Technical University of Munich
TUM School of Management

Master's Thesis Title

Reinforce sustainability and competitiveness: recommendations for the top 5 sectors of the German manufacturing industry to reduce their greenhouse gas emissions by the use of digital and green technologies

Master's Thesis for the Attainment of the Executive Master of Business Administration in Business & IT at the TUM School of Management of the Technical University of Munich

1st Supervisor	Prof Dr Helmut Krcmar Chair of Information Systems Department of Informatics (TUM)
2nd Supervisor	Prof Dr Reinhard Jung (HSG)
Person in Support **Submitted by**	Prof Dr Reinhard Jung (HSG) Olivier Bathany
Submitted on	30 March 2023

Executive Summary

Our twenty-first century is being simultaneously hit by two waves: the digital transition of our economy and society with the digital transformation, and the energy transition with the rise of non-fossil fuel energy sources like solar/wind/hydro power.

In Europe, Germany with its number-one economy in terms of gross domestic product (GDP) respectively gross value added (GVA) in comparison with the rest of the European economies, has a major stake in succeeding in riding these two waves from a competitiveness and sustainability perspective. With its resolutely export-orientated nature, Germany's manufacturing industry (excluding construction) represented over 20% of Germany's value creation; an unrivalled number in Europe.

To make a parallel with the role of the blood in our body, energy is the manufacturing industry's blood. In order to manufacture products, in simplified terms process resources like raw materials and assemble the resource-originated parts, a yearly huge amount of energy is required; it has turned out that Germany's top 5 manufacturing industry sectors are reliant on fossil fuel energy sources varying from 46% to 79%. The downside of using fossil fuel energy sources so massively is the inherent release of greenhouse gases which are adversely impacting our environment and biodiversity.

With the legally binding EU and national ambitious goals to become a climate-neutral continent by 2050, Germany's top 5 manufacturing industry sectors in particular must adapt to maintain their leadership role and competitiveness as well as assert their sustainability.

Digital, green, green digital technologies are one way to look at this challenge. Transformational factors like Industry 4.0, circular economy or make use of Germany's mechanical engineering industry with its constant innovation capability in energy efficiency for instance can make your organisation confident and forward-looking that both transitions can be successfully and concurrently overcome.

This Master's Thesis is the result of my findings, interpretations, as well as anticipations of what a cleaner value creation from German relevant industries for the business world can be. Enjoy the reading and feel free to get in touch with me for sharing any of your thoughts toward building a better world.

Foreword

From April 2021 to March 2023, I had the great opportunity to attend the Executive MBA in Business and IT from two European leading higher education institutions, namely the TUM School of Management from the Technical University of Munich in Germany, and the Institute of Information Management from the University of St. Gallen in Switzerland.

The programme is all about the management in the digital transformation age. However, based on my observation, another management component ought to be taken into account to understand our VUCA[1] world, namely the management in the ecological and energy transition age. In my Master's Thesis, I will humbly try to reflect on this component of rising significance for my adopted country in which I have been living for over thirty years.

Professor Reinhard Jung from the Institute of Information Management, University of St. Gallen, Switzerland, has served as a very dedicated and supportive mentor and supervisor during the last six months of my programme; I want to explicitly express my gratitude towards him.

Finally, I would like to dedicate my endeavour to my wife and daughter, who are always a truly transformational inspiration and the virtue of patience.

The greatest glory in living lies not in never falling, but in rising every time we fall.
Nelson Mandela

[1] Acronym that reflects on the **V**olatility, **U**ncertainty, **C**omplexity and **A**mbiguity of general conditions and situations. First used in 1987, it drew on the leadership theories of Warren Bennis and Burt Nanus (retrieved from Wikipedia, source https://en.wikipedia.org/wiki/Volatility,_uncertainty,_complexity_and_ambiguity, last accessed 14 October 2022).

Table of Contents

List of Abbreviations (Ascending Order, First Occurrence in Page)

List of Tables

List of Figures

1 – Introduction

When I wrote my dissertation (from October 2022 to March 2023), we only roughly had twenty percent of the twenty-first century behind us, and the more I was reflecting upon the past two decades, two change-driven topics keep arising: the first one is the energy transition, and the second one is the digital transition/transformation. My intellectual curiosity and motivation are a kind of bringing these two topics together, and to look at what challenges the German economy has to embark upon both transformations.

These two topics are having a massive impact on Germany, the industrial engine of the European Union and EU's first country in terms of Gross Domestic Product (GDP) (€ 3,601.8 billion in current prices) and Gross Value Added (GVA) (€ 3,258.6 billion in current prices) in 2021[2].

The production (excluding construction) industry has represented 24% (€ 783.2 billion in current prices) in 2021 of Germany's GVA[3], and its principal contributor, the manufacturing industry, even 86.7 % (€ 679.1 billion in current prices) of Germany's secondary economy sector[4]. In other words, 20.8% of Germany's GVA has come from the manufacturing industry, i.e., over one fifth of the German value-added economy – this is our first indicator to remember.

Within the manufacturing industry in 2021, five vertical sectors in a descending order in terms of GVA stood out:

1. Transport equipment.
2. Machinery and equipment.
3. Basic metals and fabricated metal products.
4. Chemicals and chemical products.
5. Food products, beverages and tobacco.

For the four years 2010, 2015, 2019 and 2020, the German residents (all economic branches plus private households) have used on 21,090 PJ on average stemming from various sources of energy (coal, petroleum, gas, wind, solar, biomass, etc.).

On average per year, 17,282 PJ (82%) were used by all German economy branches (primary, secondary and tertiary sectors) with an 85% dependency on fossil fuel energy; the

---

[2] Retrieved from DESTATIS, national accounts – at a glance, source https://www.destatis.de/EN/Themes/Economy/National-Accounts-Domestic-Product/Publications/Downloads-National-Accounts-Domestic-Product/at-a-glance-pdf-0310200.pdf?__blob=publicationFile, p. 19 for both values, last accessed on 28 October 2022.

[3] Retrieved from DESTATIS, Volkswirtschaftliche Gesamtrechnungen Inlandsproduktberechnung Vierteljahresergebnisse – Fachserie 18 Reihe 1.2, source in German https://www.destatis.de/DE/Themen/Wirtschaft/Volkswirtschaftliche-Gesamtrechnungen-Inlandsprodukt/Publikationen/Downloads-Inlandsprodukt/inlandsprodukt-vierteljahr-pdf-2180120.pdf?__blob=publicationFile, p. 18, last accessed on 28 October 2022.

[4] Same source as [3], same page.

five aforesaid industrial sectors have used 1,867 PJ (~11%) on average per year with a 95% dependency on fossil fuel energy[5].

With a mid-term/long-term outlook, is this economy model based on an evidence-based fossil fuel energy dependency sustainable, given the observable climate change effects due to Green House Gas (GHG) emissions resulting from their combustion for instance, as well as all geopolitical, geographical unrests and conflicts existing on earth, plus the stunning rise of the Chinese economy?

The purpose of my Master's Thesis is to elaborate recommendations for Germany's top 5 manufacturing industry sectors to sustainably reduce their GHG emissions. This led me to consider the following five research questions:

Research Question 1: What sword of Damocles (impeding disaster) may these five vertical sectors face in conjunction with the EU/German regulatory framework, especially against the backdrop of the GHG emissions reduction?

Research Question 2: Which vertical sector from Germany's top 5 manufacturing industries according to the gross value-added perspective can best contribute to curtail the dependency on fossil fuel energy?

Research Question 3: Considering the identified vertical sector from the second research question, what existing/emerging technologies and innovations are worth being considered?

- From the digital technology perspective.
- From the green technology perspective.
- From a combined perspective (green digital technology).

Research Question 4: What results on the fossil fuel energy dependency reduction and energy efficiency gains have already been delivered to date and how impactful and measurable are they for the identified vertical sector of the German manufacturing industry?

[5] Retrieved from DESTATIS, German publication Umweltökonomische Gesamtrechnungen – Energiegesamtrechnung, source https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/UGR/energiefluesse-emissionen/Publikationen/Downloads/umweltnutzung-und-wirtschaft-energie-xlsx-5850014.xlsx?__blob=publicationFile, sheets 2.3.3, 2.3.4, 2.3.5, 2.3.6, last accessed on 28 October 2022.

Research Question 5: What recommendations and best practices are currently available for Germany’s other top 4 manufacturing industry sectors to reduce their GHG emissions and improve their energy efficiency while staying competitive and sustainable?

Taking into consideration what I have drawn up above, it was natural to write my Master Thesis’s with the following title “***Reinforce sustainability and competitiveness: recommendations for the top 5 sectors of the German manufacturing industry to reduce their greenhouse gas emissions by the use of digital and green technologies.***”

2 – Key concepts

The key concepts will set the scene of my Master’s Thesis; in total, I will address six key concepts as follows:

- 2.1 – Germany as a leading nation
- 2.2 – Key stage of our economic model
- 2.3 – Manufacturing industry
- 2.4 – Orientation, legal framework and regulations
- 2.5 – Trilogy
- 2.6 – Transformational factors

2.1 – Germany as a leading nation

2.1.1 – Commitment to younger generations: a sustainable and competitive economy as a precondition for a stable cultural and societal environment

Two date facts: 1945 – Germany is materially and economically a destroyed nation at the end of the Second World War. Since 2007, Germany consistently ranks as the World’s fourth strongest economy in terms of GDP expressed in current US dollars (i.e., the total value of finished goods and services produced within the country’s borders) based on the historical data retrieved from the World Bank via its World Development Indicators (WDI) data base which aggregates a primary collection of country development indicators[6]. The figure below illustrates the World’s top 4 country GDP evolution (plus France as being my homeland) throughout the last fifteen years.

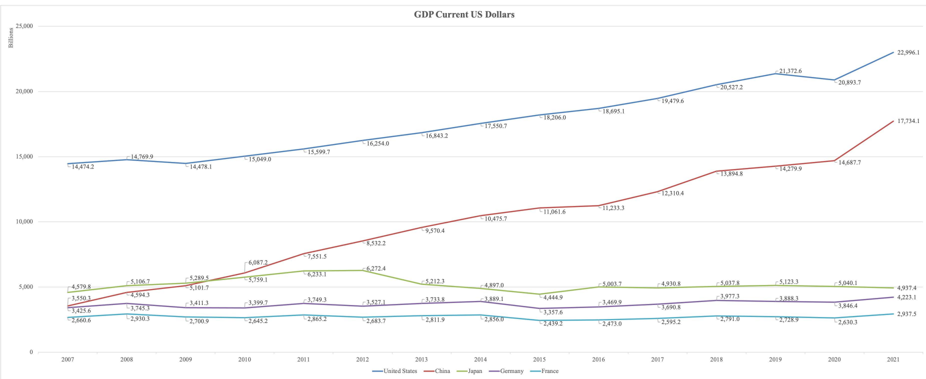


Figure 1: GDP current US dollars - USA, China, Japan, Germany and France since 2007

Part of Germany’s economic model success is the result of innovation and strong export orientation. The latter can fairly be associated with the claim “Made in Germany”. We will talk about innovation in more details in two of our master’s thesis building blocks, namely manufacturing industry and Germany’s machinery & equipment sector.

Since the seventies, Germany’s GDP has overtaken France’s one and the gap between a solidly anchored manufacturing industry nation like Germany and its weaker industrial

[6] Retrieved from the World Bank, source https://databank.worldbank.org/source/world-development-indicators with appropriate variables (data base, country, series and time), last accessed on 28 October 2022.

neighbour is growing, especially since 1990. Several fundamental orientation choices are the results of this disconnect; however, it is not my intent to analyse the root causes thereafter.

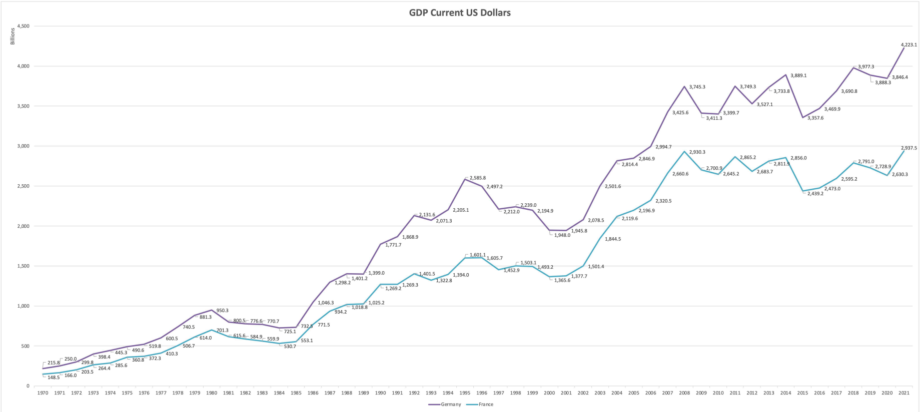


Figure 2: Germany's GDP vs. France's GDP since 1970 in current US dollars

Needless to claim that a strong economy has a highly beneficial effect on the cultural and societal environment as jobs are made available for people in the working age. Maintaining a sustainable and competitive economy is not only a call for stability but also a commitment to offering a perspective for the next generations. What does a sustainable and competitive economy look like when digital and green technologies are combined together to reduce the dependency of fossil fuel energy and produce goods and services with lower GHG emissions?

This is what I want to investigate, analyse and ultimately formulate as recommendations in my dissertation. In the end, it is about a strategic and critical programme for each company, which ought to require lots of attention and dedication from the company's management team. So, let me try to describe and understand what Germany's GDP main elements are; the next section is going to detail this out.

2.1.2 – Germany's GDP/GVA composition

From a calculation standpoint, there are three methods to evaluate the GDP: the production, use and distribution methods. My focus will be on the production method moving forward as it takes account of the GVA which is an essential element to measure the value creation of any industrial sector. In a nutshell, the GDP equals GVA plus net taxes (taxes less subsidies on products); the GDP and GVA were respectively € billion 3,601.8 and 3,258.6 at current prices in 2021[7]. Which economy sectors does the GVA derive from? Below is a table overview with reference to DESTATIS[8]:

[7] Retrieved from DESTATIS, publication national accounts, at a glance 2021, source https://www.destatis.de/EN/Themes/Economy/National-Accounts-Domestic-Product/Publications/Downloads-National-Accounts-Domestic-Product/at-a-glance-pdf-0310200.pdf, p. 19, last accessed on 28 October 2022.

[8] Retrieved from DESTATIS, publication national accounts, at a glance 2021, source https://www.destatis.de/EN/Themes/Economy/National-Accounts-Domestic-Product/Publications/Downloads-National-Accounts-Domestic-Product/at-a-glance-pdf-0310200.pdf, pp. 20-21, last accessed on 28 October 2022.

Germany's Economy Sectors	GVA (€ billion)	Weight (%)
Agriculture, forestry and fishing	30.6	0.9
Production industry	963.0	29.6
• Production industry, excluding construction	(783.2)	(81.3)
- Mining and quarrying	((7))	((0.9))
- Manufacturing industry	((679.1))	((86.7))
- Electricity, gas, steam & AC supply	((64))	((8.2))
- Water supply, sewerage, waste management & remediation activities	((33.1))	((4.2))
• Construction	(179.8)	(18.7)
Services	2,265.0	69.5

Table 1: GVA (2021, at current prices, € billion), total value: € billion 3,258.6

What does that mean? For the Germany economy in 2021, the primary sector counts for 1%, the secondary sector for 29%, and the tertiary sector for 70% of the GVA approximately. Within the secondary sector (aka production industry), the manufacturing industry counts for the lion's share with over 86%. Hence, my work will focus on the manufacturing industry.

2.1.3 – Top 5 weights of the German manufacturing industry from a GVA perspective

I have used the DESTATIS publication[9] – national accounts: at a glance 2021 – from August 2022. In order to evaluate the German heavy weights of the manufacturing industry, I have used the average data between 2016 and 2020 (2021 data was still incomplete in December 2022). Below is the table overview:

Branches of the Manufacturing Industry	GVA (€ billion)
1. Manufacture of transport equipment	148.3
• Motor vehicles, trailers and semi-trailers	(132.8)
2. Manufacture of machinery and equipment n.e.c. (not elsewhere classified)	101.0
3. Manufacture of basic metals and fabricated metal products	76.9
• Fabricated metal products	(56.3)
4. Manufacture of chemicals and chemical products	47.8
5. Manufacture of food products, beverages and tobacco	47.6

Table 2: Top 5 branches of Germany's manufacturing industry

[9] DESTATIS, source https://www.destatis.de/EN/Themes/Economy/National-Accounts-Domestic-Product/Publications/Downloads-National-Accounts-Domestic-Product/at-a-glance-pdf-0310200.pdf, p. 20, last accessed on 28 October 2022.

These top 5 branches represent almost 60% (58.3% accurately) of the manufacturing industry and are considered key contributors to GVA, hence GDP. With reference to DESTATIS[10] between 2016 and 2021, the manufacturing industry has got 7.6 million persons in employment (i.e., 17% out of the 44.7 million persons in employment in the country).

By using the above weight (60%) of the top 5 branches of Germany's manufacturing industry, one can claim that over 4.5 million employees are at stake which undoubtedly represent a key contribution to a stable cultural and societal environment in the country.

2.2 – Key stage of our economic model

2.2.1 – Transform feedstocks/raw materials into products by use of human resources, tools, machinery and processes with abundant and affordable energy

Based on my empiricism of our economic model which prevails in the geographic regions (mainly Western Europe and USA) that I have been exposed to since 1992 (the year that I started working in Germany), there is one continuum: transform feedstocks/raw materials into products by use of human resources, tools, machinery and processes with abundant and affordable energy.

With the second Industrial Revolution[11] aka Technological Revolution, which began in the late 19th century (1870) and ended with the dawn of the first World War (1914 – 1918), fuelled by scientific discovery (i.e., innovation), standardisation, mass production, and industrialisation, our economic model has changed and the main energy source was coal[12] (e.g., use of steam engines), converting thermal energy into mechanical energy.

The third Industrial Revolution[13] (late half of the 20th century), aka Digital Revolution, has added up an additional dimension to our economic model, namely the era of digital age (digitalisation) to which natural gas and oil[14] tremendously boosted the supply of energy.

With the current fourth Industrial Revolution[15], aka **Industry 4.0**, which started out in the mid-twenties of the 21st century, our economic model is still being transformed with increasing interconnectivity, Artificial Intelligence (AI), smart automation, large-scale Machine-To-Machine (M2M) communication, and Internet of Things (IoT) devices, that all

---

[10] DESTATIS, source https://www.destatis.de/EN/Themes/Labour/Labour-Market/Employment/Tables/persons-employment-sectors-economic.html, last accessed on 28 October 2022.

[11] Retrieved from Wikipedia, source https://en.wikipedia.org/wiki/Second_Industrial_Revolution, last accessed on 28 October 2022.

[12] 60%, retrieved from the Hofstra University (Prof Jean-Paul Rodrigue), USA, source https://transportgeography.org/contents/chapter4/transportation-and-energy/energy-sources-evolution/, last accessed on 28 October 2022.

[13] Retrieved from Wikipedia, source https://en.wikipedia.org/wiki/Third_Industrial_Revolution, last accessed on 28 October 2022.

[14] Coal (15%), natural gas + oil (70%), retrieved from the Hofstra University (Prof Jean-Paul Rodrigue), USA, source https://transportgeography.org/contents/chapter4/transportation-and-energy/energy-sources-evolution/, last accessed on 28 October 2022.

[15] Retrieved from Wikipedia, source https://en.wikipedia.org/wiki/Fourth_Industrial_Revolution, last accessed on 28 October 2022.

require to be powered by energy. Though the oil share went down from 39% to 31% while the coal share slightly went up from 26% to 27%, and the natural gas from 22% to 24% in the global primary energy mix in the timeframe 2000-2021, fossil fuels still account for over 80% of the worldwide primary energy use in 2021 according to the statistical review of world energy 2022 from bp[16]. For Germany[17], over 75% of its primary energy mix came from fossil fuels.

Against the backdrop of the decarbonisation theme pushed by European Governance Authorities, the initiative of reducing the fossil fuel use to produce energy is on its way. More details will be then provided in the chapter **Orientation, legal framework and regulations**.

The current reliance on the fossil fuel supply makes the German manufacturing industry sensitive and vulnerable to fossil fuel energy price changes driven by geopolitical unrests (e.g., Russian-Ukrainian armed conflict) or/and a fossil fuel demand rise coming from other manufacturing industries like China (being the World's factory with a 30% share of global manufacturing output[18] in 2021). To illustrate this, two facts: 1.) the first one refers to a comparison of business electricity prices in Germany and China before and after 2022, and 2.) the second one refers to a 2020-2021 comparison of fossil fuel demand rise between Germany and China.

1.)

	Germany[19]	**China**
Timeframe (before 2022)	Average 2017-2021	Average Sept.-Dec. 21
Industry electricity prices (kWh, tax included, euro cents) DE: Annual consumption 160,000 to 20 million kWh, medium voltage CN: Annual consumption typically 1 million kWh, medium voltage	18.52	7.92[20]
Industry electricity price variation	-57% for China	

[16] Retrieved from bp, source https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf, pp. 3 & 10, last accessed on 28 October 2022.
[17] Retrieved from bp, source https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf, p. 9, last accessed on 28 October 2022.
[18] Retrieved from State Council Information Office of China (SCIO), source http://english.scio.gov.cn/pressroom/2022-06/15/content_78271432.htm, last accessed on 28 October 2022.
[19] Retrieved from BDEW (Bundesverband der Energie- und Wasserwirtschaft e.V.), source https://www.bdew.de/service/daten-und-grafiken/bdew-strompreisanalyse/, last accessed in 28 October 2022.
[20] Retrieved from CEIC Data, source https://www.ceicdata.com/en/china/electricity-price-36-city, average from 36 Chinese cities within the defined timeframe, Chinese Yuan/EUR conversion exchange: 1 CNY=0.1311 EUR, last accessed in 28 October 2022.

Time frame (after 2022)	1H22	Mar. 22
Industry electricity prices (kWh, tax included, euro cents) DE: Annual consumption 160,000 to 20 million kWh, medium voltage CN: Annual consumption typically 1 million kWh, medium voltage	33.02	9.10[21]
Industry electricity price variation	-72% for China	

Table 3: Comparison of business electricity prices in Germany & China before/after 2022

2.)

	2020	2021
Germany: consumption of fossil fuels (oil, natural gas and coal) in Exajoules	9.17	9.56
Difference 2020/2021	+4.3%	
China: consumption of fossil fuels (oil, natural gas and coal) in Exajoules	123.24	130.40
Difference 2020/2021	+5.8%	

Table 4: Fossil fuel demand rise between 2020 and 2021 for Germany and China

With the above numbers at hand and the current geopolitical turmoil with the Russian national gas delivery stop[22], I have tried to showcase how vulnerable and exposed to output challenges the expressed principle of transforming raw materials by use of abundant and affordable energy is for Germany's manufacturing industry. Hence, there is strong call for seeking out alternatives to primary energy production through the use of clean/green technologies (i.e., neutrality in GHG emissions).

As the next step in my Master's Thesis, it is important to understand the whys and wherefores of the manufacturing industry in general while taking into account the specificities of each of the top 5 sectors of Germany's manufacturing industry.

2.3 – Manufacturing industry

2.3.1 – In general

The purpose of this section is to get an overarching understanding of what the manufacturing industry is all about, in other terms what its essential constituents are and how they work in concert.

[21] Retrieved from GlobalPetrolPrices.com, source https://www.globalpetrolprices.com/China/electricity_prices/, last accessed on 28 October 2022.

[22] Retrieved from Associated Press (AP), source https://apnews.com/article/russia-ukraine-germany-07245e4ceae0c0de233d426308827765, last accessed on 28 October 2022.

In today's effective organisational change management, the framework around People, Process and Technology (PPT) is used to secure success[23]. This framework arose in the 90's after Professor Harold Leavitt, an American psychologist of management, developed the Leavitt's Diamond Model in 1965[24]. In his book "*Fundamentals of Modern Manufacturing: Materials, Processes, and Systems (7th edition)*", Professor Mikell Groover has enhanced the PPT framework by docking two aspects with process(es), namely engineering materials and production systems (Groover, 2019, pp. iii-xiv, preface), thus shaping modern manufacturing and erecting manufacturing economy in countries like China, USA, Japan and Germany.

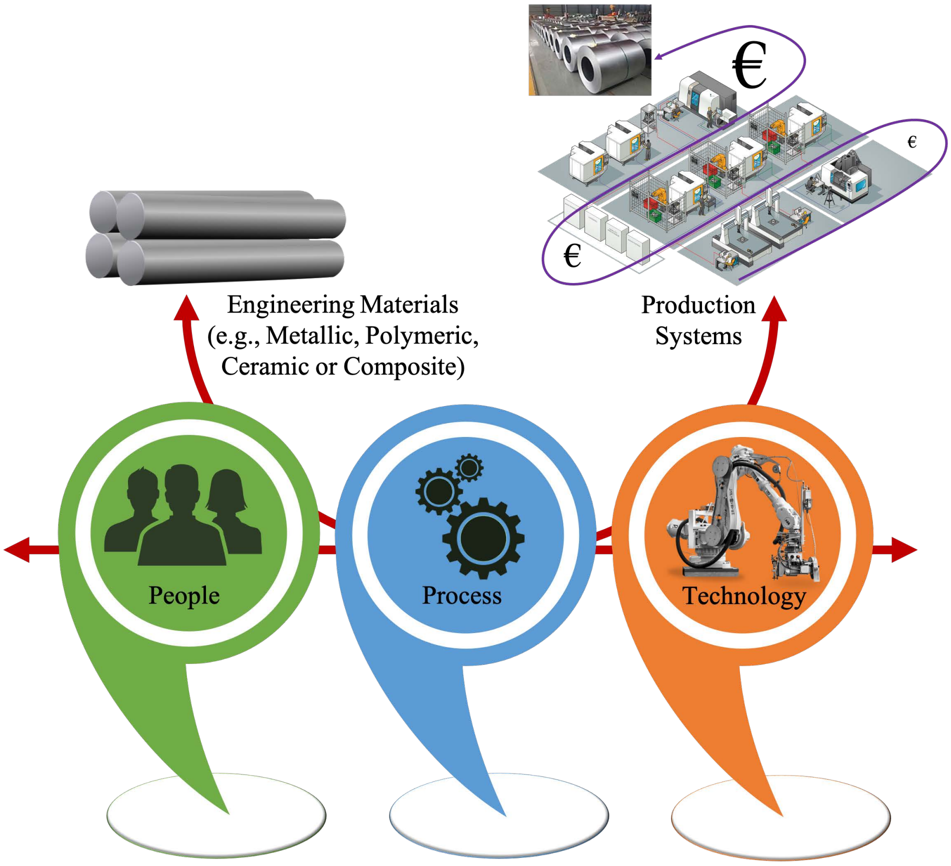


Figure 3: Visualisation of modern manufacturing based on the PPT framework enhanced with materials and systems based on Groover's book – own creation

At a macroeconomic level, the term manufacturing has got two technological and economic dimensions with reference to Groover (Groover, 2019, pp. 3-4, Chapter 1). Technologically speaking, "*manufacturing requires the application of physical and chemical processes, involving machinery, tools, power (i.e., energy) and labour to alter the geometry, properties, and/or appearance of a given starting material to make parts or products, and also includes assembly operations of multiple parts to make products out of systems.*" Economically speaking, "*manufacturing involves the transformation of materials into items of greater value*

[23] Retrieved from Plutora, source https://www.plutora.com/blog/people-process-technology-ppt-framework-explained, last accessed on 1 November 2022.
[24] Retrieved from Accipio Ltd, source https://www.accipio.com/eleadership/mod/wiki/view.php?id=1837, last accessed on 1 November 2022.

by means of one or more processing and/or assembly operations in a cost-effective and efficient manner."

In his book "*Process Planning – The Design/Manufacture Interface*" (Scallan, 2003, pp. 1-34, chapter Introduction to manufacturing), Peter Scallan has even enriched the above technological dimension by adding up two elements, namely the information flow and the quality control as two key contributors to informed decisions and adaptation to change.

In a nutshell, manufacturing is a nexus of an interdependence between (i) people, (ii) technology, (iii) process, (iv) materials and (v) systems. What do the five building blocks bring up as they largely work and interact together?

(i) As regards people, there are typically six broad functions in the systems (Scallan, 2003, pp. 7-8): (1) sales & marketing, (2) engineering with research & development and product design, (3) manufacturing with production planning, quality assurance, plant maintenance, industrial engineering, manufacturing engineering, production & materials control, and production, (4) human resources, (5) finance & accounts and (6) purchasing.

These functions primarily give rise to three types of organisational structures (either a functional structure, or a product structure or a matrix structure). As an organisation, a manufacturing strategy must be developed based on the consideration of and decision on capacity, process type, facility layout, make or buy approach, infrastructure and human capital (Scallan, 2003, pp. 6-7), and aligned with the company's business strategy for the specific business objectives attainment.

To cope with the customer's product demand, manufacturing companies have the choice between four possible manufacturing strategies for execution: make to stock (MTS, a push-type operation), assemble to order (ATO), make to order (MTO, a pull-type operation), and engineer to order (ETO) (Scallan, 2003, pp. 18-19).

Product-focused manufacturing companies are more inclined to use an MTS strategy whereas process-focused manufacturing companies are in favour of using an MTO/ETO strategy as it offers a wider product variety and a low-to-large range of product quantity (depending on the type of manufacturing system use), a strategically closer to value creation approach than the other twos.

Having a hybrid manufacturing strategy approach is considered to be the most flexible option for most of the companies.

(ii) As regards technology (and innovation) against the backdrop of the current fourth Industrial Revolution (**Industry 4.0**), advanced automation with robotics, additive manufacturing (AM), big data analytics and prediction, AI with ML techniques and algorithms, machine vision (MV) for qualitative and quantitative inspection, industrial internet of things with interconnected devices such as sensors/actuators (IIoT), extended reality (ER) with AR/VR, digital twins, distributed computing such as blockchains with non-fungible tokens

(NFT), cloud computing and cybersecurity are all significantly impacting the rise of modern (smart) manufacturing (Mair, 2019, pp. 24, 379-383, chapters 2 and 29), regardless of the manufacturing industry type (transport, machinery/equipment, metal, chemical, etc.).

Which of these technologies is ranked higher than the other?

Based on the research from the World's top 5 consulting firms (Bain & Company, Boston Consulting Group, McKinsey & Company, Booz Allen Hamilton and Ernst & Young-Parthenon), there is no universal answer as technology ought not to be a means to an end but rather to support the company's strategic business objectives while delivering value/benefit.

