not in countries and regions without an emissions price. There, external incentives for decarbonisation arise at best through calls for action by the public/customers, investors, supply chains, or as a result of other (regulatory) measures.

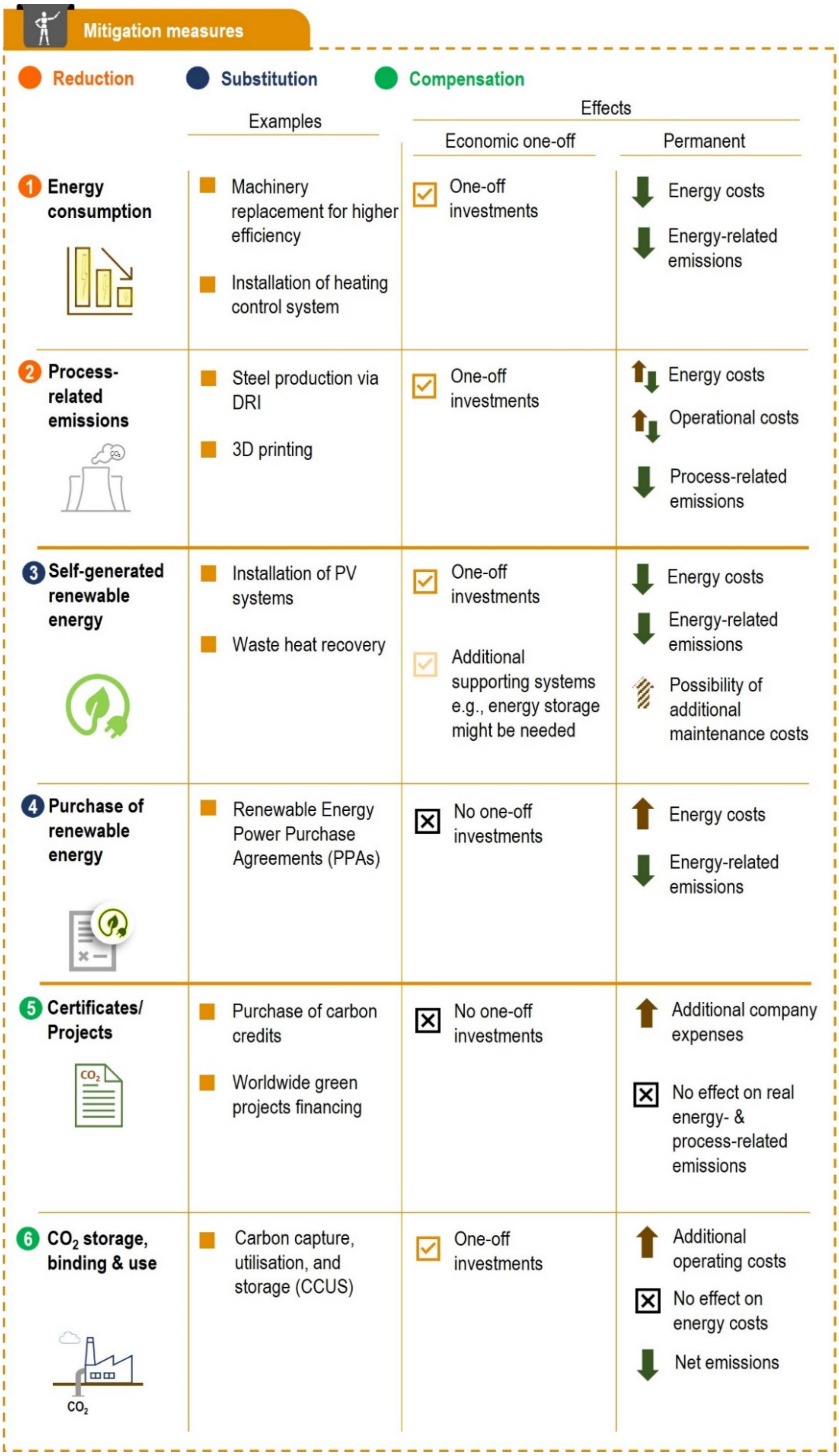


*Figure 3. Overview of the six types of measures and their impact*

Knowing the economic impacts of the described six types of measures in terms of one-off and ongoing costs, as well as knowing one's own emissions, can already help in the selection and prioritisation of possible measures to achieve net-zero emissions (cf. **Figure 3**). However, in order to determine an economic mix of measures, it is essential to also take into account higher-level interrelationships and external influencing factors.

# 3. System view: external factors with strong influence

After the general economic analysis of the types of measures, the latter have to be assessed in the context of one's own objectives and the overall system in which one operates in: taking into account, on the one hand, legal and regulatory requirements, geographical circumstances, and the availability on the market and, on the other hand, societal expectations and the impact of one's own choice of (non-)action.

With regard to an "easy" and "quick" implementation, the purchase of renewable energies (measure type 4) or the investment in emission reduction certificates, as well as in climate protection projects brokered by third parties (type 5) appear to be the obvious solution.

However, if one considers (for example) the share of renewable energies in total electricity generation in 2019 (see **Table 1**; i.e., World: 26 %, EU-27: 34 %, industrial economy, e.g., Germany: 40 %) and puts this in the context of the electricity demand of by industry (42 %, 36 %, 45 %), it becomes clear that a widespread decision for a "simple" change of the electricity tariff will lead to excess demand almost everywhere (cf. light red in **Table 1)** [49-51]. The latter particularly constitutes an ongoing issue in geographies where the expansion of renewable generation and transmission infrastructure is progressing more slowly slower than the demand for it. There is no notable change if other forms of low carbon generation (i.e., nuclear) are added, except in the case of OECD countries, as illustrated in **Table 1**: where renewable or low carbon supply (= renewables + i.e., nuclear) exceeds industry demand, the cell is highlighted green; where it is at the same level, yellow; where it is less than the industrial sector's final demand, red.

*Table 1. Share of renewable generation compared to share total electricity consumed by industry; own computation based on data from IEA World Energy Balances Highlights [49] and Eurostat [50,51].*

| 2019 | Electricity (Totals) | | | Energy (Totals) | | |
|---|---|---|---|---|---|---|
| Shares / Regions [49] | Supply | | Final Consumption | Supply | | Final Consumption |
| | renewables | low carbon | Industry | renewables | low carbon | Industry |
| World | 26% | 36% | 42% | 14% | 19% | 29% |
| OECD | 27% | 45% | 32% | 12% | 21% | 22% |
| Non-OECD Total | 25% | 30% | 49% | 16% | 19% | 35% |
| Non-OECD Americas | 68% | 70% | 38% | 34% | 36% | 28% |
| Non-OECD Europe and Eurasia | 19% | 37% | 42% | 5% | 12% | 27% |
| Non-OECD Asia (incl. China) | 25% | 29% | 55% | 14% | 16% | 43% |
| Middle East | 3% | 3% | 23% | 1% | 1% | 28% |
| Africa | 21% | 22% | 38% | 48% | 48% | 14% |
| EU-27 [50,51] | 34% | . | 36% | 20% | . | 26% |
| China | 27% | 32% | 60% | 10% | 12% | 49% |
| Germany | 40% | 52% | 45% | 16% | 22% | 25% |
| Italy | 40% | 40% | 41% | 19% | 19% | 21% |
| Japan | 18% | 24% | 36% | 8% | 12% | 29% |
| South Africa | 5% | 10% | 52% | 6% | 8% | 38% |
| USA | 18% | 37% | 20% | 8% | 18% | 17% |

Even without sector coupling, e-mobility and process decarbonisation, this (excess) demand cannot be met at present and could lead to price increases for green electricity tariffs. Moreover, in the context of the energy system, this would amount to a zero-sum game in terms of emissions, as the footprint of the standard electricity mix deteriorates to the same extent as it improves for tariff switchers (and as the overall electricity mix remains unchanged without capacity expansions). Climate risks (e.g., droughts), but also other severe events (e.g., earthquakes, wars, structural failures) can lead to reduced electricity supply as power stations cannot generate (e.g., lack of cooling for thermal and nuclear power plants) or distribute energy (if transmission lines or distribution nodes are impaired). This dynamic drives up the unit price for energy (unless self-generated or delivered in context of a PPA), especially in "merit order" driven electricity markets, where the "most expensive" source of energy determines the spot market price for all electricity sold. Climate risks and other events can also affect on-site generation, but the risk is lower, and reducing energy and resource demand in the first place promotes energy resilience to such availability and price shocks.

As already indicated, electricity is not the only form of energy that the industrial sector needs for its operations. Switching all energy needs (including oil, gas, coal, etc.) to renewable or low-carbon sources might be more difficult than switching from the standard electricity mix to low-carbon electricity. This is because (a) the gap to meet the industrial sector's needs is larger in most places (cf. **Table 1**) and (b) many of the alternatives are less mobile or require new infrastructure, unlike renewable electricity that is already connected to the grid.

Since the *availability of emission reduction certificates* and *credible climate protection projects* (and those who can identify, check, plan and implement them) is also limited, these effects of excess demand are not only connected to a shortage of renewable energies on the market. In addition, there is an increased risk of falling prey to dishonest projects that ultimately damage the company's image and have no protective effect on the climate (e.g., reforestation on an area that is explicitly cleared for this purpose or reforestation that is cleared again a few years later or protecting a forest that is not endangered)[52-55]. Therefore, it is important to look out for Certified Emission Reductions (CERs) that are in line with the Sustainable Development Mechanism (SDM). The latter succeeds the Clean Development Mechanism (CDM) introduced with the Kyoto Protocol, and follows the rules set out by Article 6 of the Paris Agreement, ensuring "permanence", "additionality" and ruling out "double-counting" [56,57]. As a consequence, there can be no legitimate CERs generated from projects located within the European Union, for example, as emission reduction projects in the region are counted directly against the EU emissions inventory; projects carried out there may be undertaken "voluntarily" but cannot be counted against one's own emissions inventory (for reasons of double counting / additionality)[58].

Furthermore, regarding the expansion of transmission infrastructure and renewable energy generation, it is significant to notice that there is already a shortage of skilled workers in the construction sector and thematically relevant trades in many geographies [59,60]. This shortage is problematic since the increasing number of net-zero declarations by countries and companies is expected to lead to an increase in commissions of on-site decarbonisation measures, renewable generation & transmission infrastructure, and projects relating to climate protection. Given the limited capacity of local authorities, whose approval is oftentimes required, longer *waiting times* and possibly higher costs for priority treatment should be expected as well.

The bottom line is that it makes sense to prioritise on-site actions (measure types 1, 2, 3, 6) and to act quickly for several reasons: firstly, to build resilience against availability/price shocks, secondly, to reduce the risk of having to wait in line, and, thirdly, to minimise the "procrastination costs" of missed cost saving opportunities.

## 4. Consideration of price fluctuations

The one-off economic effects and ongoing impacts of the different types of decarbonisation measures are complemented by the effects of energy and emission price developments, as these influence how cost savings change over time. The investment costs at the time of planning are known from quotations. Although the ongoing costs change over time, the change is often analogous to a regular price increase and can thus be easily estimated. In contrast, energy prices often fluctuate more strongly and frequently [61], e.g., due to political developments. Looking at the price development of the European Union Emissions Trading Scheme (EU ETS)[62](cf. **Figure 4**), a significant increase can be observed after the announcement of tightened EU climate targets for 2030 (from -40 % to -55 % compared to 1990) on 11 December 2020 [63].

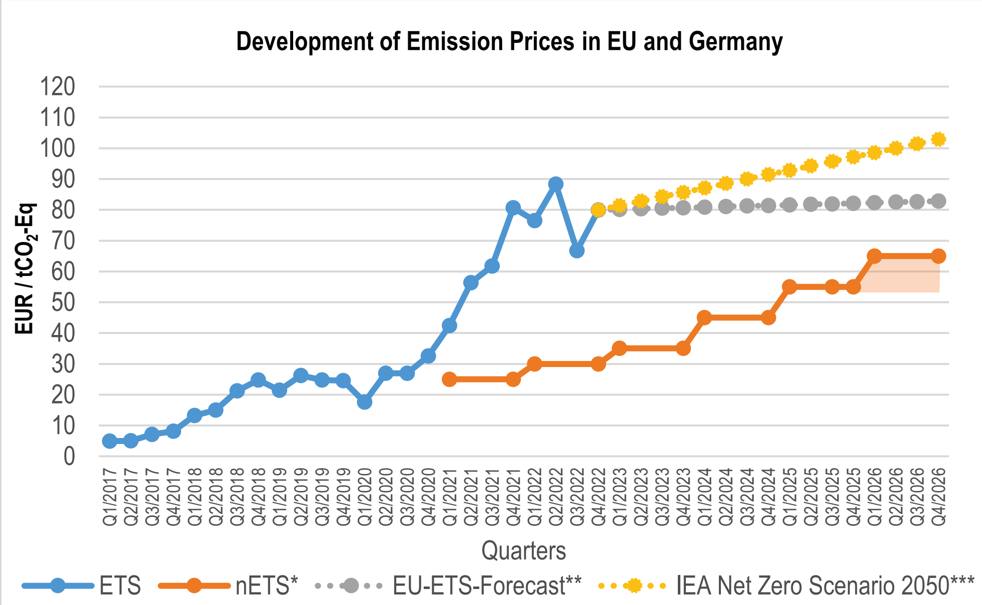


*Figure 4. Exemplary emission price development: Market based system (EU ETS) and its forecasts for 2030* [17,62,64-66][3]*, as well as fixed-price system with staggered increases (German nETS)*[67] *that is charged on energy-related emissions not covered by EU ETS* [68].

Various factors influence emissions and energy prices, but they can also influence each other. For instance, higher emission prices may lead to a rising demand for electricity from renewables and thereby increasing prices for green electricity (see **section 3**), unless the global expansion of renewable energies progresses in parallel to/in tandem with the rise in demand, effectively counteracting a price increase by augmenting supply.

Therefore, in the following deliberations, five of the six types of measures are considered with regard to the expected price fluctuations. The reference scenario, in which a company does nothing and is fully exposed to fluctuations, serves as a basis for comparison: If energy or emission prices rise, this leads to higher energy and emission costs.

**Reduction measures** (section 2.1) lead to:

- A permanent reduction in energy consumption/costs compared to the Reference Scenario (provided that energy is purchased externally, and it is a measure of the energy consumption reduction category (measure type 1)) and thus to *less dependence on the development of energy price developments, as they consume less.*
- A permanent reduction in emission(costs) compared to the Reference Scenario (regardless of which energy source is ultimately used and whether it is a reduction in energy consumption (1) or emissions (2)) and consequently to *less dependence on emission price developments, as they emit less*.

**Substitution measures** (section 2.2) lead to:

- A significant reduction in emissions as, for instance, the emission costs are lower in comparison with the reference scenario. In case of 100 % substitution with renewables (regardless of whether (3) or (4) is used) there is complete *independence from the emission price development* as no direct energy-related emissions arise.
- *A complete independence from energy prices developments* in the case of 100 % substitution through self-generation (3) in combination with buffer storage, as no direct energy costs are incurred.
- A *permanent dependence on the development of energy prices* and/or the *availability* of renewable energies when it comes to substitution through the purchase of renewable energies (4). The cold snap in Texas in February 2021  shows how quickly the

[3] * National Emissions Trading Scheme [67], ** first EU forecast for ETS price in 2030 due to "Fitfor55" at 85 EUR [65,66], *** required $CO_2$ price in IEA Net Zero 2050 Scenario for 2030 at 140 USD (2021 avg. ~ 120 EUR) [64]

availability of renewables, but also conventional energy generation, can dwindle and what massive consequences the failure of equipment can have [69,70]. The tariff and pricing of the supplier determine whether there are delivery guarantees or delivery failures, or whether a fixed price per kWh or the current spot price has been agreed – in other words, who bears the risk.

**Measures to compensate** through emission reduction certificates and climate protection projects (5, section 2.3) lead to:

- *No change in emissions* in case of offsetting 100 %, i.e., the amount of emissions is unchanged compared to the reference scenario. The emission costs are lower than the Reference Scenario, as the “penalty costs” (referring to emission prices) are higher compared to the certificate or project costs.
- *No change in energy consumption* in case of offsetting 100 %, i.e., the energy costs remain unchanged compared to the Reference Scenario.
- A complete *dependence on the certificate/project price development* if 100 % offsetting is sought through certificates or project financing (5). With steadily rising emission prices, this can, for example, result in many companies relying on offsetting via certificates or project financing (5), thus driving up the demand for certificates or projects and consequently the price for them. This price increase can be significant if there is a similar political reaction as after the Fukushima reactor disaster or if climate neutrality is targeted faster than before, both politically and socially. This case has been illustrated by the increase in EU ETS since the EU’s decision to go climate neutral (cf. **Figure 4**).

However, the opportunity costs described so far and in particular the energy and emission price fluctuations are hardly systematically taken into account in the calculation of economic efficiency or economic consideration of alternative courses of action. Therefore, a new procedure is needed that ensures both the consideration of opportunity costs and the temporal component.

# 5. Recommendation for action

## 5.1 A new economic efficiency calculation

Up to now, the payback time has typically been used as a central decision criterion in economic efficiency calculations. Especially the simplified calculation of the *(static) payback time* is common practice, although this does not sufficiently reflect the actual economic efficiency of the measure [71].

Only in a few cases is the return, for example the *return on investment* (RoI) or the *internal rate of return* (IRR), calculated considering the period of use (useful life). Therefore, the useful life and the development of energy prices, which have often been disregarded, should be taken into account in the new economic efficiency calculation. Moreover, emission prices, which are or have been introduced in many geographies in the meantime, should also be taken into account. Therefore, for this new economic efficiency calculation, it is proposed to use the following formula for each measure option to calculate the savings:

*Equation 1. Calculation of aggregated savings for a measure option*

$$
\begin{aligned}
Savings\ (N,E) = & \sum_{t=1}^{N}\sum_{e=1}^{E}\Big(Energy\ price_{Reference}(t,e) * Energy\ amount_{Reference}(t,e) \\
& - Energy\ price_{New}(t,e) * Energy\ amount_{New}(t,e)\Big) \\
& + \sum_{t=1}^{N}\sum_{e=1}^{E}\Big(Emission\ price_{Reference}(t,e) * Emission\ amount_{Reference}(t,e) \\
& - Emission\ price_{New}(t,e) * Emission\ amount_{New}(t,e)\Big)
\end{aligned}
$$

The calculation is based on the intended period of use (**N**) of the measure option (e.g., time **t** in years) during which the savings are accrued and on all energy sources (**E**) used (e.g. $e_1$ = electricity, $e_2$ = gas, etc.). The formula calculates the difference in energy and emission-related costs between the reference scenario (described in **section 2.4**) and the outcome of implementing one of the measure options (a scenario). The continuous change in energy and emission prices is also considered.

For this reason, there are two groups of variables. Variables with the suffix "Reference" refer to the scenario in which no action is taken (at any time):

- **Energy amount Reference** is the energy consumed for each energy source; since no measure is taken, the energy quantities for each energy source remain constant over time.
- **Emission amount Reference** is the sum of the energy-related emissions caused by the consumption of the **Energy amount Reference** per energy source and the process-related emissions; since no measure is taken, it also remains constant over time.
- **Energy Price Reference** is the price per unit that applies for each energy source; depending on the **Energy amount Reference** the price per unit might be different (a different price level may apply depending on the amount used); it is not constant and changes over time.
- **Emission Price Reference** is the price per unit of emissions that must be paid as an emission charge on the **Emission amount Reference**; it can change over time.