As an example, the manufacturing engineering department (who determines the best equipment and machinery required to create products), in conjunction with the industrial engineering department (who devises processes through the use of labour and machines), identifies the timeliest technology (e.g., automation with robots) to cost-effectively and efficiently manufacture products with the required qualities.

I have mapped out the aforesaid technologies deployed in the manufacturing industry with some of the key strategic business objectives of a business below. It gives an orientation what to focus on while aiming at specific strategic business goals; I have used three research sources: 1) the article entitled "Capturing the true value of Industry 4.0" from McKinsey & Company published in April 2022[25], 2) the publication entitled "AI in the factory of the future" from Boston Consulting Group (BCG) published in April 2018[26], and 3) the book "Essential manufacturing" from Gordon Mair, published in 2019 (part of the literature references).

[25] McKinsey & Company: source https://www.mckinsey.com/capabilities/operations/our-insights/capturing-the-true-value-of-industry-four-point-zero, last accessed on 15 November 2022.
[26] Boston Consulting Group: source: https://www.bcg.com/publications/2018/artificial-intelligence-factory-future, last accessed on 16 November 2022.

Company's Strategic Business Objectives	Technology Applications	Value Potential In Modern Manufacturing
• Shorten manufacturing throughput times by increasing speed of production • Increase profitability • Increase labour productivity • Improve quality • Improve labour's working conditions	Advanced automation with robotics	• 10-30%[A] • Statement with no quantitative indication[D] • 15-30%[A] • 10-20%[A] • Statement with no quantitative indication[E]
• Enhance and quicken empowered decision-making • Enable real-time forecasting and monitoring • Reduce inventory-holding costs • Reduce machinery/equipment downtime	Big Data Analytics and Prediction	• Statement with no quantitative indication[B] • Up to 85%[A] • 15-20% [A] • 30-50% [A]
• Reduce waste, errors, costly defects and delays by detecting flaws	Machine vision	• Up to 10% of the total labour costs of manufactured products[C]
• Accelerate rapid prototyping by minimising the time from product design to market for very low customised product manufacture	AM	• Statement with no quantitative indication[F]
• Accelerate product development timeline by looking at its virtual model in real world and manipulating its virtual model in artificial environment	ER with AR/VR	• Statement with no quantitative indication[G]
• Monitor use of materials by systems and initiate material replenishment from upstream suppliers to secure production continuity	IIoT	• Statement with no quantitative indication[H]
• Decentralise manufacturing operation management (MOM) systems hosting production planning and production control	Cloud Computing	• Statement with no quantitative indication[I]
• Diversify manufacture capabilities range	Digital Twins	• Offer customers alternatives for mass manufacture vs. jobbing shop manufacture[J]
• Streamline company's relationships with its suppliers and customers	Distributed Computing (Blockchains/Non-fungible Tokens)	• Traceability of used materials warranting carbon footprint and emissions offsetting[K]
• Minimise cybersecurity risks of intrusion into, access control loss and paralysis of operational technology (OT) systems	Cybersecurity	• Mitigate ransomware threats and OT system paralysis affecting product manufacture[L]
• Deploy self-optimising machinery/equipment for manufacturing process automation	AI with ML	• Reduce manufacturers' direct labour and overhead costs incurred as the results of transformation of the raw materials into finished products by up to 20%[M]

[A,B] : source Capturing the true value of Industry 4.0 from McKinsey & Company, Apr. 2022, p.3
[C] : source Essential Manufacturing from G. Mair, 2019, p. 253
[D] : source Essential Manufacturing from G. Mair, 2019, p. 218
[E] : source Essential Manufacturing from G. Mair, 2019, p. 219
[F] : source Essential Manufacturing from G. Mair, 2019, p. 379
[G] : source Essential Manufacturing from G. Mair, 2019, p. 380
[H] : source Essential Manufacturing from G. Mair, 2019, p. 381
[I] : source Essential Manufacturing from G. Mair, 2019, pp. 263 & 382
[J,K,L] : own reflexion based on my various readings
[M] : source AI in the factory of the future from BCG, Apr. 2018, p.3

Figure 4: Technology supporting company's strategic business objectives by delivering value potential in modern manufacturing, own creation

(iii) With regard to processes (Groover, 2019, pp. 10-16, Chapter 1), they are carried out as unit operations that are single actions in the sequence required to transform a starting material into a final part of product. These unit operations are then divided into (a) processing and (b) assembly operations that are accomplished by means of human labour, machinery/equipment and tooling.

(a) "A processing operation transforms a work material from one state of completion to a more advanced state that is closer to the final desired product. It adds value by changing the geometry, properties, or appearance of the starting material." Processing operations are split into three main categories dealing with shaping, property enhancement and surface processing. For material shaping procedures, four sub-operations are defined dealing with "solidification step, particulate step, deformation step and removal step". For property enhancement procedures, one sub-operation is defined dealing with "heat treatment". For surface processing procedures, two sub-operations are defined dealing with "cleaning and surface treatments" and "coating and deposition".

(b) "An assembly operation joins two or more components to create a new entity, called an assembly, subassembly, or some other term that refers to the joining process." Assembly operations are divided into two main categories dealing with permanent joining and mechanical fastening. For permanent joining procedures, three sub-operations are defined dealing with "welding, brazing and soldering, and adhesive bonding." For mechanical fastening procedures, two sub-operations are defined dealing with "threaded fasteners and permanent fastening methods.".

Figure 5: Overview of the manufacturing processes – inspired from Groover's book, p. 12

Manufacturing processes (processing and assembly operations) have one common denominator: they both need energy so that machinery, equipement and tooling can be functioned to process and assembly materials. This is consistent with the evidence-based fact that the energy criticality is the 'sinews' of any manufacturing industry activities.

(iv) As far as materials for engineering (Martin, 2006) are concerned in the manufacturing industry (Groover, 2019, pp. 8-10, Chapter 1), there are three basic categories namely (1) metals – usually alloys – as ferrous or non-ferrous, (2) ceramics – as crystalline ceramics or glasses – and (3) polymers – as thermoplastics or thermosets or elastomers –, and one advanced category namely (4) composites – as metal matrix or ceramic matrix or polymer matrix. A simplified classification of engineering materials for the manufacture is displayed beneath (Mair, 2019, pp. 71-88, Chapter 6):

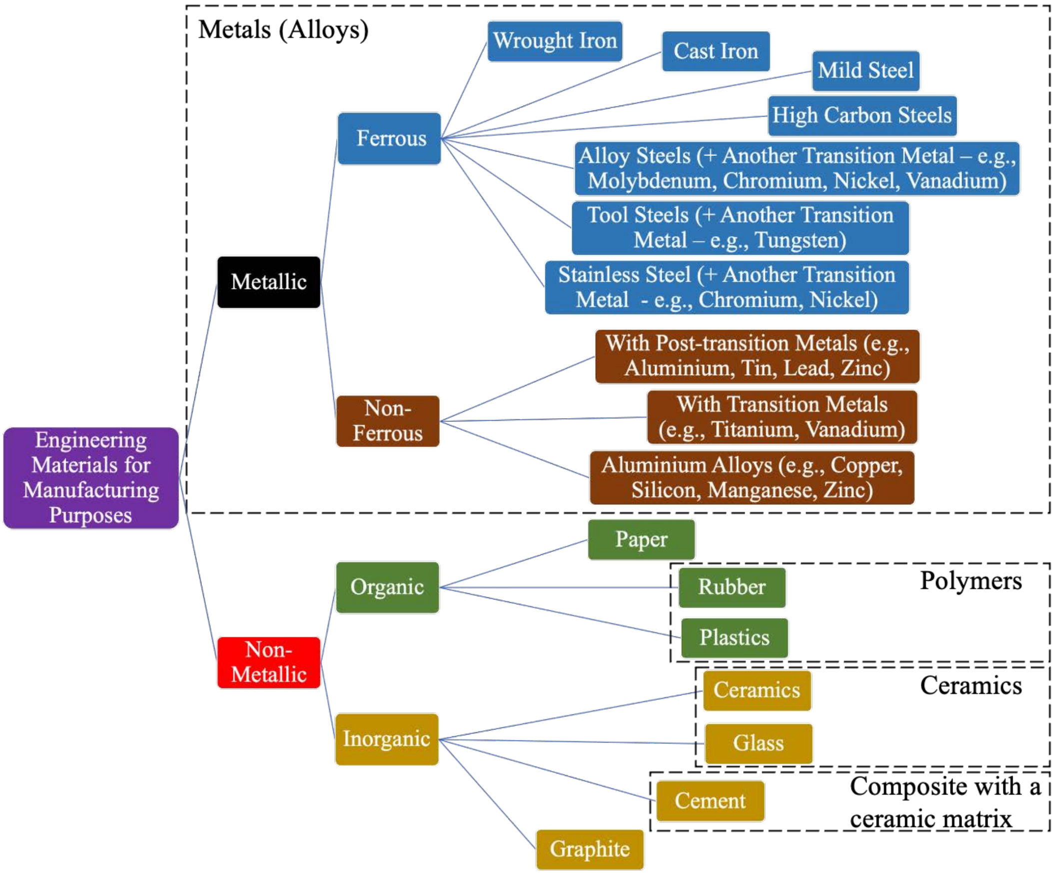


Figure 6: Simplified classification, examples of engineering materials, inspiration from Mair's book, p.71

Efficient manufacturing means that the people in charge of product design and manufacturing must have a reasonable knowledge about material costings, categories (see above), and physical properties, such as atomic (e.g., bounding, mass, number, weight, etc.), chemical (e.g., corrosion resistance, reactivity, surface energy, etc.), electrical (e.g., capacitance, electrical resistivity and conductivity, etc.), mechanical (e.g., fatigue limit, durability, elasticity, hardness, ductility etc.), magnetic (e.g., diamagnetism, permeability, etc.) and thermal (e.g., boiling and melting points, triple and critical points, etc.) properties. On the manufacturing processes, the mechanical properties such tensile, compressive and shear strengths have often the greatest influence (Mair, 2019, p. 83, Chapter 6).

(v) Regarding systems (Groover, 2019, pp. 17-20, Chapter 1), they consist of (1) production facilities, and (2) manufacturing support systems; (1) are where manufacturing processing and assembling operations take place, and (2) set forth the taken actions to (a) manage production through the appropriate processes planning and implementation, (b) solve the technical/logistics challenges encountered while ordering materials and purchasing parts, (c) move work through production facilities, and (d) ensure product quality standards compliance through quality control. Systems are primarily operated to fulfil effectiveness and efficiency objectives. In these sequences, people, process, machinery, technology, information flow and quality control are combined in a cost-effective and efficient manner and interact together.

The spectrum of the manufacturing systems spreads from discrete parts manufacturing with low product quantity and wide product variety to continuous manufacturing with high product quantity and narrow product variety (Scallan, 2003, pp. 11-16). Six types of systems arise from the spectrum, each unique through its characteristics:

(1) Project manufacture characterised by very low product quantity, wide product variety, fixed position layout (i.e., the product remains in one location in the plant, and labour and machinery/equipment come to that one work area), highly skilled manpower required, type of machinery/equipment: mixture of general and special purpose.

(2) Jobbing shop manufacture characterised by low size lots, wide product variety, wide array of processes, highly skilled manpower required, process-focused layout (i.e., labour and machinery/equipment are arranged in groups based on similar tasks and skills, and each part requires its own sequence of operations), type of machinery/equipment: general purpose and flexible.

(3) Batch manufacture characterised by medium size lots, wide product variety, skilled manpower required, process-focused layout similar to job shop manufacture, type of machinery/equipment: general purpose and flexible.

(4) Flow (or mass) manufacture characterised by high product quantity, low product variety, moderately skilled labour due to high human-machine interface, specialised machinery/equipment and specific processes required per product, product-focused layout (i.e., labour and machinery/equipment are arranged according to the product's needs and in the same sequence as the operations on the product), type of machinery/equipment: special and single purpose.

(5) Cellular manufacture characterised by linked I/U/O/T/S-shape cells featuring group technology (grouping of labour, machinery/equipment and processes required to make similar product families following the same sequence of operations), low size lots, wide product variety, high automation, hybrid layout (combination of process-focused and product-focused layouts), and cross-functional, trained manpower required, type of machinery/equipment: mixture of general and special purpose. It is a sub-section of just-in-time manufacturing and lean manufacturing.

(6) Continuous (or process) manufacture characterised by continuous production of non-discrete products that implies the uninterrupted use of machinery/equipment, high product quantity measured in volume or weight unit, low product variety, generate by-products (e.g., oil, gas from refinery), semi-skilled labour, high automation and product-focused layout.

The importance of an integrated approach to manufacturing means that the material and process selection must be closely harmonised for efficiency purposes as some material/process selection may be mutually exclusive for efficiency and cost-effectiveness rationales. Hence, the coordination between design engineering, industrial and manufacture engineering is paramount.

The manufacturing industry output (finished/manufactured products) is then classified as either consumer goods (i.e., directly purchased by consumers) or capital goods (i.e., procured by companies to produce their goods and/or provide their services). This latter will particularly be considered in the crucial role of Germany's machinery and equipment branch to act as a **major supplier to the other top 4 manufacturing industry sectors**.

As a summary, the manufacturing industry outlines a pattern in which input (materials) gets transformed into output (parts/products with value added) through the interaction between people, process, machinery/equipment, tooling, technology, system/sub-system, information flow and quality control according to detailed plans to meet business objectives in a cost-effective and efficient manner to satisfy customers' needs.

Let me know address some specificities relating to Germany's top 5 manufacturing industry branches, the first one covered being the transport equipment sector.

2.3.2 – Method for identifying the sub-branches that contribute the most to the value added

Before diving into each selected industry branch, let me briefly introduce what I will do in the next five sections. I need to figure out which sub-branches within a given industrial sector contribute the most to GVA (i.e., the value added). I will use the same approach for each of Germany's top 5 manufacturing industry branches. I have assessed the GVA (at current prices or market prices) in the Table 2 (a level 2 with two digits); however, DESTATIS does not allow me to look at more granular data (level 4 with four digits in particular).

A workaround consists in looking at the GVA at factor cost (GVA FC), which offers the sought data. This level 4 is defined in DESTATIS in compliance with the EU, referred to as NACE[27] (structure and coding system: section/division/group/class/sub-class), and first and foremost data are available through the DESTATIS database Genesis Online[28].

The level 4 (class) will give me the most granular possible breakdown of GVA FC. In a nutshell, GVA FC solely relates to the value added during the manufacturing process. GVA FC and GVA (numbers from the table 2) relate to one another as follows:

$$\text{GVA} = \text{GVA FC} + \text{Indirect Taxes} - \text{Subsidies.}$$

[27] NACE: French Acronym for "**N**omenclature statistique des **A**ctivités économiques dans la **C**ommunauté **E**uropéenne"; in English – statistical classification of economic activities in the European Community; source: https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-ra-07-015, last accessed on 21 November 2022.

[28] Retrieved from DESTATIS, Genesis Online: source https://www-genesis.destatis.de/genesis/online, last accessed on 21 November 2022.

2.3.3 – In particular for Germany relating to the transport equipment sector

As per section 2.3.2 and according to the NACE[29] taxonomy, the division 29 (manufacture of motor vehicles, trailers and semi-trailers) has four classes (namely 29.10, 29.20, 29.31 and 29.32).

Using the average data between 2016 and 2020, I could retrieve each class contribution with its GVA FC value from DESTATIS, Genesis Online[30]. Below are the details:

Division (L. 2)	**Group (L. 3)**	**Class (L. 4)**	**GVA FC (€ billion)**
29	29.1	29.10: Manufacture of motor vehicles	74.83
	29.2	29.20: Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers & semi-trailers	2.73
	29.3	29.31: Manufacture of electrical & electronic equipment for motor vehicles	2.13
		29.32: Manufacture of other parts & accessories for motor vehicles	20.49

Table 5: Class contributions with their GVA FC value, division 29, NACE

What are the learnings from table 5? My interpretation is that companies (e.g., OEMs like Audi, BMW, Mercedes-Benz, VW) and their eco-system (e.g., suppliers like Bosch, Continental, Schaeffler, ZF Friedrichshafen) that operate in the German automotive industry, contribute the most to value added.

I have used three sources that have helped me understand the specificities of the German automotive industry, and what factors drive this industry to reinvent itself: A.) the annual report 2020 from VDA, B.) the publication "automotive industry in Germany, issue 2022/2023" from GTAI, and C.) the publication "The future of the German automotive industry. Transformation by disaster or by design?" from FES.

We ought to keep in mind that our society is nowadays facing two core and interrelated transformations: a digital one and an energy one. A third aspect also comes into play: the way individuals move from one place to another one which directly relates to mobility. And the German automotive industry simultaneously deals with all three. The industry mission is to fulfil today's and address tomorrow's mobility needs with undeniable trends towards electro mobility (aka e-mobility), automation (aka self-driving vehicle), and connectivity/networking (aka connected vehicle). In one sentence, the industry's ultimate purpose is to create an

[29] Retrieved from Eurostat, NACE Rev. 2: source https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-ra-07-015, p. 68, last accessed on 21 November 2022.
[30] Retrieved from DESTATIS, Genesis Online: source https://www-genesis.destatis.de/genesis//online?operation=table&code=42251-0001&bypass=true&levelindex=0&levelid=1668783938488, parameters: Year 2016 – 2020 & WZ08X4 4-digit Manufacturing (245), data from the division 29, column "Bruttowertschöpfung zu Faktorkosten", last accessed on 21 November 2022.

environmentally friendly, sustainable, automated, autonomous and connected mobility while meeting societal and governmental demands.

On the energy transition side and with the current guidance, undoubtedly heading toward legal regulations, on the manufacture of emission-free vehicles by 2035 from the EU Commission backed up by the German Federal Government, the industry counts on some technological headways including electric, hybrid, and fuel cell technology developments for low-emission respectively zero-emission vehicles (Germany Trade And Invest, 2022a, p. 5) as well as on renewable fuels such as electricity-based fuels (aka e-fuels or synthetic fuels made from 100 percent renewable electricity, water and carbon dioxide), advanced biofuels derived from waste and residue materials (biomass), and green hydrogen (VDA, 2020, pp. 57-59). All, qualifying as favourable regenerative energy concept with a climate neutral outcome, can be used in today's internal combustion engines to push forward decarbonisation strategies (VDA, 2020, p. 51).

On the digitisation side, the industry counts on automation, autonomy and networking/connectivity (Friedrich-Ebert-Stiftung, 2018, pp. 11, 13).

With the integration of automotive-closed areas like mechatronics, microelectronics, mechanical engineering, manufacturing processes, and material sciences, the German automotive industry (Germany Trade And Invest, 2022a, pp. 6-9), vouching for high value added creation, is characterised by

- Decentralised world-class industry R&D and innovation clusters comprising OEM internal R&Ds, research institutes (e.g., Fraunhofer-Gesellschaft, Max Planck Society, Helmholtz Association, Leibniz Association) and universities (e.g., Technical University of Munich, Karlsruhe Institute of Technology),
- Wide-ranging value chain collaboration between OEMs, suppliers and service providers (e.g., mobility-as-a-service), and
- Unprecedented highly skilled workforce.

This collaborative mesh is key for maintaining the industry's competitiveness. Under the VDA impulsion and as an example, a strategic group for research, innovation and funding policy within the joint research association for automotive technology (FAT) works on the development of a technology roadmap that helps transition the industry toward the vehicles of the future. With this purpose in mind, the joint research effort focuses on five technology clusters: 1. safety & automated driving, 2. digitalisation & networking, 3. environment & road traffic system, 4. materials & methods, and 5. commercial vehicles (VDA, 2020, pp. 134-137).

On the environmentally friendly frontline and according to VDA (VDA, 2020, p. 48), the German automotive industry ecosystem has committed itself to developing tomorrow's mobility solutions that will achieve carbon neutrality by 2050 (in alignment with the European Green Deal from the EU Commission), hence contributing to achieving the Paris global climate protection targets (e.g., emissions should be reduced as soon as possible and reach net-zero by the middle of the 21st century[31]). The German automotive manufacturing industry contributes to the European/German climate protection plans by releasing presently new products like the EURO 6d emission standard vehicles that have lower nitrogen dioxide, particulate matter and ozone emissions resulting in air quality improvement. In alignment with the European Green Deal from the EU Commission, the German Federal Government devises climate, environmental, circular economy and zero pollution policies. In this way, German automotive manufacturing industry companies can define objectives for achieving climate neutrality (climate neutrality is explained in the section **From an EU perspective** inside the chapter orientation, legal framework and regulations), improving circular economy practices (circular economy is explained in the section **Circular economy**), and embracing zero pollutant targets at their production sites.

For the sake of competitiveness and compliancy, it is crucial that the German Federal Government lays down a consistent framework for tax, customs and legal policies. For each category, I wrapped up the findings beneath (VDA, 2020, pp. 92-101).

On the tax front, the reduction or even the removal of the renewable energies act (aka EEG) levy for electric vehicles as well as the reform of the motor vehicle tax based on the carbon dioxide pricing would incentivise to move e-mobility forward.

On the customs front, the promotion of a simplified customs handling system with modernised IT systems can guarantee smooth-running goods traffic after Brexit since the U.K. suppliers play an important role in the supply chain of the German automotive manufacturing industry. Also keeping track of the origin rules for battery cells is vital as different trade agreements apply (inside/outside the EU). With the rise in new innovations in networked and autonomous driving, the German automotive manufacturing industry increasingly faces risks of export control and sanctions imposed by the United States of America.

On the legal front, the German automotive manufacturing industry has to take appropriate measures to guarantee effective customer data processing/protection in motor vehicles as well as transparent customer data disclosure/retrieval from motor vehicles. In order to protect the industry from counterfeiting and piracy, the German Federal Government has changed the design protection law so that protection rights can be assigned to motor vehicle spare parts. Also, against the backdrop of the networked/connected vehicle, the German Federal Government has undertaken a patent law reform as the German automotive manufacturing industry regularly needs access to licences to standard essential mobile

[31] Retrieved from United Nations Framework Convention on Climate Change (UNFCCC), Paris Agreement, source https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, last accessed on 25 November 2022.

communication patents without systematically involving legal disputes instigated by the telecommunications industry.

2.3.4 – In particular for Germany relating to the machinery & equipment sector

By analogy with the chapter 2.3.3 and according to the NACE[32] taxonomy, the division 28 (manufacture of machinery and equipment n.e.c. (not elsewhere classified)) has twenty-one classes (namely 28.11, 28.12, 28.13, 28.14, 28.15, 28.21, 28.22, 28.23, 28.24, 28.25, 28.29, 28.30, 28.41, 28.49, 28.91, 28.92, 28.93, 28.94, 28.95, 28.96 and 28.99). The data retrieval from DESTATIS, Genesis Online[33] has led to the following table:

Division (L. 2)	**Group (L. 3)**	**Class (L. 4)**	**GVA FC (€ billion)**
28	28.1	28.11: Manufacture of engines & turbines, except aircraft, vehicle & cycle engines	11.19
		28.12: Manufacture of fluid power equipment	3.87
		28.13: Manufacture of other pumps & compressors	4.19
		28.14: Manufacture of other taps & valves	3.90
		28.15: Manufacture of bearings, gears, gearing & driving elements	7.71
	28.2	28.21: Manufacture of ovens, furnaces & furnace burners	0.95
		28.22: Manufacture of lifting & handling equipment	5.96
		28.23: Manufacture of office machinery & equipment (except computers & peripheral equipment)	0.30
		28.24: Manufacture of power-driven hand tools	1.62
		28.25: Manufacture of non-domestic cooling & ventilation equipment	5.44
		28.29: Manufacture of other general-purpose machinery n.e.c.	10.74
	28.3	28.30: Manufacture of agricultural & forestry machinery	3.67
	28.4	28.41: Manufacture of metal forming machinery	6.07
		28.49: Manufacture of other machine tools	2.20
	28.9	28.91: Manufacture of machinery for metallurgy	0.61
		28.92: Manufacture of machinery for mining, quarrying & construction	3.92

[32] Retrieved from Eurostat, NACE Rev. 2: source https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-ra-07-015, p. 68, last accessed on 21 November 2022.
[33] Retrieved from DESTATIS, Genesis Online: source https://www-genesis.destatis.de/genesis//online?operation=table&code=42251-0001&bypass=true&levelindex=0&levelid=1668783938488, parameters: Year 2016 – 2020 & WZ08X4 4-digit Manufacturing (245), data from the division 28, column "Bruttowertschöpfung zu Faktorkosten", last accessed on 21 November 2022.

		28.93: Manufacture of machinery for food, beverage & tobacco processing	2.13
		28.94: Manufacture of machinery for textile, apparel & leather production	1.58
		28.95: Manufacture of machinery for paper & paperboard production	0.54
		28.96: Manufacture of plastics & rubber machinery	2.81
		28.99: Manufacture of other special-purpose machinery n.e.c.	9.54

Table 6: Class contributions with their GVA FC value, division 28, NACE

What are the learnings from table 6? There are two heavyweights though the sector obviously looks fragmented at a class level. The first heavyweight is the manufacture of general-purpose machinery totalising € billion 55.88 at a group level (28.1 and 28.2) and the second heavyweight is the manufacture of special-purpose machinery totalising € billion 21.12 at a group level (28.9).

While using NACE, I could not find any directory of German companies at the class level (level 4). The only source I could find was at the division level (level 2), namely manufacture of machinery and equipment n.e.c.[34] with the company's 2021 sales revenues. Based on that, the top 10 company ranking is: 1. Siemens Energy (€ billion 28.48), 2. Siemens (€ billion 19.57), 3. Kion (€ billion 10.29), 4. Bosch Industrial Technology (€ billion 6.10), 5. Nordex (€ billion 5.44), 6. Exyte (€ billion 4.87), 7. Thyssenkrupp (€ billion 4.81), 8. Claas (€ billion 4.79), 9. GEA (€ billion 4.70), and 10. Voith (€ billion 4.26).

With reference to DESTATIS[35], GVA FC and sales revenues are linked with the following formula:

GVA FC = sales revenues + changes in inventories + own produced assets
- materials consumption - use of trade products - labour costs
- other intermediate inputs

I can reasonably make the assumption that the higher sales revenues are, the higher GVA FC is.

I have used two sources that have helped me understand the specificities of the German M&E (machinery & equipment) industry, and what drives this industry to look ahead and innovate: A.) the publication mechanical engineering – figures and charts 2022 from VDMA,

[34] Retrieved from Statista, source in German https://de.statista.com/statistik/daten/studie/190676/umfrage/umsatz-von-ausgewaehlten-unternehmen-im-maschinen-und-anlagenbau/, TUM Campus licence, last accessed on 30 November 2022.
[35] Retrieved from DESTATIS, source in German, https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Industrie-Verarbeitendes-Gewerbe/Publikationen/Downloads-Struktur/kostenstruktur-2040430177004.pdf?__blob=publicationFile, p. 4, last accessed on 30 November 2022.

and B.) the publication “the machinery & equipment industry in Germany, issue 2022/2023” from GTAI.

With climate protection being a top priority at European and national governmental levels, the challenge of the actual climate change can only be realistically tackled with advanced and modern production technology, carrying the vision “*climate-neutral production must become possible for all sectors*” forward. Documented in a co-authored report from VDMA and BCG (Boston Consulting Group, 2020, p. 4), up to 86 percent of the GHG emissions from already known potentials can be impeded with technological innovation brought out from the M&E manufacturing industry, also generating new growth business opportunities (VDMA, 2022, p. 4).

Not fundamentally different from the transport equipment sector at the core, there are two purposes that mobilise the whole M&E sector: 1.) help the German economy with its manufacturing industry produce goods in a more environmentally friendly and resource-efficient way by means of climate-neutral manufacturing solution innovation, and 2.) usher in a new way of decentralising production through concepts imbued with the Industry 4.0 centricity (Germany Trade And Invest, 2022b, p. 2).

This industry is presently characterised by four elements: a.) a broad network of small and medium-sized companies being Germany’s number one employer, b.) the German industrial sector that has spent the most in R&D activities (€ 17 billion), c) the World’s leading supplier of machinery and equipment with a 16% market segment share, and d.) the European Eldorado for foreign direct investments in M&E undertakings (Germany Trade And Invest, 2022b, p. 3).

With its leadership role, the German M&E sector pioneers in several key areas of the advanced manufacturing industry such as i.) additive manufacturing, ii.) energy-efficient production process technologies for achieving climate protection and cost-savings purposes, iii.) digitalisation of manufacturing with Industry 4.0-related technologies such as AI, cloud computing, IIoT, iv.) real-time information exchange and connectivity between production systems with the use of 5G networks, and v.) robotics and automation featured by industrial robots enhanced with Human-Robot Collaboration (HRC) and MV technologies. To maintain its world-class leadership in innovation and R&D excellence in thirteen out of thirty-one M&E fields of competence (e.g., Industrial Automation aka IA), the industry intensifies its collaboration with decentralised innovation clusters with national and international leading research organisations and institutes (Germany Trade And Invest, 2022b, pp. 4-9).

The German M&E sector plays a central role in fuelling and supplying other heavyweights of the German economy among others the automotive, chemicals, food & beverage, metal, and electronics industry (Germany Trade And Invest, 2022b, pp. 5-6). This interlinkage offers a cogent argument for identifying this industry as a catalyst for structural transformation and growth surge of the other four application industries in the section **Top 5 weights of the German manufacturing industry from a GVA perspective**.

With reference to Professor Karen Pittel – Director of the Centre for Energy, Climate and Resources at the Ifo Institute - Leibniz Institute for Economic Research in Munich – climate protection cannot occur without appropriate investments from the German manufacturing industry into climate neutral technologies offered by the German M&E industry, and the German Federal Government is called upon setting the right fiscal politics for inducing these investments (VDMA, 2022, p. 6).

Carrying on the exploring and analysis journey of our German industrial heavyweights, what about the specificities of the basic metals & fabricated metal products sector? This is what I am going to cover below.

2.3.5 – In particular for Germany relating to the basic metals & fabricated metal products sector

Similar to the chapters 2.3.3/2.3.4 and according to the NACE[36] taxonomy, the division 25 (manufacture of fabricated metal products, except machinery and equipment) which represents the lion's share of the basic metals & fabricated metal products sector in terms of GVA (refer to the **Table 2: Top 5 branches of Germany's manufacturing industry**), has seventeen classes (namely 25.11, 25.12, 25.21, 25.29, 25.30, 25.40, 25.50, 25.61, 25.62, 25.71, 25.72, 25.73, 25.91, 25.92, 25.93, 25.94 and 25.99). The data retrieval from DESTATIS, Genesis Online[37] has led to the following table:

Division (L. 2)	Group (L. 3)	Class (L. 4)	GVA FC (€ billion)
25	25.1	25.11: Manufacture of metal structures & parts of structures	6.07
		25.12: Manufacture of doors & windows of metal	1.75
	25.2	25.21: Manufacture of central heating radiators & boilers	0.84
		25.29: Manufacture of other tanks, reservoirs & containers of metal	0.64
	25.3	25.30: Manufacture of steam generators, except central heating hot water boilers	0.28
	25.4	25.40: Manufacture of weapons & ammunition	1.19

[36] Retrieved from Eurostat, NACE Rev. 2: source https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-ra-07-015, p. 67, last accessed on 21 November 2022.
[37] Retrieved from DESTATIS, Genesis Online: source https://www-genesis.destatis.de/genesis//online?operation=table&code=42251-0001&bypass=true&levelindex=0&levelid=1668783938488, parameters: Year 2016 – 2020 & WZ08X4 4-digit Manufacturing (245), data from the division 25, column "Bruttowertschöpfung zu Faktorkosten", last accessed on 21 November 2022.

	25.5	25.50: Forging, pressing, stamping and roll-forming of metal; powder metallurgy	7.76
	25.6	25.61: Treatment and coating of metals	3.36
		25.62: Machining	6.33
	25.7	25.71: Manufacture of cutlery	0.42
		25.72: Manufacture of locks & hinges	3.13
		25.73: Manufacture of tools	5.39
	25.9	25.91: Manufacture of steel drums & similar containers	0.16
		25.92: Manufacture of light metal packaging	0.71
		25.93: Manufacture of wire products, chain & springs	1.79
		25.94: Manufacture of fasteners & screw machine products	1.43
		25.99: Manufacture of other fabricated metal products n.e.c.	3.40

Table 7: Class contributions with their GVA FC value, division 25, NACE

What are the learnings from table 7? At a class level, four items of relatively equal weight stand out by aggregating almost sixty percent of the sector's GVA. For this purpose, I have briefly described below what output is typically meant on the practical side with reference to the Eurostat publication "NACE Rev. 2 – statistical classification of economic activities" (Eurostat, 2008).

In GVA FC descending order, the four classes are

1. 25.50 with forging, pressing, stamping and roll-forming of metal and powder metallurgy (typically production of metal objects directly from metal powders by heat treatment or under pressure) (Eurostat, 2008, p. 161).
2. 25.62 with machining (typically boring, turning, milling, eroding, planning, lapping, broaching, levelling, sawing, grinding, sharpening, polishing, welding, splicing etc. of metalwork pieces, and cutting of and writing on metals by means of laser beams) (Eurostat, 2008, p. 161).
3. 25.11 with the manufacture of metal structures and parts of structures (typically for the construction industry with e.g., towers, masts, trusses, and bridges and for the industrial applications industry with e.g., blast furnaces, lifting and handling equipment) (Eurostat, 2008, p. 159).
4. 25.73 with the manufacture of tools (typically knives & cutting blades, pliers, screwdrivers, saws & saws blades, press tools, forges, anvils, moulding boxes, vices, clamps) (Eurostat, 2008, p. 162).

What types of companies are behind each of these four classes? As I could not find any exploitable literature on the fabricated metal products division (i.e., NACE 25) that had introduced the companies to me, I devised an approach that at least had given me some clues about the company landscape. I have used the service provider North Data located in Hamburg, Germany (value proposition: provide understandable company information that is publicly available, obtained from sources such as trade registers, yearly reports, funding registers, trademark registers, patent registers and others) to collect data points at the smallest granularity level of the industry segments (e.g., at the class level of NACE).

Below are the three key findings for NACE 25.11, 25.50, 25.62 & 25.73 based on the four criteria (company is active, revenues greater than € 10 million, 2021 financial statement is published, employee number is known) and the hypothesis that sales revenue and GVA FC are alike. As a result, I have had 143 data points.

- By taking into account the definition of small and medium-sized companies in terms of employee number, only three companies have had more than 250 employees (i.e., 2.1%).
- By taking into account the definition of small and medium-sized companies by their sales revenue, 92% have had a sales revenue less than € 50 million.
- The top 5 companies in terms of sales revenue (ranging from € 520 Million to € 62 Million) namely
    - Mapal Fabrik für Präzisionswerkzeuge Dr. Kress KG located in Aalen (supplier of the automotive and aerospace industry).
    - Nemak Dillingen Casting GmbH & Co. KG located in Dillingen/Saar (supplier of the automotive industry).
    - Dressler Metallverarbeitung GmbH located in Langenenslingen (supplier of the hydraulics, automotive, agricultural machinery, machinery and equipment, and aerospace industry).
    - Pühl GmbH located in Plettenberg (specialised supplier of the wind energy, solar energy, transport and automotive industry).
    - Cotarko GmbH located in Köln (supplier in the automotive industry dedicated to the Ford brand).

  are unambiguously identified as suppliers / technology partners for the large companies of the German manufacturing industry.

All of these companies are part of the German small and medium-sized companies that imbue Germany's economy backbone thanks to their technological innovation, know-how and unique expertise/specialty in a given subject area. I have created a figure down below which has helped me build the above analysis and argumentation.

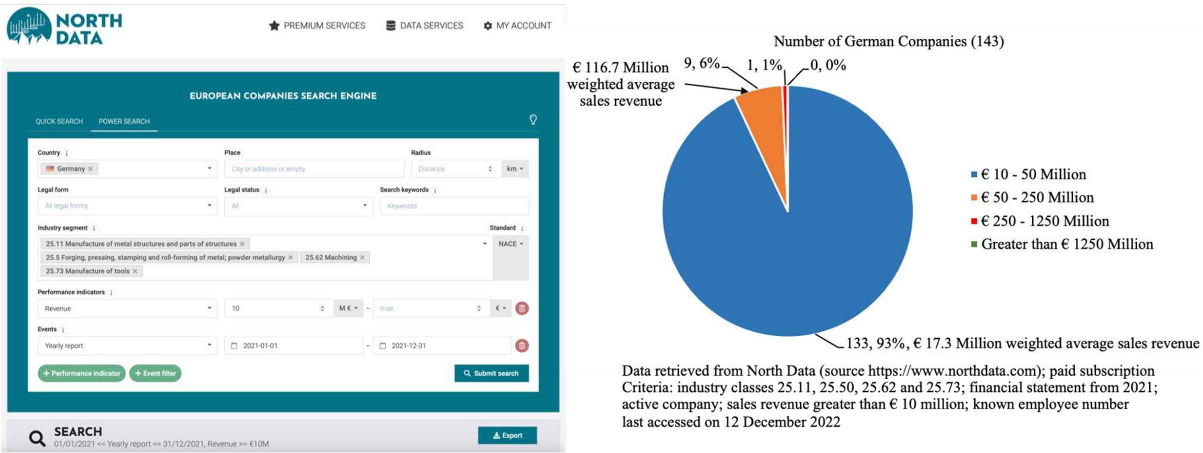


Figure 7: Who are these companies that belong to the NACE Rev.2 classes 25.11, 25.50, 25.62 & 25.73 and whose GVA FC contributes to Germany’s economic excellence?

Let me know dig into our fourth top Germany’s heavyweight in terms of GVA, namely the chemical manufacturing industry.

2.3.6 – In particular for Germany relating to chemicals and chemical products sector

Similar to the chapters 2.3.3/2.3.4/2.3.5 and according to the NACE[38] taxonomy, the division 20 (manufacture of chemicals and chemical products) has sixteen classes (namely 20.11, 20.12, 20.13, 20.14, 20.15, 20.16, 20.17, 20.20, 20.30, 20.41, 20.42, 20.51, 20.52, 20.53, 20.59 and 20.60). The data retrieval from DESTATIS, Genesis Online[39] has led to the following table:

Division (L. 2)	Group (L. 3)	Class (L. 4)	GVA FC (€ billion)
20	20.1	20.11: Manufacture of industrial gases	0.51
		20.12: Manufacture of dyes and pigments	1.12
		20.13: Manufacture of other inorganic basic chemicals	2.95
		20.14: Manufacture of other organic basic chemicals	13.40
		20.15: Manufacture of fertilisers and nitrogen compounds	1.27
		20.16: Manufacture of plastics in primary forms	6.10
		20.17: Manufacture of synthetic rubber in primary forms	0.37
	20.2	20.20: Manufacture of pesticides & other agrochemical products	0.42
	20.3	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	3.80

[38] Retrieved from Eurostat, NACE Rev. 2: source https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-ra-07-015, p. 65, last accessed on 21 November 2022.
[39] Retrieved from DESTATIS, Genesis Online: source https://www-genesis.destatis.de/genesis//online?operation=table&code=42251-0001&bypass=true&levelindex=0&levelid=1668783938488, parameters: Year 2016 – 2020 & WZ08X4 4-digit Manufacturing (245), data from the division 20, column “Bruttowertschöpfung zu Faktorkosten”, last accessed on 21 November 2022.

	20.4	20.41: Manufacture of soap and detergents, cleaning and polishing preparations	2.48
		20.42: Manufacture of perfumes and toilet preparations	1.72
	20.5	20.51: Manufacture of explosives	0.32
		20.52: Manufacture of glues	0.48
		20.53: Manufacture of essential oils	0.68
		20.59: Manufacture of other chemical products n.e.c.	5.51
	20.6	20.60: Manufacture of man-made fibres	0.59

Table 8: Class contributions with their GVA FC value, division 20, NACE

What are the lessons from Table 8? From a GVA FC perspective, three classes stand out as they aggregate sixty percent of sector's value. What is typical the output of each of the three classes? Similar to the previous chapter, I have used the Eurostat publication "NACE Rev. 2 – statistical classification of economic activities" (Eurostat, 2008).

In GVA FC descending order, the three classes are

1. 20.14 with a few easily understandable examples such as the manufacture of acyclic hydrocarbons (e.g., methane, ethane, propane and butane), cyclic hydrocarbons (e.g., benzene), acyclic and cyclic alcohols (e.g. methanol, ethanol), synthetic aromatic products, coal tar, urea (Eurostat, 2008, p. 141).
2. 20.16 with a few easily understandable examples such as the manufacture of elastomers, polymers (e.g., ethylene, propylene, styrene, acrylics), detergents, polyamides, polyurethanes, silicones, synthetic resins (Eurostat, 2008, pp. 141-142).
3. 20.59 with a few easily understandable examples such as the manufacture of gelatine, materials used in the finishing of textiles and leather, powders/pastes used in soldering, brazing or welding, prepared additives for cements, liquids for hydraulic transmission, and writing and drawing ink (Eurostat, 2008, pp. 144-145).

Operated by workforce, machinery and apparatus, each of these outputs is the result of a conversion of raw materials like coal, oil, natural gas, biomass, air, water, salts, minerals, metals respectively oil derivative feedstocks like naphtha, liquefied petroleum gases (LPGs), or natural gas liquids (NGLs) through industrial chemical processes (Jess and Wasserscheid, 2020, p. 2). For the manufacture of industrial organic chemicals regardless of its intent whether it is as basic chemicals as intermediate goods for other manufacturing industries (e.g., benzene for pharmaceuticals, ethene for solvents, propene for resins/fibres) or final chemicals (e.g., polymers, detergents), crude oil remains and will remain the primary raw material (Jess and Wasserscheid, 2020, p. 459).

At the scale of our planet and being applicable to Germany, there is a dominant role of crude oil for transportation fuels (e.g., gasoline, diesel, jet fuel, bunker fuel) and coal respectively natural gas for heat and electric power generation. These three fossil fuels also are the basis of the industrial organic chemistry, which has the highest contribution of value added to Germany's chemical industry.

Presently, fossil fuels are predominantly used as energy sources for the implementation of industrial chemical processes; however, the change from the fossil fuel-based energy sources toward more renewable energy sources (e.g., solar, wind) seems inevitable against the backdrop of climate change (Jess and Wasserscheid, 2020, p. 408).

According to VCI, the German chemical industry association, the German chemical industry has mainly focused its manufacture on three types of products (in descending order: 1. fine & specialty products, 2. pharmaceuticals, and 3. polymers), consistently aggregating over two third of the production value over the past three years (2019-2021). In comparison with the manufacture of bulk chemicals (e.g., ammonia, sulfuric acid, and sodium hydroxide), volumes are relatively low in each of these three product segments but the value added is high (VCI, 2022, pp. 3-4).

On the innovation side, the intensive exchange between businesses and non-university research organisations (e.g., Max Planck Society with fourteen institutes) in the area of applied research secures constant innovation; substantial R&D expenditures in mega trend projects like smart electromobility with lithium-ion battery materials and energy transition with high-purity silicium for solar panels are the drivers of future growth opportunities for the German chemical industry (Germany Trade And Invest, 2021a, p. 9).

On the capital expenditure front, the German chemical industry has invested in 2021 € 8.6 billion euros on property, plant and equipment with newer technology (mostly coming from the M&E industry) in order to maintain the global competitiveness of its manufacturing facilities (VCI, 2022, p. 20).

As far as the business landscape is concerned, over ninety percent of the German chemical industry consist of small and medium-sized companies (over 2,000+), the five remaining percent being the major large international players like BASF, Bayer, and Boehringer (top 3 from a sales revenue standpoint in 2021). The latter often supplies intermediate products that medium-sized companies process into end products with a higher value added (VCI, 2022, p. 15).

Below are the three key findings about the types of companies behind NACE 20.14, 20.16 & 20.59 based on the three criteria (active company, revenues greater than € 10 million, published financial statement from 2021) and the hypothesis that sales revenue and GVA FC are alike. As a result, I have had 32 data points.

- By taking into account the definition of small and medium-sized companies in terms of employee number, only two companies have had more than 250 employees (i.e., 12%). This leads to the interpretation that only 50% of the companies can be associated with "true" small and medium-sized companies (employee number less than 250 and sales revenue less than € 50 Million).
- Among the large companies (basically half of the data points), the sales revenue can vary from a factor 1 to 20 (weighted average per group: € 116.7 Million / € 674.6 Million / € 2,410 Million). There is one company in each of the three classes which indicates that value creation is across the board.
- The top 5 companies in terms of sales revenue (ranging from € 3,200 Million to € 881 Million) namely
    - INEOS Styrolution located in Frankfurt, is a styrenics [40] supplier focusing on styrene monomer, polystyrene, acrylonitrile butadiene styrene standard and styrenic specialties. It supplies the automotive, electronics, construction, health care, packaging, and toys/sports/leisure industry.
    - Altana AG, located in Wesel, is a manufacturer of specialty chemicals such as additives and effect pigments for the automotive, architecture & building industry as well as adhesives and sealants for the food and drinks, automobile and the electrical industry.
    - Jebsen & Jessen GmbH located in Hamburg, is an independent export trading company (hence an intermediary) with one division (Jebsen & Jessen Chemicals GmbH) specialised in five segments: 1. industrial chemicals such as inks, adhesives, paints, glues, and solvents, 2. chemicals derived from oil and natural gas, 3. additives for the food & beverages industry, 4. specialty chemicals for the electronics, cosmetics and painting industry, and 5. polymers such as adhesives, coatings, foams, and packaging materials.
    - Axalta Coating Systems Germany GmbH located in Wuppertal, is specialised in the development and manufacture of liquid and powder coatings such as paints that are used in the automotive, transportation construction, architecture and agriculture industry.

[40] Styrenics, also called styrenic polymers, are a family of plastic materials that use styrene as the main building block (retrieved from the source https://www.stackplastics.com/plastic-materials/thermoplastic-resins/styrenics, last accessed on 12 December 2022).

- Ardex Group GmbH located in Witten, is a manufacturer of chemistry-based special materials for the construction and building industry.

are identified as suppliers / trading partners for the large companies of the German manufacturing industry in charge of selling consumer and capital goods.

The figure down below that I have created has helped me draw up the above analysis and argumentation.

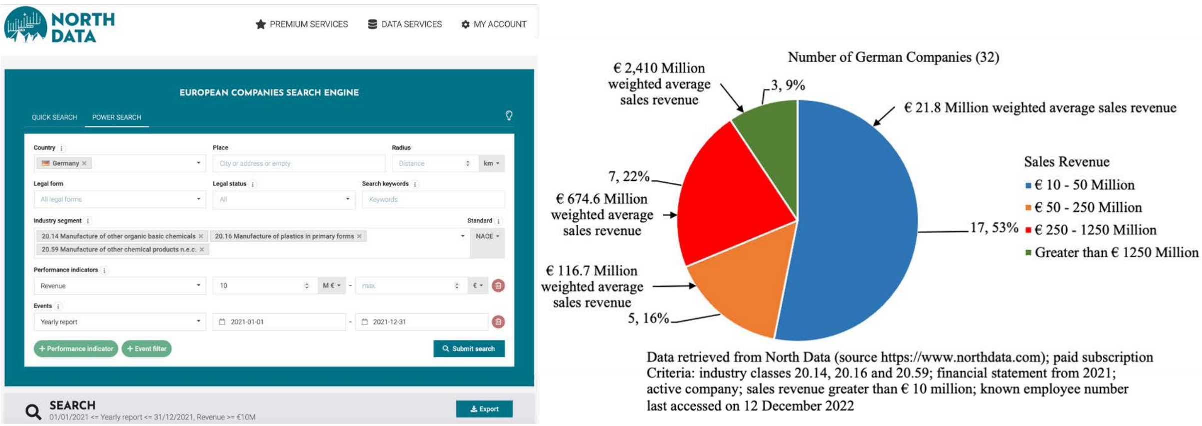


Figure 8: Who are these companies that belong to the NACE Rev. 2 classes 20.14, 20.16 & 20.59 and whose GVA FC contributes to Germany's economic excellence?

Let me know now move on to our fifth top Germany's heavyweight in terms of GVA, namely the food products, beverages and tobacco industry.

2.3.7 – In particular for Germany relating to the food products, beverages and tobacco sector

This sector consists of three divisions according to the NACE[41] taxonomy: 10 for food products, 11 for beverages and 12 for tobacco products. The division 10 (manufacture of food products) has twenty-five classes (namely 10.11, 10.12, 10.13, 10.20, 10.31, 10.32, 10.39, 10.41, 10.42, 10.51, 10.52, 10.61, 10.62, 10.71, 10.72, 10.73, 10.81, 10.82, 10.83, 10.84, 10.85, 10.86, 10.89, 10.91 and 10.92); the division 11 (manufacture of beverages) has seven classes (namely 11.01, 11.02, 11.03, 11.04, 11.05, 11.06 and 11.07); the division 12 (manufacture of tobacco products) has only one class (namely 12.00). The data retrieval from DESTATIS, Genesis Online[42] has led to the following table:

Division (L. 2)	**Group (L. 3)**	**Class (L. 4)**	**GVA FC (€ billion)**
10	10.1	10.11: Processing and preserving of meat	1.29

[41] Retrieved from Eurostat, NACE Rev. 2: source https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-ra-07-015, p. 63, last accessed on 21 November 2022.
[42] Retrieved from DESTATIS, Genesis Online: source https://www-genesis.destatis.de/genesis//online?operation=table&code=42251-0001&bypass=true&levelindex=0&levelid=1668783938488, parameters: Year 2016 – 2020 & WZ08X4 4-digit Manufacturing (245), data from the divisions 10, 11 and 12, column "Bruttowertschöpfung zu Faktorkosten", last accessed on 21 November 2022.

		10.12: Processing and preserving of poultry meat	0.50
		10.13: Production of meat and poultry meat products	4.04
	10.2	10.20: Processing and preserving of fish, crustaceans & molluscs	0.40
	10.3	10.31: Processing and preserving of potatoes	0.52
		10.32: Manufacture of fruit and vegetable juice	0.50
		10.39: Other processing and preserving of fruit & vegetables	1.09
	10.4	10.41: Manufacture of oils & fats	0.42
		10.42: Manufacture of margarine & similar edible fats	0.08
	10.5	10.51: Operation of dairies & cheese making	3.83
		10.52: Manufacture of ice cream	0.25
	10.6	10.61: Manufacture of grain mill products	0.71
		10.62: Manufacture of starches & starch products	0.41
	10.7	10.71: Manufacture of bread; manufacture of fresh pastry goods & cakes	8.68
		10.72: Manufacture of rusks & biscuits; manufacture of preserved pastry goods & cakes	0.74
		10.73: Manufacture of macaroni, noodles, couscous & similar farinaceous products	0.11
	10.8	10.81: Manufacture of sugar	0.54
		10.82: Manufacture of cocoa, chocolate & sugar confectionery	2.52
		10.83: Processing of tea & coffee	0.83
		10.84: Manufacture of condiments & seasonings	1.43
		10.85: Manufacture of prepared meals & dishes	0.82
		10.86: Manufacture of homogenised food preparations & dietetic food	0.23
		10.89: Manufacture of other food products n.e.c.	1.79
	10.9	10.91: Manufacture of prepared feeds for farm animals	0.74
		10.92: Manufacture of prepared pet foods	0.87
11	11.0	11.01: Distilling, rectifying and blending of spirits	0.39
		11.02: Manufacture of wine from grape	0.34
		11.03: Manufacture of cider and other fruit wines	Not Available
		11.04: Manufacture of other non-distilled fermented beverages	Not Available

		11.05: Manufacture of beer	2.70
		11.06: Manufacture of malt	0.11
		11.07: Manufacture of soft drinks; production of mineral waters & other bottled waters	2.25
12	12.0	12.00: Manufacture of tobacco products	1.88

Table 9: Class contributions with their GVA FC value, divisions 10, 11 and 12, NACE

What are the learnings from table 9? Six classes roughly represent sixty percent of the GVA FC, namely in descending order 10.71, 10.13, 10.51, 11.05, 10.82 and 11.07, which refer to the food and beverage groups. Not surprisingly is that the tobacco products class does not belong to this ranking. In comparison with the previous sections, I do not anticipate a need to detail out what type of products are behind each of those classes by using the statistical classification of economic activities (NACE – Rev. 2) as each class heading is self-explanatory enough.

With reference to the GTAI 2022/2023 publication "the food and beverage industry in Germany", Europe's food and beverage market leader, is committed to delivering not only high-quality products and services but also undergoing change due to consumers' shifting food habits with a particular focus on health, wellbeing and alternatives (e.g., plant-based milk products, functional drinks, vegetarian/vegan foods, meat/dairy substitutes, gluten-free/lactose-free produce), which has unavoidably led the industry to emphasise the product-market fit. Growth drivers are linked to more locally and organically produced foodstuffs and sustainable manufacturing approaches (Germany Trade And Invest, 2022c, pp. 3-8).

R&D activities (with a special attention to industrial collective research that generates shared knowledge and benefits between the involved parties) and innovation are principally geared towards new product development (over one fifth of the available product portfolio related to new a product in 2021), nutrition enhancement and general food safety improvement. To follow on the current trends of sustainability and healthy diet, digitalisation and new machinery & equipment investments are two key concerns for improving manufacturing processes, energy efficiency, agricultural raw materials use, and customer satisfaction along with consumer information transparency (Germany Trade And Invest, 2022c, p. 9) & (Bundesvereinigung der Deutschen Ernährungsindustrie, 2022, pp. 37-40).

As far as the digitalisation is concerned, the industry progressively relies on concepts related to industry 4.0 such as smart packaging solutions allowing to digitally monitor foodstuff shelf life and agricultural raw material traceability or the use of 3D printers to create custom food for singular customer segments. According to BVE (the federal association of the German food and drink industry), two industry 4.0 offensives are simultaneously occurring on two frontlines: on the production unit side on the one hand, and on the supply chain side on the other hand; both decisive in attaining the sustainability and quality objectives (Bundesvereinigung der Deutschen Ernährungsindustrie, 2022, p. 44).

As regards sustainability, its key aspect lies in the art of balancing consumption and production out. As an example, the industry intensifies its fight against food losses through upcycling (i.e., offer a second life to something that was no longer in use and give a new function to it) to avoid raw materials waste, and the industry has taken actions into the reduction of plastic usage in packaging by substituting it with paper- or plant-based packaging (Bundesvereinigung der Deutschen Ernährungsindustrie and Innova Market Insights, 2021, pp. 7, 25).

Sustainability is strongly driven by the consumers' choice to be informed about specific quality criteria and characteristics of the manufactured products; the industry's response has translated into the implementation of labels (so-called green claims). Key green claims cover up topics such as clean label (i.e., a product is free of genetically modified organisms, additives, pesticides and conservatives), local/regional sourcing, fair trade with social responsibility, higher animal welfare standards, and use of renewable energy sources in the manufacturing processes (Bundesvereinigung der Deutschen Ernährungsindustrie and Innova Market Insights, 2021, p. 12).

Regarding the German business landscape, the industry aggregates over 6,100 companies and is characterised by small and medium-sized businesses, a broad and segmented (i.e., specialised in certain types of products; e.g., lactose-free products) diversification, and has got an export share of over one third of its sales revenue, especially towards the EU (Bundesvereinigung der Deutschen Ernährungsindustrie, 2022, p. 37).

Below are the two key findings about the types of companies behind NACE 10.13, 10.51, 10.71, 10.82, 11.05 and 11.07 based on the three criteria (active company, revenues greater than € 10 million, published financial statement from 2021) and the hypothesis that sales revenue and GVA FC are alike. As a result, I have had 139 data points.

- Among the 107 identified businesses, the weighted average sales revenue is € 20.3 Million for an average headcount of 170 employees. This cluster typically represents the German family-owned businesses in operation since several generations and are highly specialised in their craftsmanship.
- The top 5 companies in terms of sales revenue (ranging from € 5,474 Million to € 338 Million) namely
    - DMK Deutsches Milchkontor GmbH located in Zeven, is Germany's largest dairy cooperative that processes milk into high-quality food products such as cheese, dairy products, ingredients and vegan products to baby food, ice cream and whey products.

- Zott SE & Co. KG located in Mertingen, is a dairy company that produces dairy products including milk and cheese products, desserts, cream, and yogurts.
- Meierei Barmstedt eG located in Barmstedt, is a dairy farm that transforms raw and skimmed milks into cheese, butter, and milk/whey (aka milk serum) concentrates.
- Bierverlag Peterke Ahlers Beteiligungs-GmbH & Co. KG located in Achim, is the holding company that controls Getränke Ahlers GmbH, a beverage specialist wholesaler who primarily supplies the catering trade.
- ARYZTA Bakeries Deutschland GmbH located in Lutherstadt Eisleben, is Germany's market leader for frozen baked goods with a selection of over 5,000 products, and is a global supplier for the food service, retail and quick service restaurant sectors.

are unambiguously identified as specialised businesses that supply their value-added products to their clients such as the German food retail industry or food service industry.

The figure down below that I have created has helped me draw up the above analysis and argumentation.

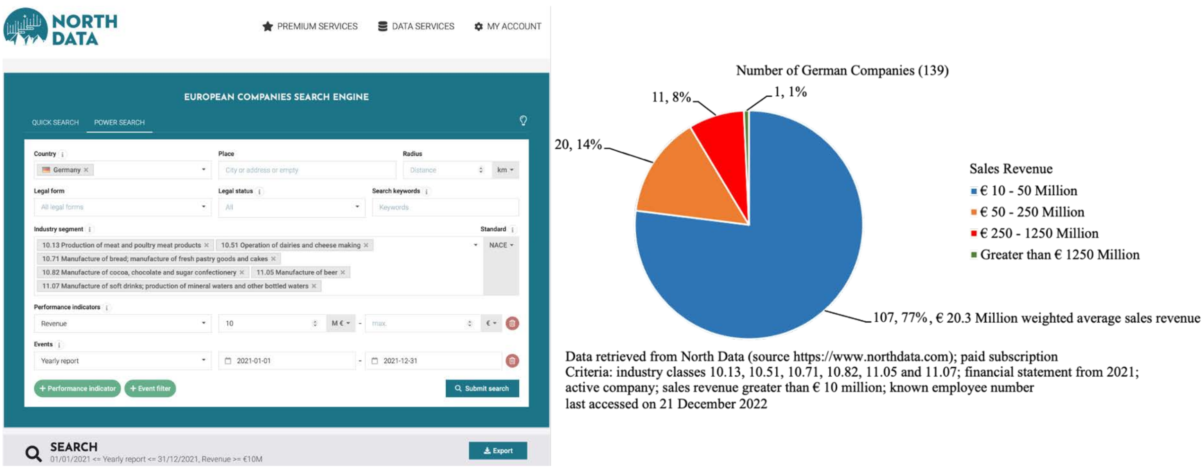


Figure 9: Who are these companies that belong to the NACE Rev. 2 classes 10.13, 10.51, 10.71, 10.82, 11.05 & 11.07 and whose GVA FC contributes to Germany's economic excellence?

To conclude with the German manufacturing industry section, I have beneath drawn up a figure that helps understand how these sectors are closely intertwined and where the value added resides.

2.3.8 – A powerful German economy: result of an interlinked manufacturing industry

As different sectors are linked together (i.e., output from one particular industry is reused by one or several industries) within an economy, the interdependence link means that a change in one sector can affect the rest, positively or negatively. Through the findings from chapter 2.3.3 to chapter 2.3.7, one essential point is that the M&E sector is a key enabler and a mission-critical supplier of the other top 4 manufacturing industries through a strong interdependence link. The other interdependence links are not as prominent as the M&E sector ones from a GVA FC perspective but still contribute to the German economy power. I have below drawn up the visualisation of the interdependence links between Germany's top 5 weights of the manufacturing industry.