  Depending on the region/country and energy source, the emissions price may already be included in the energy price (e.g. for electricity in the EU, as electricity producers are covered by the EU ETS and pass on the cost of this in the electricity price). This is not the case for the examples in the following sections.

Variables with the suffix "New" reflect the measure option considered:

- **Energy amount New** can be lower than the **Energy amount Reference** (measure type 1) and the energy sources can be different (3, 4);
- **Emission amount New** can be lower than the **Emission amount Reference** (1, 2, 3, 4);
- **Energy Price New** differs from the **Energy Price Reference** in case of a change of energy sources (3, 4) or a decrease in energy consumption (1) which leads to the application of a different price level;
- **Emission Price New** differs from the **Emission Price Reference** as it is the price for emission reduction certificates and projects (5) or the price to capture and store emissions (6).

The variables with the suffix "Reference" and "New" are primarily intended for the calculation of savings compared to the initial state. In this context, "New" is not always identical with the (total) remaining amount of energy or emissions after implementation of a measure.

This can occur in the following cases:

- if only a part of the emissions or energy consumption is addressable/addressed by the measure and the old price (Reference) is applied for the "remaining ones".
- if the emissions are addressed but still exist (CCUS, (6)).

As a result, for example, the **Emission amount New** in the calculation of measure types 4 and 6 is lower than the **Emission amount Reference**. For measure type 4, this is consistent with the facts: renewable energies cause fewer emissions. For measure type 6, on the other hand, the emission quantities remain the same in reality, since storage does not change the existence of the emissions themselves.

The following procedure is suggested for applying the formula:

1) Map the current situation by determining
   a) the energy consumption and energy costs separated by energy sources,

b) the emissions of the consumed energy (using the emission factors of each energy source), converted in $CO_2$-equivalents, and the corresponding emission costs,

c) the process-related emissions, converted in $CO_2$-equivalents, and the associated emission costs (if applicable)

to obtain all reference variables.

2) Make assumptions about

a) the future development of energy prices, which can be made on the basis of scenarios of the International Energy Agency (IEA), such as the Stated Policies Scenario (STEPS) [72],

b) the future development of emission costs, whereby staggered fixed prices for emission allowances (such as in the nETS under the German Fuel Emission Trading Act BEHG until 2025 [16]) or forecasts of emission price developments can be used,

c) the impact of the measure option on, for example, the amount of energy, energy-related emissions, or process-related emissions

to obtain all new variables.

3) Calculate the aggregate savings (**N, E**) until year **($t_x$)** with the above-mentioned formula (cf. **Equation 1**).

## 5.2 Guiding remarks for applying the new economic efficiency calculation

In order to realistically depict the effect of energy and emission price developments in the following examples, one can either (a) use scenarios (e.g. from the IEA [72]), or (b) use actual data from the recent past. If it is only a matter of practising the application of the formula, (c) a simple linear development or (d) constant prices can be assumed for the calculation.
If there is no price on emissions in the region of the intended application, one can set the value for this to 0 in the formula and can still see what price effect any voluntary measures or measures demanded by the customers/destination country have.

Similarly, performance data of projects that have already been carried out can be used to obtain a realistic estimate for investment costs, ongoing costs (maintenance, etc.) and the associated changes in emissions and energy consumption. Whether these projects have been carried out by the company itself, originate from an offer, or represent the best-practice example of a third party is irrelevant for the example calculation.
As the many measures within the described categories of measure can be quite different and the assumption of "any" figures could give a wrong impression about the financial performance of the measure, we only address the savings in the examples, but not the required investments and related costs.
Moreover, this aspect is used in many calculation approaches and should therefore be sufficiently familiar.

For more complex scenarios with multiple energy sources, differing energy- and emission prices the formula(s) (cf. **Equation 1**, etc.**)** needs to be applied accordingly. This includes, but is not limited to, different unit prices depending on the type of energy chosen (i.e., taking into account the frequent mark-up for renewable energy tariffs), different costs per tonne of emissions for emission prices, emission reduction certificates and climate protection projects (including the associated transaction costs). In the examples provided, this is also the case when less than 100 % of the energy or emissions are addressed by one measure: in such case, the "old" energy price or emission price (Reference price) is applied to the amount of energy or emissions not addressed by the sample measure. The share addressed by the measure is charged the "new" energy or emission price.

## 5.3 Applying the new economic efficiency calculation: examples for the six measure types

To illustrate the calculation, examples of different measures with exemplary figures are provided in this sub-section. A number of simplifying assumptions are made to ease the application. Then the calculation is carried out for the Reference Scenario and the six types of measures.

**Assumptions:**

To highlight the differences between measures, the examples of the new economic efficiency calculation are kept simple and contain fixed assumptions to make the economic effects more visible:

1) One energy source: electricity with an emission factor of 0.4 $gCO_2$-eq/kWh
2) Energy price: 20 ct[4]/kWh with a linear increase of 2 % per year
3) Emission price: 30 EUR/$tCO_2$-eq with an increase of 5.00 EUR per $tCO_2$-eq per year

In all example calculations, it is assumed that a company, in the base year (**t** = 0 = $\mathbf{t_0}$) has a total energy consumption of **1,000 MWh** (electricity only) and annual emissions of **600 $tCO_2$-eq** (400 $tCO_2$-eq *energy-related* and 200 $tCO_2$-eq *process-related*). It is further assumed that in the base year the company sets the target to achieve net-zero emissions within 30 years (t = 30 = $\mathbf{t_{net\text{-}zero}}$). To work towards this goal, it successfully implements a measure option during $t_0$. The full effect of the implemented measure option is visible starting from the first full year (t = 1 = $\mathbf{t_1}$). To show the effect of the measure over time, the values of the individual variables are calculated for the first five years, the first milestone after 10 years (t = 10 = $\mathbf{t_{milestone}}$) and the target year ($\mathbf{t_{net\text{-}zero}}$).

Additional assumptions are made for the calculation of the exemplary scenarios (cf. scenario description).

To improve the visibility of the effect of implemented measures, the variables with the suffix "New" are not shown in the tables if they have the same value as the variables with the suffix "Reference".

**Reference Scenario: No action is taken**

In the reference scenario, the company (located in an area where emission charges are levied) decides not to set an emission savings target and not to act. Therefore, **energy consumption** and the **annual emission amounts** remain the same over the years, whereas the total (ongoing) costs (= energy costs + emission costs) increase every year due to rising prices (see assumptions). **Table 2** displays the cost development over time, from $\mathbf{t_0}$ to $\mathbf{t_{net\text{-}zero}}$.

*Table 2. Exemplary reference scenario with assumed amounts and prices for energy and emissions.*

| | Energy amount Reference | Energy price Reference | Energy costs Reference | Emission amount Reference | Emission price Reference | Emission costs Reference | Total Costs Reference |
|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR |
| $t_0$ | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 |
| $t_1$ | 1.000 | 20.40 | 204,000 | 600 | 35.00 | 21,000 | 225,000 |
| $t_2$ | 1.000 | 20.81 | 208,080 | 600 | 40.00 | 24,000 | 232,080 |
| $t_3$ | 1.000 | 21.22 | 212,242 | 600 | 45.00 | 27,000 | 239,242 |
| $t_4$ | 1.000 | 21.65 | 216,486 | 600 | 50.00 | 30,000 | 246,486 |
| $t_5$ | 1.000 | 22.08 | 220,816 | 600 | 55.00 | 33,000 | 253,816 |
| (...) | | | | | | | |
| $t_{10}$ | 1.000 | 24.38 | 243,799 | 600 | 80.00 | 48,000 | 291,799 |
| (...) | | | | | | | |

[4] Ct = Eurocent, 10 Ct = 0,10 EUR

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $t_{30}$ | 1.000 | 36.23 | 362,272 | 600 | 180.00 | 108,000 | 470,272 |

**Measure type 1: Energy efficiency**

In this scenario, the company takes action and implements one measure of type 1 (energy efficiency) in **$t_0$**, which leads to a decrease in energy consumption in **$t_1$** (700 MWh instead of 1000 MWh, cf. dark green in **Table 3**) and to less energy-related emissions (280 $tCO_2$-eq instead of 400 $tCO_2$-eq, cf. light green in **Table 3**). As a result, the ongoing energy and emission costs decrease, leading to savings in total (ongoing) costs compared to the reference scenario. The column **Savings (N,°E,°t)** lists the savings (**Total Costs** $_{\text{Reference}}$ **(t)** – **Total Costs** $_{\text{New}}$ **(t)**) for the respective year **$t_x$**.

*Table 3. Exemplary scenario in which a measure of type 1 (energy efficiency) is implemented.*

| | Energy amount (New) | Energy price (Reference) | Energy costs (New) | Emission amount (New) | Emission price (Reference) | Emission costs (New) | Total Costs (New) | Savings (N, E, t) |
|---|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR | **EUR** |
| $t_0$ | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 | **0** |
| $t_1$ | 700 | 20.40 | 142,800 | 480 | 35.00 | 16,800 | 159,600 | **65,400** |
| $t_2$ | 700 | 20.81 | 145,656 | 480 | 40.00 | 19,200 | 164,856 | **67,224** |
| $t_3$ | 700 | 21.22 | 148,569 | 480 | 45.00 | 21,600 | 170,169 | **69,072** |
| $t_4$ | 700 | 21.65 | 151,541 | 480 | 50.00 | 24,000 | 175,541 | **70,946** |
| $t_5$ | 700 | 22.08 | 154,571 | 480 | 55.00 | 26,400 | 180,971 | **72,845** |
| (…) | | | | | | | | |
| $t_{10}$ | 700 | 24.38 | 170,659 | 480 | 80.00 | 38,400 | 209,059 | **82,740** |
| (…) | | | | | | | | |
| $t_{30}$ | 700 | 36.23 | 253,591 | 480 | 180.00 | 86,400 | 339,991 | **130,282** |

**Measure type 2: process decarbonisation**

In this scenario, the company implements one measure of type 2 (process decarbonisation) in **$t_0$**, which leads to a decrease in process-related emissions in **$t_1$** (150 $tCO_2$-eq instead of 200 $tCO_2$-eq, cf. dark green in **Table 4**). This reduces the ongoing emission costs and consequently the total (ongoing) costs compared to the reference scenario. The column **Savings (N,°E,°t)** lists the savings (**Total Costs** $_{\text{Reference}}$ **(t)** – **Total Costs** $_{\text{New}}$ **(t)**) for the respective year **$t_x$**.

*Table 4. Exemplary scenario in which a measure of type 2 (process decarbonisation) is implemented.*

| | Energy amount (Reference) | Energy price (Reference) | Energy costs (Reference) | Emission amount (New) | Emission price (Reference) | Emission costs (New) | Total Costs (New) | Savings (N, E, t) |
|---|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR | **EUR** |
| $t_0$ | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 | **0** |
| $t_1$ | 1,000 | 20.40 | 204,000 | 550 | 35.00 | 19,250 | 223,250 | **1,750** |
| $t_2$ | 1,000 | 20.81 | 208,080 | 550 | 40.00 | 22,000 | 230,080 | **2,000** |
| $t_3$ | 1,000 | 21.22 | 212,242 | 550 | 45.00 | 24,750 | 236,992 | **2,250** |
| $t_4$ | 1,000 | 21.65 | 216,486 | 550 | 50.00 | 27,500 | 243,986 | **2,500** |
| $t_5$ | 1,000 | 22.08 | 220,816 | 550 | 55.00 | 30,250 | 251,066 | **2,750** |
| (…) | | | | | | | | |
| $t_{10}$ | 1,000 | 24.38 | 243,799 | 550 | 80.00 | 44,000 | 287,799 | **4,000** |
| (…) | | | | | | | | |
| $t_{30}$ | 1,000 | 36.23 | 362,272 | 550 | 180.00 | 99,000 | 461,272 | **9,000** |

**Measure type 3: self-generation of renewable energy**

In this scenario, the company implements one measure of type 3 (self-generation of renewable energy) in **t** $_0$. Half of the annual energy demand can be self-generated, which means 500 MWh out of 1,000 MWh (cf. dark green in **Table 5**). Only 500 MWh still have to be purchased externally. This leads to a decrease in energy costs and the energy-related emissions in **t** $_1$ (cf. dark green in **Table 5**) compared to the reference scenario. The column **Savings (N,°E,°t)** shows the savings (**Total Costs** $_{\text{Reference}}$ **(t)** – **Total Costs** $_{\text{New}}$ **(t)**) for the respective year **t** x.

*Table 5. Exemplary scenario in which a measure of type 3 (self-generation of renewable energy) is implemented.*

| | Energy amount New | Energy price Reference | Energy costs New | Emission amount New | Emission price Reference | Emission costs New | Total Costs New | Savings (N, E, t) |
|---|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR | **EUR** |
| **t** $_0$ | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 | **0** |
| **t** $_1$ | 500 | 20.40 | 102,000 | 400 | 35.00 | 14,000 | 116,000 | **109,000** |
| **t** $_2$ | 500 | 20.81 | 104,040 | 400 | 40.00 | 16,000 | 120,040 | **112,040** |
| **t** $_3$ | 500 | 21.22 | 106,120 | 400 | 45.00 | 18,000 | 124,121 | **115,121** |
| **t** $_4$ | 500 | 21.65 | 108,243 | 400 | 50.00 | 20,000 | 128,243 | **118,243** |
| **t** $_5$ | 500 | 22.08 | 110,408 | 400 | 55.00 | 22,000 | 132,408 | **121,408** |
| **(...)** | | | | | | | | |
| **t** $_{10}$ | 500 | 24.38 | 121,899 | 400 | 80.00 | 32,000 | 153,899 | **137,899** |
| **(...)** | | | | | | | | |
| **t** $_{30}$ | 500 | 36.23 | 181,136 | 400 | 180.00 | 72,000 | 253,136 | **217,136** |

**Measure type 4: purchase of renewable energy**

In this scenario, the company implements one measure of type 4 (purchase of renewable energy) in **t** $_0$. All the energy consumed originates from renewable sources. This means the energy-related emissions drop to zero. Only the process-related emissions remain (200 MWh, cf. dark green in **Table 6**), leading to a decrease in emission costs in **t** $_1$ compared to the reference scenario. The column **Savings (N,°E,°t)** lists the savings (**Total Costs** $_{\text{Reference}}$ **(t)** – **Total Costs** $_{\text{New}}$ **(t)**) for the respective year **t** x.

*Table 6. Exemplary scenario in which a measure of type 4 (purchase of renewable energy) is implemented.*

| | Energy amount Reference | Energy price Reference | Energy costs Reference | Emission amount New | Emission price Reference | Emission costs New | Total Costs New | Savings (N, E, t) |
|---|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR | **EUR** |
| **t** $_0$ | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 | **0** |
| **t** $_1$ | 1,000 | 20.40 | 204,000 | 200 | 35.00 | 7,000 | 211,000 | **14,000** |
| **t** $_2$ | 1,000 | 20.81 | 208,080 | 200 | 40.00 | 8,000 | 216,080 | **16,000** |
| **t** $_3$ | 1,000 | 21.22 | 212,242 | 200 | 45.00 | 9,000 | 221,242 | **18,000** |
| **t** $_4$ | 1,000 | 21.65 | 216,486 | 200 | 50.00 | 10,000 | 226,486 | **20,000** |
| **t** $_5$ | 1,000 | 22.08 | 220,816 | 200 | 55.00 | 11,000 | 231,816 | **22,000** |
| **(...)** | | | | | | | | |
| **t** $_{10}$ | 1,000 | 24.38 | 243,799 | 200 | 80.00 | 16,000 | 259,799 | **32,000** |
| **(...)** | | | | | | | | |
| **t** $_{30}$ | 1,000 | 36.23 | 362,272 | 200 | 180.00 | 36,000 | 398,272 | **72,000** |

**Measure type 5: compensation through certificates or projects**

In this scenario, the company implements one measure of type 5 (compensation through certificates or projects) in **t** $_{0}$. All (energy-related and process-related) emissions are offset by certificates, whereby the costs for certificates are 40% lower than for emission allowances (cf. dark green in **Table 7**). This leads to a decrease in the emission costs in **t** $_{1}$ compared to the reference scenario. The column **Savings (N, E, t)** shows the savings (**Total Costs** $_{Reference}$ **(t)** – **Total Costs** $_{New}$ **(t)**) for the respective year **t** $_{X}$.

*Table 7. Exemplary scenario in which a measure of type 5 (compensation through certificates or projects) is implemented.*

| | Energy amount Reference | Energy price Reference | Energy costs Reference | Emission amount Reference | Emission price New | Emission costs New | Total Costs New | Savings (N, E, t) |
|---|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR | **EUR** |
| **t** $_{0}$ | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 | **0** |
| **t** $_{1}$ | 1,000 | 20.40 | 204,000 | 600 | 21.00 | 12,600 | 216,600 | **8,400** |
| **t** $_{2}$ | 1,000 | 20.81 | 208,080 | 600 | 24.00 | 14,400 | 222,480 | **9,600** |
| **t** $_{3}$ | 1,000 | 21.22 | 212,242 | 600 | 27.00 | 16,200 | 228,442 | **10,800** |
| **t** $_{4}$ | 1,000 | 21.65 | 216,486 | 600 | 30.00 | 18,000 | 234,486 | **12,000** |
| **t** $_{5}$ | 1,000 | 22.08 | 220,816 | 600 | 33.00 | 19,800 | 240,616 | **13,200** |
| **(...)** | | | | | | | | |
| **t** $_{10}$ | 1,000 | 24.38 | 243,799 | 600 | 48.00 | 28,800 | 272,599 | **19,200** |
| **(...)** | | | | | | | | |
| **t** $_{30}$ | 1,000 | 36.23 | 362,272 | 600 | 108.00 | 64,800 | 427,072 | **43,200** |

**Measure type 6: carbon capture, storage, binding and use**

In this scenario, the company implements one measure of type 6 (carbon capture, storage, binding and use) in **t** $_{0}$. Almost all process-related emissions are captured and stored with CCS technology, so that emission costs are only incurred for energy-related emissions (400 of the 600 $tCO_2$-eq, cf. dark green in **Table 8**). This leads to a decrease in emission costs in **t** $_{1}$ compared to the reference scenario. The column **Savings (N, E, t)** shows the savings (**Total Costs** $_{Reference}$ **(t)** – **Total Costs** $_{New}$ **(t)**) for the respective year **t** $_{X}$.

*Table 8. Exemplary scenario in which a measure of type 6 (carbon capture, storage, binding and use) is implemented.*

| | Energy amount Reference | Energy price Reference | Energy costs Reference | Emission amount New | Emission price Reference | Emission costs New | Total Costs New | Savings (N, E, t) |
|---|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR | **EUR** |
| **t** $_{0}$ | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 | **0** |
| **t** $_{1}$ | 1,000 | 20.40 | 204,000 | 400 | 35.00 | 14,000 | 218,000 | **7,000** |
| **t** $_{2}$ | 1,000 | 20.81 | 208,080 | 400 | 40.00 | 16,000 | 224,080 | **8,000** |
| **t** $_{3}$ | 1,000 | 21.22 | 212,242 | 400 | 45.00 | 18,000 | 230,242 | **9,000** |
| **t** $_{4}$ | 1,000 | 21.65 | 216,486 | 400 | 50.00 | 20,000 | 236,486 | **10,000** |
| **t** $_{5}$ | 1,000 | 22.08 | 220,816 | 400 | 55.00 | 22,000 | 242,816 | **11,000** |
| **(...)** | | | | | | | | |
| **t** $_{10}$ | 1,000 | 24.38 | 243,799 | 400 | 80.00 | 32,000 | 275,799 | **16,000** |
| **(...)** | | | | | | | | |
| **t** $_{30}$ | 1,000 | 36.23 | 362,272 | 400 | 180.00 | 72,000 | 434,272 | **36,000** |

## 5.4 Economic effects of the sequence of implementation of measure types

The calculations of the exemplary scenarios for the six types of measure types show the different economic effects of each measure type. However, the sequence of implementation is also important.