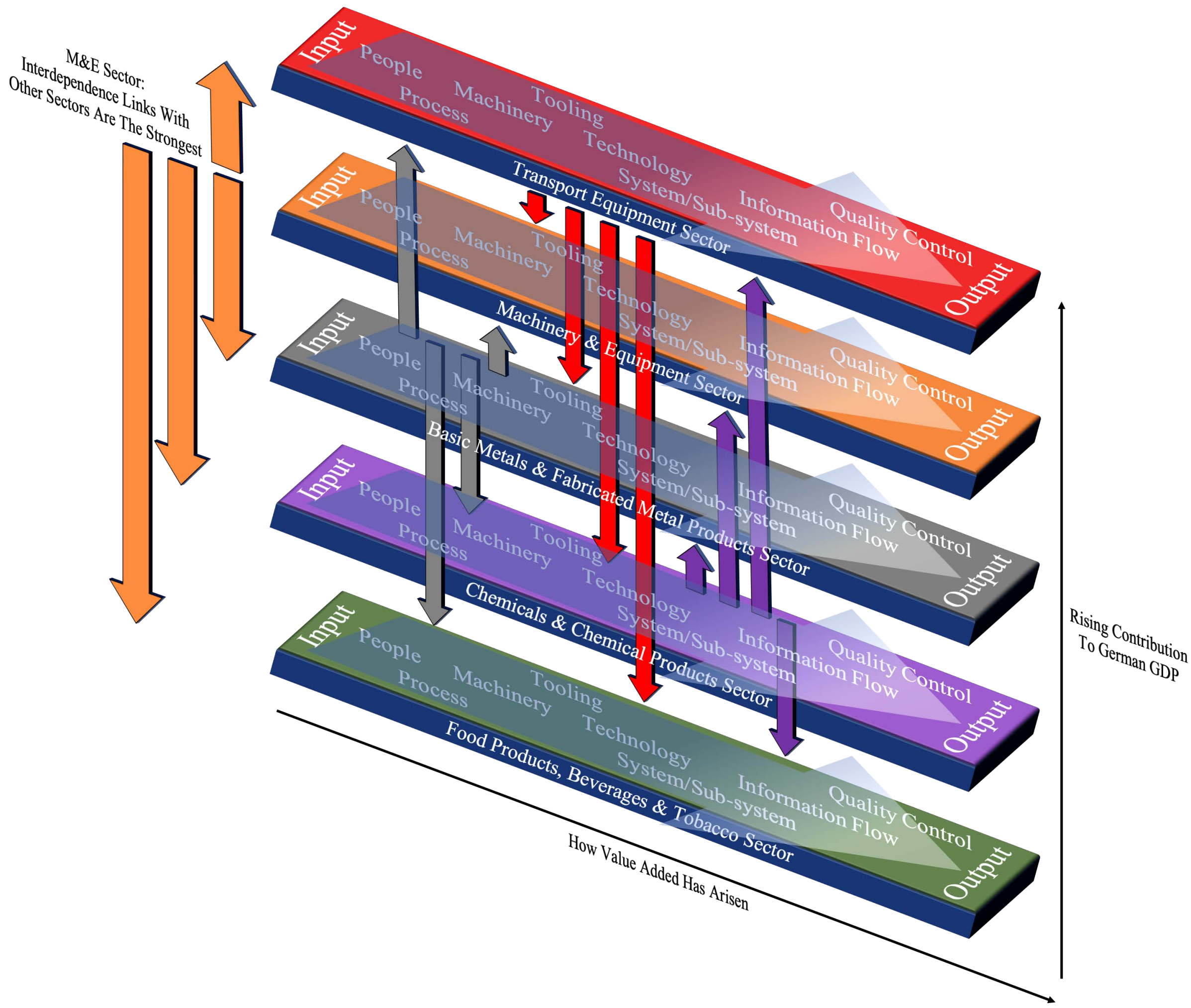


Figure 10: Interdependence links among the German economy, strongest with the M&E sector

Abundant and affordable energy is crucial for any manufacturing industry as described in the chapter 2.2.1. What are Germany's energy sources? What about its manufacturing industry? How much does Germany's manufacturing industry consume? This is what the next chapter will answer.

2.3.9 – Energy sources & consumptions of the German manufacturing industry

The purpose of this section is to figure out what types of energy sources are used by the German manufacturing industry in general and by its top 5 heavy weights in particular and its related energy consumptions in PJ.

My two data sources are DESTATIS and AGEB (a German association of three federations of the energy industry and five research institutes that comprises a working group on energy balances). For consistency's sake between both data providers, I have used the data between 2016 and 2020 (i.e., five data sets).

First, let me take a look at a country level. With reference to AGEB, Germany's average primary energy consumption for the five selected years was 12,968 PJ with a 79% fossil fuel energy sources dependency (Arbeitsgemeinschaft Energiebilanzen, 2022, p. 10). The primary energy consumption measures Germany's total energy demand that is supplied through naturally occurring energy sources such as coal, oil, gas, wind, solar, nuclear[43]. Below is its table representation whose numbers are consistent with the ones from DESTATIS.

Energy Sources	**Average Primary Energy Consumption (PJ, Absolute Numbers)**	**Average Primary Energy Consumption (Relative Numbers)**
Petroleum (Crude Oil)	4,457	35%
Gas (e.g., Natural Gas, Liquefied Petroleum Gas)	3,140	24%
Renewable (e.g., Wind, Solar, Hydro, Geothermal, Biomass)	1,830	14%
Brown Coal (Lignite)	1,324	10%
Hard Coal (Anthracite)	1,321	10%
Nuclear (e.g., Uranium)	821	6%
Others (Unspecified)	75	1%

Table 10: Germany's yearly average primary energy consumption in PJ, btw. 2016 and 2020

Second, let me take a look at the German manufacturing industry in its entirety (i.e., from the divisions 10 to 33 according to NACE Rev.2). With reference to DESTATIS[44], the yearly average primary energy consumption of Germany's all manufacturing industry branches is 3,912 PJ between 2016 and 2020; this is 30% of Germany's primary energy consumption, ahead of any other German economic branches including the energy, construction and transport sectors. Below, I have drawn up a table visualisation of Germany's manufacturing industry branches (fifteen clusters according to RACE Rev.2) with their respective primary energy consumption; the top 5 branches of Germany's manufacturing industry from a GVA perspective (chapter **2.1.3**) are featured with an underline font.

[43] Retrieved from Eurostat, glossary, source https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Primary_energy_consumption, last accessed on 2 January 2023.
[44] Retrieved from DESTATIS, German publication Umweltökonomische Gesamtrechnungen – Energiegesamtrechnung, source https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/UGR/energiefluesse-emissionen/Publikationen/Downloads/umweltnutzung-und-wirtschaft-energie-xlsx-5850014.xlsx?__blob=publicationFile, sheet 3.4, last accessed on 2 January 2023.

Manufacturing Industry Branches	**Average Primary Energy Consumption (PJ, Absolute Numbers)**	**Average Primary Energy Consumption (Relative Numbers)**
Manufacture of chemical products (division 20, RACE Rev. 2)	1,315	34%
Manufacture of basic metals	650	17%
Manufacture of coke and refined petroleum products	500	13%
Manufacture of rubber, plastic products and other non-metallic mineral products	381	10%
Manufacture of wood and paper products and printing	337	9%
Manufacture of food products, beverages and tobacco (divisions 10, 11 & 12, RACE Rev. 2)	228	6%
Manufacture of motor vehicles, trailers and semi-trailers (division 29, RACE Rev. 2)	120	3%
Manufacture of fabricated metal products (division 25, RACE Rev. 2)	100	3%
Manufacture of machinery and equipment n.e.c (division 28, RACE Rev. 2)	79	2%
Manufacture of pharmaceutical products	62	2%
Manufacture of electrical equipment	31	1%
Manufacture of computer, electronic and optical products	31	1%
Manufacture of furniture, other manufacturing	29	1%
Manufacture of textiles, wearing apparel and leather products	22	1%
Repair and installation of machinery and equipment	15	0%
Manufacture of other transport equipment	12	0%

Table 11: Yearly average primary energy consumption of Germany's manufacturing industry branches in PJ, btw. 2016 and 2020

Noticeable is that the top 5 branches of Germany's manufacturing industry from a GVA perspective have represented 47% of the average primary energy consumption from the entire

German manufacturing industry between 2016 and 2020. Not unexpectedly stands the chemical industry out with over one third of the average primary energy consumption, given the energy-intensive needs of its many transformation processes for the manufacture of chemical products.

In the next section, I have made use of the DESTATIS web service Genesis Online (DESTATIS, 2022a) to find out what types of energy sources Germany's top 5 manufacturing industry branches from a GVA perspective rely on for their operations, and have visualised the findings in the five figures beneath. On a side note, nuclear energy was not mentioned at all.

- *Chemical products industry, 2016 - 2020*

Energy Sources	**Yearly Average Primary Energy Consumption Per Energy Type (PJ, Absolute Numbers)**	**Yearly Average Primary Energy Consumption Per Energy Type (Relative Numbers)**
Petroleum (Crude Oil)	652,602	50%
Gas (e.g., Natural Gas, Liquefied Petroleum Gas)	352,332	27%
Others (Unspecified)	240,989	18%
Renewable (e.g., Wind, Solar, Hydro, Geothermal, Biomass)	34,160	3%
Brown Coal (Lignite)	18,544	1%
Hard Coal (Anthracite)	16,667	1%
Lowest dependency on fossil fuel energy sources: 79%; Total of yearly average primary energy consumption: 1,315,294 PJ		

Table 12: Yearly average primary energy consumption per energy source type in PJ btw. 2016 and 2020, chemical products industry

- *Food products and beverages industry, 2016 - 2020*

Energy Sources	**Yearly Average Primary Energy Consumption Per Energy Type (PJ, Absolute Numbers)**	**Yearly Average Primary Energy Consumption Per Energy Type (Relative Numbers)**
Gas (e.g., Natural Gas, Liquefied Petroleum Gas)	118,398	52%
Others (Unspecified)	82,650	36%
Petroleum (Crude Oil)	15,593	7%

Brown Coal (Lignite)	4,700	2%
Hard Coal (Anthracite)	3,255	1%
Renewable (e.g., Wind, Solar, Hydro, Geothermal, Biomass)	3,121	1%
Lowest dependency on fossil fuel energy sources: 63% Total of yearly average primary energy consumption: 227,717 PJ		

Table 13: Yearly average primary energy consumption per energy source type in PJ btw. 2016 and 2020, food products and beverages industry

- *Transport equipment industry with the manufacture of motor vehicles, trailers and semi-trailers, 2016 - 2020*

Energy Sources	**Yearly Average Primary Energy Consumption Per Energy Type (PJ, Absolute Numbers)**	**Yearly Average Primary Energy Consumption Per Energy Type (Relative Numbers)**
Others (Unspecified)	62,676	52%
Gas (e.g., Natural Gas, Liquefied Petroleum Gas)	34,077	28%
Petroleum (Crude Oil)	15,779	13%
Hard Coal (Anthracite)	6,862	6%
Renewable (e.g., Wind, Solar, Hydro, Geothermal, Biomass)	928	1%
Brown Coal (Lignite)	0	0%
Lowest dependency on fossil fuel energy sources: 47% Total of yearly average primary energy consumption: 120,323 PJ		

Table 14: Yearly average primary energy consumption per energy source type in PJ btw. 2016 and 2020, transport equipment industry with the manufacture of motor vehicles, trailers and semi-trailers

- *Metal industry with the manufacture of fabricated metal products, 2016 - 2020*

Energy Sources	**Yearly Average Primary Energy Consumption Per Energy Type (PJ, Absolute Numbers)**	**Yearly Average Primary Energy Consumption Per Energy Type (Relative Numbers)**
Others (Unspecified)	50,964	51%

Gas (e.g., Natural Gas, Liquefied Petroleum Gas)	36,393	37%
Petroleum (Crude Oil)	10,806	11%
Hard Coal (Anthracite)	1,326	1%
Renewable (e.g., Wind, Solar, Hydro, Geothermal, Biomass)	35	0%
Brown Coal (Lignite)	0	0%
Lowest dependency on fossil fuel energy sources: 48% Total of yearly average primary energy consumption: 99,524 PJ		

Table 15: Yearly average primary energy consumption per energy source type in PJ btw. 2016 and 2020, metal industry with the manufacture of fabricated metal products

- *Machinery and equipment industry, 2016 - 2020*

Energy Sources	Yearly Average Primary Energy Consumption Per Energy Type (PJ, Absolute Numbers)	Yearly Average Primary Energy Consumption Per Energy Type (Relative Numbers)
Others (Unspecified)	41,701	52%
Gas (e.g., Natural Gas, Liquefied Petroleum Gas)	24,355	31%
Petroleum (Crude Oil)	10,994	14%
Renewable (e.g., Wind, Solar, Hydro, Geothermal, Biomass)	1,368	2%
Hard Coal (Anthracite)	645	1%
Brown Coal (Lignite)	35	0%
Lowest dependency on fossil fuel energy sources: 46% Total of yearly average primary energy consumption: 79,098 PJ		

Table 16: Yearly average primary energy consumption per energy source type in PJ btw. 2016 and 2020, machinery and equipment industry

Based on my findings and interpretations, Germany's top 5 manufacturing industry sectors are reliant on fossil fuel energy sources (lowest considered dependency spans from 46% to 79%) for their operations although the magnitude of dependency is not uniform across the board with both chemical products and food products & beverage industries being the most exposed to. Another possible interpretation could be that the three industries, 1.) machinery & equipment industry, 2.) transport equipment industry with the manufacture of motor vehicles, trailers and semi-trailers industry, and 3.) metal industry with the manufacture of fabricated metal products, were further and more diversified in a mix of energy sources than both chemical products and food products & beverage industries; the outcomes of our quantitative survey ought to reinforce this statement later on.

In the next chapter, I will address the topic around the GHG emissions.

2.3.10 – GHG emissions of the German manufacturing industry

A good way to understand and assess the GHG emissions is to look at the data around man-made air emissions aggregated by DESTATIS. With reference to its German publication (DESTATIS, 2022b, p. 4), the use and handling of resources (e.g., fossil fuels, raw materials, feedstocks) through combustion-related activities and industrial processes generate waste materials and pollutants that cause GHG emissions and particulates. GHGs impact the environment/climate while particulates impact the living organisms and biodiversity through their immission (i.e., diffusion into).

The former manifests itself in the form of CO_2, CH_4, N_2O, FC with hydrofluorocarbon and perfluorocarbon, SF_6 and NF_3, while the latter manifests itself in the form of SO_x, SO_2, NO_X, Particulate Matters 10µm & 2.5µm, Pb, C_6H_6 and CO.

As documented in the Kyoto Protocol in 1997, GHG emissions are responsible for climate change and global warming to a large extent. For the sake of my paper, I will focus on GHGs moving forward. In order to delineate a common base for measuring all GHG emissions, a common unit of measurement is used – the so-called tons of CO_2 equivalent expressed in thousands or millions – as the CO_2 emissions of the German economy sectors altogether represent an average of 87% of the total GHG emissions stemming from the German economy sectors over the four years 2000, 2010, 2015 and 2020 (DESTATIS, 2022b, pp. 13-16).

For Germany, I have below put together a table that provides an overview of all relevant information about nine measures of GHG emissions for the four available years 2000, 2010, 2015 and 2020 (DESTATIS, 2022b, pp. 13-16).

Measures	Thousand Tons of CO_2 Equivalent	Pct In Comparison to Country	Pct In Comparison to Economy	Pct In Comparison to Manufacturing Industry
Average Total GHG Emissions, Country	971,969			
Average Total GHG Emissions, Economy (Primary, Secondary & Tertiary Branches)	804,925	82.8%		

Average Total GHG Emissions, Energy Industry	318,677	32.8%	39.6%	
Average Total GHG Emissions, Manufacturing Industry	220,356	22.7%	27.4%	
Average Total GHG Emissions, Chemical Products Industry	34,566	3.6%	4.3%	15.7%
Average Total GHG Emissions, Food Products & Beverages Industry	12,316	1.3%	1.5%	5.6%
Average Total GHG Emissions, Transport Equipment Industry with the Manufacture of Motor Vehicles, Trailers and Semi-Trailers	4,296	0.4%	0.5%	1.9%
Average Total GHG Emissions, Metal Industry with the Manufacture of Fabricated Metal Products	3,360	0.3%	0.4%	1.5%
Average Total GHG Emissions, Machinery & Equipment Industry	2,868	0.3%	0.4%	1.3%

Table 17: Germany, nine measures of GHG emissions in a given context with their percentage distribution according to a specific criterium

What are the lessons of table 10? I have so far identified two essential ones. 1.) the manufacturing industry is the second contributor after the energy industry to GHG emissions and both represent over two-third of the German economy GHG emissions, and 2.) the chemical products industry with over fifteen percent and the food products & beverages industry with over five percent are standing out against the other top 3 manufacturing industries from a GVA perspective on the manufacturing industry frontline. As a result of this, driving down the reduction of their respective GHG emissions would have the biggest impact on the overall manufacturing industry GHG emissions reduction while maintaining their GVA.

In the next chapter, I will address the topics around the EU/German guidance, legal framework and regulations on the green (e.g., reduce GHG emissions and attain climate neutrality) and digital (e.g., scale up industry 4.0 deployment) transition agendas.

2.4 – Orientation, legal framework and regulations

2.4.1 – From an EU perspective

Based on my understanding and in a nutshell, the EU has set up a system/an organisation with seven Institutions and seven Bodies that delineates its policy, direction, orientation, priorities and objectives, as well as devises, votes and applies laws/legal frameworks/regulations for currently twenty-seven countries and their citizens[45]. For the 2019-2024 five-year term, the European Council (basically composed of the heads of state or government of the EU member states, the President of the European Council, and the President of the European Commission) has defined a strategic agenda with four priorities (cluster A) and the President of the EU Commission has delineated six political priorities (cluster B)[46].

As regards cluster A, the third priority (A.3), namely cited "*building a climate-neutral, green, fair and social Europe*", states "*Investing in green initiatives that improve air and water quality, promote sustainable agriculture and preserve environmental systems and biodiversity. Creating an effective circular economy (where products are designed to be more durable, reusable, repairable, recyclable and energy-efficient) and a well-functioning EU energy market that provides sustainable, secure and affordable energy. A faster transition to renewables and energy efficiency, while reducing the EU's dependency on outside energy sources. Implementing the European Pillar of Social Rights.*"[47]. A.3 is about sustainable development, circular economy, energy transition and efficiency.

With regard to the cluster B, the first (B.1) and second (B.2) priorities, namely individually cited "*European Green Deal*" and "*Europe fit for the digital age*", respectively state "*Transforming the EU into a modern, resource-efficient and competitive economy, while preserving Europe's natural environment, tackling climate change and making Europe carbon-neutral and resource-efficient by 2050*"[48] and "*Embracing digital transformation by investing in businesses, research and innovation, reforming data protection, empowering*

[45] Retrieved from the EU website, source https://european-union.europa.eu/institutions-law-budget/institutions-and-bodies/types-institutions-and-bodies_en, last accessed on 10 January 2023.
[46] Retrieved from the EU website, source https://european-union.europa.eu/priorities-and-actions/eu-priorities_en, last accessed on 10 January 2023.
[47] Retrieved from the European Council website, A new strategic agenda for the EU – 2019-2024, source https://www.consilium.europa.eu/en/eu-strategic-agenda-2019-2024/, last accessed on 10 January 2023.
[48] Retrieved from the European Commission website, A European Green Deal, source https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en, last accessed on 10 January 2023.

people with the skills necessary for a new generation of technologies and designing rules to match"[49].

B.1 is about fostering an energy-efficient, resource-efficient, carbon-neutral, and environmentally friendly economy while B.2, through the use of digital technology, is about encouraging people to enhance their life and businesses to build a better aligned value delivery customer-centric technical and operational base that allows for adaptation, evolution and response to change.

A.3 and B.1 are inter-related and share a common action plan in support of the energy transition to fight off GHG emissions inducing climate change: the European Green Deal. One of the deal's goals is to "*transform the EU into a modern, resource-efficient and competitive economy, ensuring the reduction of the net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels, and no net emissions of greenhouse gases by 2050.*"[50], i.e., becoming a climate-neutral economy and society by 2050.

Revolving round A.3 and B.1, a legal framework, known as the European Climate Law, has set the legally binding GHG emissions reductions and hence supports the European Green Deal; it came into force in June 2021. Each EU Member State has its own NECP which sets out the path to climate neutrality by 2050 and gives some GHG emissions reduction roadmap guidance to its economy branches in terms of goal expectations; a progress on the GHG emissions reductions achievement is reviewed every five years and corrective actions may take place if necessary[51].

To make the European Green Deal tangible, the EU Commission has put together a working initiative around ten topics[52]; for the purpose of my paper, the three areas of the European Green Deal that I have selected are 1.) the energy topic[53], 2.) the industry topic[54], and 3.) the research & innovation topic[55].

---

[49] Retrieved from the European Commission website, A Europe fit for the digital age, source https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age_en, last accessed on 10 January 2023.
[50] Same as [49].
[51] Retrieved from the European Commission website, European Climate Law, source https://climate.ec.europa.eu/eu-action/european-green-deal/european-climate-law_en, last accessed on 10 January 2023.
[52] Retrieved from the European Commission website, A European Green Deal, source https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en, last accessed on 10 January 2023.
[53] Retrieved from the European Commission website, Energy and the Green Deal, source https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/energy-and-green-deal_en, last accessed on 11 January 2023.
[54] Retrieved from the European Commission website, A New Industrial Strategy for Europe, source https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0102&from=IT, last accessed on 11 January 2023.
[55] Retrieved from the European Commission website, Research and innovation for the European Green Deal, source https://research-and-innovation.ec.europa.eu/strategy/strategy-2020-2024/environment-and-climate/european-green-deal_en#documents, last accessed on 11 January 2023.

1.) In line with my findings on the German GHG emissions measures from **Table 17**, the production and industrial use of energy in the EU account for the lion's share of GHG emissions (*the EU Commission even states three-quarter*). Hence, transitioning to a cleaner (by use of renewable energy) European energy system while decarbonising the EU's currently fossil fuel energy-based energy system is the path that largely contributes to reach the 2030 climate objectives on GHG emissions reductions and the 2050 carbon neutrality objectives of the EU region set by the European Commission.

    Throughout each national NECP implementation and roll-out phase, these goals are monitored. The focus of each NECP is to address five priorities: energy efficiency, use of renewable sources of energy to produce electricity (wind, solar, etc.), GHG emissions reductions, smart energy systems interconnection between the national economy sectors and even beyond the borders, and research & innovation (will be covered under 3.)).

2.) Europe's industrial sector presently undergoes two simultaneous transitions: an energy transition with an emphasis on the use of green/clean/sustainable technology for energy production, and a digital transition with an emphasis on digitalisation with **Industry 4.0**.

    As I have already stated in the chapter 2.2.1, industrial activities are closely tied to energy use. With the Green Deal's goals to reduce GHG emissions by at least 55% in 2030 compared to 1990 levels and embark on the carbon neutrality path by 2050, the European industry with its high value-added products and services, integrated value chains, and traditionally export-orientated businesses has to pave the way to a successful contribution by harnessing the potential of clean technology solutions, such as CCS, hydrogen fuel cells, Na-ion/solid state batteries, that fundamentally drive the European economy transformation.

    On the digital transition side of the transformation of Europe's industrial sector, digitalisation helps transform its products and services towards more individualised, personalised customer experience and service, as well as grow to meet demand.

    To join the efforts for successful green and digital transitions of the European industry, strategic industrial alliances such as the European Clean Hydrogen Alliance, the European Battery Alliance, the European Solar Photovoltaic Industry Alliance, the Renewable and Low-Carbon Fuels Value Chain Industrial Alliance, the European Raw Materials Alliance, or the European Industrial Cloud & Edge Computing (European Commission, 2020, p. 3) regrouping governmental, institutional, investing, financing, and industrial partners have been initiated and are expressly supported by EU fundings and legal guidance.

3.) Research and innovation are catalysers of change and enablers of solutions to challenges; they both play an essential role in the various transition phases of any change. Any change process requires assumption making, identification, analysis, discovery, evaluation, interpretation, validation and adaptation. In other terms, research and innovation are the vital fuel for transformation.

However, research and innovation are heavily depending on funding. As an example, the EU Commission made a € 1 billion funding programme under the name Horizon 2020 available to seventy-three projects. With Horizon Europe, an overarching € 95.5 billion funding programme for research and innovation during the time frame 2021-2027, the EU Commission has put together a framework for fuelling EU's scientific and technological excellence and strengthening the European research area with specialised industrial partnership clusters (e.g., in health, digital, energy, mobility, industry, climate, food.).

To accommodate the rather risk-adverse EU legislation, regulatory direction, and policy-making framework with the rather risk-tolerant research and innovation mission of fostering novelty (to express innovation in the Intellectual Property language), the EU Commission has introduced the Innovation Principle which creates a regulatory framework for innovation/entrepreneurship to thrive, and hence be less focused on precaution (e.g., this applies to emerging technologies like AI and DLT).

With reference to its publication (European Commission, 2021, p. 1), the EU Commission seeks to fulfil its clean energy transition and climate neutrality goals by means of research and innovation. In order to address 1.) the prevention of CH_4 leaks, 2.) the market entry acceleration of renewable and low-carbon gases, 3.) the encouragement to renovate buildings, 4.) the development of carbon removal systems, and 5.) the social and labour impacts of the climate transition, the EU Commission relies on the two funding programmes Horizon 2020 and Horizon Europe.

Switching over to B.2 (President of the EU Commission's second political priority), the priority that consists of making Europe fit for the digital age, is centred on a framework (referred to as Digital Decade) that sets out Europe's digital transformation impacting EU citizens and economies/businesses with four key areas: ICT skills, business transformation, secure and sustainable digital infrastructures, and digitalisation of public services[56].

[56] Retrieved from the European Commission website, Europe's Digital Decade, source https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade, last accessed on 15 January 2023.

Its € 7.5 billion funding programme, called DIGITAL, provides strategic financial backing to selected multi-country projects in five key areas: supercomputing, AI, cybersecurity, advanced digital skills (for citizens/businesses/public services/infrastructures), and digital innovation hubs (support facilities helping companies improve their products and services and associated business/production processes by means of digital technology).

Digital Decade, with its investment power into digital technologies and infrastructures, ought to be a key enabler for reaching the European Green Deal objectives and promoting a sustainable, circular and climate-neutral EU economy (I cover the topics of **Sustainability** and **Circular economy** later on). Each EU country is requested to draw up a national digital decade strategic roadmap that takes digital targets into account (e.g., edge computing nodes for distributed data-processing capabilities, deployment of high-speed secure digital infrastructures with wired Gigabit/wireless 5G access, engagement in either AI, or cloud computing services, or big data or all of them of 75% of EU businesses, secure electronic identification and authentication with the eIDAS regulation), and submit its strategic roadmap to the EU Commission by October 2023. The EU Commission plans on consolidating all national strategy roadmaps by end of 2013 and having a first progress report on Digital Decade available by January 2024[57].

In the next section, I look at what Germany undertakes to synchronise up with the EU Commission.

2.4.2 – From a German perspective

How does the German Federal Government translate the EU energy and digital policies into action? As far as the energy transition is considered, I have used three sources: 1.) Germany's integrated NECP (German Federal Ministry for Economic Affairs and Climate Action, 2020, pp. 9-14), 2.) Germany's energy efficiency strategy 2050 (German Federal Ministry for Economic Affairs and Climate Action, 2019, pp. 6-31), and 3.) the targeted GHG emission reductions (focus on CO_2) of Germany's economy in particular with the industrial sector respectively the manufacturing industry[58]. As regards the digital transition, I have used one single source: 4.) the German digital strategy (German Federal Ministry of Transport and Digital Infrastructure, 2022, pp. 2-5 and 28-38).

1.) Germany's NECP is a two-pronged approach to reconcile energy and climate; both topics are fundamentally inclusive, meaning that one topic cannot be left alone without referring to the second one. It is about Germany's energy and climate policy.

[57] Retrieved from the European Commission website, Decision establishing the Digital Decade Policy Programme 2030, source https://eur-lex.europa.eu/eli/dec/2022/2481/oj, last accessed on 15 January 2023.
[58] Retrieved from the German Federal Environment Agency, German publication Treibhausgasminderungsziele Deutschlands, source https://www.umweltbundesamt.de/daten/klima/treibhausgasminderungsziele-deutschlands, last accessed on 16 January 2023.

Germany's NECP is comprised of five central goals: 1.) Decarbonisation achieved through GHG emissions reduction and renewable energy, 2.) Energy efficiency, 3.) Energy security, 4.) Internal energy market, and 5.) Research, innovation and competitiveness.

For each goal, a corresponding strategy has been developed. Germany's NECP entails energy and climate goals to be achieved, for instance Germany's climate goals for its economy branches (refer to **Figure 11**) between now and 2030, and even beyond. These measurable goals are contained in Germany's Climate Action Programme 2030, key component of Germany's NECP.

Two catalysers ought to boost the energy transition: a 30% increase in use of renewable energy sources (e.g., wind, solar, biomass, hydropower, etc.) by 2030 compared to 1990 levels, and the use of energy-efficient (adding up two adjectives green/clean) technologies (I will touch base on this topic in the section **5.2**) to drive a 30% **primary energy consumption** reduction by 2030 compared to 2008 levels. Also, on the country's competitiveness side (I will touch base on this topic in the section **2.5.2**) with the energy transition, the NECP ought to carry on the country's attractiveness to do business (e.g., by maintaining the FDIs) with its economic partners.

As far as climate is concerned, the objectives of reducing GHG emissions by 55% by 2030 and attaining net zero GHG emissions by 2050 play a pivotal contribution. In its execution, it is paramount that the energy transition finds its equilibrium between affordability as the country's power grid modernisation and expansion require huge investments, reliability of supply to guarantee the country's energy demand at all times, and environmental legitimacy as it has both economic and societal impact on the country.

2.) Under the acronym NAPE (2.0, the second version as amendments were introduced in 2022), the German action plan on energy efficiency is the centrepiece of Germany's Energy Efficiency Strategy 2050 that is Germany's interpretation of the European EED, a by-product of the European Green Deal (energy transition and climate change topics).

The main goal of this cross-sectoral plan that encompasses buildings, industries, commerce, trade, services, energy, and transport is two-fold: 1.) reduce the primary energy consumption by 30% in 2030 (and even by 50% in 2050) compared to the 2008 levels, which is a key contributor to the GHG emissions reduction by 55% in 2030 compared to the 1990 levels, and 2.) enable the German economy to carry on its value added while manufacturing in a sustainable and competitive manner. All with the purpose of attaining Germany's climate goals for EU conformance. Where are we on this journey? With reference to AGEB results (Arbeitsgemeinschaft Energiebilanzen, 2022, p. 10), Germany's current primary energy consumption indicator provides the following result: in 2008 – 14,380 PJ; in 2020 11,895 PJ, in 2030 (reduction of 30% vs. 2008) – 10,066 PJ, and in 2050 (reduction of 50% vs. 2008) – 7,190 PJ per extrapolation according to NAPE.

The two key enablers of the cross-sectoral plan are the expansion of the renewable energy sources (in the electricity mix, the renewable energy sources should represent a 65% share by 2030), and the energy-efficient technological innovations that power the industrial sectors' machinery and equipment.

While addressing specific efficiency measures toward each sector, NACE is closely interlinked with NECP (the previous topic) as the former is a sub-section of the latter. Against the backdrop of my paper that focuses on the manufacturing industry, NAPE tackles the challenge of 1.) replacing progressively the currently extensively used fossil fuel energy sources with renewable energy sources, 2.) making possible the analysis of connected machines' energy needs through smart meters to predict demand, and 3.) performing an energy-efficient control and monitoring of the manufacturing processes.

3.) In August 2021, Germany tightened the path to reach the objectives of its Federal Climate Protection Act to align them with the ones from the EU fit-for-55 package of the European Climate Law (those two objectives: a 55% reduction of net GHG emissions by 2030 compared to the 1990 levels, and the climate neutrality by 2050). As a result of the tightening, Germany has developed a climate protection programme with the following legally binding metrics: reduce GHG emissions by at least 65% by 2030, at least 88% by 2040, by achieving net GHG emission neutrality by 2045 and by achieving negative greenhouse gas emissions after 2050. Also have the German economy sectors' GHG emission reduction targets been updated to match the new requirements. Below is a visual representation of the historical and target data of the six economy branches.