To illustrate the differences, the calculation for two measure types (energy efficiency (1) and purchase of renewable energy (4)) is shown below in different orders.

**Scenario 1: first measure type 1, second measure type 4**

In this first scenario, the company takes action and implements a measure of type 1 (energy efficiency) in **t 0**, which leads to a decrease in energy consumption in **t 1** (700 MWh instead of 1000 MWh, cf. dark blue in **Table 9**) and fewer emissions (480 $tCO_2$-eq instead of 600 $tCO_2$-eq, cf. light blue). One year later, in **t 1**, another measure (type 4 – purchase of renewable energy) is implemented, which leads to fewer emissions in **t 2** (200 $tCO_2$-eq instead of 480 $tCO_2$-eq, cf. orange).

*Table 9. Exemplary scenario in which first a measure of type 1 and then a measure of type 4 is implemented.*

| | Energy amount New | Energy price Reference | Energy costs New | Emission amount New | Emission price Reference | Emission costs New | Total Costs New | Savings (N, E, t) |
|---|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR | **EUR** |
| **t 0** | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 | **0** |
| **t 1** | 700 | 20.40 | 142,800 | 480 | 35.00 | 16,800 | 159,600 | **65,400** |
| **t 2** | 700 | 20.81 | 145,656 | 200 | 40.00 | 8,000 | 153,656 | **78,424** |
| **t 3** | 700 | 21.22 | 148,569 | 200 | 45.00 | 9,000 | 157,569 | **81,672** |
| **t 4** | 700 | 21.65 | 151,541 | 200 | 50.00 | 10,000 | 161,541 | **84,946** |
| **t 5** | 700 | 22.08 | 154,571 | 200 | 55.00 | 11,000 | 165,571 | **88,245** |
| **(...)** | | | | | | | | |
| **t 10** | 700 | 24.38 | 170,659 | 200 | 80.00 | 16,000 | 186,659 | **105,140** |
| **(...)** | | | | | | | | |
| **t 30** | 700 | 36.23 | 253,591 | 200 | 180.00 | 36,000 | 289,591 | **180,682** |

**Scenario 2: first measure type 4, second measure type 1:**

In this second scenario, the order of measures is reversed compared to scenario 1 to show the effects of prioritising measures (cf. **Table 10**).

*Table 10. Exemplary scenario in which first a measure of type 4 and then a measure of type 1 is implemented.*

| | Energy amount New | Energy price Reference | Energy costs New | Emission amount New | Emission price Reference | Emission costs New | Total Costs New | Savings (N, E, t) |
|---|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR | **EUR** |
| **t 0** | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 | **0** |
| **t 1** | 1.000 | 20.40 | 204,000 | 320 | 35.00 | 11,200 | 215,200 | **9,800** |
| **t 2** | 700 | 20.81 | 145,656 | 200 | 40.00 | 8,000 | 153,656 | **78,424** |
| **t 3** | 700 | 21.22 | 148,569 | 200 | 45.00 | 9,000 | 157,569 | **81,672** |
| **t 4** | 700 | 21.65 | 151,541 | 200 | 50.00 | 10,000 | 161,541 | **84,946** |
| **t 5** | 700 | 22.08 | 154,571 | 200 | 55.00 | 11,000 | 165,571 | **88,245** |
| **(...)** | | | | | | | | |
| **t 10** | 700 | 24.38 | 170,659 | 200 | 80.00 | 16,000 | 186,659 | **105,140** |
| **(...)** | | | | | | | | |
| **t 30** | 700 | 36.23 | 253,591 | 200 | 180.00 | 36,000 | 289,591 | **180,682** |

When looking at the savings it is obvious that the scenario 1 leads to higher savings in total. The reason for this is that measure type 1 has an effect on the amount of energy consumed and on the amount of emissions, making it is economically very attractive as it reduces both energy costs and emission costs. The decision to implement measure type 1 first leads to a savings advantage. Once both measures are implemented, the annual savings are equal.

## 5.5 Economic effects for different implementation scenarios

As described in **section 3**, it can be most attractive in terms of effort to change the energy tariff and to purchase renewable energy, as well as to compensate for remaining emissions (mainly process-related emissions).

Above all, taking measures on one's own property (energy efficiency, process decarbonisation and/or CCUS and self-generation of renewable energy) largely decouples one's business from external risks and shocks and thus increases resilience. Nevertheless, even then a certain amount of emissions and energy may remain that cannot be addressed locally (e.g. due to lack of space, technical inability to switch fuels or unavoidable process emissions).

"Self-sufficiency" makes little sense in most cases and usually requires further investment in various types of energy storage and forms of local generation, as well as in technologies that capture all remaining energy and process-related emissions.

Within the following scenarios, the general principle of reducing consumption first, substituting the remaining energy and material needs second, and then offsetting all remaining emissions is applied.

**Scenario 3: On-Site (first measure type 1, second measure type 2, third measure type 3)**

In this scenario, the company takes three on-site actions in sequential order. First, it implements a type 1 measure (energy efficiency) in **$t_0$**, which leads to a decrease in energy consumption (700 MWh instead of 1000 MWh, cf. dark blue in **Table 11**) and fewer emissions (480 $tCO_2$-eq instead of 600 $tCO_2$-eq, cf. light blue) in **$t_1$**. One year later, in **$t_1$**, another measure (type 2 – process decarbonisation) is implemented (430 $tCO_2$-eq instead of 480 $tCO_2$-eq, cf. orange). Then, a third measure (type 3 – self-generation of renewable energy) is implemented, resulting in less externally sourced energy consumption and fewer emissions in **$t_3$** (200 MWh instead of 700 MWh and 200 $tCO_2$-eq instead of 480 $tCO_2$-eq, cf. purple).

The remaining emissions could be reduced even further to zero if measure type 6 is implemented. For this to happen, however, it is necessary to capture the emissions effectively and as centrally as possible and either invest substantially in further infrastructure, which would not make sense given the small quantities in this example or transfer the emissions via a pipeline or something similar to someone with CCUS infrastructure for emissions storage. Therefore, some other off-site measures are needed to achieve net-zero emissions (i.e., purchase of renewables and compensation).

*Table 11. Exemplary scenario „On-Site" in which measures of type 1, 2 and 3 are implemented sequentially.*

| | Energy amount New | Energy price Reference | Energy costs New | Emission amount New | Emission price Reference | Emission costs New | Total Costs New | Savings (N, E, t) |
|---|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR | **EUR** |
| **$t_0$** | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 | **0** |
| **$t_1$** | 700 | 20.40 | 142,800 | 480 | 35.00 | 16,800 | 159,600 | **65,400** |
| **$t_2$** | 700 | 20.81 | 145,656 | 430 | 40.00 | 17,200 | 162,856 | **69,224** |
| **$t_3$** | 125 | 21.22 | 26,530 | 200 | 45.00 | 9,000 | 35,530 | **203,711** |
| **$t_4$** | 125 | 21.65 | 27,061 | 200 | 50.00 | 10,000 | 37,061 | **209,426** |
| **$t_5$** | 125 | 22.08 | 27,602 | 200 | 55.00 | 11,000 | 38,602 | **215,214** |
| **(...)** | | | | | | | | |
| **$t_{10}$** | 125 | 24.38 | 30,475 | 200 | 80.00 | 16,000 | 46,475 | **245,324** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (...) | | | | | | | | |
| **$t_{30}$** | 125 | 36.23 | 45,284 | 200 | 180.00 | 36,000 | 81,284 | **388,988** |

**Scenario 4: Off-Site (first measure type 4, second measure type 5):**

In this scenario, switching to a clean energy tariff at the end of $\mathbf{t_0}$ (type 4) leads to a reduction of emissions in $\mathbf{t_1}$. Due to a shortage of clean energy supply, only 70 % of the energy demand can be covered by the clean energy tariff (320 $tCO_2$-eq instead of 600 $tCO_2$-eq, cf. orange in **Table 12**). The company has succeeded in identifying and supporting climate protection projects (type 5) at the end of $\mathbf{t_1}$ and receiving certified emission reductions CERs for them from $\mathbf{t_2}$ onwards (200 $tCO_2$-eq instead of 320 $tCO_2$-eq remain, cf. purple).

*Table 12. Exemplary scenario „Off-Site“ in which measures of type 4 and 5 are implemented sequentially.*

| | Energy amount Reference | Energy price Reference | Energy costs Reference | Emission amount New | Emission price New | Emission costs New | Total Costs New | Savings (N, E, t) |
|---|---|---|---|---|---|---|---|---|
| | MWh | ct/kWh | EUR | $tCO_2$-eq | EUR/$tCO_2$-eq | EUR | EUR | **EUR** |
| **$t_0$** | 1,000 | 20.00 | 200,000 | 600 | 30.00 | 18,000 | 218,000 | **0** |
| **$t_1$** | 1.000 | 20.40 | 204,000 | 320 | 35,00 | 11,200 | 215,200 | **9,800** |
| **$t_2$** | 1.000 | 20.81 | 208,080 | 320[5] | 34,00 | 10,880 | 218,960 | **13,120** |
| **$t_3$** | 1.000 | 21.22 | 212,242 | 320 | 38,25 | 12,240 | 224,482 | **14,760** |
| **$t_4$** | 1.000 | 21.65 | 216,486 | 320 | 42,50 | 13,600 | 230,086 | **16,400** |
| **$t_5$** | 1.000 | 22.08 | 220,816 | 320 | 46,75 | 14,960 | 235,776 | **18,040** |
| (...) | | | | | | | | |
| **$t_{10}$** | 1.000 | 24.38 | 243,799 | 320 | 68,00 | 21,760 | 265,559 | **26,240** |
| (...) | | | | | | | | |
| **$t_{30}$** | 1.000 | 36.23 | 362,272 | 320 | 153,00 | 48,960 | 411,232 | **59,040** |

**Cumulated ongoing energy and emission costs**

The cumulative ongoing costs of the **Reference Scenario** form the basis for the comparison of the different scenarios. In **Table 13**, the cumulative total (ongoing) costs from $\mathbf{t_1}$ to $\mathbf{t_5}$, as a possible internal milestone year of the company, lead to a total of 1,196,624 EUR. The cumulative total costs after 10 years ($\mathbf{t_{milestone}}$), as a possible political milestone year, amount to 2,578,743 EUR and after 30 years ($\mathbf{t_{net\text{-}zero}}$), as a possible political target year for net-zero, add up to a total of 10,210,888 EUR.

In the scenarios 1, 2, 3 and 4, 200 $tCO_2$-eq remain in $\mathbf{t_2}$ ($\mathbf{t_3}$ for scenario 3). The measures are implemented within only 3 years and after 5 years savings of up to around 700,000 EUR are possible. If we also consider the period of 10 years, savings of up to around 1,900,000 EUR are possible. Over 30 years, the savings increase to more than 8,000,000 EUR. So if the measures require investments of around 500,000 EUR, the payback is achieved within less than 5 years and the implementation of the measures is more than profitable in the long term.

*Table 13. Comparison of overall costs and savings of the scenarios 1, 2, 3 and 4 compared to the reference scenario.*

| | **Total (ongoing) costs** [EUR] | | | **Savings** [EUR] | | |
|---|---|---|---|---|---|---|
| | **$t_1 - t_5$** | **$t_1 - t_{10}$** | **$t_1 - t_{30}$** | **$t_1 - t_5$** | **$t_1 - t_{10}$** | **$t_1 - t_{30}$** |
| **Reference scenario** | 1,196,624 | 2,578,743 | 10,210,888 | 0 | 0 | 0 |
| **Scenario 1** | 797,937 | 1,688,420 | 6,447,922 | 398,687 | 890,323 | 3,762,966 |
| **Scenario 2** | 853,537 | 1,744,020 | 6,503,522 | 343,087 | 834,723 | 3,707,366 |
| **Scenario 3** | 433,649 | 650,164 | 1,935,432 | 762,975 | 1,928,579 | 8,275,456 |
| **Scenario 4** | 1,124,504 | 2,391,823 | 9,154,768 | 72,120 | 186,920 | 1,056,120 |

[5] 120 of the 320 tonnes are compensated at a price of 34 EUR per $tCO_2$-eq (in $\mathbf{t_2}$). Although 320 tonnes are still emitted, only 200 tonnes (charged at the reference price) remain uncompensated.

When comparing the different savings of the four scenarios, it is vital to think about the selection (type 1 measures reduce energy consumption and emissions and thus lead to higher savings than type 4 or 5 measures, which only lead to emission reductions) as well as the order of the measures to be implemented (higher savings can be achieved by preferentially implementing type 1 measures).

If we look at the (total) remaining energy demand (in MWh) and the remaining emissions ($tCO_2$-eq) in the example calculations for the 6 types of measures, instead of the quantities affected by the measures (cf. dark blue in **Table 14**, i.e. taking into account also the "untouched", remaining quantities), three groups can be distinguished: Reduction in both energy and emissions (type 1), reduction in emissions (types 2, 3 and 4) and no reduction (types 5 and 6). For type 2, other assumptions could be made so that it can fall into any of the three groups. With the exception of type 2, the three categories happen to correspond to the three categories described in **section 2**.

*Table 14. Effect of measure types on energy and emission amounts*

| | **Energy amount** [MWh] | | **Emission amount** [$tCO_2$-eq] | |
|---|---|---|---|---|
| | (total) remaining | for calculation | (total) remaining | for calculation |
| **Reference Scenario** | 1.000 | | 600 | |
| **Measure type 1** | 700 | | 480 | |
| **Measure type 2** | 1.000 | | 550 | |
| **Measure type 3** | 1.000 | 500 | 400 | |
| **Measure type 4** | 1.000 | | 200 | |
| **Measure type 5** | 1.000 | | 600 | |
| **Measure type 6** | 1.000 | | 600 | 400 |

In all scenarios, a residual amount of 200 $tCO_2$-eq remains. Combining the ecological-economic effect (**Table 13**) and the influence of the types of measures (**Table 14**), the strategy is to first implement reduction measures (Type 1), then substitution measures (Types 3 and 4) and finally compensation measures (Types 5 and 6).

As energy and emission prices rise over time, off-site measures with ongoing costs become increasingly more expensive per tonne saved than on-site measures with a one-off investment. This means that it makes sense to ensure (through measures 1-3 and possibly 6) that the shares of type 4 and 5 measures that are unavoidable for achieving and maintaining net-zero emissions decrease over time.

## 5.6 Expenditure

Despite the savings examined in the previous sections, it must be recognised that measure types 1, 2, 3 and 6 require one-off investments (and possibly additional ongoing costs) that have to be deducted from the savings. This is addressed in more detail in this section.

As illustrated in **Equation 2**, the investment costs (**Investment(N)**) consist of both acquisition costs (**costs $_{acquisition}$**) and ongoing costs (such as operation, maintenance, etc., **costs $_{ongoing}$**). The temporal component is integrated in both parts of the formula, as the costs for acquisition may not only be incurred at the beginning **$t_1$**, but also later, depending on the period of use (useful life) **(N)**.

*Equation 2. Calculation of aggregated investments for a measure option*

$$Investment\ (N) = \sum_{t=1}^{N} costs_{acquisition}(t) + \sum_{t=1}^{N} costs_{ongoing}(t)$$

To economically assess a measure, both expenditure and revenue (here: savings, cf. **Equation 1**) have to be considered. Therefore, the first step is to calculate the **Investment (N)** for the implementation of the considered measure option as well as the resulting energy and emissions **Savings (N, E)** if the measure was implemented. The second step is to calculate the difference: **Savings (N, E) - Investment (N)**.

In principle, a measure is economically viable if the total savings of a measure (**savings (N, °E)**) minus the costs of a measure (**Invest (N)**) are larger than zero *within the period of use of the measure* **(N)** (cf. **Equation 3**).

*Equation 3. Determining economic viability for a measure option within period of use.*

$$Savings\ (N,\ E) - Investment\ (N)\ \geq 0$$

The point in time, when the difference reaches zero (breakeven) is defined as the adjusted payback time $\mathbf{t_{adj.payback}}$ (cf. **Equation 4**):

*Equation 4. Determining the adjusted payback time.*

$$Savings\ \left(t_{adj.payback},\ E\right) - Investment\ \left(t_{adj.payback}\right)\ = 0$$

If the payback period $\mathbf{t_{adj.payback}}$ is shorter than the period of use **(N)**, the measure is economically viable. The net savings of the measure up to a certain point in time ($\mathbf{t_x}$) can be determined by subtracting the cumulated investments (and associated transaction and measure-related ongoing costs) from the cumulated savings up to the desired point in time $\mathbf{t_x}$ and comparing the result to the Reference Scenario up to $\mathbf{t_x}$ (cf. **Equation 5**)

*Equation 5. Determining the net savings in (t), provided t < N*

$$net\ savings\ (t) = Savings\ (t,\ E) - Investment\ (t) > 0\ ; \quad t < N$$

The economic efficiency calculation presented here for the assessment of measures represents a minimum requirement that takes two aspects into account. On the one hand, it considers the period of use (and not only the payback period as the sole decision criterion) and, on the other hand, the temporal component (and thus the changes in energy and emission prices as well as energy and emission quantities). The latter allows one to assess the economic performance over time, such as savings and/or additional expenditures (i.e., for replacements).

## 5.7 Selection of measures: combining economic efficiency and system view

Looking at the different scenarios and comparing their outcomes, as discussed in **sections 5.3-5.5** and highlighted in **Table 13**, it makes sense to prioritise on-site actions (1, 2, 3, 6). It is crucial to keep an eye on the economic factors, but also on all external factors, and to act quickly if one wants to (a) build resilience against availability-, price- and other shocks, (b) reduce the risk of having to wait in line, and (c) minimise the "procrastination costs" of missed savings opportunities.

The latter illustrate that a "good" choice of measures is also subject to temporal changes: If climate neutrality is to be achieved in the short term, it makes sense to focus on measures (4) and (5). In order to minimise the costs of climate neutrality and build resilience, it is advisable to initiate accompanying local efficiency measures (1) and on-site energy generation (3). These have a longer implementation horizon but generate the savings that then allow one to initiate measures against (2) or to capture (6) (process) emissions and finally to reduce the purchase of energy from external sources (4) and offsets (5) (cf. **Figure 5**).

Bosch has taken a similar approach to become $CO_2$-neutral within 18 months. At least half of the two billion euros invested for this purpose will have paid themselves off by 2030 through the savings from (1), (2) and (3) [73]. The pay-off of the decisions taken could be even higher: Firstly, the European emissions price ETS has more than doubled since May 2019 [62], secondly, a national emissions price has now been introduced in Germany for energy sources that do not fall under the European Emissions Trading Scheme ETS [68], thirdly, the European Union is further tightening the ETS and extending it to energy sources beyond electricity [74,75], and fourthly, the social trend towards climate neutrality has become increasingly influential [12].

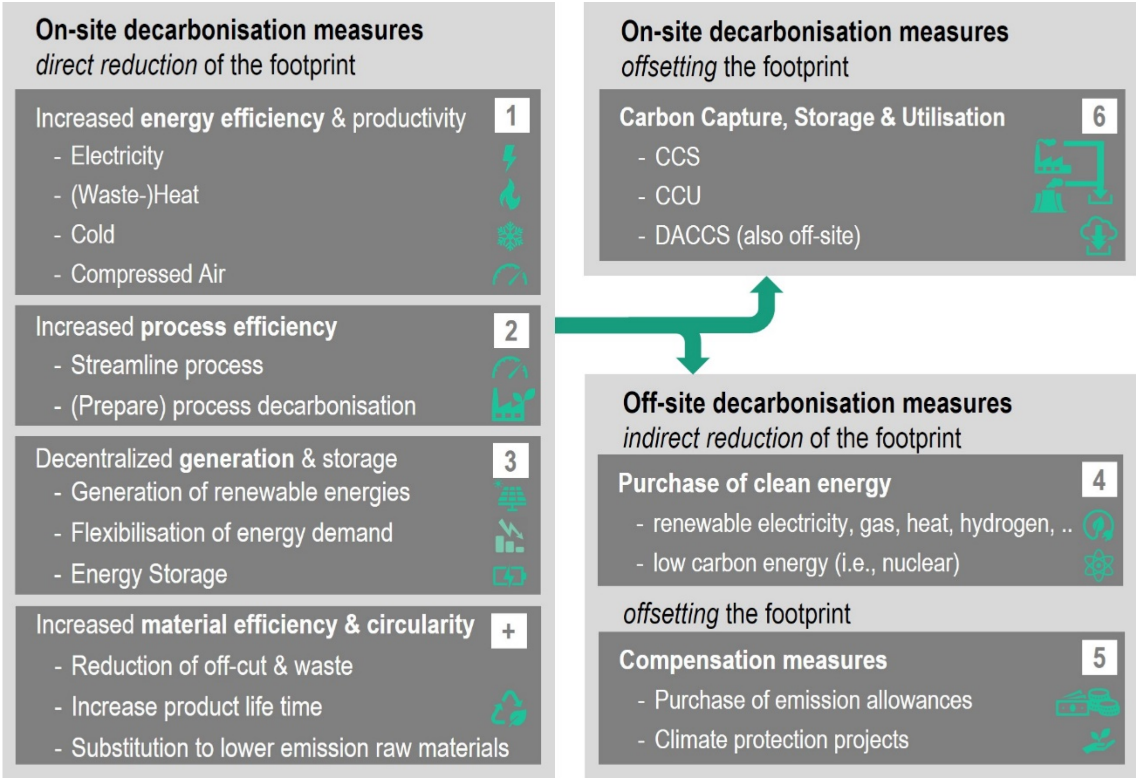


*Figure 55. On-site and Off-site decarbonisation measures (own illustration based on EEP/Fraunhofer IPA)*

## 5.8 Creating a ranking system to determine one's ideal mix of measures

To determine a mix of measures, ideal to one's situation, not only the **economic performance of theoretically suitable measures** is of relevance. As important as the economic performance of a measure in relation to the envisaged intermediate- and target year is how:

a) it fits into the general (decarbonisation) strategy of the company, notably the **reason why** decarbonisation is pursued,

b) it performs in respect to the company's **decision-making determinants** and

c) its impact depends/builds on and **interacts**/is **compatible with other measures**,

d) it contributes to company risks, production **risks or resilience** (if at all), and how

e) effective it is to reach the **ambition level** (certain GHG savings by certain time).

Buettner describes seven steps to identify a decarbonisation strategy: chief among these are the establishment of clarity regarding the target dimension, the goal, the timeframe, the area of observation and particularly the 'why' – the motivation for doing so [76]. Motivators can be: long-term economic advantages, corporate social responsibility, reduction of cost risk, customer requirements, image improvement, government or investor requirements [12]. As numerous of the points **(a-e)** relate to the company strategy, **(a)** primarily refers to how well a measure serves the (primary) motivators of the company.

Decision-making determinants **(b)** include: the costs per avoided tonne of $CO_2$-eq or cost per $kW_p$ (Kilowatt peak) of energy generation capacity, or per kWh saved, the level of investment, technical aspects, implementation competence, and, overlapping with the motivators, also expected increase in productivity and image effects [4].

Especially in times of crisis, uncertainty, and vulnerable supply chains, but also more generally when a needed commodity is in short supply, it can play an important role whether and in which way a measure **increases or decreases risks or resilience** of a company (or its production) **(d)**. This resilience, for instance, can be achieved by prioritising on-site measures as they reduce dependency on others or by diversifying supply. For the latter, a company should either work towards a flexibility in respect to the energy source (i.e., bivalence, allowing processes to be powered by two different types of energy), the supplier of energy, or the type and location of self-generation of energy).

The **level of ambition (e)** influences whether measures can be undertaken in sequence to optimise for the most cost-effective mix, or whether measures of a similar type need to run in parallel, reducing the cost-effectiveness, but allowing quick(er) achievement of the net zero goal. The path of quickly achieving net zero, for instance, was chosen by Bosch, which simultaneously undertook many types of measures to reach net zero in a very short period. However, this achievement also required compensation and the purchase of green energy while energy efficiency measures, self-generation, etc. were put in place, gradually allowing the company to scale down their compensation and purchasing efforts [73].

This notion as well as changing environments, respectively external effects, can considerably change the situation and subsequently the overall "value" and performance of a measure. Therefore, it is advisable to mirror the calculation model introduced above (cf. **sections 5.1 and 5.6**) into a digital model into which the figures and values are entered for the both the individual measures, but also the overall considerations. If connected to external sources, such as energy and emission market figures or their respective forecasts, the system could constantly update the ranking of measures (in consideration of those already implemented).

To enable such a ranking, it is necessary to introduce a scoring model that reflects all ingredients (i.e., **a-e** above) that are of relevance in the company's decision-making process. In the context of this report, such a model may include binary (yes/no), scaled/ordinal (from low to high or negative to positive), nominal (i.e., different applicable characteristics) or metric (i.e. amount of investment or useful life) variables. Such variables, especially nominal ones, allow measures to be ranked by category – i.e., measures addressing process emissions, versus measures addressing energy-related emissions. Filters in metric variables allow one to, for example, exclude measures whose investment level is too high (i.e., exceeds own budget) or which are too expensive per unit of energy/emissions saved. As highlighted in **section 1.4**, spatial, technical or strategic aspects may lead to a pre-selection or the exclusion of some conceivable measures. Indeed, some companies exclude certain measures such as offsets in principle, whereas others may not have the space for on-site renewables or refrain from technical interventions that would endanger product quality or process stability. For measures that are excluded from the outset for these reasons the assessment procedure described in **sections 5.1-5.8** should not be carried out. However, it should be applied to all remaining conceivable, individual measures.

All binary, ordinal and metric variables, including the score, can be used to rank the remaining measures according to this variable. A weighting factor can be introduced to assign different levels of importance to the variables, which then influence the score of a measure and subsequently its rank in the ranking (see exemplary depiction in **Table 15** in combination with **Table 16**).

In summary, this means that the model described can be mathematically optimised for individual or combinations of aspects (i.e., quickest or cheapest decarbonisation, highest resilience, etc). As scoring models are a much-researched topic [77,78], this report does not go into further detail on these.

*Table 15. Possible indicators of a scoring model / table (by variable type)*

| **metric (years)** | **metric (figures)** | **binary or ordinal** | **nominal** | **filter** |
|---|---|---|---|---|
| useful life | net savings (t) | impact on resilience | type of measure | on-/off-site measure |
| intermediate target | investment height | risk of failure/to operations | requirement for measure | investment < ... |
| target year | GHG savings | addressing motivators | type of emission addressed | cost per … < ... |
| adjusted payback time | *rank* | meeting decision criterion | scope addressed | skills exist |
| … | *weighting factor* | fits to strategy | description of measure | net savings (t) > 0 |
| | *score* | … | ... | adj.PT < useful life |
| | … | | | … |
| **Definitions** | | | **optimise for (i.e.)** | |
| ∑(weighting factors) =! 1 | | z = number of measures | goal achieved cheapest [or quickest] | |
| Score = ∑(weighting factor x measure score), the higher the better | | | best impact on ... (resilience, image, risk, strategy, ..) | |

It is not unlikely that there are measures, which are actually economic, but whose useful life is shorter than the time span until the milestone year. Therefore, an assessment of all economic measures is necessary to compile the ideal mix of measures for achieving the intermediate objectives (i.e., a certain reduction target by 2030), the overall objective (i.e., achieving net-zero by 2040), but also for sustaining the desired outcome (i.e., maintaining a net-zero emission footprint infinitively), taking into account useful lives and changing prices.

*Table 16. Exemplary shape of ranking table extract (random figures)*

**Target Year** 20XX **Milestone Target Year** 20YY

| **Measure** | **Type** | **Score** | **Rank** | **meeting decision criterion [Filter]** | **impact on resilience** | **addressing motivator** | **figure of numeric decision criterion** | **net savings (t)** | **GHG saved p.a.** | **…** | **depends on** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Description | 1-6 | metric | [1 … z] | [ 0 ; 1 ] | [ -1 ; 0 ; 1] | [ 0 … 5 ] | metric | metric | metric | … | |
| **Example using <u>random</u> figures** | | | | cost per tonne saved < 150€/$t_{CO2}$ | | image | cost per tonne saved | | energy-related t $_{CO2eq}$ | … | |
| *Weighting Factor* | | | | | *20%* | *10%* | *15%* | *25%* | *30%* | | |
| Solar PV | 3 | 25.3 | 1 | 1 | 1 | 5 | 119.00 € | 100,812 € | 200 | … | (roof)space |
| Green Tariff | 4 | 22.6 | 2 | 1 | -1 | 3 | 2.65 € | 90,000 € | 400 | … | availability |
| EE-Measure | 1 | 11.4 | 3 | 1 | 1 | 4 | 125.00 € | 45,487 € | 120 | … | skill |
| $CO_2$-allowance | 5 | 10.9 | 4 | 1 | 0 | 0 | 45.00 € | 43,300 € | 200 | … | availability |
| ProcessDecarb. | 2 | -47.2 | 5 | 0 | 0 | 3 | 200.00 € | - 188,750 € | 0 | … | skill |
| CCUS | 6 | -238.7 | 6 | 0 | 0 | 1 | 250.00 € | - 955,000 € | 0 | … | regulation |

**Table 16** shows an extract from a ranking table using random numbers. It lists the economic performance according to the above formulas in t = 5, assuming a period of use of about 20 years per implemented measure and a mark-up of 1 % for the use of renewable energy. Apart from this, the assumptions and figures of the previous sections apply. As highlighted in **Table 14**, the different types of measures affect the net GHG footprint in different ways, sometimes directly, sometimes indirectly. In the case of measures that primarily aim to reduce the amount of energy purchased (types 1 and 3), the saving in energy costs is the decisive factor. The amount of the reduction in greenhouse gas emissions that occurs as a side effect also depends primarily on the emission content of the (previous) energy source and says little about the quality of the measure. If only the $CO_2$ avoidance costs are considered, these measures appear excessively expensive, which is why the cost per kWh saved or kWh generated must also be taken into account in a complete ranking. Therefore, energy- <u>and</u> emission cost savings should always be considered and compared with the compatible action alternatives. The principle applies equally to the saved process emissions per year (types 2 and 6) and the consideration of the estimated financial performance for several points in time (**$t_x$**) (e.g. **$t_{milestone}$, N**) instead of just one (see **Table 15**).

Measure types 2 and 6 illustrate that treating process emissions can be quite costly. However, if measure 2 takes place in the context of a replacement investment for machinery, the cost of the measure is only the price difference between the "standard replacement" and the lower emission process technology, thus reducing the investment cost and improving the financial performance of the measure. As CCUS works best at emission-intensive sites for processes with high emission concentrations (figuratively speaking: sticking the technology on the exhaust), it makes more sense for larger emitters. However, measure types 2 and 6, together with some related technologies, are the only means to "actually" address process emissions in the long term [39].

# 6. Conclusion

Depending on the nature of one's own economic activity, above all how energy- and emission-intensive one's own company is, how large it is and how far into the future one plans, the one-off and the permanent (ongoing) costs play a different role. Moreover, this *role can change over time.* For example, if the framework conditions change or if the most cost-effective measures have been implemented but the emission reduction target has not yet been reached.

The economic efficiency calculations of the individual measures should then be evaluated and prioritised, taking into account the exposure of each type of measure to fluctuating energy and emission prices. The calculations described would need to be *carried out for all available alternative actions* - i.e., individual measures or interconnected groups of measures - in order to determine the most economic mix of measures *at that time*.

Due to the variability of energy and emission prices and the effort required to evaluate the possible alternative actions, it makes sense to *map* the described economic aspects together with technical and other influencing factors in a spreadsheet or*, ideally, in a digital model*. Only in this way is it possible to consider the (remaining) options for measures dynamically, to optimise them for the target time and update them over time, as well as to rank them according to the most economic combination of measures.

Often there is a set of intermediate targets and associated timetables: internally, this is at least the year in which the target emission level is to be achieved ($t_{target}$), often supplemented by intermediate milestone years and emission levels ($t_{milestone}$). However, political milestones are also of great importance. Many countries and regions have set intermediate targets for 2030 ($t_{intermediate}$) and aim to achieve net-zero emissions by 2050 ($t_{net\text{-}zero}$) at the latest. In view of a rapidly changing environment and in order to enable comparability with conventional economic efficiency calculations, it makes sense to also include the first three years after the start ($t_2$, $t_3$ and $t_4$) in this consideration. An ideal mix cannot be static, it evolves over time and should especially take into account the financial performance of the selected measures up to the internally determined target year ($t_{net\text{-}zero}$), as well as the intermediate political milestone year (i.e., 2030). This avoids choosing a mix that turns out to be very costly in the long run, while ensuring that measures are implemented which are economically superior from the perspective of the target year(s) but would not have been chosen under conventional calculation approaches.

It is important to remember that reaching the desired target does not mean it ends there. Like the "desired weight" that must be maintained after it has been reached, the net-zero state needs to be maintained over time as well. This may require changing the mix of measures in light of technological change and replacement needs energy- and emission prices, resilience and other considerations, including new/revised internal or external targets or requirements. The formulas and mechanisms introduced in this report can support this continuous process.

Furthermore, one should note that *prices, policies and availabilities differ greatly across the world*: not only electricity is priced very differently across countries, but also the price ratios between electricity, gas and other forms of energy can differ substantially (due to subsidies, taxes applied, ease of acquisition and supply). Similarly, emission factors may vary markedly depending on the energy-mix. There are regions with and without emission charges on different energy carriers, and in all or just some sectors. The state of the infrastructure, regulations, availability of skilled labour or simply access to technology determine whether measures can be implemented at all. Moreover, they can expand the range of feasible measures, but they can also limit them. Additionally, the approaches taken by policymakers and the political systems differ. In consequence, the economic viability of the same measure may be very different across countries and the acquisition costs may pay off easily in one region and not during the useful life of the measure in another.

Nevertheless, the principles described in this report, particularly *the formulas, are robust against these differences* and can be applied irrespective of different realities, be it geographical, political or any other dimensions. Indeed, the figures can be very different, and the resulting ranking order may highlight a very different set of measures, but the formula into which the figures are entered does not change. If, for instance, there is no emission price in one region a "0" is entered into the formula to account for the emission cost of the Reference Scenario. Similarly, other factors could be non-existent ('0'), constant ('1'), increase/decrease or vary. The functionality of the formula is not affected.

This creates a *scientifically and technically sound decision-making and planning tool* for short- to long-term monitoring and impact assessment that also takes into account the factors that can be influenced to a greater or lesser extent. For example, assume that the production processes are adjusted in terms of time and quantity to the availability of renewable energy. In that case, procurement can be optimised and a contribution can be made to grid stability [27].

Considering the measures, interdependencies, and calculation methods described the possibility of quasi-dynamically *determining the most economic mix of measures for net-zero emissions is within reach* if digital mapping is used.

Applying the principles and determinants described in this report for one's economic assessment of industrial decarbonisation measures should hence allow one to determine one's optimal pathway to reducing the greenhouse gas footprint in manufacturing (and beyond).

**Author Contributions:** Conceptualization, S.M.B.; methodology, S.M.B. and D.W.; formal analysis, D.W. and S.M.B.; investigation, S.M.B. and D.W.; writing—original draft preparation, S.M.B. and D.W.; writing—review and editing, S.M.B. and D.W.; visualization, S.M.B. and D.W.; supervision, S.M.B.; project administration, S.M.B.; funding acquisition, S.M.B. All authors have read and agreed to the published version of the manuscript.

**Institutional Review Board Statement:** Not applicable.

**Data Availability Statement:** Not applicable

**Acknowledgments:** This research would not have been possible without the continuous support of the Karl-Schlecht-Foundation and the Heinz und Heide Dürr Foundation, as well as those reviewing and supporting in progress of developing this report notably Marina Gilles, Igor Litvinyuk, Christian Schneider, Thomas Renaldy, Lukas Bebensee, Sebastian Trost, Sonja Ziehn, Manja Hies, Eckard Beer and Nihal Darraj.

**Conflicts of Interest:** The authors declare no conflict of interest.

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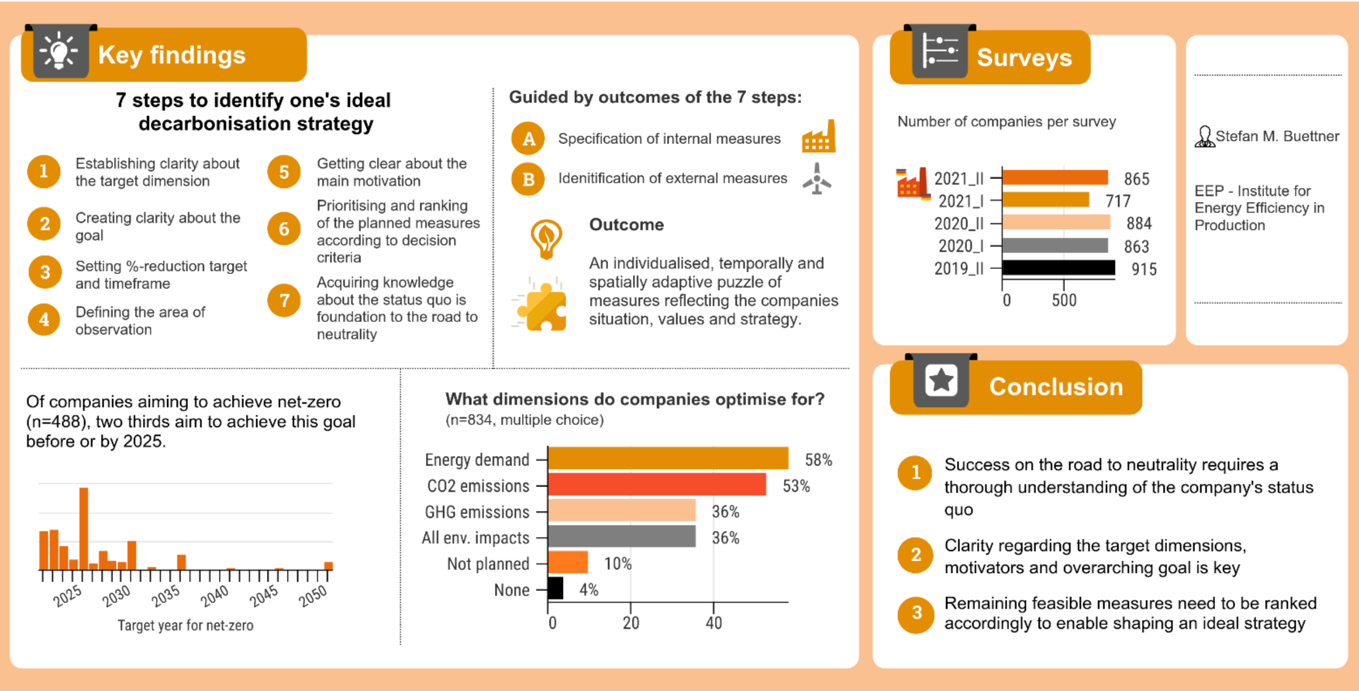
# 8 Roadmap to Neutrality — What Foundational Questions Need Answering to Determine One's Ideal Decarbonisation Strategy

**Abstract:**




(Published as: Buettner, Stefan M., 2022. Roadmap to Neutrality - What Foundational Questions Need Answering to Determine One's Ideal Decarbonisation Strategy. *Energies*, **15**, 3126. DOI: https://doi.org/10.3390/en15093126. Licence: CC BY 4.0) (Buettner 2022) *energies*

*Article*

# Roadmap to Neutrality—What Foundational Questions Need Answering to Determine One's Ideal Decarbonisation Strategy

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**Abstract:** Considering increasingly ambitious pledges by countries and various forms of pressure from current international constellations, society, investors, and clients further up the supply chain, the question for companies is not so much whether to take decarbonisation action, but what action and by when. However, determining an ideal mix of measures to apply 'decarbonisation efficiency' requires more than knowledge of technically feasible measures and how to combine them to achieve the most economic outcome: In this paper, working in a 'backcasting' manner, the author describes seven aspects which heavily influence the composition of an 'ideal mix' that executive leadership needs to take a (strategic) position on. Contrary to previous studies, these aspects consider underlying motivations and span across (socio-)economic, technical, regulatory, strategic, corporate culture, and environmental factors and further underline the necessity of clarity of definitions. How these decisions influence the determination of the decarbonisation-efficient ideal mix of measures is further explored by providing concrete examples. Insights into the choices taken by German manufacturers regarding several of these aspects stem from about 850 responses to the 'Energy Efficiency Index of German Industry'. Knowledge of the status quo, and clarity in definitions, objectives, time frames, and scope are key.