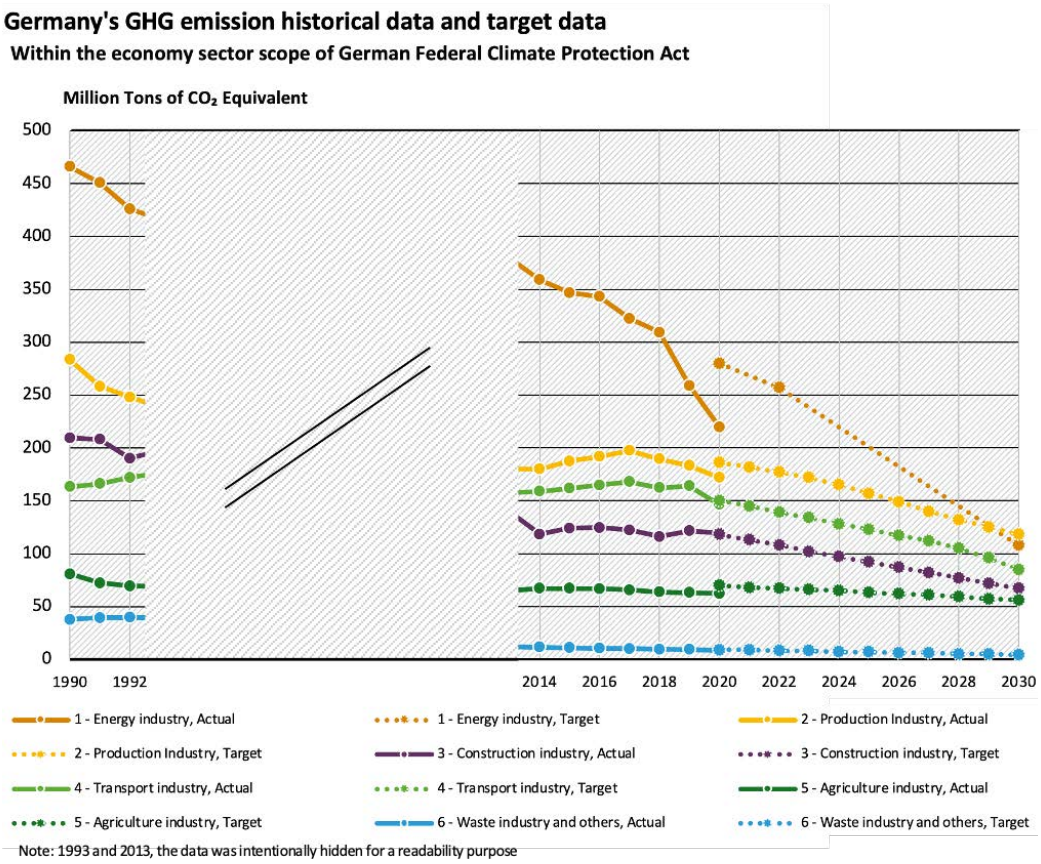


Figure 11: Germany's GHG emission historical and target data for six economy sectors based on the 2021 Federal Climate Protection Act

The orange line refers to the industrial sector of the German economy. By 2030, its GHG emissions reduction effort in comparison with the 2020 level, -37%. Making the assumption that the numbers of **Table 17** are under the same patter as the data above, the transposed GHG emissions for the German manufacturing industry ought to be looking like

Measures	**Thousand Tons of CO_2 Equivalent**	
	Average (2000, 2010, 2015, 2020)	**2030**
Total GHG Emissions, Manufacturing Industry	220,356	138,824
Total GHG Emissions, Chemical Products Industry	34,566	21,776
Total GHG Emissions, Food Products & Beverages Industry	12,316	7,759
Total GHG Emissions, Transport Equipment Industry with the Manufacture of Motor Vehicles, Trailers and Semi-Trailers	4,296	2,706

Total GHG Emissions, Metal Industry with the Manufacture of Fabricated Metal Products	3,360	2,117
Total GHG Emissions, Machinery & Equipment Industry	2,868	1,807

Table 18: Targeted (transposed) GHG emission reductions by 2030, German manufacturing industry, top 5 weights of the German manufacturing industry from a GVA perspective

4.) To cover and align with the EU programme Digital Decade (referred to B.2 under the section 2.4.1), the German Federal Government has shaped up the central framework for its digital policy, a strategy with a three-pronged scheme that focuses its action plan on society with an emphasis on sovereignty and connectivity, economy with a focus on data, and government with an emphasis on digital public services (aka e-government), all for the sake of citizens' lives improvement, with eighteen funded PoV projects (an example: one of them is the Digital Hub Initiative with twelve centres in charge of Made-in-Germany digital innovation). To relate to my paper, I have selected the topic relating to economy with three out of its eight sub-sections, namely data, science & research, and protection of the climate, environment and resources.

Regarding the first sub-section, data is to a digitally orientated environment what blood is to the body: i.e., indispensable as data ought to become the new currency of our economy, and lays the base for the country's economy and innovation competitiveness. It is crucial that, while maintaining data integrity, availability and security, data can effectively be collected, shared and interpreted. Data infrastructures (like data motorways, data platforms) that connect cloud and edge services must be built up; data ecosystems must also be erected. One of the German Federal Government's objectives is to build leading centres of excellence in AI and to foster AI-based data use toward SMEs. With digital innovation in AI applications stemming from science & research, data is enhanced and allows informed decision-making.

As far as the second sub-section is concerned, the German Federal Government fosters and subsidises research data collaboration and exchange initiatives between university researchers, enterprise R&D departments, and non-university research institutions to jointly develop the best digital innovations.

With regard to the third sub-section, the German Federal Government is keen on harnessing the potentials of new opportunities powered by digital technologies such as environmental big data and AI to advance its environmental policy measures and regulatory framework to tackle climate change, biodiversity loss and environmental pollution and drive Germany's NECP and NAPE goals forward.

Let me know address the topics of sustainability, competitiveness, and circular economy in the next section.

2.5 – Trilogy

I share the idea that sustainability, competitiveness and circular economy represent altogether a group of three related topics; hence the word trilogy to unify them. It is part of the transformation that our European economy while becoming more and more innovation-driven and data-driven, is currently experiencing. This particularly applies to the German economy. With that said, let me briefly address the three topics in the sections below.

2.5.1 – Sustainability

Given the scope of my Master's Thesis, I am going to focus on sustainability against the backdrop of manufacturing. With reference to Professor Guenther Seliger's book Sustainable Manufacturing - Shaping Global Value Creation, sustainability is characterised by "*the creation of sustainable products and processes, which conserve energy and natural resources, have minimal negative impact upon the natural environment and society, and adhere to the core principle of sustainability by considering the needs of the present without compromising the ability of future generations to meet their own needs.*" (Seliger, 2012, pp. v-vi, Preface). As we have learned from the section 2.2.1, manufacturing has always been a transformation process while creating value, but with sustainability in mind reinforced by effectiveness (do the right things), efficiency (do things right), use of digital technologies (e.g., industry 4.0), and use of green technologies (economy decarbonation), sustainable manufacturing is becoming the new pattern, in alignment with the United Nations' 2030 agenda for sustainable development that sets out seventeen SDGs[59]. Sustainable manufacturing is paramount in bolstering UN's SDG #9 (build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation) and #12 (ensure sustainable consumption and production patterns), where non-renewable resources must not be disposed anymore but rather be regained in product and material cycles (Seliger, 2012, pp. 3-8).

A good way to visualise the difference between non-sustainable manufacturing and sustainable manufacturing is to get inspired by the book "The ManuFuture Road – Towards Competitive and Sustainable High-Adding-Value Manufacturing" (Jovane et al., 2009, pp. 31-52). The transition from one manufacture model to the other one is referred to as "*from economic to sustainable development*". Below, I have represented as a visual a pathway to reach sustainability in the manufacturing industry.

[59] Retrieved from the United Nations' website, sustainable development goals, source https://sdgs.un.org/goals, last accessed on 30 January 2023.

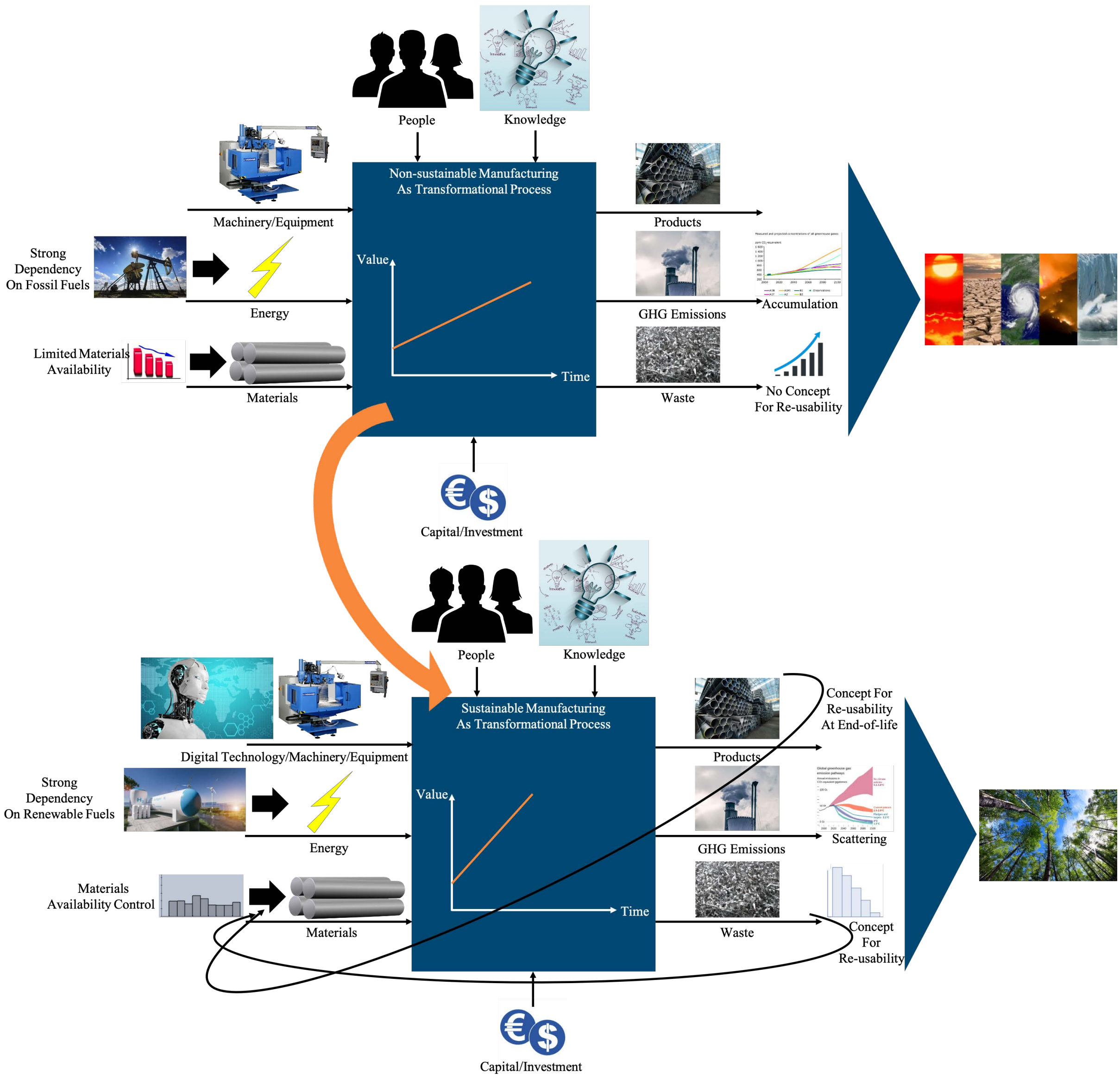


Figure 12: A pathway from non-sustainable to sustainable manufacturing

I now address the topic of competitiveness.

2.5.2 – Competitiveness

Generally speaking, competitiveness is the outcome of the combination of several individual elements/factors, such as technological advancement and autonomy, innovation, skilled workforce, advanced machinery and equipment, legal and regulatory framework, access to abundant and unexpensive energy, physical/transport infrastructure, integrated supply chain, price calculation, etc. In other words, this is a complex dimension of an economy, respectively industry as the above elements/factors are even incomplete: on the positive side, I should have added access to (raw) materials, intellectual property protection management, antitrust and product liability laws, carbon footprint in the manufacturing processes, use of sustainable energy sources and material resources, increasingly environment and climate aware end customers, etc., and on the rather negative side from a European/German perspective, labour policy complexity, high corporate tax rates and disadvantageous fiscal policies.

With reference to the most recent Deloitte publication published in 2016, (Deloitte Touche Tohmatsu Limited et al., 2016, pp. 4-42), I am about to precise a little bit more based on this report. Advanced manufacturing technologies, such as both smart products and factories with IoT, predictive analytics, advanced materials, digital twins, advanced robotics and automation, are perceived as paramount to unlocking competitiveness and delivering higher-value products and services. Heading to the fourth industrial revolution with Industry 4.0 as standard is essential to preserve its competitive advantage against others nations (e.g., China, USA). Skilled labour workforce is the number 1 top driver of manufacturing competitiveness, followed respectively by cost competitiveness, workforce productivity, and strong supplier network/ecosystem. Also plays a public policy environment an increasing role in competitiveness enablement; for instance, by allowing technology transfer between countries.

Another key aspect of competitiveness is, at least within Europe and more specifically in Germany, the awareness of investing in and building up national innovation clusters/ecosystems which link individuals, resources, policies, and organisations to purposefully, effectively and efficiently translate new concepts into commercialised products and services.

Last but not least, society's and end customers' expectations in terms of how much manufacturing capabilities are impacting their environment, are gaining some ground in Europe and more specifically in German with the consideration of GHG emissions reduction, net-zero carbon production, use of renewable energy sources and sustainable material resources.

Let me now close the trilogy section with the circular economy topic.

2.5.3 – Circular economy

I have used two insightful sources to cover the topic at an introductory level: A.) Symposium Circular Economy from the Technical University of Munich (TUM Senior Excellence Faculty et al., 2022) and B.) the publication "circular economy roadmap for Germany" from the circular economy initiative Deutschland (Circular Economy Initiative Deutschland, 2021).

With EU Green Deal's overarching objective to create a European climate-neutral economic territory by 2050, it is pretty obvious that our current unbridled consumption lifestyle and interrelated throw-away culture, and its nurturing pattern of manufacture/production since the first industrial revolution need to be transformed. This is where the concept of CE kicks in as opposed to our current economy pattern (aka the take-make-use-dispose pattern). With reference to A.) (TUM Senior Excellence Faculty et al., 2022, pp. 48-58, especially p. 57 for the visual representation), I have devised a visual representation of both the models in the figure below. The transformation is mainly driven by the use of green and digital technologies (e.g., renewable energy, smart manufacturing with Industry 4.0, and the purposefulness of identifying a service usefulness for re-entering the economy by following one of the five R strategies (either as Recycled, or Remanufactured, or Refurbished, or Repaired, or Reused, referred to as product-as-a-service in the businesses' circular economy-supportive business model).

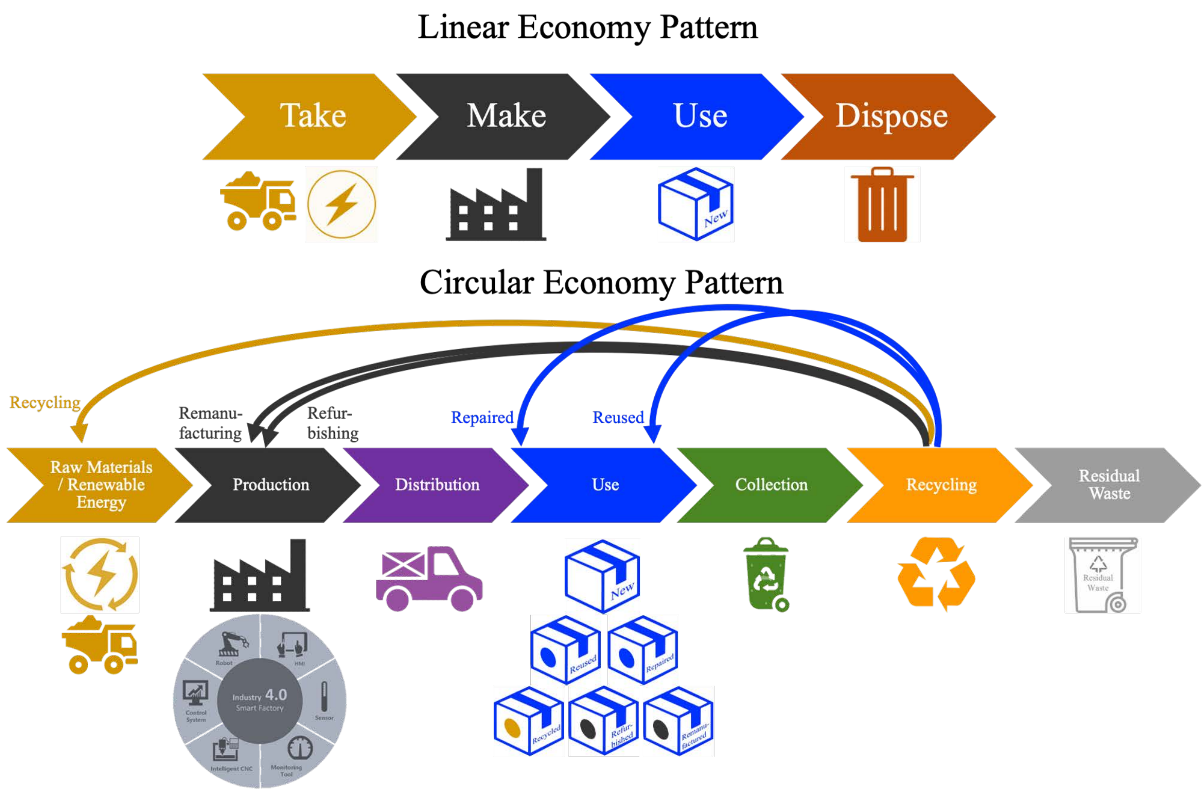


Figure 13: Representation of the circular economy pattern versus the linear economy pattern

With reference to B.) (Circular Economy Initiative Deutschland, 2021, pp. 6-16), CE is a cornerstone for sustainable development, fuelling Germany's sustainable development goals brought in its 2030 agenda[60], is decoupling economic growth from resource/raw materials consumption, is bolstering local value added, and is reconciling the economy to the environment in the long-term (for example by increasing secondary raw materials availability, i.e., regained from products exiting their use cycle). A relevant change for businesses will be to reconsider their approach to designing products and embedding the "serviceability" of products when reaching their end-of-life.

To conclude, the trilogy sustainability, competitiveness, and circular economy will be a key impulse to maintain Germany's manufacturing industry leadership throughout our twenty-first century.

2.6 – Transformational factors

2.6.1 – Industry 4.0

Nowadays, Industry 4.0 is internationally associated with the digitalisation of the industry. Noteworthily, Germany has coined the term "Industrie 4.0", whose English translation is Industry 4.0.

[60] Retrieved from the German Federal Government website, topic Germany's sustainable development strategy, source: https://www.bundesregierung.de/breg-en/issues/sustainability/germany-s-sustainable-development-strategy-354566, last accessed on 3 February 2023.

According to the German Federal Ministry of Research and Education[61], "Industrie 4.0" first appearance was associated with a project against the backdrop of the German Federal Government's future high-tech strategy in 2011. Later, the advisory board for economy and science Forschungsunion, and the national academy for science and engineering acatech under Professor Henning Kagermann's leadership (he used to be both SAP former Chairman of the Executive Board and Chief Executive Officer), turned this project into a strategic initiative for securing the future of the German manufacturing industry. The strategic initiative's implementation recommendations were then published in April 2013 in a report (Communication Promoters Group of the Industry-Science Research Alliance, 2013) and have moulded the cradle of the Fourth Industrial Revolution.

What are the fundamentals of Industry 4.0 and how do they interact with each other? A look at the Forschungsunion/acatech report's summary (Communication Promoters Group of the Industry-Science Research Alliance, 2013, pp. 5-7) has brought some insightful information.

For several decades and to a large extent, mechanisation/automation, electricity and ICT have been supporting most industrial manufacturing processes of the German industrial sector. With the ascendancy of the Internet, new perspectives have arisen, and with the introduction of IoT and Internet of Services (IoS: with reference to the journal article from (Terzidis et al., 2012) a systematic use of the Internet through resources such as technical systems, information, based on the service-orientated architecture pattern for delivering services that perform some arranged functions and generate a benefit/value to the end-users) into the manufacturing industry landscape, businesses can build up global networks that encompass M&E, warehouse systems, and production plants in the shape of Cyber-Physical Systems (CPS).

The particularity of these CPS is that they are able to autonomously share information, trigger actions, and independently control each other, thus facilitating industrial process improvement and optimisation, and making smart/advanced factories come true. As a result, a new approach to manufacturing/producing is made possible; CPS are vertically linked to the companies' business processes, and horizontally linked to the distributed value network aka ecosystem.

While Industry 4.0 profoundly focuses on interconnectivity, automation, machine learning, and real-time data, it brings about benefits/opportunities for value creation (e.g., through the integration of personalised customer requirements), new service-orientated business models (e.g., data analytics and interpretation for quicker decision-making), cross-

[61] Retrieved from the German Federal Ministry of Education and Research's website, German source: https://www.bmbf.de/bmbf/de/forschung/digitale-wirtschaft-und-gesellschaft/industrie-4-0/industrie-4-0.html, last accessed on 4 January 2023.

organisational collaboration (e.g., improve communication between manufacturers and suppliers to solve raw materials bottlenecks), new ways to organise work (e.g., labour force focuses on creative and value-added activities), resource productivity optimisation (e.g., avoid machine downtimes with predictive maintenance), resource efficiency gains (e.g., use the least amount of resources to maximise the output such as energy and raw materials), and work force to develop new skills (e.g., overcome the shortage of skilled workers).

While Germany has got a global leadership in the machinery and equipment sector for the manufacturing industry, Industry 4.0 opens up a unique opportunity to develop Germany's leadership in smart manufacturing technologies.

Research and Development is playing a key role in designing and developing disruptive technologies such as AI, ER, Cloud Computing, Big Data Analytics, to enable advanced industrial manufacturing. Only with adequate industrial policy decisions can innovation be a driver for Industry 4.0.

Safety and security (cybersecurity) are also two areas that are essential to the success of smart manufacturing; one has to make sure that the manufacturing facilities and the manufactured products are safe for the labour force and environment while the generated data and information are effectively protected against misuse and unauthorised access.

With a blend of design-based and process-based approaches, Industry 4.0 fosters closed material cycles with the objective of resource efficiency, hence enabling circular economy, contributing to environment protection, and mitigating climate change.

Last but not least is the cultural impact of Industry 4.0 on organisations. More participative and collaborative organisations are needed across the entire value creation chain as opposed to organisations working in silos. This is a real shift in organisational culture where executive leaders are on a regular basis solicited to accompany their human resources to harness transformation factors such as Industry 4.0.

As a final element to the key concepts covered in my Master's Thesis, I will briefly talk about Industry 5.0 below.

2.6.2 – Industry 5.0

First of all, based on my humble knowledge about industrial revolutions and through my diverse readings, our World still deals with the fourth Industrial Revolution. Hence, Industry 5.0 has to be interpretated as thought topic rather than another transition of the industry into a new industrial area. However, the topic seems to be increasingly evaluated by academia.

I have used two literature sources to cover this section: A.) a concept paper (Nahavandi, 2019) from the Institute for intelligent systems research and innovation, Deakin University Australia, and B.) a chapter (Draghici and Ivascu, 2022, pp. 17-64) from a book covering sustainable manufacturing.

As already highlighted in the previous chapter, automation with process optimisation is a source of resource productivity and efficiency gains for the manufacturing industry. With reference to A.) and B.), the idea behind Industry 5.0 is to place the labour force at the centre of the manufacturing operations and processes.

With reference to B.), customers are expecting more and more personalised, customer-centric products, introducing two levels of requirements for the manufacturing industry: on the one hand being able to manufacture standard products based on non-creative, repetitive, lower value-added activities while on the other hand being able to involve the human touch for creative, higher value-added activities. For lower value-added activities, robotic process automation (RPA) can be deployed. Soliciting the human hand to become more involved in the design process rather than the manufacturing process, opens the door to let machines/robots collaborate with the labour force to take on the latter. Ultimately, the robots become autonomous.

Both literature sources introduce the word cobot (merging of the two words collaboration and robot) which refers to a collaborative robot. Cobots are intended to take over from the labour force so that an optimised, automated/robotised, resource efficiency/productivity gains-driven, streamlined, and waste reducing and preventive manufacturing process can take place. This way, flexibility and change readiness in the manufacturing process is orchestrated by the labour force in alignment with the customer’s request.

With reference to A.), autonomous robots as intelligent agents collaborating with the labour force will enable autonomous manufacturing. Advanced/emerging technologies for manufacturing autonomy such as network sensors, big data processing, computer vision using AI with deep learning and its artificial neural networks, smart sensing devices (e.g., functional near-infrared spectroscopy used for analysing human brain signals), are key enablers for the transition from programmable-only robots to cognitive/knowledge-based cobots.

This concludes the key concepts section of my Master’s Thesis. To sum it up, a comprehensive analysis of over twenty percent of Germany’s gross value added generated in its secondary economic sector within one year (a colossal amount of € 679.1 billion in current prices in 2021). A genuine gold mine, isn’t it?

3 – Framing of the challenge

The chapter's objective is to come to grips with my first research question "**What sword of Damocles (impeding disaster) may these five vertical sectors face in conjunction with the EU/German regulatory framework, especially against the backdrop of the GHG emissions reduction?**".

I support the idea that there is one fundamental aspect to keep in mind for grasping the EU mechanics: the founding agreements[62]. While citing the first sentence of the source, "*the EU is based on a rule of law*", it evidently paves the way how EU policy applies to each member country with the principles of subsidiarity, and conferral based on competence rules.

To illustrate the above statement, I will refer to two examples. The first one refers to the main purpose of EU's last main treaty – Treaty of Lisbon which came into force on 1 December 2009 – which is "*… and better able to address global problems, such as climate change, … The Lisbon treaty clarifies which powers belong to the EU, belong to the EU member countries, and are shared…*". The second one refers to what some of Lisbon treaty articles[63] clearly put forward as far as obligation and competence are concerned. I took two examples:

- "*Article 3A, § 3, …The Member States shall take any appropriate measure, general or particular, to ensure fulfilment of the obligations arising out of the Treaties or resulting from the acts of the institutions of the Union. The Member States shall facilitate the achievement of the Union's tasks and refrain from any measure which could jeopardise the attainment of the Union's objectives.*"
- "*Section Categories and Areas of Union Competence, Article 2A, §1, 2 and 3, …*
  1. When the Treaties confer on the Union exclusive competence in a specific area, only the Union may legislate and adopt legally binding acts, the Member States being able to do so themselves only if so, empowered by the Union or for the implementation of Union acts.
  2. When the Treaties confer on the Union a competence shared with the Member States in a specific area, the Union and the Member States may legislate and adopt legally binding acts in that area. The Member States shall exercise their competence to the extent that the Union has not exercised its competence. The Member States shall again exercise their competence to the extent that the Union has decided to cease exercising its competence.

[62] Retrieved from EU Commission website, founding agreements page, source: https://european-union.europa.eu/principles-countries-history/principles-and-values/founding-agreements_en, last accessed on 29 January 2023.

[63] Retrieved from EU Commission website, document C2007/306/01 Treaty of Lisbon: Amending the Treaty on European Union and the Treaty Establishing the European Community, source https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.C_.2007.306.01.0001.01.ENG&toc=OJ%3AC%3A2007%3A306%3ATOC#d1e585-1-1, last accessed on 29 January 2023.

3. The Member States shall coordinate their economic and employment policies within arrangements as determined by this Treaty, which the Union shall have competence to provide.".

Taking my Master's Thesis scope into account, according to the Treaty of Lisbon Article 2 C, the Union shall share competence with Germany in the environment and energy fields while according to Article 2E, the Union shall have the competence to carry out actions to support, coordinate or supplement Germany's undertakings in the industry field.

Needless to say, that Germany cannot alone delineate its policy without the EU Commission's approval. In adverse cases, the EU has devised a coercion-orientated instrument referred to as the infringement procedure[64], which could eventually end up in financial sanctions/penalties for the pleader; as an illustration of the above, the EU Commission has presently 106 active cases of infringement aiming at Germany[65].

Regarding the GHG emissions reduction, a topic that is eminently devoted to the environment policy, the competence is obviously shared on both sides based on the above statements. As the topic of Germany's GHG emissions reduction is tied to both **NECP** and **NAPE**, which are intimately linked to the EU NECP and NAPE of the EU Green Deal as explained in the section 2.4.1, I cannot imagine that the EU Commission is not involved in the decision-making process with regard to Germany's GHG emissions fight-off measures. As an indication, based on my calculation, **Table 18** (second column) gives some hints on the German manufacturing industry GHG emissions reduction.

With the above information analysis and interpretation, I have formulated two questions to address my first research question, namely:

Q1: For the green transition that currently surrounds our economy and society, Europe's Climate Law and its respective member state enactment have the ambition to reduce the greenhouse gas emissions by 2030 by a minimum of 55% in comparison with the 1990s level. Do you concur that Germany's leading manufacturing industry in terms of value-added can take over a leadership role by largely impacting this EU goal?

[64] Retrieved from the EU Commission website, infringement procedure, source https://commission.europa.eu/law/law-making-process/applying-eu-law/infringement-procedure_en, last accessed on 29 January 2023.

[65] Retrieved from the EU Commission website, infringement decisions, source https://ec.europa.eu/atwork/applying-eu-law/infringements-proceedings/infringement_decisions/index.cfm?lang_code=EN&typeOfSearch=false&active_only=1&noncom=0&r_dossier=&decision_date_from=&decision_date_to=&EM=DE&title=&submit=Search, last accessed on 29 January 2023.

Q2: In the event of missing Germany's manufacturing industry greenhouse gas emissions reduction goal to align with the EU Green Deal's objectives (one is to reduce the EU emissions by at least 55% by 2030), the potential infringement procedures risks against Germany would impact your company's financial growth.

The next step consists in developing approaches that will best prevent from adverse events hampering the overall GHG emissions reduction objective for the German manufacturing industry, and more particularly the top 5 weights of the German manufacturing industry from a GVA perspective.