**Keywords:** decarbonisation; climate neutrality; industrial energy saving; strategic decision making; net-zero; road mapping; energy efficiency; ideal mix; sustainability strategy; energy efficiency index

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**Citation:** Buettner, S.M. Roadmap to Neutrality—What Foundational Questions Need Answering to Determine One's Ideal Decarbonisation Strategy. *Energies* **2022**, *15*, 3126. https://doi.org/10.3390/en15093126

Academic Editors: Sergio Ulgiati, Hans Schnitzer and Remo Santagata

Received: 8 February 2022
Accepted: 22 April 2022
Published: 25 April 2022



## 1. Introduction

### 1.1. Background

Ahead of the United Nations' Climate Conference COP26 in Glasgow, a vast array of severe weather incidences across the globe—floods, storms, droughts, increase in temperature, melting ice shelves, etc. [1], underlined the warnings presented by various bodies [2–5]. The latter stress that significant action is required by policymakers to still be able to limit global warming to less than 2 °C, ideally 1.5 °C, above pre-industrial levels, as agreed in the Paris Climate Agreement [6].

The Intergovernmental Panel on Climate Change (IPCC), the International Energy Agency (IEA), the German Energy Agency, and many other bodies have published reports, roadmaps, and scenarios [4,7,8] on actions necessary to meet the set target. The pace of environmental change suggests that actions should be taken sooner rather than later to keep the required action trajectory manageable and maintain the ability to meet the target. Nonetheless, unforeseen situations, such as the conflict between Russia and the Ukraine and the linkages to energy-dependency, can further increase the urgency of decarbonisation and switching to renewables [9]. In fact, events of an imminent magnitude can trigger stakeholders to societally endorsed changes of policy and concerted action in a time of crisis. For example, this was the case with the COVID-19 pandemic and also with the nuclear reactor catastrophe in Fukushima, which led Germany to move away from nuclear energy and announce the *Energiewende* [10].

Ahead of COP26, an increasing number of countries have reacted by declaring their ambitions for net-zero emissions in line with the requirement to submit updated intended nationally determined contributions (INDCs) to the United Nations Framework Convention on Climate Change. According to the Climate Action Tracker [11], "over 140 countries had announced or are considering net-zero targets, covering 90% of global emissions". Net-zero means that emissions remaining after reduction efforts are balanced out through offsetting (i.e., via carbon sinks or compensatory projects) [12]. While many countries pledge to reach net-zero emissions by 2050, some aim at reaching this goal earlier (e.g., Germany 2045), some later (e.g., China 2060). Moreover, whereas some countries target carbon neutrality, others target climate neutrality (e.g., European Union 2050) [13]. Carbon neutral only refers to carbon-dioxide emissions ($CO_2$), whilst climate neutral includes other emissions such as methane, etc. How countries aim to achieve these goals, however, remains vastly vague.

As setting a target never automatically leads to its achievement or even further actions, it is crucial to equip policymakers with the insights needed (on how) to achieve net-zero in actuality and effectively. Looking at the demands faced by governments to fight and prioritize climate change, it may seem like it is up to the governments alone to mitigate climate change. However, by *direct* action, governments only account for the emissions of their immediate actions and on their premises. Conversely, they have *indirect* influence on the emissions of their entire economy through regulatory measures and policies. These may include bans, minimum requirements, mandatory actions, the provision of infrastructure, incentives, and subsidies.

Typically, most emissions are caused by energy generation and key economic sectors, such as transport, industry, housing, and agriculture [14,15]. Therefore, achieving climate change targets essentially comes down to getting these sectors to reduce their emissions, usually with the aforementioned set of policy measures.

Specifically, the challenge is to identify which set of measures is effective and economic to decarbonise which part of the economy. Instructive measures have proven impactful in the past (i.e., minimum standards, phasing-out of incandescent light bulbs, etc.) [16,17]. Nonetheless, given that achieving net-zero requires emissions to be cut or removed across the board, it is necessary that individual and intrinsic actions are as broad as possible. Hence, it is essential to find effective means to trigger such intrinsic wish in stakeholders to reduce emissions, in other words, convincing them to 'buy-in'. This way, rather than avoiding regulations and trying to find loopholes, stakeholders proactively look for means with which they can succeed in meeting their self-set targets.

Two key challenges arise: Firstly, one has to identify means that successfully trigger the (intrinsic) decision to decarbonise and, secondly, to provide those who have taken this decision (or are at least contemplating to) with the means to decarbonise effectively.

As stakeholders are principally aware of their own operations, they have a good chance finding ways to reduce their emission footprint. The cumulative proactive efforts of stakeholders then allow governments to shift attention from the spot-policing of compliance (with instructed policies) to ensuring a suitable environment for stakeholders to be able to decarbonise (i.e., planning capacities, generation and transmission infrastructure, support mechanisms). Furthermore, potential gaps in stakeholder ambitions to meet the countries' goals can then be addressed.

### *1.2. Industrial Sector of High Relevance for Achieving Net-Zero—But How to Get Started?*

One of the most relevant groups in the energy transition is the industrial sector. Not only does it account for a large proportion of most countries' energy consumption, but also for associated energy- and process-related emissions [18–22]. Furthermore, this sector determines the shape, performance, and durability, as well as the energy and resource consumption of goods during production and service life, but also their repairability, recyclability, and how and where the required raw materials are sourced. Hence, the industrial sector influences all other sectors by controlling product and machinery characteristics as well as their modes of operation (e.g., power stations, turbines, transmission infrastructure equipment, vehicles, materials for new buildings and retrofits, machinery, electronics, clothing, or furniture). These decisions largely determine the embedded emissions of all produce, a factor which is rapidly gaining in importance. This is further underlined by both the 'Sustainable Product Initiative', which is developed by the European Commission at present, including "requirements on mandatory sustainability labelling and disclosure of information to consumers on products along value chains" [23], and a 'Resource Passport' for buildings that the German government plans to introduce, along with reshaping its support programmes from purely considering energy-related characteristics to the whole lifecycle footprint [24].

Therefore, decarbonisation in manufacturing can be considered a critical enabler to the question of how to achieve carbon or climate neutrality on a country-wide level and beyond. A growing number of studies thus explore pathways for deep decarbonisation, particularly of energy-intensive industries. According to Nurdiawati et al. [25] (p. 2), many of these studies "focused much on the technological pathways and less on the supportive enabling reforms that would facilitate their uptake". Bauer et al. [26] explore pathways for decarbonising four emission-intensive sectors, even moving beyond direct emissions to also considering value-chain and end-consumers emissions. Bataille et al. [27] (p. 1) present an "integrated [policy] strategy for a managed transition" in energy intensive industries, also including technology options, and Rissman et al. [28] review policy options, sociological, technological, and practical solutions in detail.

These studies address decarbonisation of industry from either a policy, a supply-side, or technology perspective—often with a focus on energy intensive industries—but are short of giving corporate stakeholders (irrespective of their company's energy intensity) *concrete* advice on how to get started from an individual company's perspective. Similarly, studies such as the one by Johnson et al. [29] analyse and compare *national* roadmaps for decarbonising the heavy industry on a global scale, alongside factors such as ambition, financial effort, and mitigation measures. Nevertheless, this approach again leaves a gap when it comes to company-tailored advice.

Consultancies and advisories fill this gap insufficiently. While they generally indicate which steps have to be taken by a stakeholder to shape a decarbonisation roadmap from a company perspective [30–32], they either do not go into sufficient detail, or do not address the prerequisite, qualifying steps, notably those of strategic decision making. These, such as the motivation leading to the decision to decarbonise, however, often have serious implications on the shape of an 'ideal' decarbonisation strategy and how it can be implemented effectively.

An effective way to develop decarbonisation roadmaps could involve applying approaches from the backcasting framework literature. This concept, established by Robinson [33], refers to a strategy where stakeholders/policymakers set up a target (energy consumption/emissions) and work backwards from this target to reach it in the future. This framework is widely applied in designing emission-reduction pathways. In this context, a new strand of the scenario literature includes a focus on low-carbon scenario road mapping. As part of this new literature, Hughes and Strachan find "that low carbon scenarios tend to focus either on qualitative, social trend-based approaches to developing futures, or on purely technological, engineering-based views of an energy system" [34] (p. 46). In particular, technologically focused studies, such as Bataille et al. [35] and Manders et al. [36], often operate within a 'backcasting' framework explained by Holmberg and Robèrt [37]. However, they argue that road mapping the future is always, to some extent, hampered by uncertainty and that therefore the system level, as well as the actor and the technology level, must be considered. Thus, one may argue, that due to the uncertainty and inaccuracy of existing studies and roadmaps, they remain low in their ability to give *concrete* advice.

Having said that, studies that not only focus on either technology, individual, social, or system level are still rare. Similarly, there is a lack of studies that take into account the whole industrial/manufacturing sector instead of only focusing on its energy-intensive parts. Closing this gap, and thus contributing to effective decarbonisation roadmaps, is the aim of this article.

### *1.3. The Issue: Enabling Corporate Stakeholders to Decarbonise Effectively*

The present article addresses this gap by answering the following research question: What foundational questions matter and need answering to provide practical guidance to corporate stakeholders on how to shape an effective and tailored decarbonisation strategy?

Derived from professional practice and applying a mix-methods approach based on data gathered via the Energy Efficiency Index of German Industry (EEI) [38], this work addresses underlying motivations and spans across (socio-)economic, technical, regulatory, strategic, corporate culture, and environmental factors. It further underlines the necessity of a mutual understanding, clarity, and communication of definitions and targets.

Plenty of companies have already made pledges related to emission reductions. However, these companies constitute only a small proportion of the global manufacturing industry, even though they might be big in size individually. Nonetheless, to achieve net-zero on a societal level, it is not sufficient to address the largest emitters only, but to find ways to reach at best all emitters. Specifically, it is crucial to get their 'buy-in', irrespective of their emission intensity or size, and empower them (and the communities they are embedded in) to take action.

Tackling these challenges, this work aims at aiding executive leadership, as well as other company functions relevant to the transition, in shaping their pathway to net-zero effectively. It further provides insights to policy makers, service providers, financiers, and the general public on (often not obvious) obstacles, needs for support, and infrastructure, as well as interdependencies along the process. Several of the general principles may also apply and, therefore, prove to be helpful to other sectors, state actors, communities, or individuals.

The motivation for this article partly arose out of a meeting with a company invested in advancing energy efficiency, but which had not yet seen the point in decarbonisation. Following an explanation of why it is in their best interest to take decarbonisation seriously (by highlighting a series of external pressure points), the manager expressed the belief that immediate action was necessary. To brief the company's CEO, the manager then enquired what aspects the executive leadership of a manufacturing company needs to consider to shape an effective and economic strategy. Although the analysis may generally be broadly applicable to many stakeholder-types, the author focuses on (predominantly manufacturing) companies that have taken the decision to decarbonise or contemplate whether to do so.

Following a backcasting approach, this article provides an overview of seven foundational questions that need answering to enable a general understanding, as well as to provide practical guidance on how to shape an effective and tailored decarbonisation strategy. The results demonstrate that clarity in definitions, objectives, timeframes, and scope, as well as a thorough understanding of the status quo and the technically feasible options, are key. In light of changing emission and energy prices, as well as the goal of ensuring resilience against external shocks, digital solutions, and an adjusted approach to economic viability calculations are needed to help with keeping such a strategy ideal.

## 2. Methods and Materials

As discussed earlier, previous studies about decarbonisation road mapping tend to focus either on the system (national roadmaps) or on the individual level (specific sectors). Furthermore, they tend to concentrate either on policy or technological factors. This article digs a bit deeper by taking most of these factors into consideration and combining them, thus eventually requiring a combination of qualitative and quantitative elements.

The associated methodology applied by the author is a backcasting method, as described by Robinson [33] (p. 339), that is adjusted for the context of company decision-makers and the goal of decarbonisation. The resulting seven individual steps take inspiration from the six steps originally proposed by Robinson but differ in their shape and nature. 'Backcasting' in this context means working backwards from the desired outcome to the ingredients that need to be obtained or taken into account to reach that future. It is thus an explicitly normative approach [33] (p. 337).

In an iterative process, starting in May 2019, the author analysed manufacturing companies' stand towards decarbonisation with a particular focus on local decarbonisation efforts, notably around energy efficiency.

The qualitative element of the analysis of companies' actions, ambitions, and intentions is based on primary sources. Direct conversations with companies allow for a first-hand understanding of their viewpoints and needs. The businesses consulted were manufacturing companies that are either clients in energy efficiency or decarbonisation projects, participate in the Energy Efficiency Index of German Industry (EEI), seek guidance on the topic or partook in events concerning industrial decarbonisation. In addition, business press, newspaper articles, press releases, and pledges from companies, as well as feedback received in context of public speeches and outcomes from expert discussions have been taken into account. These kinds of observations promise to shed light on aspects concerning willingness and efforts to decarbonise.

Afterwards, these observations were tested quantitatively within the framework of the Energy Efficiency Index of German Industry (EEI) to confirm the anecdotal evidence and assess the actual progress of decarbonisation. Introduced in 2013, EEI surveys German manufacturing companies of all sizes, energy intensities, and across 27 sub-sectors twice a year. It aims at gaining an understanding of companies' stands, expectations, plans, opinions, experiences towards energy efficiency, and increasingly also decarbonisation. EEI data is gathered applying a mixed-methods approach combining online (ca. 10%) and telephone surveys (ca. 90%) [38].

An iterative process was applied to deepen the understanding of interdependencies and elements that are the foundational ingredients that enable—or hold back—decarbonisation. Whenever the EEI uncovered a relevant finding, the next data collection, after pre-testing, was utilised to drill deeper. In total, evidence from five data collections is considered in the context of this article (cf. Table 1).

**Table 1.** Energy Efficiency Index of German Industry (EEI) datasets referred to [39–43].

| EEI Data Collection | Data Collection Period | Observations |
|---|---|---|
| 2019/2 | October–November 2019 | 915 |
| 2020/1 | May 2020 | 863 |
| 2020/2 | October–November 2020 | 884 |
| 2021/1 | April–May 2021 | 717 |
| 2021/2 | November 2021–January 2022 | 865 |

To provide a general overview, a series of EEI questions of the past five data collections were identified to illustrate selected aspects: (a) whether companies plan to decarbonise, and (b) if so, by when. What level of ambition they have for (c) 2025 and (d) for 2030 and (e) optimising for which dimension(s). Based on (f), what motivation they do so, and (g) what weight different determinants have in deciding for decarbonisation measures. Beside the area of observation (h), EEI explores the increasing relevance of product carbon footprints (i). The awareness of companies' emission footprint (j), along with knowledge about energy consumption and type (k, l) and energy saving potentials (m), are explored to assess companies' knowledge of their status quo [39–43].

## 3. Results

Before making a decision, one often considers the implications and repercussions of that decision. Nevertheless, even after a thorough consideration it is not unlikely that an aspect that significantly impacts the overall ambition is overlooked—unless one has succeeded in a very similar or identical undertaking before. Decarbonising one's business is to some extent like building a house for the first time. After completion, one has learnt much about what to do better or differently the next time. Nonetheless, in many instances one only builds one house (if any). Roughly the same applies in the case of decarbonisation: once it is achieved—however (in-)efficiently—there is rarely a situation where one does it again from scratch (unless a company has multiple sites and started with a pilot one or offers the experience as a service to others). Again, similar to one's house, there remains the prospect of continuous optimisation. While some improvements might be incremental, other interventions would require significant interference if at all possible (for example switching from a radiator-based heating system to underfloor heating to allow the installed heat pump to serve the home with heat more efficiently [44]). Setting a clear target to be reached in the future and being aware of multidimensional factors, which might influence how it is reached, is the ultimate goal for a successful decarbonisation strategy.

Therefore, it is of high relevance—to stakeholders of any sector—to *find answers to seven foundational questions*, ideally before, but at least simultaneously to taking action. Only the response to these questions allows one to determine one's ideal decarbonisation strategy, or to make an informed decision whether to go ahead and act, or even to openly pledge to take action.

(1) Terminology;
(2) Optimisation variable;
(3) Level of ambition;
(4) Area of observation;
(5) Motivation and needs;
(6) Priorities;
(7) Status quo.

Based on the responses to these, it is then possible to derive (a) general, and (b) specific routes of action to determine a decarbonisation strategy suiting one's situation, goals, and opportunities. Making use of (c) digitalisation and (d) a modified form of economic viability calculations allows one to find one's ideal roadmap to neutrality and to adjust it dynamically to changing environments.

Why these seven, one could argue. Essentially, every one of them is guided by the notion of what could go wrong (or has gone wrong elsewhere), what could reduce the efficiency and/or effectiveness of a decarbonisation strategy, and how this can be avoided.

As mentioned when discussing the backcasting framework and also as explained by Rissmann et al., "the best practice in designing efficient industrial operations is to analyse the entire process by working "backwards" from the desired application to the energy consuming-equipment" [28] (p. 16). Transposed to the context of this article, the "desired application" reflects the desired outcome.

In this context, however, the outcome needs to be further specified as decarbonisation can be understood differently, achieved differently, and should be pursued differently, if it is to address different motivations or to consider different priorities. Therefore, as Rissman et al. stated referring to increasing efficiency of industrial systems and processes, "design should be an integrative process that accounts for how each part of the system affects other parts." [28] (p. 16).

In this article, "design" refers to the preliminary steps (i.e., strategic considerations) that need to be taken, typically by executive leadership, to allow them, and subsequently their company to shape and pursue an effective and efficient roadmap to neutrality.

Other than the practical "design layers" that describe step by step the "how" of increasing efficiency [28] (p. 16) [45], the seven foundational questions address the "what", "where", "by when", and "why", as well as the "how". Nevertheless, they apply on a more strategic than a specifically practical level.

The following sections will provide a more detailed explanation of the seven dimensions (Sections 3.1–3.7), followed by an overview of how they guide implementation in general and more individually (Sections 3.8 and 3.9), as well as steps to make and keep a strategy ideal (Sections 3.10 and 3.11).

### *3.1. Terminology*

The foundation of an effective decarbonisation strategy, as of any other work in any other area, is to establish mutual understanding and clarity across all stakeholders involved regarding the terms used and how they are understood. Otherwise, misunderstandings or misperceptions will lead to either unnecessary action being taken or, worse, essential actions being overlooked.

Buettner [46] points out that a key reason for the frequent mixed-up between carbon- and climate neutrality is that, while $CO_2$-equivalents ($CO_2$-eq.) are the 'currency' to measure greenhouse gas (GHG) emissions adversely affecting our climate, the suffix "-eq" (standing for equivalents) gets easily lost on the way. This is particularly the case in oral or simplified conversation and correspondence.

Apart from this, it is further possible that the difference between carbon neutrality, climate neutrality, and environmental neutrality itself is not clear. However, this unclarity has fortunately been decreasing over the past three years. In short, climate neutrality exceeds the ambition of carbon neutrality by also addressing methane and all other gases that have a warming potential for the atmosphere (GHGs), such as nitrous oxide and hydrofluorocarbons. Environmental neutrality reaches even further and addresses all other gases and substances that have a negative impact on the environment (such as particulate matter and sulphur dioxide, cf. Figure 1) [46].

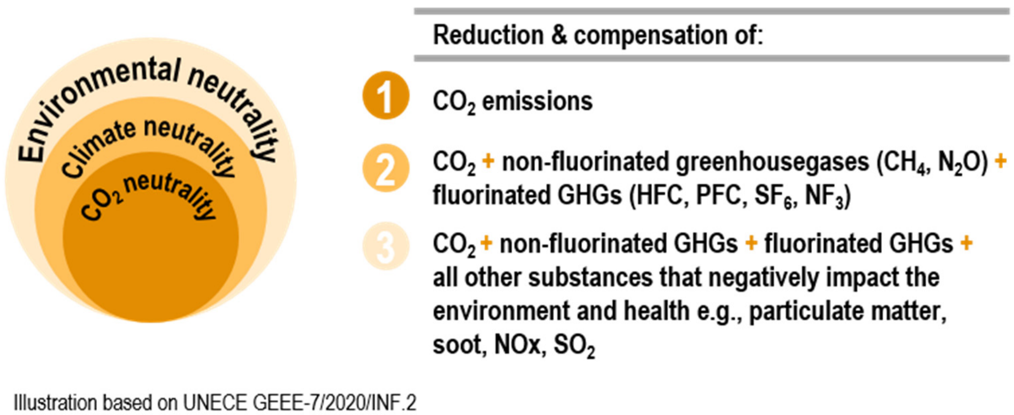


**Figure 1.** Defining different neutralities and what is needed to achieve them [46,47].

This frequent lack in clarity regarding definitions can also be observed beyond private sector stakeholders, in the public sector, in politics, public discussion and in media, for instance when reporting on targets: The German business paper Handelsblatt and the New York times diverge over the target set by Japan in late 2020. According to Handelsblatt [48], Japan is aiming for climate neutrality, while the New York Times [49] reports carbon neutrality to be the target. Without the means to retrieve the information from the original source in the language of origin, one will not know which neutrality is being targeted by Japan.

Therefore, establishing clarity of the target dimension and how it is being defined is crucial [46] for all stakeholders involved in the process (i.e., within a company), thus making it the *first success criterion* to any kind of net-zero pledge.

### *3.2. Optimisation Variable*

Even if the terminology is commonly understood, a strategy can only be effective if it serves achieving a clearly defined objective, in this instance one or multiple target dimensions that serve as variable(s) that are optimised for [50]. In context of emission reduction optimisation, common variables are (not exhaustive):

(a) Reduction of energy consumption (reduces emissions);
(b) $CO_2$-neutrality (usually includes reduction of **a**);

(c) Climate neutrality (includes **a** and **b** and is policy goal of, e.g., EU and Germany);
(d) Environmental neutrality (includes **a**, **b** and **c**).

For stakeholders in general, but also for a company in particular, it makes sense to pursue pragmatic pathways to effectively achieve what is needed. However, it is also relevant to observe the legislator's target setting, notably its target dimension. If climate neutrality is the country's target, policies are very likely tailored to serve this goal and companies are well-advised to take this into consideration rather than looking only at a subset of this dimension (e.g., carbon neutrality).

Even though the optimisation variables **a–d** are not mutually exclusive, the Energy Efficiency Index of German Industry (EEI) observed in its second data collection 2020 [41] that the 834 participating manufacturers on average optimise their companies towards two target dimensions. This suggests that within a further reaching optimisation variable, they also aim at optimising for (at least) one of its components in particular:

Most companies (58%) optimise towards a reduction of energy demand, second most (53%) for the reduction of $CO_2$-emissions. The fact that just over a third of companies indicate they want to optimise for GHG reductions (36%) or overall environmental impacts (36%) leads to the surmise that GHG reductions or, in other words, the means to reach climate neutrality remain abstract in the industrial context. This stands in opposition to the fact that climate neutrality has been the known target of both Germany and the European Union (EU) at the time of the data collection (cf. Figure 2) [41].

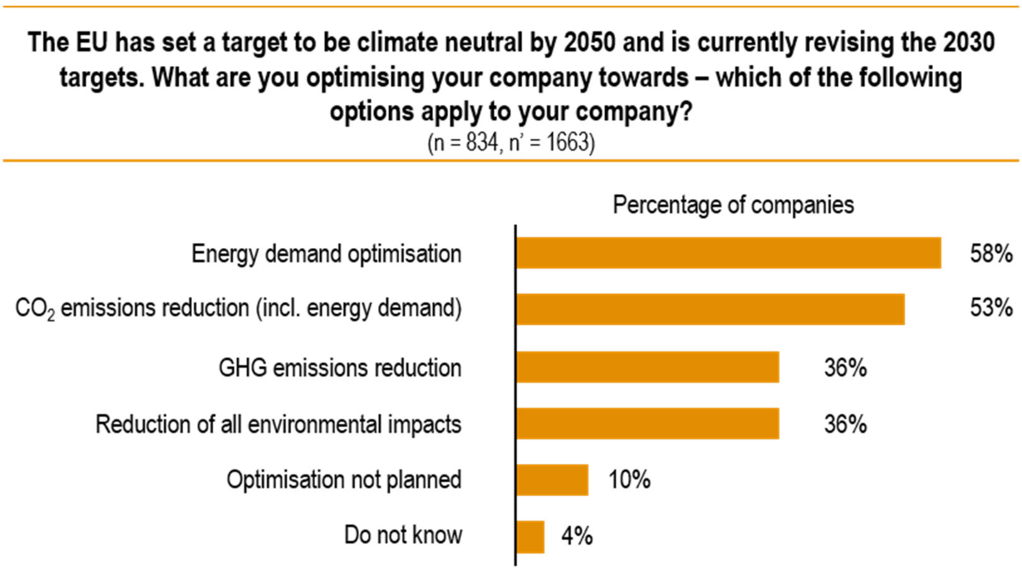


**Figure 2.** Target dimensions companies optimise towards [41].

Addressing the potential issue of climate neutrality being rather complex due to some of its hard to identify and quantify sub-components (e.g., nitrous oxide and hydrofluorocarbon.), the United Nations Economic Commission for Europe's Task Force on Carbon Neutrality is pursuing an in-between target dimension: Carbon neutrality plus methane reduction (and hydrogen) in its carbon neutrality project [51] (para 17) [52]. An agreement to reduce global methane emissions in context of COP26, counting more than 100 countries to date [53], indicates the notion of 'carbon neutrality +' to be tangible for those that find it difficult to commit to the further reaching climate neutrality goal.

After awareness of terminologies, determining the optimisation variable(s) as target dimensions and overarching goals that stakeholders are aiming to work and orient their forthcoming actions towards is thus the *second success criterion* on the path to net-zero.

### 3.3. Level of Ambition

The choice of target dimension (e.g., carbon or climate neutrality) only provides a limited indication of the level of ambition, as it remains unclear by when it is to be achieved. Very timely target years usually suggest a high level of ambition, whereas far into the future targets indicate either a very cautious regime, limited means to reach the goal earlier or simply lacking ambition. The German energy provider RWE plans to become climate neutral two years after the scheduled German coal phase-out—in 2040 [54]. Very timely target years, however, often significantly depend upon compensatory measures rather than actual emission reductions [55].

Clarity on the level of ambition is only achieved when it is also determined (a) *by when* the goal should be achieved and (b) *what percentage reduction* of the target dimension this is set to be. The latter is of high relevance, as there are scenarios in which a 100% reduction either cannot be achieved or simply is not the goal. This is the case if the target dimension is energy consumption, or if proportions of the energy- or process-related emissions cannot be avoided through reduction, substitution, or other alike means. In such cases, it could be attempted to balance remaining emissions through offsets (e.g., compensation) to manage a 'net-zero' instead of the 'actual zero' state in respect to their target dimension. Nevertheless, several stakeholders the author works with object to compensatory projects by principle and exclude these from their feasible set of decarbonisation measures, thus excluding themselves from the option of reaching 'net'-zero.

Beyond defining an ambition in terms of the finish line, it makes sense to also consider *interim milestones* to ensure the target can be met and potentially unpopular interventions are not being postponed to the future. Moreover, interim milestones ensure that the trajectory required to achieve the target is the same as the actual trajectory and adjustments are made if necessary. While there is no requirement to determine interim goals for companies, it is logical to do so in terms of year and level of achievement by then.

Many countries have set milestones for (at least) 2030 [56] (p. 41). As thorough assessments by these countries into the state of play are to be expected, it makes sense for stakeholders operating in these countries to define a milestone that ideally is already following the country's target for the respective year(s), too. The cases of Germany and the Netherlands being successfully sued at their constitutional courts over insufficient short- to medium-term action towards their 2030 targets underlines that additional interim milestones and, if necessary additional actions could be of relevance [57,58]. This is also why the outcome of the Glasgow Climate Conference COP26 encourages revisiting the current level of action, status, and subsequent tightening of pledges in shorter cycles than originally agreed upon in the Paris Climate Agreement (Art. 4 (9)) [6,59]. The current crisis, which has led to a desire in many European countries to quickly reduce dependence on fossil fuel imports, adds an additional and concrete urgency [9].

Nonetheless, countries can only succeed in meeting their (climate) goals, if they get the individual emitters, notably across building, transport, and industrial sectors, to reduce their (energy- and process-related) emissions.

Looking at the ambitions of German manufacturing, 59% of the 852 companies participating in the EEI in autumn 2019, ahead of the COVID-19 pandemic, indicated they plan to achieve net-zero. Of these 488, two thirds aim to have met this goal already before or by 2025 (cf. Figure 3). Peaking numbers in 2025, 2030, 2035, 2040, and 2045 (highlighted in yellow) suggest that semi-decades are chosen by many companies as their target years or at least milestones. The data further suggests that a vast majority of companies participating in the EEI prefer taking substantial immediate or at least short-term action [39].

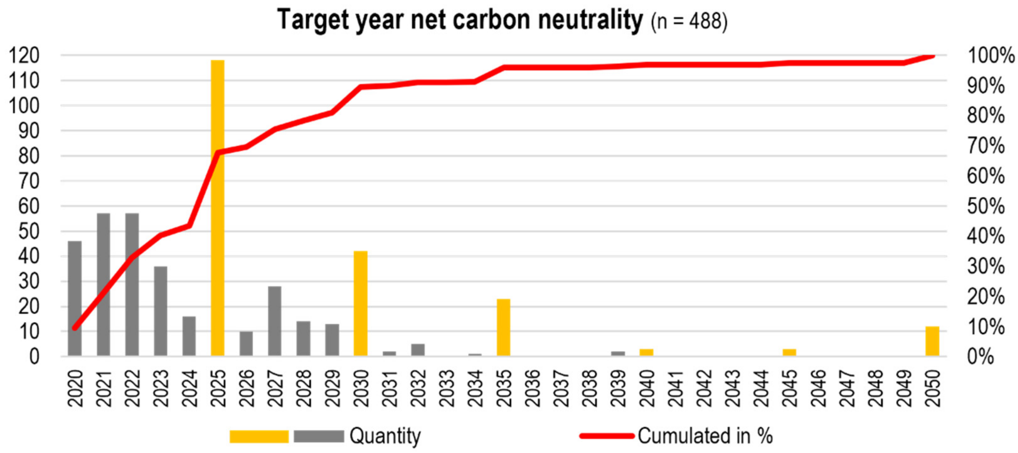


**Figure 3.** By when do companies plan to reach net carbon neutrality [38,39]?

Taking the likely impact of the COVID-19 pandemic into consideration and addressing the apparently important milestone year 2025, the first iteration of EEI in 2020 found that the 611 participating companies on average, and based on 2019 figures, aim (on average) at reducing their GHG emissions by 22.1% by then [40]. Asking for their 2030 ambitions at the time when the enhanced target of the European Commission for 2030 was being discussed (autumn 2020), 415 companies participating in the second data collection of EEI in 2020 expressed to aim (on average) for a 26.4% GHG reduction (based on 2019) [41]. This data confirms that (at least participating) companies consider substantial short-term action, accounting for more than 80% of what is planned for the whole decade, to happen within its first half. The arising curve of ambition appears to follow a path similar to limited growth functions, whereas policy action is often perceived to follow the opposite path of an exponential growth curve slowly growing towards 2030 and then taking up pace. The action gap arising from this/from what stakeholders need to enable them to meet their goals, and the current impact of policy, is explored further by Buettner et al. [60].

The level of ambition—the combination of target dimension, percentage-goal, and due date—can either be 'simply' determined by stakeholders, or be set once 'all cards are on deck', meaning all relevant (limiting) factors and potentials, feasible measures, as well as their costs are known. Irrespective of when exactly this decision is taken, setting and announcing a level of ambition is the *third success criterion* on the path to net-zero.

### *3.4. Area of Observation*

In the context of target setting, the area of observation, or the 'system barrier' is not always clear and obvious. Like the necessity to establish clarity of definitions, it is necessary to define to what the set target dimension and level of ambition refer.

This leads to three questions that need to be considered by stakeholders.

(1) Does the target apply to one site, multiple sites, or all sites of the stakeholder, or only to those in countries where some form of $CO_2$-levy is operational or considered. Does it only apply to sites in selected countries, e.g., Germany? Intuitively, it would be understandable if stakeholders prioritise those sites where there is an elevated levy-induced 'incentive' to take action, respectively those where the enabling environment makes it easier to succeed when taking action. From the author's practical experience, companies often initially focus on one site, or sites within their home country and then, when actions prove to be successful, they gradually expand beyond both geographically and in terms of efforts taken on the initial site.

(2) Are we referring to emissions and energy use in relation to this site/these sites only and, if so, including or excluding the corporate vehicle fleet (Scope 1 + 2). Or does the ambition go beyond the direct and indirect emissions that are under quasi-direct control of the stakeholder? Such Scope 3 emissions arise indirectly from one's action but are often

outwit direct control, and include business travel, the workforce's commute and additional emissions arising along up- and downstream supply chains (cf. Figure 4) [61].

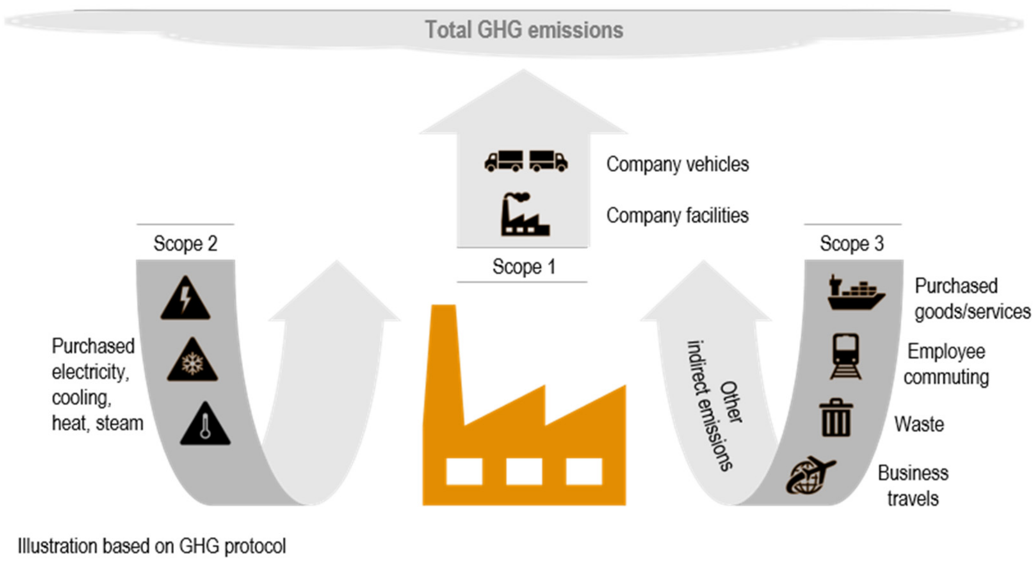


**Figure 4.** Carbon footprint assessment [38,52].

To the author's experience, most companies initially only address their energy-related emissions (Scope 2), as well as emissions directly arising from their work (Scope 1), due to the complexities of addressing Scope 3 emissions. Complexities arise predominantly out of potential double counting: Scope 1 emissions of one company might be Scope 3 emissions of another company [61,62]. Currently under investigation by EEI in its second data collection 2021, the interim analysis suggests that 77% of the 848 (846, 843) companies responding to this question strive to address Scope 1 emissions or have done so successfully already, 78% target Scope 2 and 75% Scope 3 emissions (cf. Figure 5). Further analysis of the new data will allow an examination of whether companies on average only address Scope 3 after a head start on Scope 1 and 2. The interim analysis suggests so: the progress is furthest in respect to Scope 2, followed by Scope 1 and with a substantial gap in Scope 3, which is understandable, as Scope 2 is 'easiest' to achieve by optimising energy supply contracts [43].