4 – Exploration and analysis of the challenge

The chapter's objective is to come to grips with my second research question "**Which vertical sector from Germany's top 5 manufacturing industries according to the gross value-added perspective can best contribute to curtail the dependency on fossil fuel energy?**".

The following argumentation is now based on our findings from **Table 12** (chemical products industry), **Table 13** (food products and beverages industry), **Table 14** (transport equipment industry with the manufacture of motor vehicles, trailers and semi-trailers), **Table 15** (metal industry with the manufacture of fabricated metal products), **Table 16** (machinery and equipment industry), and **Table 18** (targeted (transposed) GHG emission reductions by 2030). Another key finding from the section 2.3.4 was that the **German M&E sector plays a central role** to supply heavyweights of the German economy according to the Germany's economic development agency GTAI (Germany Trade And Invest, 2022b, pp. 5-6). The general idea is to gradually exclude one sector after the one.

Based on the above, the two sectors from Germany's top 5 weights of the manufacturing industry from a GVA perspective that are currently very dependent on fossil fuel energy are the chemical products industry (79%), and the food products and beverages industry (63%). Hence, their dependency has to significantly decrease. As a result, the two aforementioned sectors can be excluded.

Pertaining to the transport equipment sector (section 2.3.3), it is deeply anchored in an OEM/supplier dependency model, as well for both since they profoundly depend on machinery and equipment. This naturally leads to its exclusion.

We now have two remaining sectors: the machinery and equipment sector, and the basic metals & fabricated metal products sector. Our previous findings from the respective sections 2.3.4 and 2.3.5 unmistakeably speak for their role as either strategic supplier for the former, or as **suppliers / technology partners** to large companies for the latter. With the argumentation from Professor Karen Pittel, Leibniz Institute for Economic Research in Munich, "***climate protection cannot occur without appropriate investments from the German manufacturing industry into climate neutral technologies offered by the German M&E industry***".

With the above information analysis and interpretation, I have formulated a third question to address my second research question, namely:

Q3: Based on my research, Germany's top 5 heavyweights of the manufacturing industry from a gross value-added perspective are in descending order: 1. Manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers, 2. Manufacture of machinery and equipment, 3. Manufacture of fabricated metal products, 4. Manufacture of chemicals and chemical products, and 5. Manufacture of food products and beverages. They are presently reliant on fossil fuel energy sources (lowest dependency

varying from 46% for the machinery and equipment industry to 79% for the chemical industry). While focusing on your manufacturing operations, which vertical sector from the five ones can best contribute to decrease the fossil fuel energy dependency in your industry?

As a result of the above, I can reasonably retain the German M&E sector to move on to the next sections of my Master's Thesis.

4.1 – Germany's machinery & equipment sector: major supplier to the other top 4 manufacturing industry sectors

Based on the findings from the key concepts section of my Master's Thesis, the German M&E industry is a central element to Germany's economy strength and competitiveness, is at the forefront of Industry 4.0, and broadly supplies other German manufacturing industry heavyweights with its bespoke products and services via an existing network of more than 6,000+ small- and mid-sized companies.

VDMA well illustrates in its publication "mechanical engineering – figures and charts 2022" (VDMA, 2022, p. 35) the supremacy of the German M&E industry in terms of world trade shares: in thirteen product categories such as plastics and rubber machinery, or process plant and equipment, or food processing and packaging machinery, it ranks #1, and in eight product categories such as precision tools, or power systems, or gas welding, it ranks #2.

In its publication "the robotics & automation industry in Germany" (Germany Trade And Invest, 2021b), GTAI points out that the German robotics and automation (R&A) sector is Europe's robotics and automation technology hub for industrial robots. By means of industrial and service robotics with HRC, MV and integrated assembly and handling technologies, the German R&A sector with leading companies such as KUKA, Wipro Hochrainer, Stäubli Robotics, Intelligente Peripherien für Roboter (IPR), or ROBOWORKER Automation, pushes the German manufacturing industry towards the adoption of Industry 4.0 with its advanced manufacturing topic.

Another rather anecdotal example from the R&A sector: in 2019, the German automotive industry had with 1,311, the World's largest number of industrial robots installed per 10,000 employees[66].

With the above information analysis and interpretation, I have formulated a fourth question to address my second research question, namely:

Q4: Following up with the previous question, as a *strategic supplier* to your industry in terms of value creation and still focusing on your manufacturing operations, which sector from the five ones do you select?

[66] Retrieved from the International Federation of Robotics website, press release, source https://ifr.org/ifr-press-releases/news/us-robot-density-in-car-industry-ranks-7th-worldwide, last accessed on 10 February 2023.

The next section deals with the transformational capabilities that the German M&E sector brings in.

4.2 – Germany's machinery & equipment sector: catalyst for industrial transformation

Innovation is a powerful catalyst for transformation, particularly for the manufacturing industry which faces several challenges against the backdrop of the energy and digital transitions to upgrade its business model by taking into account process efficiency, resource scarcity, and environmental-friendly energy use in order to make climate-neutral production possible.

With reference to the VDMA publication "mechanical engineering – figures and charts 2022" (VDMA, 2022, p. 22), a good indicator of the innovative strength of German M&E sector companies, is to measure their innovation with the number of patent application filings: in 2020, 21% of the 36,590 filed European Patent (EP) applications came from mechanical engineering – ahead of the USA (second) and Japan (third).

According to a BCG publication (Boston Consulting Group, 2020) in cooperation with VDMA, the M&E sector has an impactful role to play in lowering customers' carbon footprint as its innovation-driven products and services provide efficiency gains.

The best example is illustrated thereafter: based on the United Nations figures of emitted tons of CO_2 equivalents in 2017, an aggregation of thirty-six countries that belonged to either the Organisation for Economic Co-operation and Development (OECD) or the five leading emerging economies (BRICS), emitted 35 Gigatons of CO_2 equivalents out of the global 51 Gigatons of CO_2 equivalents. The BCG publication has reported out two things as regards the GHG emissions from the aggregated countries: 1.) 37% can be reduced by the use of economically feasible existing technologies from the M&E sector, and 2.) another 49% can be lowered by the use of not yet economically feasible workable technologies from the M&E sector, totalising a GHG emissions reduction potential of 86% (Boston Consulting Group, 2020, pp. 3-4). On a side note, even focusing on 1.) would be a huge leap ahead for walking the talk by kickstarting a shift toward climate protection.

Still using the BCG publication's numbers, the manufacturing industry of the thirty-six aggregated countries has accounted for 34% (11.9 Gigatons of CO_2 equivalents) of the GHG emissions, related to either process-related activities, or power generation-related activities such as the machinery and equipment operations by converting one energy source into another one (e.g., fossil fuel into heat/steam/electricity). To relate to my Master's Thesis, both German chemical products and food products and beverages manufacturing industries as heavyweight of GHG emissions (**Table 18**), ought to leverage any M&E sector technological breakthroughs.

Regardless of a limited or at-scale feasibility of the M&E advanced technology-based solutions, colossal investments are required from the buyers. It is a duty of the policy makers at a cross-nation/local level to create some legal frameworks that foster other manufacturing industries to invest into new carbon-reducing technological levers.

With the above information analysis and interpretation, I have formulated a fifth question to address my second research question, namely:

Q5: Still following up with the third question, as a *catalyst for industrial transformation* (e.g., digital/green/green digital technology) and still focusing on your manufacturing operations, which sector from the five ones do you select?

The next section deals with industrial transformational solutions from a digital and green technology perspective that the German M&E industry can bring in.

5 – Design of solutions

The chapter's objective is to come to grips with my third research question "**Considering the identified vertical sector from the second research question, what existing/emerging technologies and innovations are worth being considered?**", from three perspectives. To align with the scope of my Master's Thesis determined in the section **2.1.3**, the section will be limited to Germany's other top 4 manufacturing industry sectors from a GVA perspective (hence the M&E sector is excluded).

Based on the work done before, my assumption is that there are solely two technology-related dimensions in the design of the solutions: the digital and the green one. Thus, the first perspective is going to be tied to the transformation of the manufacturing industry driven by digital technology, and the second perspective is going to be tied to the transformation of the manufacturing industry driven by green technology. The third perspective is going to be an attempt to consolidate the two aforementioned dimensions.

In order to go beyond the pure aspect of identifying the technology-based solutions, I will also try to gauge a Market and Technology Readiness Level (MTRL) whenever possible based on my understanding of my sources. Each of the components assesses market and technology maturity respectively. The MTRL framework has been developed by "*Frank Khan Sullivan, Michel Drescher from the Oxford University e-Research Centre, and Frank Bennett at Cloud Industry Forum, and was originally used to support several European Research & Innovation projects in cloud software and security to develop a go-to-market strategy*" [67]. The authors published the framework in 2017 (Khan Sullivan et al., 2017). The nine Technology Readiness Level (TRL) (Khan Sullivan et al., 2017, pp. 3-4) and the nine Market Readiness Level (MRL) (Khan Sullivan et al., 2017, pp. 5-6) can be outlined as follows:

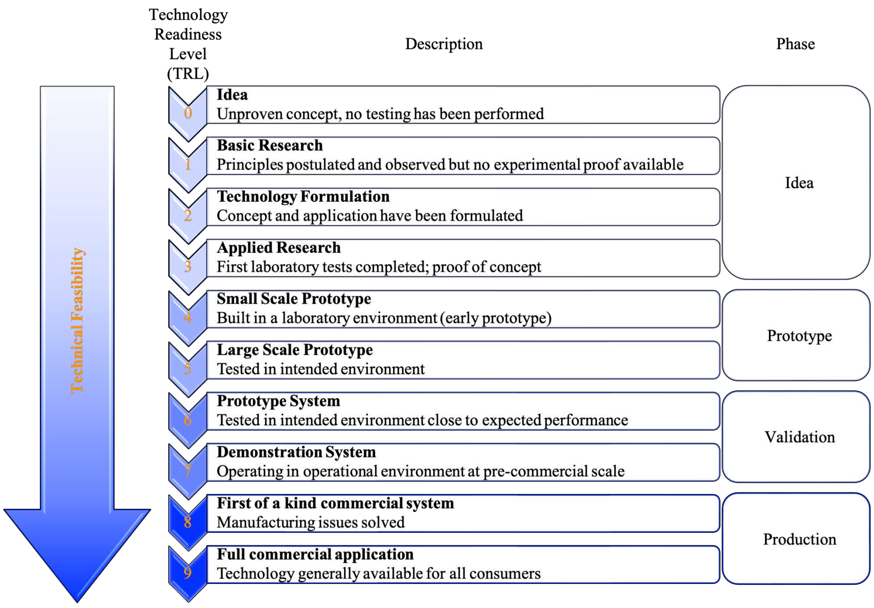


Figure 14: Definitions of the TRLs (own creation)

[67] Retrieved from the LinkedIn website, article, source https://www.linkedin.com/pulse/market-technology-readiness-mtrls-frank-khan-sullivan, last accessed on 13 February 2023.

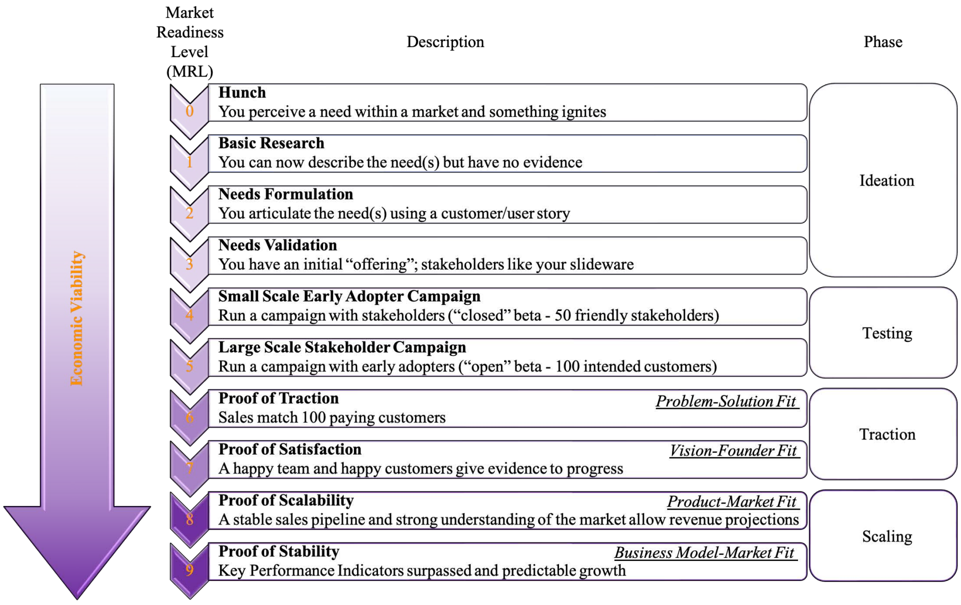


Figure 15: Definitions of the MRLs (own creation)

As a result of both TRL and MRL dimensions, one can visualise where a technology/solution is on a chart. TRL values will be then referred to as TRL 0…TRL 9 while MRL values will be then referred to as MRL 0… MRL 9.

However, I would like to weight the expectations of being able to identify both dimensions for any given technology. As the breadth of my information sources is non-exhaustive, it is paramount that I stay objective in my interpretation of the information sources. Therefore, I will act accordingly and do my best.

5.1 – From the digital technology perspective

Moving away from silo-like, partly fragmented manufacturing operations, more and more businesses are harnessing a transformation toward connected, defragmented manufacturing operations by embracing the concept of smart manufacturing. There are two transformational ingredients to smart manufacturing: Industry 4.0 – whereby connected machinery and equipment monitor and improve manufacturing processes through self-optimisation and autonomous decision making, collect data through sensors and actuators that are then scrutinised via data analytics to determine the actions required for improving performance and efficiency of manufacturing operations, identify opportunities for operations automation, and Industry 5.0 – which focuses on re-integrating the labour force on higher value-added activities and have a complementary dual system man-cobot.

In this context, the IIoT has taken off and emerged; by combining IT with operational technology (OT) such as the monitoring and control of industrial processes and systems, IIoT turns into a vital component of smart manufacturing that redefines manufacturing operations.

As an essential supplier of smart manufacturing, the German industrial M&E sector is redeploying its trump cards against the backdrop of sustainable and efficient manufacturing operations. What types of digital technology does it make use of? What TRL/MRL can be assigned to? This is what I seek to answer beneath.

I have used two literature sources to mould this section: 1.) a publication report "Global Machinery & Equipment Report 2022 – Thinking Outside the Machine" from Bain and Company (Bain & Company, 2022), 2.) a study "Customer centricity as key for the digital breakthrough" co-authored by VDMA and McKinsey (McKinsey & Company, 2020).

With reference to 1.), the global industrial M&E sector is evolving from a single products-based business model to an integrated hardware, software, and service offerings-based business model; the German industrial M&E sector is not exempt from this shift. Machinery and equipment can no longer thrive based on the sole one-dimensional hardware approach; exposed to the hardware commoditisation threat driven by a competitive landscape, innovation requires to re-think about machinery and equipment value proposition with a multi-dimensional approach, namely hardware, software (i.e., strategic choice of the technology stack for product/application design and development), automation (i.e., robotics), services/applications (e.g., predictive maintenance, remote maintenance, operational efficiency, fault detection), and industry-specific bespoke solutions. While the hardware dimension still exists, software and automation capabilities drive the interoperation with other connected machines while the market/business solutions are specifically adapted to clients' needs (a minimum of problem-solution fit has been attained; MRL 6 and beyond).

Two indicators have emphasised a transformation of the (industrial) M&E sector while comparing the time period 2011-2015 with the time period 2016-2020: a.) the number of mergers and acquisitions made by machinery and equipment companies related to software, cloud services/cloud computing, and data analytics, and b.) the number of patent applications filed by machinery and equipment companies related to software, cloud services/cloud computing, and data analytics. At a global level (i.e., not specific to Germany) for a.): a rise of 76% while a decline of 11% for companies just focusing on hardware, and for b.) a rise of 27% while a decline of 10% for companies just focusing on hardware. These two indicators are denoting that the digitalisation of the industrial M&E sector is clearly under way.

Through data compilation and data analytics use, the industrial M&E sector can improve machinery and equipment function, optimise their industrial output and quality, and rise their overall industrial process performance. By dint of AI with ML, the disruption/failure and maintenance reports of machinery and equipment can be scrutinised to identify patterns that will lead to downtime prevention.

With reference to 2.), I am going to tackle two topics that were not directly addressed in 1.): platforms (as a PaaS model) and applications (as a SaaS model). The findings from the VDMA/McKinsey study were not specific to the German industry; they came from the Western European industry. However, I have made the assumption that the insights shared in the study are applicable to the German industry to a large extent.

While raising the assumption that IIoT is similar to IoT from an architecture standpoint, digital platforms and applications are both part of the IoT technology stack, a series of multiple layers of hardware, software and communication technologies that connect things over the Internet for monitoring and controlling purposes. With its perception, network, middleware, application, and business layers, the IoT technology stack can be represented in a 5-layer architecture (Khan et al., 2012, Figure 3). While focusing on customer centricity and industry-specific needs, what digital solutions should the industrial M&E sector do? Should it develop industry-specific IIoT/IoT platforms or should it rather develop applications?

This is what I am going to tackle beneath. My idea is to decipher the findings from 2.) and create a table taking account of the top 4 heavyweights of the German manufacturing industry from a GVA perspective, and the two aforesaid solutions (platforms | applications) with their corresponding estimated TRL/MRL indicator as well as with whom they have decided to partner with in order to build up their own solution.

	Solutions from the industrial M&E manufacturing industry			
	Platforms (IIoT)		Digital Applications	
	Focus / Observations / Rationale / TRL / MRL			
Manufacture of motor vehicles, trailers and semi-trailers				
	Not a focus. Industry end customers have the tendency to partner with technology players (e.g., Microsoft with Azure IoT, Amazon with AWS IoT, and IBM with IBM Watson IoT Platform) who establish digital platform standards. As a result, the platform is either being designed or has already been implemented[68] on the OEM/supplier ecosystem side.		Is a focus; 1st focus on improving effectiveness, efficiency, ease of integration into a heterogeneous machinery and equipment park, and tracking downstream, current, and upstream processes end to end as well as data quality; 2nd focus on improving end-customer service/support through technology allowing remote monitoring, installation, and AR-enhanced interaction; 3rd focus on application compatibility with a broad machinery and equipment variety; 4th focus on open standards and universal interfaces that embrace manufacturer independency.	
	TRL0-3	MRL0-3	TRL6-9	MRL6-9

[68] Examples: BMW Open Manufacturing Platform (Microsoft Azure), Volkswagen Industrial Cloud (Amazon Web Services).

Manufacture of fabricated metal products				
	Is a focus; given the end customers' diversity and speciality (typically SMEs) as highlighted in the **section 2.3.5**, an industry-specific platform, aligned with the end customers' value added expectations, could be successful.		Is a focus. Special-purpose applications due to the nature of decentralised static processes (cellular manufacture with fixed machinery and equipment) and the heterogeneity of the machinery and equipment park (e.g., for smelting, moulding, drilling, milling). Emphasis on improving process quality and logistics.	
	TRL4-5	MRL2-3	TRL6-9	MRL6-9
Manufacture of chemicals and chemical products				
	Not a focus; it is similar to a large extent to the transport equipment sector relating to the manufacture of motor vehicles, trailers and semi-trailers with technology players already well positioned in offering IIoT platforms for this industrial sector (e.g., BASF with brains.app powered by IntelliSense.io).		Is a focus; 1st focus on manufacturer-independent applications for cellular respectively continuous manufacture within one (direct sequence) or several (indirect sequence) production lines. 2nd focus on operational efficiency, effectiveness, reliability, and safety.	
	TRL0-3	MRL0-3	TRL6-9	MRL6-9

Manufacture of food products & beverages				
	Opportunity to create an industry-specific but standards-based platform centred on production lines & processes as well as on open standards for the integration of existing in-house systems and heterogeneous machinery and equipment.		Focus on developing applications centred on resources use optimisation (e.g., raw material reduction, energy efficiency improvement), production line flexibility, and shortened changeover[69] times.	
	TRL6-7	MRL4-5	TRL6-7	MRL4-5

Table 19: Solutions from the industrial M&E manufacturing industry for the top 4 heavyweights of the German manufacturing industry from a GVA perspective

Based on the above table, digital applications from the M&E manufacturing industry that clearly focus on improved service, higher equipment output and optimised resources use represent the bulk of opportunities in the IIoT context regardless of the targeted manufacturing industry (any of our top 4 heavyweights from a GVA perspective).

For the four analysed manufacturing industries, there is so far no industry standard for digital platforms to date from the industrial M&E manufacturing industry; however, the latter expects standards for platforms, such as Open Platform Communications Unified Architecture (OPC UA), to become available in the mid-term, allowing real-time data exchange from the factory shop floor to the cloud with the benefits of simplification, superior security, and seamless machine interconnection irrespective of the machinery and equipment manufacturer and its operating system, resulting in pushing forward the MRL indicator.

From an end customer’s perspective, platforms facilitate the applications enablement. With operational purposes in mind, end customers from any of our top 4 manufacturing heavyweights from a GVA perspective are inclined to invest in software-based services/applications that have a financial impact on maintenance, repair costs reduction, and overall equipment effectiveness (the de facto standard for measuring manufacturing productivity).

With the above information analysis and interpretation, I have formulated a sixth question to address my third research question, precisely:

[69] In a given production line, elapsed time to transition the machinery and equipment to working on a new product.

Q6: Assuming that the German machinery and equipment manufacturing industry is instrumental in the success of connected, responsive, and flexible manufacturing operations by reorienting its value proposition with a multi-pronged strategy geared toward hardware, software, automation/robotics and service/application offerings integration, this integrated approach enables new business opportunities for your organisation.

To broaden out the scope of this section, I have found enlightening to show a map of use cases based on Industry 4.0 in the German manufacturing industry that features the type of digital technology implemented. As practise-based evidence, the map showcases the "pulse measurement of the German manufacturing economy for embracing Industry 4.0-related solutions. The non-exhaustive data source comes from the German Federal Ministry for Economic Affairs and Climate Action (Bundesministerium für Wirtschaft und Klimaschutz – BMWK)[70] that kickstarted the initiative Plattform Industrie 4.0 back then in April 2013. Below is a snapshot of the map with its 105 use cases; the data base contains use cases that are between four and eight years old.

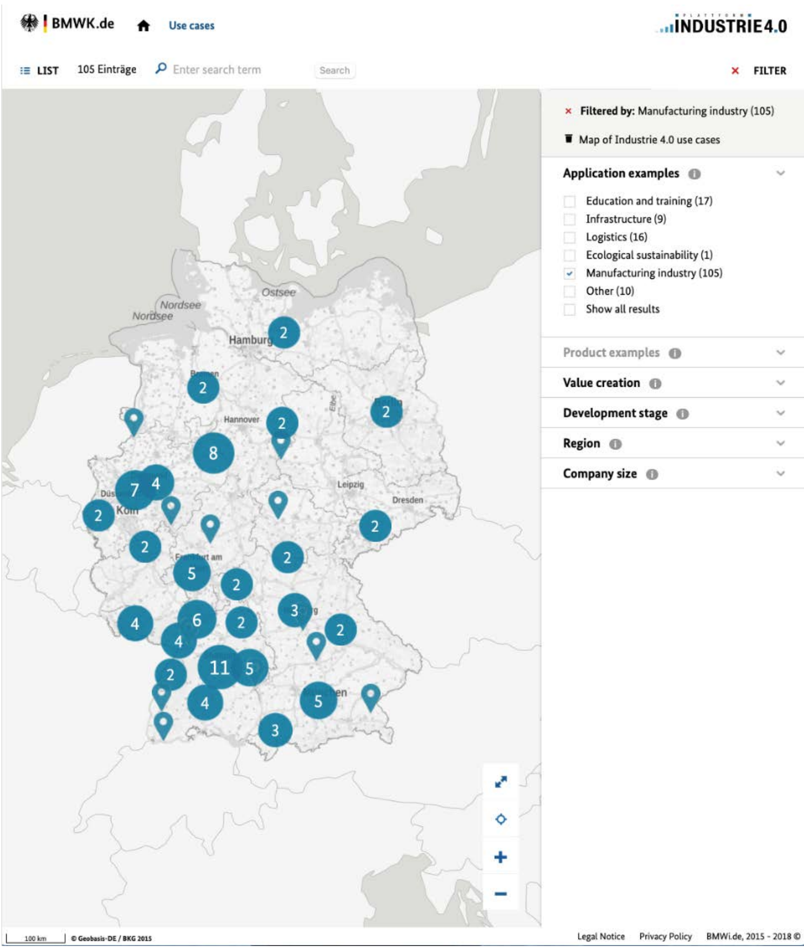


Figure 16: Map screenshot of the 105 use cases, manufacturing industry

[70] BMWK, Plattform Industrie 4.0, source: https://www.plattform-i40.de/IP/Navigation/Karte/SiteGlobals/Forms/Formulare/EN/map-use-cases-formular.html, last accessed on 28 February 2023.

There are four development stages (from the least to the most mature): R&D project, demonstrator, market launch/piloting, and market-ready/productive use. I have assigned a TRL/MRL to each of these development stage; the transposition looks then like as follows: R&D project = TRL2-3/MRL2-3, demonstrator: TRL4-5/MRL4-5, market launch/piloting: TRL6-7/MRL6-7, and market-ready/productive use: TRL8-9/MRL8-9.

I have analysed each of these 105 records and made the raw data available in the appendix A; my next step was to filter out the relevant information (appendix B) for the visual representation of the 105 use cases with the main Industry 4.0-based digital technology categories below (click on the figure snapshot for its enlarged version appendix C).

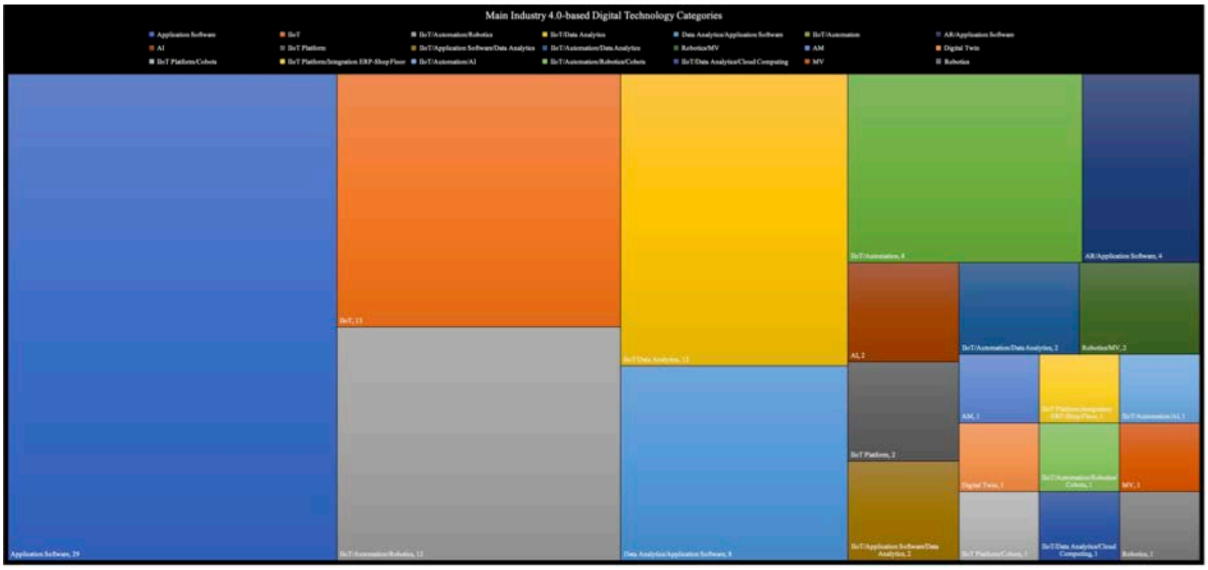


Figure 17: 105 use cases with the main Industry 4.0-based digital technology categories, source BMWK, Plattform Industrie 4.0

From the information above, I have retrieved three observations. 1.) the following five digital technologies – application software, automation, data analytics, IIoT, and robotics – whether as single or combined with another ones, have approximatively made 80% of the use cases, 2.) AR in conjunction with application software, and AI are both digital technologies that are gathering momentum in the manufacturing industry world, and 3.) cobots ought to be presently rather considered as a trial field at its onset.

By looking at the data from an industry perspective (considering our top 5 manufacturing industries from a GVA perspective), it has turned out that the blend of digital technology varies from one industry to the other one.

- For the transport equipment manufacturing industry featuring the automotive industry, AR, data analytics and application software are leading the way with a high degree of TRL/MRL maturity.
- For the M&E manufacturing industry, application software, data analytics and IIoT are standing out with a mature TRL/MRL.

- For the fabricated metal products sector, the opportunities offered by application software and data analytics with a high degree of TRL/MRL contribute the most to help transform the industry towards smart manufacturing.
- For the chemical manufacturing sector, IIoT, data analytics, automation, and robotics are the drivers for transitioning the industry towards the next increment in value added thanks to their high degree of TRL/MRL.
- For the food products and beverages sector, IIoT, data analytics, and automation/robotics are the two most impactful digital technologies that accompany the industry in its quest for adapting its manufacturing processes and capabilities towards smart manufacturing.

To close this section, I have formulated a seventh question to address my third research question, namely:

Q7: Following on from the previous question, the success of your digitalisation toward smart, effective, and efficient manufacturing operations resides in a still-to-be-defined equilibrium between industrial internet of things, automation/robotics, data analytics, artificial intelligence with machine learning, and apps.

After the digital dimension of the solutions design topic, I am going to address the green dimension of the solutions design in the next section.

5.2 – From the green technology perspective

With a scholar’s eyewear, what does green technology mean and how does green technology enable green manufacturing? This is what I am going to cover now.

There are two literature sources that I have used: 1.) a journal article “Green Technology” co-authored with Professor Matthew Sadiku (Sadiku et al., 2018), 2.) Professor Matthew Sadiku’s book “Emerging Green Technologies” with chapter 14 pertaining to green manufacturing (Sadiku, 2020, pp. 145 - 155), and 2.) Professor David Dornfeld’s book “Green Manufacturing - Fundamentals and Applications” (Dornfeld, 2013).