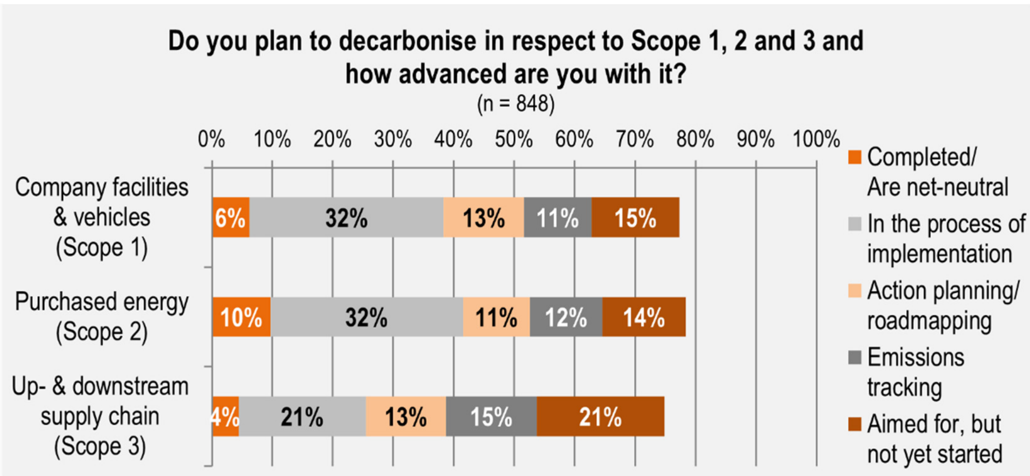


**Figure 5.** Companies' plans and current state in respect to Scope 1–3 [43].

(3) Approaching emissions from a different, a product angle: are only those emissions considered up to the point when (a) a product leaves the premises or arrives at the customer/the shop? Or is the additional emission footprint of the product (b) arising during its useful life, or (c) even until it is fully disassembled and recycled of relevance, too? Particularly in the automotive industry (b), this is of high relevance to meet the European Union's requirement on new vehicles to not exceed 95 g of $CO_2$-eq per km on fleet average to avoid being fined 95 Euros per gram and vehicle exceeding the average [63]. Considering the large footprint carried by the manufacture of lithium-ion batteries, but also steel, aluminium etc., manufacturers such as Volkswagen work to sell their electric vehicles with a net-zero footprint at the point of handover [64]. A significant undertaking, as many end products' Scope 3 emissions make up more than 75°% of the overall "Product Carbon Footprint" (PCF)—82% in the automotive industry [65] (p. 9).

The automotive industry is not the only sector where PCFs are increasingly found. The chemical giant BASF announced the assessment of the carbon footprint of all its products, as well [66]. Interim analysis of the EEI's second data collection in 2021 suggest that 37% of 829 companies responding to this question consider the PCF until the point of handover, 13% until the end of useful life, and 21% until the product is fully recycled/disposed of. However, 29% do not consider their products' PCF at all at this point. In total, almost 71% of companies work to offer products with a 'net-zero' footprint in one form or another, at least in respect to the point of handover (cf. Figure 6) [43], which is a good move in context of the EU's sustainable product legislative initiative mentioned earlier [23].

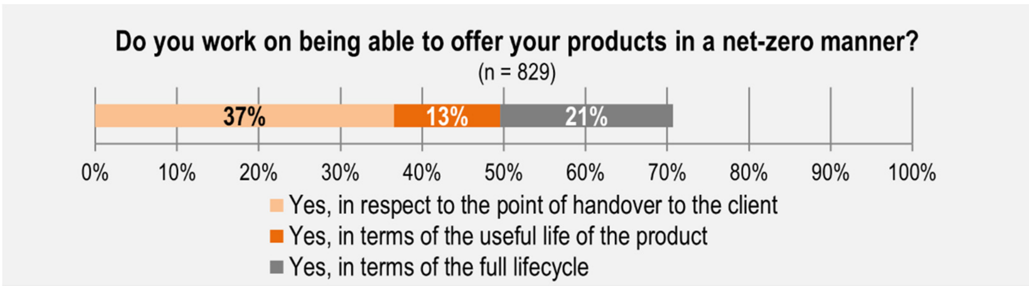


**Figure 6.** Companies' goals in relation to their products' carbon footprint [43].

As the bandwidth and efforts required largely differ depending on what system barriers are being set, defining the area of observation, the spatial, as well as the scope of reduction, constitutes the *fourth success criterion* to reach net-zero.

### 3.5. Motivation and Needs

Beyond the somewhat technical questions of what, by when, and how far, it is of critical relevance to explore *why* decarbonisation is sought. What is the underlying motivation of the executive leadership and the stakeholder for pursuing net-zero? Motivation plays a large role in determining one's ideal strategy and mix of measures, as elements that are of high internal (e.g., corporate culture) or external (e.g., legislation) relevance may be emphasised over a purely technical composition of measures. The motivation also determines how the topic of decarbonisation is embedded in the stakeholder's overall strategy. Common motivators include (not exhaustive) [67]:

- Requirements of the upstream supply-chain;
- Requirements of investors/shareholders;
- Image improvement: display leadership and innovativeness;
- Image improvement: attracting and retaining skilled personnel;
- Pursuing societal responsibility and corporate culture;
- Meeting societal expectations;
- Demands from policymakers and meeting legal requirements;
- Long-term economic advantages, including building up competency;

- Risk reduction regarding external shocks, such as energy price and acquisition and emission costs;
- Ensuring security of supply arising from (micro-) outages.

As Buettner and König [67] outline analysing these motivators, there is an increasing pressure to take action, triggered by both, but not only, investors and up-stream supply-chains. The latter has just been confirmed by EEI [43]: around a third of 836 participating companies are facing emission-related contractual demands from their upstream supply-chain. Image is not only of relevance to remain able to sell one's products but also to attract and retain scarce skilled personnel. The steeply increasing price of (a) $CO_2$ within the European Emission trading system (EU ETS, currently at 96 EUR/t$CO_2$-eq, [68]), (b) electricity, and (c) gas are an increasing cause of concern among stakeholders [69–72], even more so since Ukraine was attacked.

As decarbonisation measures that best address the various motivators can differ widely, getting a clear picture of the main motivator(s) for the decision to act constitutes the *fifth success criterion* on the path to net-zero.

### 3.6. Priorities

While answering the question of why, when, and what is the essential foundation of determining a roadmap to neutrality, the latter can only succeed if further decision criteria are being determined. These criteria are needed to rank and filter feasible measures simultaneously or after scoring how well these measures address the key motivators. Decision criteria include (not exhaustive) [73]:

- Level of investment;
- Investment cost per tonne of $CO_2$-eq. avoided;
- Emission cost savings (absolute or relative to invest);
- Image effect through visible measures;
- Expected increase in productivity
- Technical aspects and risks (complexity and difficulty level);
- Disruption of operations (cross-cutting-, support processes or core processes);
- Implementation competence (experience with type of measure or access to personnel with necessary skills);
- Impact on company valuation
- Payback time (including emission-related opportunity costs of inaction);
- Availability of required material and equipment (supply bottlenecks).

Analysing data of the EEI [40], Buettner and König found that economic factors such as absolute and relative level of investment have the highest priority as decision criterion [73]. Given that, they also found that technical aspects are the third most frequently mentioned primary decision criterion, having asked 787 companies. They further identified that the aggregate findings diverge significantly when assessing the top three decision factors from a company size, energy intensity, or sub-sectorial perspective. In context of the GHG reduction target, looking at the primary decision factor only, implementation competence stands out (cf. Figure 7). Either companies setting a particularly ambitious GHG reduction target (understandably) look particularly at their implementation competence when deciding which action(s) to pursue *or*, companies that have (access to) implementation competence (are able) to set more ambitious targets. At least, these two readings appear to play a role for the upper two quartiles of companies illustrated in Figure 7, indicating 'implementation competence' to be their primary decision criterion when selecting of individual measures, as the median GHG reduction target is at the same level as for the other primary decision criteria [40].

As the criteria according to which measures are vetted for feasibility and ranked have a significant impact on how the set of individual measures of a decarbonisation roadmap will look like, deciding upon the top three determinants or their ranking order is the *sixth success criterion* on the way to net-zero.

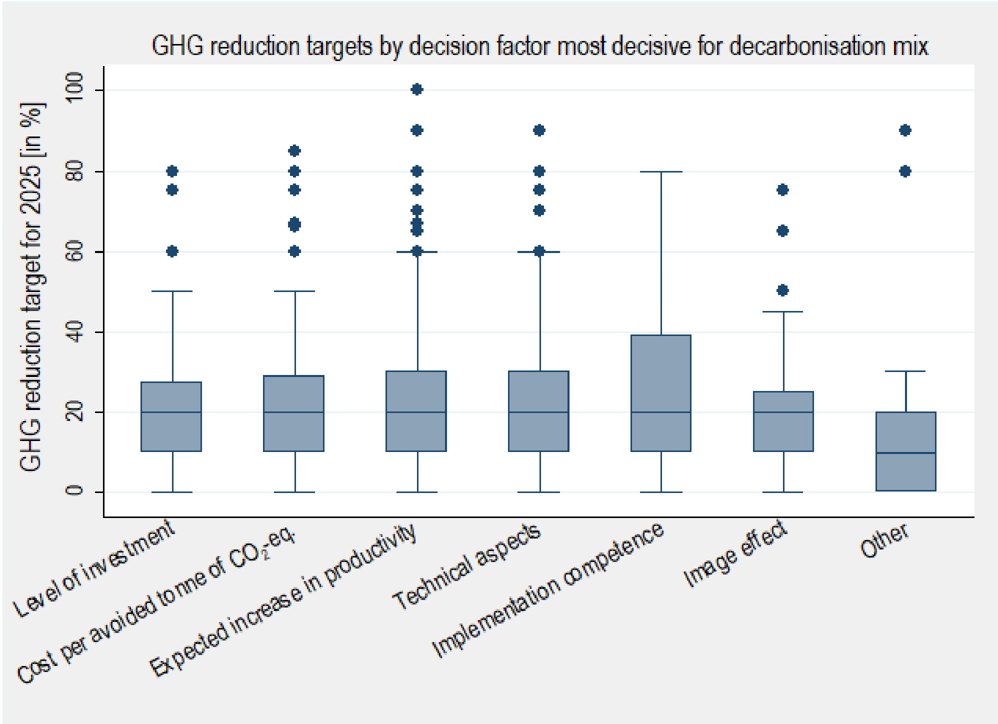


**Figure 7.** GHG reduction targets by decision factor most decisive for decarbonisation mix [40].

### *3.7. Status Quo*

While the first six success criteria are largely a strategic and economic decision to be taken by the stakeholder, they are still insufficient to derive a successful decarbonisation strategy. Determining one's ideal decarbonisation strategy and subsequently a concrete set of measures is dependent on knowing about where one stands right now-the status quo. As simple as determining the status quo sounds, it requires a thorough assessment across various dimensions:

(a) *What has already been done?* How is the state of the sites, machinery, and equipment? Are there any obvious low hanging fruits?

(b) *What intervention is approaching anyway?* This can be replacement investments, a restructuring of the production line, process, or product range.

(c) *How 'safe' is the site in its existence?* This is of relevance if investing into high efficiency technologies that are pricey to acquire but promise large relative energy and emission savings. If the (non-environmental) sustainability of the business model or production technology is questionable it might, however, not make sense to invest large sums at that site.

(d) *What is the current energy consumption per type of fuel and site, and what are the energy and process-related emissions in respect to the target dimension and area of observation?* Based on this information, stakeholders will know where they are starting from and potentially also where interventions might promise the biggest impact per effort taken.

(e) *What are the local conditions?*

- Are there undeveloped areas or available roof spaces? For instance, for on-site generation of renewable energy, energy storage, or heat recovery systems.
- How are the climatic conditions? This includes temperature range (e.g., for air/air heat pumps or air conditioning needs and level of insulation), solar radiation (to harness solar energy), wind and air corridors (to apply micro wind generation or use passive ventilation), adjacent waters (for micro-hydro or air/water heat pumps), geology (regarding earthquake risk and for geothermal energy including air/ground heat pumps) and environmental protection

zones (e.g., limited development due to protected species or drinking water protection areas).

- How is the surrounding infrastructure? Is there access to overland power lines, proximity to wind farms, solar parks, or hydro power stations? Are there nearby plots of land that would be suitable for these technologies (for off-premises self-generation)?
- Who is in the neighbourhood? This is primarily the proximity to entities with whom a symbiotic relationship could be built, typically a sender or recipient of secondary energy or secondary raw materials either on the stakeholders' site (i.e., pre-heating of processes), the industrial estate or in the borough (i.e., feeding waste heat into district heating grid, as Aurubis does for Hamburg's Hafencity [74]). Here, it also plays a role how ambitious the local authority is, as well as the state, region, and country the site is located in and further, whether there are support- and co-funding schemes or other support-mechanisms in place to benefit from or to reduce the overall investments.

According to EEI, about half of participating companies have not been aware of their energy- or process-related emission footprint at the time of participation (cf. Figure 8) [41].

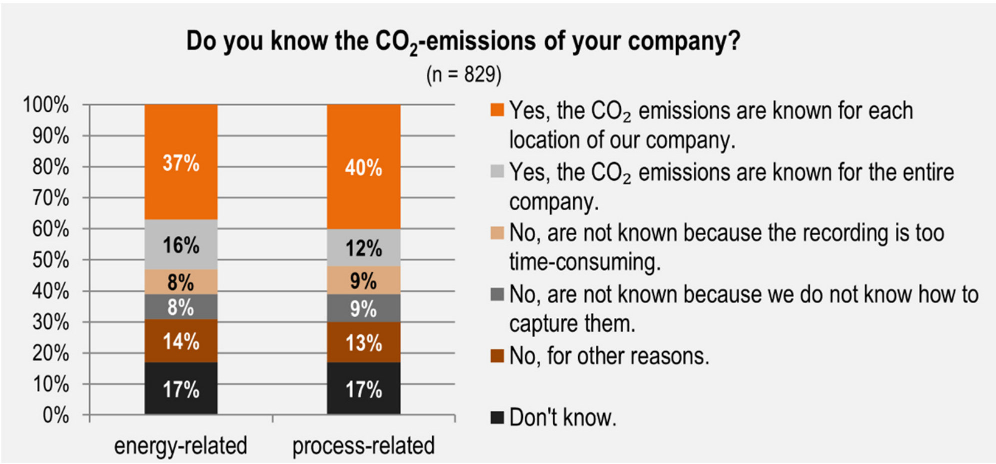


**Figure 8.** Companies' knowledge of energy- and process-related $CO_2$-emissions [41].

Apart from lighting, the majority of companies were also not aware of their percentage energy saving potentials of the cross-cutting technologies they use (cf. Figure 9) [42].

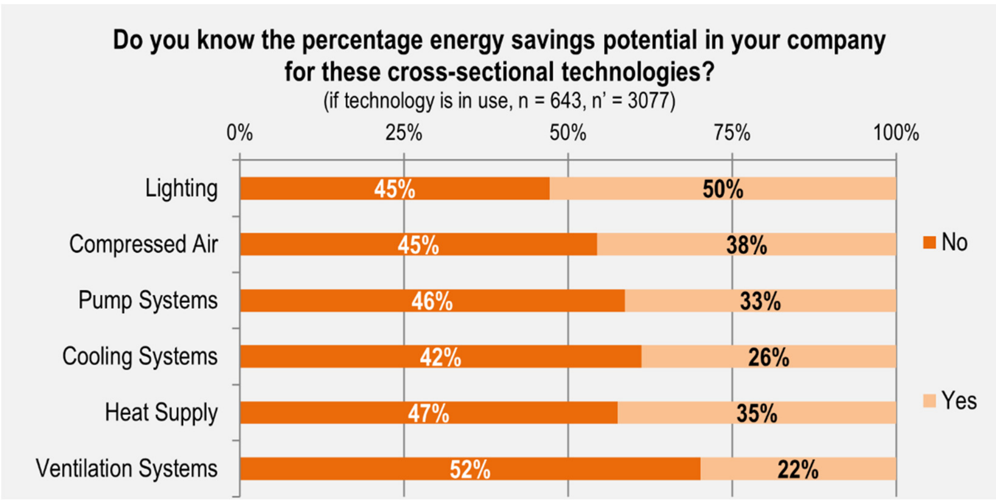


**Figure 9.** Companies' knowledge of their percentage energy savings potential in cross-cutting technologies they use [42].

More than four out of ten companies were unaware of what proportion of their energy is used for heating and cooling (cf. Figure 10). The latter are, in contrast to electricity, rather immobile, harder to electrify, and difficult to decarbonise, but they offer great potentials for waste energy utilisation, which 22% of participating companies do not harness at all (cf. Figure 11) [42].

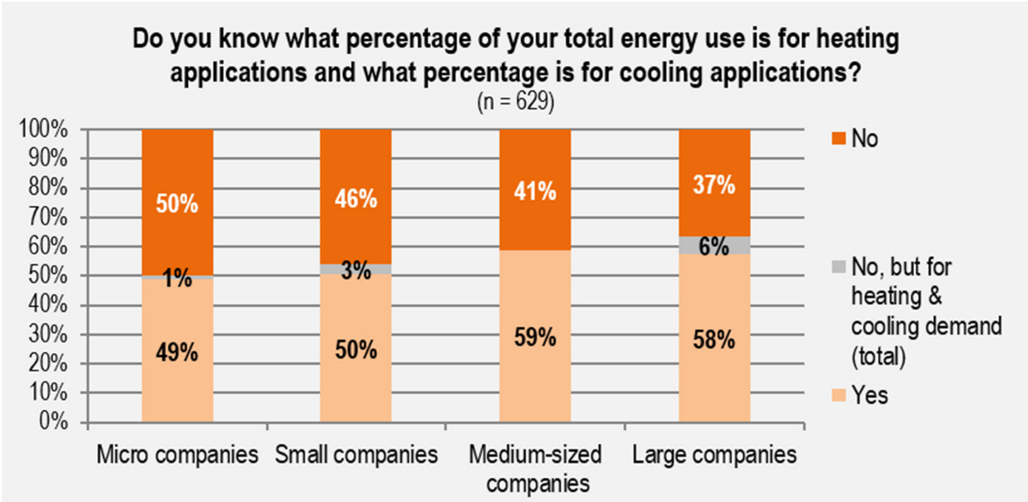


**Figure 10.** Companies' knowledge of share of energy used for heating and cooling [42].

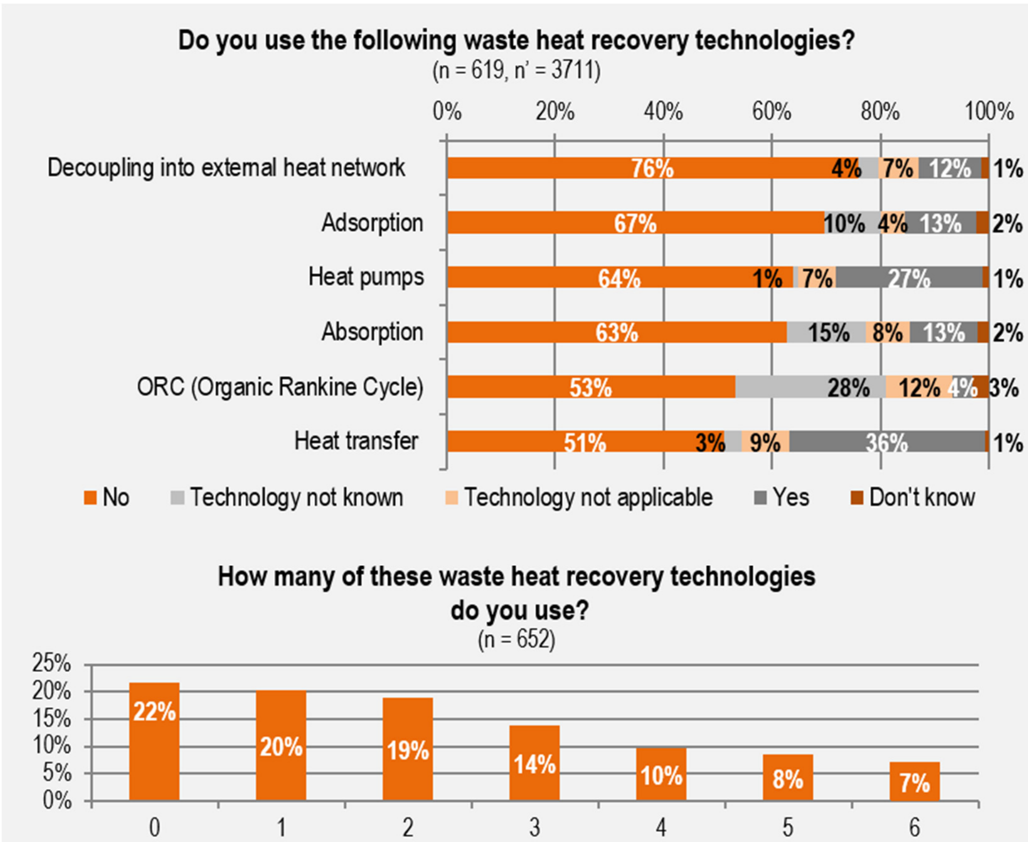


**Figure 11.** Waste heat recovery technologies used [42].

Acquiring a fair understanding of the status quo, the foundation the road to neutrality is built on, is the starting point of all further steps and hence the *seventh success criterion*.