Etymologically, there are two meanings in the expression “green technology”. Let me start with technology. According to 1.), technology is the application of knowledge; as knowledge enables innovation, new advancements in the mankind’s life arise. This has been the case for thousands of years since the Egyptian Civilisation. However, technology generates advantageous and less advantageous outcomes, and among the less advantageous outcomes, baseline (in comparison with green) technologies have generated visible negative effects on the mankind’s environment like pollution, climate change, GHG emissions rise, natural resources and raw materials depletion, unbridled consumption, disproportionate production scheme, etc. Let me continue with green now; in order to offset these less advantageous outcomes from technology, green is kicking in and is trying to restore the original state of living (for people) and operating (for businesses) in a more sustainable and environmentally-friendly manner. It is a common ground to associate green technology with sustainable technology, environmental technology, or clean technology; other terminologies like carbon-reducing technology, or climate-neutral technology are being increasingly used.

Making a parallel between baseline technology and green technology as described in the previous paragraph, according to 2.) green manufacturing is the response to offset all less advantageous outcomes resulting from the baseline manufacturing industry (e.g., decarbonisation of the industrial manufacturing processes, energy consumption and efficiency, least resources utilisation, waste reduction, etc.), and re-integrates the environmental impact as a criterion of sustainability.

With reference to 3.), section 1.1.2, p. 4, green manufacturing is defined with two complementary intents in mind: the first one is that "*green manufacturing is a process or system which has a minimal, non-existent or negative impact on the environment*", and the second one is that it drives "*the creation of manufacturing products that use materials and processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound*", even heading toward sustainable manufacturing. As an ingredient to green manufacturing, green technology is one enabler, the two other ingredients remaining people and (sustainable) processes as denoted in **Figure 3**.

As green technology is inherently tied to decarbonisation, what are the GHG emissions-reducing technologies and what are their TRL/MRL? This is what I am going to elaborate beneath.

Many of my information sources are not specific to Germany. Hence, I have raised the assumption that what applies to one industry/several industries of either another country or an aggregation of countries in the case of the BCG publication (Boston Consulting Group, 2020), I have transposed the findings to the corresponding German manufacturing industries.

With reference to the BCG publication (Boston Consulting Group, 2020, pp. 6-7) with its multi-country basis, the four identified carbon-reducing technologies with an evaluated TRL and MRL in the range of 8-9 are the heat optimisation and waste heat recovery technology, increased electrical and mechanical efficiency technology, energy management systems (EMS) technology, and heat, air ventilation and cooling (HVAC) technology. With an evaluated TRL in the range of 6-7 and MRL in the range of 4-5, the identified technology is the recycling rate increase technology. With an evaluated TRL and MRL in the range of 2-5 (not yet technologically and/or economically applied) depending on the technology type and the remaining amount of endeavours to reach the problem-solution fit stage (**Figure 15**), the identified technologies are fuel substitutes technology, green hydrogen (H_2) as feedstock technology, and the carbon capture, utilisation and storage (CCUS) technology.

Below, a carbon-reducing technology/industry matrix can be found; the higher the contribution to reduce GHG emissions is, the bigger the sphere is; the sphere size is relative to the highest identified contribution (immediate or potential); largest: CCUS for chemical products; smallest: HVAC for food products & beverages.

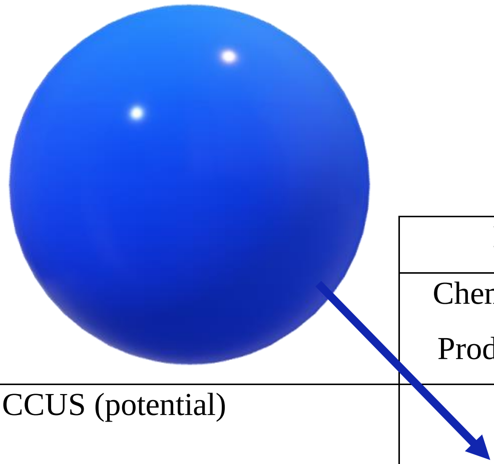
		Identifiable Manufacturing Industries		
		Chemical Products	Food Products & Beverages	Transport Equipment Products
Technologies	CCUS (potential)		N/A	N/A
	Fuel substitutes (potential)			
	Heat optimisation and waste heat recovery (immediate)			
	Electrical & mechanical efficiency (immediate)			
	Energy management systems (immediate)	N/A	N/A	
	HVAC (immediate)	N/A		N/A
	Green H_2 as feedstock (potential)		N/A	N/A
	Recycling rate increase (potential)		N/A	N/A

Table 20: Carbon-reducing technology/industry matrix, immediate and potential GHG emissions reductions

For the four immediate technology categories, there are key machinery and equipment technologies that lower GHG emissions. Let me briefly walk you through them while using the BCG publication as a reference (Boston Consulting Group, 2020, pp. 11-14).

For the purpose of heat optimisation and waste heat recovery, the technically and economically accessible technologies are heat exchangers (a core technology for recovering waste heat), high-efficiency burners (a core technology for pre-heating air and fuel to raise effective operation), systems that recover the waste heat from exhaust gases and send it to other heat consumers, heat pumps (a core technology for raising the waste heat temperature to levels needed in other manufacturing processes), and effective heat storage systems (a core technology for waste heat storage with on-demand heat redistribution).

For the purpose of electrical & mechanical efficiency of manufacturing machinery and equipment, the technically and economically accessible technologies are highly-efficient electric motors with variable-speed drives and intelligent controls for on-demand operation (a core technology for producing the same mechanical power while consuming less electrical energy, extending operations lifetime, and offering interconnection for smart manufacturing capabilities). Also, pumps, compressors, fans contribute to energy cost savings.

For the purpose of energy management systems, monitoring and benchmarking systems enable to review energy usage patterns of machinery and equipment while diagnosing energy consumption reduction potentials. This adds up another contributor to reduce global GHG emissions through energy savings.

Regarding the last category, for the purpose of HVAC, energy-efficient, automated and on-demand HVAC systems also contribute to energy cost savings while optimising heat and energy use and storage.

For the four potential technology categories, the M&E sector has also got trump cards to play. I will just focus on the three most likely impactful technologies, namely CCUS, fuel substitutes, and H_2 as feedstock. Let me briefly walk you through them while using the BCG publication as a reference (Boston Consulting Group, 2020, pp. 16-17).

For the purpose of CCUS, I consciously limit the scope to industrial processes, like for example the production of petrochemicals or ammonia (NH_3) for fertilisers or plastics in the chemical products manufacturing industry. As the used fossil fuels cannot be economically replaced with green fuels, two types of CCUS technology can be used to capture the released carbon-dioxide at the industrial facilities: pre-combustion carbon capture or oxy-fuel combustion systems (more costly but with a higher effectiveness). The economic feasibility of CCUS largely depends on the storage facilities availability, on the storage facilities transport cost, and on the purity of the gas being captured (the purer the gas is, the less costly it is to process the gas for other uses). For industrial processes whose feedstocks are inherently tied to fossil fuels, CCUS technology represents a major contributor to GHG emissions reduction (a nod to the 80/20 Pareto Principle).

Regarding the fuel substitutes technology, it is the second biggest potential contributor to decarbonisation. It is about a technology that involves the substitution of fossil fuels with green fuels or e-fuels, which are produced with electricity from renewable energy sources (e.g., solar, wind, biomass, geothermal power, hydroelectric power). There are two types of green fuels: the most basic one referred to as green H_2, and the more advanced ones referred to as Power-to-X (P2X) fuels such as power-to-gas, power-to-liquid, power-to-heat. As regards green H_2, it is the result of splitting water into oxygen and hydrogen by means of an electrolyse. Then, green H_2 can be used either directly as a fuel for internal combustion engines (relevant for the transport equipment manufacturing industry), or as a core component for the synthesis of other liquid/gaseous e-fuels; one example of gaseous e-fuel is the synthetic natural gas (SNG) in combination with carbon capture from industrial exhaust gases. Regarding P2X fuels as power-to-liquid, methanol is a relevant example to the transport equipment manufacturing industry, and ammonia (NH_3) is a relevant example to the chemical products manufacturing industry. Regarding fuel as power-to-gas, synthetic methane made from green H_2 and CO_2 captured from the air or exhaust gases at the industrial facilities site, which is then used as feedstock for the chemical products manufacturing industry. On a side note, VDMA refers to P2X (VDMA, 2021, p. 11) as a key technology for the energy transition, and the M&E sector supplies many of the components necessary for its successful usage.

Regarding the green H_2 as feedstock technology, one lighthouse application is the construction of electrolysis facilities for its production; it can then be fed into the chemical products manufacturing industry.

For our top 4 manufacturing industry heavyweights from a GVA perspective, substantial capital expenditures into new capital goods bought from the machinery and equipment manufacturing industry are and will be required to pull all immediate and potential (future) decarbonisation technology levers. For the sole country of Germany, this represents € billion opportunities for the German M&E sector, at a multi-country scale, even € trillion opportunities, while paving the way for attaining sustainable development goals.

In order to cross the chasm from TRL/MRL 2-5 to TRL/MRL 8-9 (another nod to the inescapable reference book "crossing the chasm" from Geoffrey Moore), R&D and innovation clusters need to purse their endeavours to bring the not yet technically and economically feasible technologies/solutions (e.g., CCUS, fuel substitutes, green H_2 as feedstock) to a maturity degree that will make businesses confident to invest in to get in return the expected value.

Regardless of immediate or potential GHG emissions reductions, every responsible business from the three identifiable manufacturing industries (transport equipment sector, chemical products sector, and food products & beverages sector) ought to use the full range of decarbonisation technologies. Our policy makers should create temporary financial incentives (e.g., corporate tax reduction) in order to let businesses free up investments for a sustainable transformation.

With the above information analysis and interpretation, I have formulated an eighth and a ninth question to address my third research question, namely:

Q8: Assuming that the German machinery and equipment sector is key to accelerate the decarbonisation of other industries, I have identified in my research four technically and economically accessible technologies with immediate decarbonisation levers: 1.) Heat optimisation and waste heat recovery, 2.) Electrical & mechanical efficiency, 3.) Energy management systems, and 4.) Heating, ventilation, and air conditioning (HVAC). Based on your operational needs and your own experience, which technology, taken individually or combined, currently contributes the most to your organisation's greenhouse gas emissions reduction objectives?

Q9: Assuming that the German machinery and equipment sector is key to accelerate the decarbonisation of other industries, I have identified in my research three not yet fully technically and economically accessible technologies with potential decarbonisation levers: 1.) Carbon capture, utilisation, and storage (CCUS), 2.) Fuel substitutes, 3.) Green hydrogen as feedstock. Based on your operational needs and your own knowledge, which technology, taken individually or combined, would/shall contribute the most to your organisation's greenhouse gas emissions reduction objectives?

5.3 – From a combined perspective (green digital technology)

Let me first allow to delineate my understanding of the terminology green digital technology. Based on the introductory findings in the section 5.2, green describes the attribute of a whole (i.e., a single thing of many parts) that concerns with the use of whatever type of resources in such a manner that negative impacts such as raw materials depletion, waste creation, material loss (i.e., scrap), inefficient energy usage, on a bigger system like our environment can be mitigated.

As a major supplier of Germany's top 4 manufacturing industries from a GVA perspective, the M&E sector in general and the German one in particular, must take its responsibility to embrace an active and role model culture (in a sense of setting actions and behaviours) from sustainable and effective machine design over energy and material efficient operation through to environmentally friendly machine recycling; a true transparent, traceable end-to-end process along the entire supply chain as a matter of fact.

To illustrate this section with a practical example, I would like to refer to a concrete example from one of Germany's leading providers of automation technology and industry software, namely Siemens, as I have found the case both revealing and informative of what green digital technology can be.

I have discovered the case thanks to a YouTube video from the publisher INDUSTRYforward[71] whose speaker was Siemens Chief Technology and Strategy Officer, Dr

[71] YouTube, publisher INDUSTRYforward, German source: https://www.youtube.com/watch?v=vZdI6rQhc1k, last accessed on 6 March 2023.

Peter Körte, at the IFS 2022 conference. After five minutes, he took the example with the manufacture of smartphones and asked the audience how many CO_2-equivalents a smartphone owner generates during the whole smartphone lifecycle. Based upon a certain type of calculation model, total emissions account for 740 kg of CO_2 equivalents, and 58% find their origin during the manufacture, the remainder being associated with usage. From these 58%, as a smartphone manufacturer, you are in control of only 10% of the total emissions, meaning that the remaining 90% find their origin in the supply chain, an organisation that is out of your control. How can you then address the topic of supply chain decarbonisation?

Imagine that you need to know the CO_2 emission-related data (e.g., in the form of product carbon footprints aka PCF) linked to your battery suppliers from a trustworthy and transparent source: with the help of the green digital twin application, commercialised under the name SiGreen[72] based on DLT (i.e., blockchain technology that supports the verifiable credentials creation and exchange while maintaining data integrity and confidentiality), Siemens has designed an ecosystem-based solution for the PCF exchange between manufacturers and suppliers in cooperation with its horizontally integrated cross-industry network Estainium[73]. For both manufacturers and suppliers, they gain in efficiency as the focus is on managing, certifying and offsetting PCFs, and not on data collection.

This leads me to the formulation of a tenth question to address my third research question, namely:

Q10: With climate protection being a top priority at European and national governmental levels, ecosystem-based solutions from the German machinery and equipment manufacturing industry embracing green digital technology can effectively contribute to make carbon-neutral product manufacture happen across many and various sectors of the manufacturing industry. Within the next 12-24 months, there will be a rising need for green digital technology such as solutions dealing with product carbon footprint traceability and transparency that will help your organisation reach its carbon neutrality objectives.

[72] Siemens, SiGreen website, source: https://app.sigreen.siemens.com, last accessed on 6 March 2023.
[73] Siemens, press release website, source: https://press.siemens.com/global/en/pressrelease/siemens-has-developed-ecosystem-based-approach-exchange-emission-data, last accessed on 6 March 2023.

6 – Evaluation of the solutions

The chapter's objective is to come to grips with my fourth research question "**What results on the fossil fuel energy dependency reduction and energy efficiency gains have already been delivered to date and how impactful and measurable are they for the identified vertical sector of the German manufacturing industry?**".

From our chapter **Design of solutions**, the principal lesson is that there is neither a universal nor no one-size-fits-all solution for the German M&E manufacturing industry. Each organisation dealing with manufacturing operations needs to identify, assess, build, measure, learn and adapt its own approach. To tackle both fossil fuel energy dependency reduction and energy efficiency gains, a unified approach in leveraging digital, green and ever digital green technology is likely to produce the best results. As a matter of fact, the digital and green dimensions of a given technology complement each other.

Based on the findings from the previous sections (especially chapter 5) and my interpretation, I have drawn up a table below that summarises what the respective industry nowadays focuses on.

Industry	Digital Dimension	Green Dimension	Green Digital Dimension
Manufacture of machinery & equipment	IIoT, digital platforms (as PaaS), automation/robotics, application software, service offerings, digital applications (as SaaS), AI with ML, data analytics, cloud computing	Heat optimisation & waste heat recovery, increased electrical & mechanical efficiency, energy management, increase of recycling rate	Simulation and prediction of product carbon footprints based on distributed ledgers
Manufacture of transport equipment (motor vehicles, trailers and semi-trailers)	IIoT, digital applications, AI with ML, autonomous automation/robotics, data analytics, cloud computing, AR, application software,	Heat optimisation & waste heat recovery, increased electrical & mechanical efficiency, energy management systems, e-fuels	Could not be identified, survey data could not shed any light on that topic

Manufacture of chemicals & chemical products	IIoT, digital applications, automation/robotics, data analytics	Heat optimisation & waste heat recovery, increased electrical & mechanical efficiency, carbon capture, utilisation and storage, green H_2 as feedstock, e-fuels, increase of recycling rate	Could not be identified, survey data could not shed any light on that topic
Manufacture of food products & beverages	IIoT, digital platforms, digital applications, automation/robotics, data analytics	e-fuels, increased electrical & mechanical efficiency, heat optimisation & waste heat recovery	Could not be identified, survey data could not shed any light on that topic
Manufacture of fabricated metal products	IIoT, digital applications, digital platforms (potentially), application software, AM, data analytics	Could not be identified, survey data could not shed any light on that topic	Could not be identified, survey data could not shed any light on that topic

Table 21: Summary of the digital, green and green digital dimensions
of Germany's top 5 manufacturing industries from a GVA perspective

With the above information analysis and interpretation, I have formulated an eleventh and twelfth question to address my fourth research question, namely

Q11: Now, I would like to turn this question to the online survey participants, who work in the machinery and equipment sector with at least some manufacturing operations in Germany (the point being that I have targeted the German manufacturing industry and its top 5 heavyweights from a gross value-added perspective as per the third question of the online survey). What results on the fossil fuel energy dependency reduction and energy efficiency gains have already been delivered to date?

Q12: Following up with the previous question, how impactful and measurable are the results on the fossil fuel energy dependency reduction and energy efficiency gains?

6.1 – Online quantitative survey

When I wrote my Master's Thesis, my exposure to the German manufacturing industry was limited; hence, I could not leverage a representative network of leaders and experts who could have shared with me precious data, insights into the topics of my research questions.

For this reason, I have conceived a twelve-question online quantitative survey with SurveyMonkey, a product from Momentive[74], that made empirical data gathering, evaluation and interpretation possible. Each question has been detailed out in the appendix section (Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, and Q12), and a screenshot gives you the look and feel of the survey when it was released. The survey started out on 9 March 2023 and seventeen (17) replies had been collected up to 28 March 2023. The answers are appended to each question (individual results for Q1 as an example).

What are the main survey outcomes?

- Q1: the respondents have shared to *a very large extent* the viewpoint that the German leading manufacturing industry in terms of value-added can play a role model by largely contributing to reduce GHG emissions by 2030 by a minimum of 55% in comparison with the 1990s level.
- Q2: the respondents have shared to *a large extent* the viewpoint that the legal framework in conjunction with the EU Green Deal's objectives could represent a risk for their company's financial growth.
- Q3: with a nearly equal distribution of the answers (29.4%, 23.5%, and 29.4%), the *three industrial sectors* manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers, manufacture of machinery and equipment, and manufacture of chemicals and chemical products have stood out to *directly* curtail fossil fuel energy dependency. This clearly underlies the fact that any other given industry will not start showing any progress on fossil fuel energy dependency reduction till tangible results are achieved in any of these three industrial heavyweights. This again shows how strong the link between the various German manufacturing industries is.
- Q4: as a strategic partner for curtailing fossil fuel energy dependency, two sectors have stood out: *manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers*, and *manufacture of chemicals and chemical products* equally at 35.3% (comment: one respondent was referring to the manufacture of raw plastics materials which is ultimately part of the chemical industry). The manufacture of machinery and equipment came third

[74] SurveyMonkey, logged-in area, source: https://www.surveymonkey.com, last accessed on 28 March 2023.

with 17.7%. This again reinforces the fact that the contributions of some are the results of others.

- Q5: as a catalyst for industrial transformation, *almost 50%* of the respondents have identified the manufacture of machinery and equipment as their first choice, while less than one quarter (25%) of the respondents have equally identified manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers, and manufacture of chemicals and chemical products as their first choice. This unambiguously lays stress on the central role of the M&E sector in pushing ahead other industries to embrace Industry 4.0.
- Q6: *over 80%* of the respondents have concurred with the fact that with a broader value proposition (not limited to hardware), the M&E sector is an enabler of new business opportunities for their industry through a new breadth of connectivity, responsiveness, flexibility, and adaptivity for their manufacturing operations.
- Q7: *over 60%* of the respondents have concurred with the fact that digitalisation of their manufacturing operations is going to be the resulting force between IIoT, automation/robotics, data analytics, AI with ML, and applications.
- Q8: pertaining to technically and economically accessible technologies with immediate decarbonisation levers, *over 40%* of the respondents have answered that the combination of heat optimisation and waste heat recovery, electrical & mechanical efficiency, energy management systems, and HVAC currently contributes the most to their organisation's GHG emissions reduction objectives. The M&E sector has wide recourse to these technologies.
- Q9: pertaining to not yet fully technically and economically accessible technologies with potential decarbonisation levers, *almost 30%* of the respondents have answered that the combination of CCUS, fuel substitutes, and green H_2 as a feedstock would contribute the most to their organisation's GHG emissions reduction objectives. Thanks to its innovation capability, the M&E sector is vigorously looking into solutions that recourse to all of these three technologies.
- Q10: *over 80%* of the respondents have shared the viewpoint that a rising demand for green digital technology, such as solutions dealing with product carbon footprint traceability and transparency, *is likely* to help their organisation reach their carbon neutrality objectives. As ecosystem-based innovation powerhouse, the M&E sector knowingly invests in designing and developing green digital technology-based appropriate solutions.

- Q11: the data interpretation is a bit tricky as only thirteen (13) out of seventeen (17) respondents have answered; this logically scales our sampling down. Seven (7) out of thirteen (13) respondents have selected either "no opinion" or "I could not objectively answer the question". Out of the six (6) remaining respondents, four (4) had selected "reproducible". One (1) respondent gave the insight that digital innovation/technology has **not** played an active role while another respondent has indicated the opposite (has played an active role). Thus, I have concluded that *some levels of reproducible results* on the fossil fuel energy dependency reduction and energy efficiency gains have already been delivered to date; it is *likely* that *digital innovation/technology is a driver*, but not the sole driver.
- Q12: the same two first comments apply as in Q11 – only thirteen (13) answers, six (6) have selected either "no opinion" or "I could not objectively answer the question". For the seven (7) remaining respondents, the results on the fossil fuel energy dependency reduction and energy efficiency gains were moderately impactful and measurable for four (4) respondents, and highly impactful and measurable for two (2) respondents, and weakly impactful and measurable for one (1) respondent. This might indicate that in a particular organisational context, the measures resulting in reducing the fossil fuel energy dependency and gaining energy efficiency, have taken effect and positively impact their operations. Whether or not digital innovation/technology has been a driver has remained unknown. One (1) respondent has indicated that the results on the fossil fuel energy dependency reduction and energy efficiency gains have strengthen their competitiveness.

After the data interpretation of the survey, there comes the time to aggregate all findings and discoveries as objectively as possible in the last section of my Master's Thesis, and draw some conclusion.

7 – Outlook for Germany's other top 4 manufacturing industry sectors

The chapter's objective is to come to grips with the fifth research question "**What recommendations and best practices are currently available for Germany's other top 4 manufacturing industry sectors to reduce their GHG emissions and improve their energy efficiency while staying competitive and sustainable?**".

Based on my findings from the chapter 2.3.8 **A powerful German economy: result of an interlinked manufacturing industry** and backed up with the information collection from my online survey with Q3 (to a large extent), Q4 (to some extent), and Q5 (to a large extent), the German M&E sector seems to be in the strongest position to bolster up the transformation of Germany's other top 4 manufacturing industries from a GVA perspective through both digital and energy transitions, while consolidating their competitiveness (i.e., create a better value to customers than their competition), and laying the groundwork for their sustainable manufacturing (i.e., make use of resources without depleting them irreversibly).

With the rise of individualised manufacturing with the lot-size-one concept addressing the ever-changing end-customer expectations and the resource depletion caused by the manufacture of mass-produced goods as a result of an unconstrained consumption, the German M&E manufacturing sector strives for innovating, designing, developing, building, testing, measuring, improving, and maintaining resource-efficient, energy-efficient, adaptive, versatile, data-driven, and distributed solutions.

Through my findings in the chapter 5 **Design of solutions** and backed up with the information collection from my online survey with Q6, the German M&E sector is well positioned to deliver on the awaited collaborative dual system human-being/machine thanks to its broader value proposition that takes account of the combination between hardware, application software, digital applications, services, automation, and human knowledge and skill. This way, the manufacturing tasks/activities can be carried out by the most appropriate means based on quality-related data and resource/material usage optimisation metrics.

7.1 – Recommendations and best practices

Decarbonising the manufacturing industry should not just be talking the talk; it should be walking the walk as a respect toward future generations. Germany, with its powerful, innovative, and quality-driven manufacturing industry, can sustainably turn this branch of her economy into a climate-neutral gross value-added creator.

With the hypothesis that the German M&E sector's role is central to the other German gross value-added manufacturing sectors, I have drawn up a 12-point recommendation and best practice scheme. It should drive Germany's other top 4 manufacturing industry heavyweights from a GVA perspective (namely the manufacture of transport equipment dedicated to motor vehicles, trailers and semi-trailers, the manufacture of fabricated metal products, the manufacture of chemicals and chemical products, and the manufacture of food products and beverages) to curtail GHG emissions and improve energy efficiency.

1. Challenge your product design from a perspective of raw material consumption (e.g., use of nesting technology with computer-aided manufacturing software in the sheet metal manufacturing industry) and energy efficiency and look for alternatives and substitutions.
2. Design and build products with the circular economy principles in mind (e.g., the five R’s strategy of waste management).
3. Re-evaluate the environmental impact of the used process technology (e.g., production of ammonia used as a fertiliser and raw material for a large number of basic chemicals: away from a fossil fuel energy-intense chemical process technology like the conversion of natural gas, liquified petroleum gas, or petroleum naphtha into gaseous hydrogen to adopt solid oxide electrolyser cells technology).
4. Implement and manage the product carbon footprint traceability and transparency of your raw materials to give you a competitive advantage.
5. Fostering the usage of renewable energy sources for your manufacturing activities.
6. Nurture and sustain a supply chain ecosystem that supports your objectives of decarbonisation and climate neutrality, and mitigates company’s financial risks for a non-compliance with legally binding GHG emissions reduction.
7. Co-invest with your ecosystem in processes, technologies, manufacturing facilities that harness the simultaneous adoption of digital and non-fossil fuel energy sources usage transitions.
8. Identify the best solution approach for energy efficiency and productivity in your plants (for example by identifying which machines that consume more energy than others because of leakages) and deploy the retained solution diligently across the board.
9. Leverage a strategic alliance with a pioneer in a given technology category (e.g., process specialisation in producing synthetic fuels from hydrocarbons resulting from the combination of green H_2 produced by electrolysis of H_2O with power from renewables, and CO_2 captured either from flue gases from an industrial site or from the air) even at a TRL4-5/MRL4-5 to gain feasibility and testing experience.
10. Foster a highly collaborative human-being/robot environment through digitalisation in your manufacturing facilities to drive process efficiency.

11. Sharpen the informed decision-making in adopting corrective actions of your process inputs and outputs as well machinery and equipment usage through the broad use of digital technology like AI with ML and data analytics.
12. Do not let your competition to surf the wave of irreversible digital and energy transitions ahead of you as they will likely give rhythm to our economy mutation and beyond for a couple of decades (at least) in this twenty-first century. Act now!