With the answers to these seven foundational questions, spanning across economic, technical, strategic, principled, and geo-spatial dimensions, it is then feasible for stakeholders to derive both *general* (Section 3.8) and *specific* ways (Section 3.9) forward.

### 3.8. General

Building on the answers to the seven foundational questions, it is now necessary to determine the proportion to which the goal is to be achieved through measures that can be *implemented locally* and measures that are to be *implemented externally or by others*.

As described by Buettner et al. [38], *internal measures* can include:

- Reduction of energy consumption (and of the connected load) through energy efficiency measures, including utilising waste energy and passive resources such as passive ventilation or solar gains.
- Reduction of process-related or process-induced emissions, for instance by substituting (metallurgical) coke with green hydrogen in steel production, by identifying alternative chemical transformation pathways that are less emission intensive but lead to an equivalent outcome, or by developing more resource efficient processes and products that require a smaller proportion of emission intensive ingredients (e.g., cement clinker in the cement industry).
- Self-generation of renewable energies and their storage, such as solar-, wind-, hydro- or geothermal energy, including means of flexibilising the energy demand.

*External measures* are all other measures, such as:

- Acquisition of renewable energy (e.g., electricity, hydrogen, biomass, biogas, district heating).
- Procurement of (intermediate) products, raw materials, services, and mobility that have a net-zero emission footprint—either directly acquired on the market or via requirements set for suppliers.
- Offsetting emissions through projects (e.g., afforestation or efficiency-replacement programs through one's own products—comparable to a self-initiated scrappage scheme).
- Offsetting through purchase of certificates.
- Acceptance of the payment of emission charges (in this case 'net-zero' is out of reach in most scenarios).

Carbon capture and storage or utilisation (CCU/CCS/CCUS) is an additional measure, but it does not avoid the emergence of emissions, it only prevents them from being emitted into the atmosphere. While emissions are captured locally (*internal* measure), their further treatment can take place locally as well as elsewhere (*external* measure) [47]. A vast range of studies (such as Cresko et al. [45] and Rissmann et al. [28]) provide further and concrete detail on internal and external measures.

To determine the sequence of measures and the split between local and external measures, both the prioritisation procedures and the scoping outcomes are instrumental as the potential effect of individual measures, investment cost, complexity, payback time, and other key performance indicators will differ and need to be weighted.

It needs to be stated that the split will change over time and with progressing implementation. Bosch, for instance, announced in May 2019 that it would reach carbon neutrality by 2020 [55]. This was only feasible by launching activities in all areas. As local measures could not all be implemented within such a short period, the coverage gap was addressed through offsetting via climate protection projects and the acquisition of green energy. With the progressing implementation of local measures, these external measures can be melted down to a degree until the optimal constellation for net-zero carbon emission is reached. In the meantime, Bosch has changed to the political target dimension of the European Union, climate neutrality, and clarified that succeeding in their original area of observation (Scope 1 + 2), they are now working on Scope 3 [75].

Unless addressed when responding to the seven foundational questions, it is essential to make the decision of whether the tool of compensation through projects or certificates is within one's toolkit. Offsetting does allow reaching net-zero in an expedited manner at the additional cost of the certificates/for the projects—literally buying time until emission saving measures implemented locally take an effect. Accepting emission costs until these can be avoided 'naturally' is the alternative. In the author's experience, several companies rule out compensation as an instrument of their decarbonisation toolkit, as they consider it cheating, since it does not help them reach actual zero emissions. Furthermore, they may wish to avoid the repercussions if such projects are found to be dubious or faulty, or simply want to work towards zero 'naturally' [76–78].

### 3.9. Specific

Beyond the general types of measures described in the previous sub-chapter, there are further interventions, very specific to the situation of a stakeholder and their status quo, that present an opportunity to take a *technology leap* on the way to shape a net-zero business model. This is to replace existing machinery and equipment with innovative cutting-edge ones that also allow for capitalisation on the opportunities presented by automation, digitalisation, and machine learning. This can, for instance, be control systems that adjust the source of energy, storage, and a range of energy flexibility means by the current availability and price of clean energy, including virtual storage [79]. Another example is factory operation systems that report machine data to a central dashboard in a plug-n-play manner. Similar to the interoperability of "Internet of Things" (IoT) devices in more recent smart home systems or computer operating systems, they adjust to different form factors via drivers built around a core operating system [80]. Other studies also highlight the growing importance of digitalisation in other areas of sustainable business performance, such as cloud-manufacturing, recyclability, and circular economy [81].

In addition to this, Sustainability Key Performance Indicators (KPIs) can be defined based on the decisions made until this point to allow strategic management to monitor the progress on and effectively pursue the road to net-zero, but also as a basis for sustainability reporting [82,83].

### 3.10. Economic Viability

Buettner and Wang [47] point out that in the context of decarbonisation it is necessary to reconsider traditional economic viability calculations to assess the economic performance of technically feasible measures. The traditional model does neither account for increasing energy costs, nor for the increasing costs of inaction in the format of emission pricing (the price within the EU Emission Trading System (EU ETS), for instance, has risen by over 50% between 1 November 2021 and 1 February 2022 [68]). Further, a short payback time is often a key decision criterion due to various reasons, including business cycles, useful life of machinery, etc. However, in the context of decarbonisation, it makes sense to look for the best constellation for the respective milestone or target year.

To apply this, all types of measures remaining up to this point are to be assessed based on their economic merits, including emission costs avoided, and then weighted and scored as defined by the stakeholder. Simplified, the resulting ranking order constitutes the ideal configuration at that very point of time. 'Simplified', as some measures might depend on each other, are not compatible or only unleash their highest efficiency if applied in a bundle.

### 3.11. Dynamic Adjustment to Changing Environments

As energy prices and emission costs change over time, the ideal configuration changes over time, as well. To keep one's optimal decarbonisation strategy up to date with energy and emission price developments, it is advisable to make the ranking table of measures described in Section 3.10 dynamically respond to such changes. This is of particular relevance, as these cost-changes can have a significant impact on the ranking order of potential measures in a multiple year timeframe. As described by Buettner and Wang [47], building on energy and emission cost schedules and forecasts, it is then feasible to optimise the mix of measures based on specific milestone or target years, or a combination of these, respectively.

Combining all of the factors discussed in this chapter result in a focus-, situation-, priority- and specificity-driven approach, which is a very individual puzzle that changes its configuration over time.

## 4. Conclusions and Discussion

Within this article, the author illustrated how the methods applied lead to an understanding of how everything is connected. Using the backcasting method, he provides a step-by-step overview of seven foundational aspects that require attention, thereby helping decision makers in shaping a successful and effective decarbonisation strategy.

Even though the general approach towards what needs to be done may be similar to approaches applied by others, this roadmap to neutrality differs by (a) taking the perspective of an executive decision maker on the demand-side and (b) going a level deeper, where most other approaches indicate what needs to be done, either in general from a system or country level [28,29], or on a micro level (i.e., technical optimisation options and procedures) [25,26,45]. In addition, where existing approaches outline technical roadmaps [45] or indicate what must be done but not always how [30–32,84] and stop short of putting it into context, the approach presented explains the underlying strategic aspects that need to be considered beforehand. Firstly, such considerations raise awareness of the implications of decisions (to be) made and, secondly, ensure the ability to take decarbonisation actions in the best manner and interest of the company. Finally, this approach differs in its methodology by combining qualitative and quantitative data, which (a) allows one to validate learnings from individual cases on a much wider basis, and (b) to interpret broad quantitative findings in context, as sometimes multiple readings appear plausible.

Determining one's ideal decarbonisation strategy, associated decarbonisation roadmap and range of concrete measures essentially comes down to considering one's situation, priorities and motivations, and focus. With these points—addressed by the seven success criteria—one's specific puzzle of measures falls into place.

As shown in the step-by-step approach, clarity regarding the terminology of the target dimension (e.g., carbon vs. climate neutrality; Section 3.1) and the optimisation variables, inferable from this target dimension (Section 3.2), are the first two steps. This is important, as a target can only be set and achieved effectively if it is clearly defined, and ideally is also in line with general country- and regional-level goals. Given this, the level of ambition (Section 3.3) needs to be clarified, as it goes beyond the previously mentioned dimensions, including time-targets and reduction goals. Here, it may also make sense to establish interim milestones to assess progress in smaller steps. Next, stakeholders should define the area of observation and the system barriers (Section 3.4), as well as the scope of emission reductions. This includes the chosen sites the company intends to decarbonise (spatial) and the scopes of emission—scope 1, 2, and 3—that are supposed to be reduced. Besides these rather technical decisions, the identification of one's intrinsic motivation to decarbonise can also be crucial (Section 3.5). Such motivators can reach from purely economic rationales and legal requirements to reputational issues and social responsibility. Being clear about their motivations, stakeholders also need to formulate their priorities, which serve as criteria for the implementation of measures (Section 3.6). Data from EEI shows that, on average, companies rank investment level highest and that the ranking largely depends on company size and energy-intensity level. Finally, yet importantly, it is essential that companies know their starting point—their status quo (Section 3.7). Only those who are aware of their fundamentals can hope to effectively build on them. This includes current levels of energy consumption and emissions but also many other factors, such as surrounding infrastructure and climatic conditions.

After one has fulfilled all of the abovementioned points, further decisions on whether to take external (e.g., acquisition of renewable energy) or internal (e.g., reduction of energy consumption) measures to reach the target need to be made (Section 3.8). Deciding on whether to count on compensation measures or not is part of this process. More specific decisions on which measures to take depend on the individual situation of a company (Section 3.9).

Nevertheless, it remains to be underlined that the road to net-zero does not end with meeting the (milestone-)targets set within time. Like reaching one's ideal weight, it is one challenge to reach it, and another one to keep it. The ideal mixture of measures to maintain it is likely to change with time, situation, and environment.

An adjusted form of economic viability assessment (Section 3.10), as well as a continuous adjustment to current prices, availabilities, changing environments and policies (Section 3.11) will ease the challenge of keeping the decarbonisation strategy and associated mix of measures ideal over time.

Data of the Energy Efficiency Index of German Industry illustrated that a significant proportion of manufacturers participating in the survey are already on a good path. However, the remaining companies need to be picked up, and much work remains to be done across all areas looked at to successfully transition to a net-zero economy and to keep it net-zero.

Even though most of the evidence was gathered from German manufacturers and reflects the situation in Germany, it can be argued that the seven foundational questions are likely to remain valid irrespective of geography or culture. In contrast, the answers to the seven questions are likely to be different depending on those factors. Therefore, the currently ongoing data collection via the Energy Efficiency Barometer of Industry and the exchange with bodies, stakeholders, and companies in other geographies is of particular interest. Whether the seven questions can be also applied to areas outside the industry remains to be assessed by further analysis.

**Funding:** The article processing charge was funded by the Deutsche Forschungsgemeinschaft (DFG) in the funding programme Open Access Publishing.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy issues.

**Acknowledgments:** The underlying research in the form of the Energy Efficiency Index of German Industry (EEI, #EEIndex) would not have been possible without the continuous support of the Karl-Schlecht-Foundation and the Heinz und Heide Dürr Foundation, as well as the companies participating and the network of partners of the EEI, including those reviewing and supporting in progress of developing this paper and the EEI data collection process, notably Samuel Wörz, Frederick Vierhub-Lorenz, Marina Gilles, Anabel Reichle, Ole Pfister, and Werner König, the decarbonisation team and the team of student researchers. In Germany, evidence is usually collected each April/May and October/November (www.eep.uni-stuttgart.de/eei; accessed on 21 April 2022); the #EEBarometer runs all year round in nine further languages across 88 countries (www.eep.uni-stuttgart.de/eeei; accessed on 21 April 2022). The summarised results and recordings of briefings on the results can also be found there. All conclusions, errors, or oversights are solely the responsibility of the author.

**Conflicts of Interest:** The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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# 9 Conclusion and Outlook

While there is a significant proportion of companies that have set a decarbonisation goal and know how to achieve it, there is probably also a large proportion of companies that either want to pursue decarbonisation but need help to figure out how to do so, or reject decarbonisation efforts because they are already facing too many challenges ("pains") in the current polycrisis and are not aware that the tools of decarbonisation can very likely alleviate their "pains".

This dissertation had the aim of providing a multi-perspective analysis of *how climate neutrality can be achieved for industry*. For this purpose, it provided an overview of how the industrial sector is deeply intertwined with the overall ability of countries to achieve net-zero emissions, as evidenced in particular by the ongoing energy crisis, rising prices, disrupted supply chains and the desire for resilience (**Chapter 1**).

Taking account of the differences across company types (i.e., sector, size, energy intensity), it revealed that there is already a high preparedness to decarbonise (**Chapters 3**, **4** and **8**), but that there are gaps in both the provision of sufficient green generation infrastructure and qualified personnel (**Chapter 4**) as well as in the knowledge of their own status quo (**Chapter 8**).

"Being on the same page", which requires a mutual and identical understanding of definitions, is essential to effectively work towards common goals (**Chapter 8**) and therefore adequate definitions are needed as a solid foundation (**Chapter 2**).

**Chapter 5** has provided a better understanding of the main motivations of different types of companies to decarbonise, so that approaches can be developed to mobilise companies by triggering their intrinsic motivation rather than through direct regulatory coercion, in other words: »Change through anticipative steering, #CTAS« (Buettner 2017). Gaining knowledge and insights into the individual "pains" of companies that are not yet decarbonising may promise to bridge the gap between the pains and taking action using market-ready technologies.

Depending on a company's motivations for decarbonisation, the configuration of measures to achieve net zero emissions will look different. Similarly, their decision factors have a major influence on which measures are part of the mix. Often, but not for all companies, the most decisive factors are the level of investment — as the investment amount needs to be within the available investment budget — or the cost per tonne of emissions saved, together with technical aspects (**Chapter 6**).

However, **Chapter 7** emphasises that it is important to ensure that such comparisons of costs per [X] between measures are valid. Comparing measures whose main purpose is, for example, to reduce energy consumption (which indirectly leads to emission reductions) with measures that only reduce emissions is likely to highlight the first measure as excessively expensive per tonne of carbon saved. Thus, such a comparison would ignore the first measure's benefits in reducing energy costs and the fact that energy-related emissions depend solely on the emission factor of the energy source. Apart from this, **Chapter 7** assesses the economic, energy and emission-related one-off and ongoing impacts of the established and emerging types of decarbonisation measures. It underlines that, in contrast to production line-oriented investments (which usually have to pay off within a very short time to be considered for implementation), measures to achieve a factory-wide target should be economically optimised in terms of decarbonisation milestones and target years. The introduction of different formulas facilitates the calculation of the economic performance of measures up to a certain future point in time, considering changing energy and emission prices. In order to provide an overall assessment of measures that also takes motivations and decision criteria into account, it proposes the use of scoring models that are built in such a way that they can dynamically adapt to changing circumstances.

**Chapter 8** elaborates on the key questions that decision-makers need to find an answer to when they want to develop their own decarbonisation strategy based on the insights gained in **Chapters 2 - 7**. Developed in the context of practical experience, it underlines that it is both necessary to know one's status quo in terms of energy and resource consumption as well as one's existing footprint, and to define the area of observation and the level of ambition. It equally needs to be determined which optimisations are compatible with the set-up and geographical location of the companies and, naturally, why decarbonisation is being pursued and which decision-making factors matter for composing their specific and effective roadmap to neutrality.

Overall, it is important to recognise that many companies have expressed their willingness to decarbonise (around 78 % according to the latest sample in January 2022 (Buettner 2022, p.11)). As prices were already high at the time, leading companies to shut down or limit production (Stratmann 2022), the steep price increases since the start of the war in Ukraine on 24 February 2022 may have led companies to focus on reducing costs and increasing resilience, including cutting investments or reactivating the use of available fossil fuels (Olk & Stratmann 2022). On the one hand, in the greater scheme of things, the war has highlighted the importance of reducing dependence on external energy sources. On the other hand, the extreme price levels have led to energy efficiency measures paying off much faster, while reducing ongoing costs and vulnerability to external shocks. As the EU has agreed on expanding the emissions trading system (EU ETS) as well as phasing out the free allocation of emission allowances (Council of the European Union 2022), the number of companies seeking to decarbonise, directly or indirectly, is likely to continue to grow.

To channel these ambitions and learn from the vulnerability of European energy systems' dependence on gas, it is crucially important to remove the bottlenecks that prevent faster expansion of renewable generation and its transmission from generation areas to consumption areas (UNECE 2022). This is essential to make the grid robust and to avoid load shedding in industrial centres (= partial shutdown of production) and the shutdown of (e.g.) wind power plants because the grid cannot absorb a higher load. Cross-country interconnectors and redundancy in the system design can help (UNECE 2022). However, all these measures depend on speeding up the planning processes and sufficient public support so that the expansion of this critical infrastructure is not blocked by lengthy court cases. The need to shorten planning times also applies to all on-site measures that either require planning permission or need to be signed off by someone before they can go online. In addition to streamlining, modernising and prioritising planning regulations and digitising processes, this also requires sufficient capacity in local authority planning offices, the courts and the recruitment and training of qualified staff, which is essential for the implementation of all these measures across the country and industry.

The mere provision of technology roadmaps is not sufficient to facilitate net-zero emissions in either the industry or the economy as a whole. Furthermore, while programmes and roadmaps for energy-intensive industries address about 76 % of industry's energy consumption (destatis 2022a), to achieve net zero, all groups of companies need to be addressed. Accordingly, not just those companies should be addressed that consume the most energy but account for "only" 16 % of gross value added and roughly the same shares in terms of the number of companies and employees in industry (destatis 2022a).

That is why it is also necessary to better understand the specific goals of the different types of companies, their respective progress in achieving these goals and, most importantly, whether or what help they need along their way. While **Chapter 8** touches on this notion (Buettner 2022, pp.11-12), it remains the task of further work to clearly work out what help is needed, when and by whom, while looking out for and pointing out possible "unknown unknowns" where companies state that they do not need help, mainly because they are unaware of their hidden potentials or will only discover knowledge/capacity gaps when the task is immediately at hand. A forthcoming study (Buettner & Förther 2023) will address some of the highlighted issues, others will be addressed in a foresight study further ahead.

If we manage to engage companies (Buettner et al. 2020), enable them to consciously plan and take the path of decarbonisation, and support them along the way with the necessary framework conditions, then companies will be able to achieve net-zero emissions and thus create the products that will gradually lead to a climate-neutral economy and thus — it is hoped — halt climate change or avoid crossing tipping points.

Whether we manage to earn the "clean ticket" and get off the "highway to hell" in time depends solely on how well, how effectively and how quickly we get moving.

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