Literature References

1 Groover, M. P. (2019). *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems* (7 ed.). Wiley. https://www.wiley.com/en-gb/Fundamentals+of+Modern+Manufacturing%3A+Materials%2C+Processes%2C+and+Systems%2C+7th+Edition-p-9781119475217

2 Scallan, P. (2003). *Process Planning: The Design/Manufacture Interface*. Elsevier Science.

3 Mair, G. (2019). *Essential Manufacturing*. Wiley.

4 Martin, J. W. (2006). *Materials for Engineering* (3 ed.). Woodhead Publishing. https://www.sciencedirect.com/book/9781845691578/materials-for-engineering

5 Germany Trade And Invest (MacDougall, William). (Publication Date: 22 June 2022). *The Automotive Industry in Germany - Issue 2022/2023*. https://www.gtai.de/en/invest/service/publications/the-automotive-industry-in-germany-64580, last accessed on 23 November 2022

6 VDA (Press and Communications Department). (Publication Date: 12 November 2020). *Annual Report 2020. The automotive industry in facts and figures.* https://www.vda.de/vda/en/news/publications/publication/anual-report-2020, last accessed on 23 November 2022

7 Friedrich-Ebert-Stiftung (Bormann, René; Fink, Philipp; Holzapfel, Helmut). (Publication Date: October 2018). *The future of the German automotive industry*. https://library.fes.de/pdf-files/wiso/14450.pdf, last accessed on 23 November 2022

8 Boston Consulting Group (Lorenz, Markus; Lueers, Martin; Ludwig, Max; Rees, Simon; Rauen, Hartmut; Zelinger, Matthias; Stiller, Robert). (Publication Date: 14 July 2020). *For machinery makers, green tech creates green business*. https://www.bcg.com/publications/2020/for-machinery-makers-green-tech-creates-green-business, last accessed on 10 February 2022

9 VDMA (Wiechers, Ralph; Scholl, Florian; Paul, Holger). (Publication Date: 13 April 2022). *Mechanical engineering – figures and charts 2022*. https://www.vdma.org/documents/34570/6128644/Maschinenbau%20in%20Zahl%20und%20Bild%202022.pdf/43a31467-dc91-1bd9-41ee-97413c4e769d, last accessed on 30 November 2022

10 Germany Trade And Invest (MacDougall, William). (Publication Date: 20 April 2022). *The Machinery & Equipement Industry in Germany - Issue 2022/2023*. https://www.gtai.de/en/invest/service/publications/the-machinery-and-equipment-industry-in-germany-64586, last accessed on 30 November 2022

11 Eurostat (Carré, H.). (Publication Date: 10 July 2008). *NACE Rev. 2 - statistical classification of economic activities in the European Community*.

https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-ra-07-015, last accessed on 6 December 2022

12 Jess, A. and Wasserscheid, P. (2020). *Chemical Technology: From Principles to Products*. Wiley-VCH.

13 VCI (Kellermann, Christiane). (Publication Date: 29 August 2022). *Portrait of the German Chemical Industry - July 2022*. https://www.vci.de/vci-online/die-branche/zahlen-berichte/branchenportraet-der-deutschen-chemisch-pharmazeutischen-industrie.jsp, last accessed on 8 December 2022

14 Germany Trade And Invest (MacDougall, William). (Publication Date: 27 January 2021). *The Chemical Industry in Germany - Issue 2021*. https://www.gtai.de/en/invest/service/publications/the-machinery-and-equipment-industry-in-germany-64586, last accessed on 30 November 2022

15 Germany Trade And Invest (MacDougall, William). (Publication Date: 28 January 2022). *The Food & Beverage Industry in Germany - Issue 2022/2023*. https://www.gtai.de/en/invest/service/publications/the-food-beverage-industry-in-germany-63994, last accessed on 19 December 2022

16 Bundesvereinigung der Deutschen Ernährungsindustrie (Minhoff, Christoph). (Publication Date: 21 June 2022). *Jahresbericht - 2021/2022*. https://www.bve-online.de/presse/infothek/publikationen-jahresbericht/bve-jahresbericht-ernaehrungsindustrie-2022, last accessed on 19 December 2022

17 Bundesvereinigung der Deutschen Ernährungsindustrie and Innova Market Insights (Minhoff, Christoph;Williams, Lu Ann). (Publication Date: 5 October 2021). *Sustainability trends in the food and drink industries in 2021*. https://www.bve-online.de/presse/infothek/publikationen-jahresbericht/bve-innova-studie-nachhaltigkeit, last accessed on 19 December 2022

18 Arbeitsgemeinschaft Energiebilanzen (Nieder, Thomas). (Publication Date: 22 September 2022). *Evaluation Tables of the Energy Balace for Germany - Energy data for the years 1990 to 2021*. https://www.bve-online.de/presse/infothek/publikationen-jahresbericht/bve-jahresbericht-ernaehrungsindustrie-2022, last accessed on 1 January 2023

19 DESTATIS (Hagenkort-Rieger, Susanne). (Publication Date: 2022). *Use of energy: Germany, years, homogeneous branches, energy carriers*. https://www-genesis.destatis.de/genesis/online?sequenz=tabelleErgebnis&selectionname=85131-0002&language=en, last accessed on 3 January 2023

20 DESTATIS (Hagenkort-Rieger, Susanne). (Publication Date: 26 September 2022). *Umweltökonomische Gesamtrechnungen - Anthropogene Luftemissionen*. https://www.destatis.de/DE/Themen/Gesellschaft-

Umwelt/Umwelt/UGR/energiefluesse-emissionen/Publikationen/Downloads/anthropogene-luftemissionen-5851103207004.pdf?__blob=publicationFile, last accessed on 8 January 2023

21 European Commission (Slotboom, Outi). (Publication Date: 10 March 2020). *A new Industrial Strategy for a globally competitive, green and digital Europe*. https://ec.europa.eu/commission/presscorner/detail/en/fs_20_425, last accessed on 11 January 2023

22 European Commission (Directorate-General for Research and Innovation). (Publication Date: 15 December 2021). *Research & Innovation to Drive The Clean Energy Transition & Climate Neutrality*. https://op.europa.eu/en/publication-detail/-/publication/e71ed105-6dd9-11ec-9136-01aa75ed71a1/language-en/format-PDF/source-250595614, last accessed on 11 January 2023

23 German Federal Ministry for Economic Affairs and Climate Action (Ewers, Daniela). (Publication Date: 10 June 2020). *Integrated National Energy and Climate Plan*. https://energy.ec.europa.eu/system/files/2022-08/de_final_necp_main_en.pdf, last accessed on 16 January 2023

24 German Federal Ministry for Economic Affairs and Climate Action (Ewers, Daniela). (Publication Date: 19 December 2019). *Energy Efficiency Strategy 2050*. https://www.bmwk.de/Redaktion/DE/Publikationen/Energie/energieeffiezienzstrategie-2050.html, last accessed on 16 January 2023

25 German Federal Ministry of Transport and Digital Infrastructure (Reinfried, Ulrich). (Publication Date: 19 October 2022). *Digital Strategy - Creating Digital Values Together*. https://digitalstrategie-deutschland.de/static/eb25ff71f36b8cf2d01418ded8ae3dc2/Digitalstrategie_EN.pdf, last accessed on 16 January 2023

26 Seliger, G. (2012). *Sustainable Manufacturing - Shaping Global Value Creation*. Springer. https://doi.org/10.1007/978-3-642-27290-5

27 Jovane, F., Westkämper, E., and Williams, D. J. (2009). *The Manufuture Road - Towards Competitive and Sustainable High-Adding-Value Manufacturing*. Springer. https://doi.org/10.1007/978-3-540-77012-1

28 Deloitte Touche Tohmatsu Limited, Global Consumer and Industrial Products Industry Group, and Council on Competitiveness (Giffi, Craig A.; Drew Rodriguez, Michelle; Gangula, Bharath; Roth, Aleda V.;Hanley, Tim). (Publication Date: 21 April 2016). *2016 Global Manufacturing Competitiveness Index*. https://www2.deloitte.com/lk/en/pages/manufacturing/articles/global-manufacturing-competitiveness-index.html, last accessed on 31 January 2023

29 TUM Senior Excellence Faculty, TUM Institute for Advanced Study, and Preservation, I. f. E. S. (Reichwald, Ralf; Fröhling, Magnus;Herbst-Gaebel, Birgit; Molls, Michael;Wilderer, Peter). (Publication Date: 30 May 2022). *Circular Economy*. https://d-nb.info/1263687474/34, last accessed on 1 February 2023

30 Circular Economy Initiative Deutschland (Kadner, S; Kobus, J; Hansen, E; Akinci, S; Elsner, P; Hagelüken, C; Jaeger-Erben, M; Kick, M; Kwade, A; Kühl, C; Müller-Kirschbaum, T; Obeth, D; Schweitzer, K; Stuchtey, M; Vahle, T; Weber, T; Wiedemann, P; Wilts, H; von Wittken, R.). (Publication Date: 11 May 2021). *Circular Economy Roadmap for Germany*. https://www.circular-economy-initiative.de/circular-economy-roadmap-for-germany, last accessed on 1 February 2023

31 Communication Promoters Group of the Industry-Science Research Alliance, a. (Kagermann, Henning; Wahlster, Wolfgang; Helbig, Johannes). (Publication Date: 8 April 2013). *Recommendations for implementing the strategic initiative INDUSTRIE 4.0*. https://en.acatech.de/publication/recommendations-for-implementing-the-strategic-initiative-industrie-4-0-final-report-of-the-industrie-4-0-working-group/, last accessed on 4 February 2023

32 Terzidis, O., Oberle, D., Friesen, A., Janiesch, C., and Barros, A. (2012). *The Internet of Services and USDL*. pp. 1-16, February 2012. https://doi.org/10.1007/978-1-4614-1864-1_1, last accessed on 5 February 2023

33 Draghici, A. and Ivascu, L. (2022). *Sustainability and Innovation in Manufacturing Enterprises*. Springer Nature Singapore. https://doi.org/10.1007/978-981-16-7365-8

34 Germany Trade And Invest (MacDougall, William). (Publication Date: 18 November 2021). *The Robotics & Automation Industry in Germany - Issue 2022*. https://www.gtai.de/en/invest/service/publications/the-robotics-automation-industry-in-germany-64312, last accessed on 10 February 2023

35 Khan Sullivan, F., Drescher, M., Wallom, D., and Bennett, F. (2017). *A New & Improved Approach to Technology & Market Readiness*. 9 Pages. http://frankbennett.co.uk/wp-content/uploads/2017/07/MTRL-Methodology-v7-5.pdf

36 Bain & Company (Staebe, Michael; Strangfeld, Andreas; Grosselfinger,Christian). (Publication Date: 25 April 2022). *Global Machinery & Equipment Report 2022 - Thinking Outside The Machine*. https://www.bain.com/insights/topics/global-machinery-equipment-report/, last accessed on 20 February 2023

37 McKinsey & Company (Hattrup-Silberberg, Martin; Herring, Dorothee). (Publication Date: 18 September 2020). *Customer centricity as key for the digital breakthrough*. https://www.mckinsey.de/news/presse/2020-09-18-maschinenbau, last accessed on 20 February 2023

38 Khan, R., Khan, S. U., Zaheer, R., and Khan, S. (2012). *Future Internet: The Internet of Things Architecture, Possible Applications and Key Challenges*. 2012 10th International Conference on Frontiers of Information Technology, pp. 257-260, 17-19 Dec. 2012. https://doi.org/10.1109/FIT.2012.53, last accessed on 23 February 2023

39 Sadiku, M. N. O., Musa, S. M., Shadare, A. E., and Omotoso, A. A. (2018). *Green Technology*. International Journal of Trend in Scientific Research and Development, ISSN No.: 2456-6470, 3(1), pp. 1137-1139, November - December 2018. https://doi.org/10.31142/ijtsrd20199, last accessed on 10 February 2023

40 Sadiku, M. N. O. (2020). *Emerging Green Technologies* (Vol. First Edition). CRC Press. https://doi.org/10.1201/9780429344213

41 Dornfeld, D. A. (2013). *Green manufacturing*. Springer. https://doi.org/10.1007/978-1-4419-6016-0

42 VDMA (Holger, Paul; Richtberg, Oliver). (Publication Date: 19 March 2021). *Engineering Change – Annual Report October 2016 – October 2020*. https://vdma.org/documents/34570/3514293/VDMA+Geschaeftsbericht+2016-2020.pdf/ff7f2e2a-5ecf-882a-8b81-6c86d6ccb434?t=1603963736750, last accessed on 14 February 2023

Appendices

Appendix A (BMWK, Plattform Industrie 4.0, 3 screenshots, total of 105 use cases)

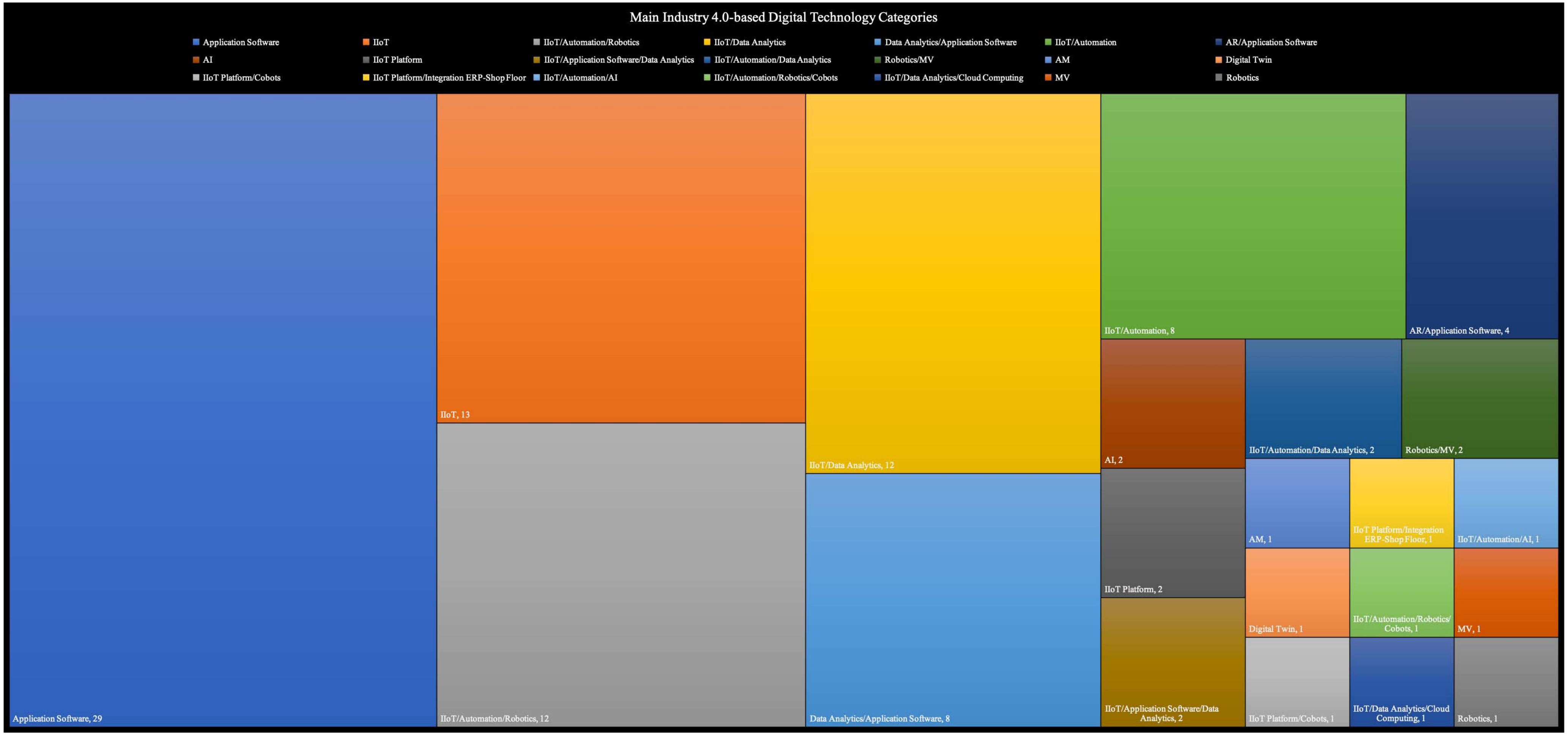
Record	Company	Industry	Purpose	Industry 4.0-based Digital Technology Category	TRL/MRL
1	Siemens	M&E	3D printing of gas turbine components	AM	6-7
2	Huawei Technologies	ICT	Degrees of automation in man-robot collaboration	IIoT/Automation/Robotics	2-3
3	BINSERV	IT Services	Web-based acquisition of measurement data for QA purposes	Application Software	8-9
4	Rexroth (Bosch Group)	Engineering	Interactive communications platform for the manufacturing industry	Application Software	6-7
5	Alfing Montagetechnik	M&E	Intelligent networking of nutrunning equipment (pneumatic torque wrench)	Application Software	8-9
6	VW	Automotive	Improving intralogistics and manual picking via pick-by-vision solution	AR/Application Software	8-9
7	University of Bochum, Chair for Production Systems	Education/Research	Smart knowledge services for smart production	Application Software	2-3
8	C-ECO	Service Provider	Artificial intelligence for circular economy	AI	4-5
9	ASYS Group	M&E	Smart assistance systems for production	Application Software	8-9
10	Bosch	Industrial Technology	Autonomous floor roller	IIoT/Automation/Robotics	4-5
11	ABB	M&E	Barrier-free assembly station	IIoT/Automation/Robotics	8-9
12	Bender	Electrical Engineering	Integrated production system in the Bender final assembly plant	IIoT/Automation/Robotics	8-9
13	BEUMER Group	M&E	Packaging lines in the age of Industry 4.0	IIoT	8-9
14	Bizerba	M&E	RetailApps concept	Application Software	8-9
15	Rexroth (Bosch Group)	Engineering	Horizontally and vertically connected factory	IIoT/Automation/Robotics	8-9
16	thyssenkrupp	Metal Manufacturing	Camshaft Production	IIoT/Data Analytics	8-9
17	WIBU-SYSTEMS	Security Technology Provider	Protecting know-how and production data	Application Software	8-9
18	WIBU-SYSTEMS	Security Technology Provider	CodeMeter as a demonstrator for intelligent production	Application Software	8-9
19	Siemens / Linde	M&E	COMOS in use during plant engineering	Application Software	8-9
20	Kinexon	Technology Provider	Fully automated end-to-end material flow	IIoT Platform	8-9
21	Techniciency Consulting	Services	Consistent research and development	Application Software	6-7
22	Phoenix Contact	System Integrator	Consistently digital – from circuit diagram to production	IIoT/Automation/Robotics	4-5
23	Phoenix Contact	System Integrator	Convertible production	IIoT/Automation/Robotics	8-9
24	CHT	Chemical	Crosslinked process control in chemistry production	IIoT/Automation/Robotics	8-9
25	University of Kaiserslautern / Mondi Gronau	Packaging	Cross-Linked Resource-optimized production of polymer films	Data Analytics/Application Software	6-7
26	ABB	M&E	Collaborative software platform	Application Software	6-7
27	CENTRUM INDUSTRIAL IT	Education/Research	Demonstrator for a versatile assembly system	IIoT/Automation/Robotics	4-5
28	Desoutter	M&E	Smart factory line	Application Software	8-9
29	Desoutter	M&E	Industrial smart hub CONNECT	IIoT	8-9
30	Siemens	M&E	Development and production without 2D drawing	Application Software	8-9
31	DFKI & Hitachi	Research / Industrial Technology	Artificial intelligence technology for human activity recognition of workers	AI	4-5
32	University of Bochum, Chair for Production Systems	Education	Digital learning scenarios	Application Software	2-3
33	Laserline	M&E	Digitalization of laser systems	Data Analytics/Application Software	6-7
34	Electromobility Laboratory Aachen	Education/Research	Big Data demonstrator in lithium-ion cell production to reduce end-of-line test costs	Data Analytics/Application Software	4-5
35	ELSCHUKOM	Metal Processing	Production Monitoring in Wire Manufacturing	Application Software	8-9
36	Mimatic	M&E	Eltimon: total solution monitoring system for driven tools in turning and milling machines	Application Software	8-9
37	Weidmüller	M&E	Energy-efficient process optimization	Data Analytics/Application Software	6-7
38	Hochhuth	M&E	MESSDAS® energy management system	IIoT Platform	8-9
39	ESTA Apparatebau	M&E	Extraction System FILTOWER 4.0	IIoT	6-7
40	EVO Informationssysteme	Software Engineering	Universal Retrofit Packages for Industrie 4.0	Application Software	8-9
41	Helmut Beyers	Electronics Manufacturing Service	FactoryConductor, tailor-made manufacturing execution system for manufacturing process monitoring and optimisation	Application Software	8-9
42	Siemens	M&E	Factory for devices with seamless digital integration	Application Software	8-9
43	Festo	M&E	Learning factory: an integral part of production	IIoT	8-9
44	BÄR Automation	Transport Equipment	Flexible assembly in vehicle production	IIoT/Automation/Robotics	8-9
45	Fraunhofer Institute for Industrial Automation	Research	Assistance system for monitoring networked systems	Application Software	4-5
46	GEMÜ Gebrüder Müller Apparatebau	M&E	CONEXO – RFID-based valve management	IIoT	8-9
47	Greif-Velox Maschinenfabrik	M&E	Intelligent and networked product handling for Smart Factories	IIoT/Automation	8-9
48	Haba	Toys & Furniture	Day-to-day commission-based production in the furniture industry	IIoT	8-9
49	Hofmann	Printing	Printing according to Industrie 4.0	IIoT/Automation	8-9
50	Bosch	Industrial Technology	Holistic Industrie 4.0 approach	IIoT/Automation	8-9

Record	Company	Industry	Purpose	Industry 4.0-based Digital Technology Category	TRL/MRL
51	PI4 Robotics	M&E	Production of workerbot humanoid robots with workerbots	Robotics/MV	8-9
52	Rexroth (Bosch Group)	Engineering	Hydraulic valve assembly	IIoT	8-9
53	Simon Wotton	Engineering	i4.0-Box	IIoT	6-7
54	Würth Industrie Service	M&E	iDISPLAY + CPS MOBILE	Robotics/MV	2-3
55	ifm electronic	M&E	Individual components for system solutions for Industrie 4.0 implementation	IIoT/Data Analytics	8-9
56	Fraunhofer Institute for Machine Tools and Forming Technology IWU	Research	Intelligent predictive maintenance	IIoT/Data Analytics	6-7
57	Bosch	Industrial Technology	Innovation network RtP2: excellence through Industrie 4.0	IIoT/Data Analytics	8-9
58	Bosch	Industrial Technology	Application of the production rules configurator	Application Software	8-9
59	WITTENSTEIN	M&E	Digital planning board and mobile production management	IIoT/Data Analytics	4-5
60	Bosch	Industrial Technology	Monitoring of tightening processes via sensor technology	IIoT/Data Analytics	8-9
61	Technical Universtity Dortmund, Institute of Production Systems	Research	Cyber System Connector (CSC) – smart creation and usage of technical documentation	IIoT/Automation/Robotics	4-5
62	Siemens	M&E	Integrated data management platform	Application Software	8-9
63	catkin	IT Solutions Provider	Generate synergies by sharing transport capacity with catkin	Application Software	6-7
64	Phoenix Contact	System Integrator	Interconnected line automation in the Tool Shop	IIoT/Automation	8-9
65	KASTO	M&E	Integrated switch cabinet assembly and production logistics	IIoT/Automation	8-9
66	KUKA	M&E	Roboter production and assembly at KUKA roboter	IIoT/Automation/Robotics	8-9
67	MAN Energy Solutions	M&E	Trendsetting commissioning by use of smart glasses in intralogistics	MV	8-9
68	Mosca	M&E	MOSCA 4.0 - more individual, flexible and faster	IIoT/Automation	8-9
69	Audi	Automotive	Assistive systems integrated directly into the workplace using in-situ projection for augmented reality	AR/Application Software	4-5
70	Mangelberger Elektronik	M&E	Networked production and automated configuration	IIoT/Automation/Data Analytics	8-9
71	WS System	M&E	Networking and visualization of processes	IIoT Platform/Cobots	8-9
72	Bosch	Industrial Technology	Optimization of maintenance processes by online monitoring of vibration data	IIoT/Data Analytics	8-9
73	Rota Yokogawa	M&E	On-time shipping control using the digital pull system	IIoT	6-7
74	Rexroth (Bosch Group)	Engineering	Efficient software engineering for merging machine automation with IT solutions and technologies	Application Software	8-9
75	thyssenkrupp	Metal Manufacturing	From shop floor to top floor: operating data	Data Analytics/Application Software	8-9
76	Pfizer	Pharmaceutical	Continuous production as the core of the Fully Automated Supply and Transport concept	IIoT/Automation	8-9
77	Daimler	Automotive	Predictive analytics to increase productivity in powertrain production	Data Analytics/Application Software	8-9
78	PrintoLUX	M&E	Production of industrially used labels based on digital printing	IIoT/Automation	8-9
79	RUCH NOVAPLAST	Chemical	Producing more efficient with manufacturing execution system	IIoT/Data Analytics	8-9
80	ABB	M&E	Remote robot monitoring	Application Software	8-9
81	Mayr Power Transmission	Automotive	ROBA-DSM the torque measuring machine element	Data Analytics/Application Software	8-9
82	Carpentry Eigenstetter	Wood Processing	Robot milling centre	Robotics	8-9
83	SaarGummi Neo	Automotive	Augmented reality support glasses	AR/Application Software	8-9
84	Schnellecke Group	M&E	Material flow optimization in just-in-sequence logistics through intelligent container tracking	IIoT	8-9
85	Schuler Group	M&E	Smart press shop	IIoT/Data Analytics	6-7
86	Siemens	M&E	Seamless process chain CAD-CAM-CNC	Application Software	8-9
87	ABB	M&E	Service platform offers remote access	Application Software	8-9
88	Siemens	M&E	Digital factory	IIoT/Automation/Data Analytics	8-9
89	Siemens	M&E	Digital manufacturing planning tools promote rapid organic growth	Application Software	8-9
90	Gambro Dialysatoren (Baxter Group)	Medical Devices	Smart Data Management improves manufacturing efficiency	IIoT/Automation/AI	8-9
91	WS System	M&E	Optimising production and quality assurance with workers guidance solution and smart glasses	AR/Application Software	8-9
92	Bosch	Industrial Technology	Smart international production networks	IIoT/Data Analytics	8-9
93	Spanflug Technologies	Technology Integrator	B2B platform for the manufacturing of CNC parts	Application Software	8-9
94	statmath	Software Engineering	Quality monitoring and predictive maintenance - flexible and efficient integration of machine learning algorithms into the production process	Data Analytics/Application Software	6-7
95	Limtronik	Simulation	The Smart Electronic Factory	IIoT/Data Analytics	4-5
96	Schaeffler Technologies	Industrial Technology	Tool machine 4.0	IIoT/Data Analytics/Cloud Computing	8-9
97	Lenze	M&E	Identification and traceability of electronic devices and components	IIoT	8-9
98	Weidmüller	M&E	The Factory of the future – transparent, interconnected and ecofriendly	IIoT/Data Analytics	8-9
99	TRUMPF Werkzeugmaschinen	M&E	Intelligent networking of human, machine and component	IIoT/Automation/Robotics/Cobots	8-9
100	Sächsisches Textilforschungsinstitut	Research	Research and test area for the textile factory of the future	IIoT	4-5
101	Maschinenfabrik Reinhausen	M&E	ValueFacturing®. With assistance to high perfomance production	IIoT Platform/Integration ERP-Shop Floor	8-9
102	viastore SYSTEMS	Logistics	Virtual commissioning	Digital Twin	8-9
103	Bosch	Industrial Technology	Transparence of the value stream via RFID	IIoT	8-9
104	WERMA Signaltechnik	M&E	SmartMONITOR: the smart alternative to machine data collection	IIoT/Application Software/Data Analytics	8-9
105	WERMA Signaltechnik	M&E	StockSAVER - Kanban, the third generation	IIoT/Application Software/Data Analytics	8-9

Appendix B (data from appendix A rearranged by number of records per main industry 4.0-based digital technology category)

Number of Records	Main Industry 4.0-based Ditigal Technology Category	Average TRL/MRL
2	AI	4.5
1	AM	6.5
29	Application Software	7.7
4	AR/Application Software	7.5
8	Data Analytics/Application Software	7.0
1	Digital Twin	8.5
13	IIoT	7.7
2	IIoT Platform	8.5
1	IIoT Platform/Cobots	8.5
1	IIoT Platform/Integration ERP-Shop Floor	8.5
2	IIoT/Application Software/Data Analytics	8.5
8	IIoT/Automation	8.5
1	IIoT/Automation/AI	8.5
2	IIoT/Automation/Data Analytics	8.5
12	IIoT/Automation/Robotics	6.7
1	IIoT/Automation/Robotics/Cobots	8.5
12	IIoT/Data Analytics	7.5
1	IIoT/Data Analytics/Cloud Computing	8.5
1	MV	8.5
1	Robotics	8.5
2	Robotics/MV	5.5

Appendix C (105 use cases with the main Industry 4.0-based digital technology categories, source BMWK, Plattform Industrie 4.0)



Appendix D (12 Questions)

Research Question	Covered Sections of My Master’s Thesis	Addressed Topics in My Master’s Thesis	Questions for the Online Quantitative Survey
RQ1: What sword of Damocles (impeding disaster) may these five vertical sectors face in conjunction with the EU/German regulatory framework, especially against the backdrop of the GHG emissions reduction?	3	GHG emissions reduction, German manufacturing industry leadership role	*Q1*: For the green transition that currently surrounds our economy and society, Europe’s Climate Law and its respective member state enactment have the ambition to reduce the greenhouse gas emissions by 2030 by a minimum of 55% in comparison with the 1990s level. Do you concur that Germany’s leading manufacturing industry in terms of value-added can take over a leadership role by largely impacting this EU goal? *Answer options*: ①: Strongly Agree ②: Agree ③: Disagree ④: Strongly Disagree

Individual Results

ANSWER CHOICES	RESPONSES	
Strongly agree	47.06%	8
Agree	41.18%	7
Disagree	11.76%	2
Strongly disagree	0.00%	0
TOTAL		17

Research Question	Covered Sections of My Master's Thesis	Addressed Topics in My Master's Thesis	Questions for the Online Quantitative Survey
RQ1: What sword of Damocles (impeding disaster) may these five vertical sectors face in conjunction with the EU/German regulatory framework, especially against the backdrop of the GHG emissions reduction?	3	GHG emissions reduction, German manufacturing industry contribution, infringement procedure in case of missing objective	*Q2*: In the event of missing Germany's manufacturing industry greenhouse gas emissions reduction goal to align with the EU Green Deal's objectives (one is to reduce the EU emissions by at least 55% by 2030), the potential infringement procedures risks against Germany would impact your company's financial growth. *Answer options*: ①: Strongly agree ②: Agree ③: Disagree ④: Strongly disagree

Individual Results

ANSWER CHOICES	RESPONSES	
Strongly agree	5.88%	1
Agree	52.94%	9
Disagree	35.29%	6
Strongly disagree	5.88%	1
TOTAL		17

Research Question	Covered Sections of My Master’s Thesis	Addressed Topics in My Master’s Thesis	Questions for the Online Quantitative Survey
RQ 2: Which vertical sector from Germany’s top 5 manufacturing industries according to the gross value-added perspective can best contribute to curtail the dependency on fossil fuel energy?	4	Innovation, reduce fossil fuel energy dependency and impact	*Q3*: Based on my research, Germany’s top 5 heavyweights of the manufacturing industry from a gross value-added perspective are in descending order: 1. Manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers, 2. Manufacture of machinery and equipment, 3. Manufacture of fabricated metal products, 4. Manufacture of chemicals and chemical products, and 5. Manufacture of food products and beverages. They are presently reliant on fossil fuel energy sources (lowest dependency varying from 46% for the machinery and equipment industry to 79% for the chemical industry). While focusing on your manufacturing operations, which vertical sector from the five ones can best contribute to decrease the fossil fuel energy dependency in your industry? *Answer options*: ①: In our industry, we do not have a fossil fuel energy dependency ②: No opinion ③: Manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers (e.g., for mobility) ④: Manufacture of machinery and equipment (e.g., for automation) ⑤: Manufacture of fabricated metal products (e.g., for tooling) ⑥: Manufacture of chemicals and chemical products (e.g., for treatment) ⑦: Manufacture of food products and beverages (e.g., for substitution) ⑧: Another industry (thank you for being specific and telling me the reason why in the text field below)

Individual Results

ANSWER CHOICES		RESPONSES	
In our industry, we do not have a fossil fuel energy dependency		0.00%	0
No opinion		0.00%	0
Manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers (e.g., for mobility)		29.41%	5
Manufacture of machinery and equipment (e.g., for automation)		23.53%	4
Manufacture of fabricated metal products (e.g., for tooling)		0.00%	0
Manufacture of chemicals and chemical products (e.g., for treatment)		29.41%	5
Manufacture of food products and beverages (e.g., for substitution)		11.76%	2
Another industry (thank you for being specific and telling me the reason why in the text field below)	Responses	5.88%	1
TOTAL			17

Research Question	**Covered Sections of My Master's Thesis**	**Addressed Topics in My Master's Thesis**	**Questions for the Online Quantitative Survey**
RQ 2: Which vertical sector from Germany's top 5 manufacturing industries according to the gross value-added perspective can best contribute to curtail the dependency on fossil fuel energy?	4.1	Strategic major supplier's contribution to your value added	*Q4*: Following up with the third question, as a **strategic supplier** to your industry in terms of value creation and still focusing on your manufacturing operations, which sector from the five ones do you select? *Answer options*: ①: No opinion ②: Manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers (e.g., for mobility) ③: Manufacture of machinery and equipment (e.g., for automation) ④: Manufacture of fabricated metal products (e.g., for tooling) ⑤ Manufacture of chemicals and chemical products (e.g., for treatment) ⑥: Manufacture of food products and beverages (e.g., for substitution) ⑦: Another industry (thank you for being specific and telling me the reason why in the text field below)

Individual Results

ANSWER CHOICES		RESPONSES	
No opinion		5.88%	1
Manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers (e.g., for mobility)		35.29%	6
Manufacture of machinery and equipment (e.g., for automation)		17.65%	3
Manufacture of fabricated metal products (e.g., for tooling)		0.00%	0
Manufacture of chemicals and chemical products (e.g., for treatment)		29.41%	5
Manufacture of food products and beverages (e.g., for substitution)		5.88%	1
Another industry (thank you for being specific and telling me the reason why in the text field below)	Responses	5.88%	1
TOTAL			17

Research Question	**Covered Sections of My Master's Thesis**	**Addressed Topics in My Master's Thesis**	**Questions for the Online Quantitative Survey**
RQ 2: Which vertical sector from Germany's top 5 manufacturing industries according to the gross value-added perspective can best contribute to curtail the dependency on fossil fuel energy?	4.2	Strategic major supplier's contribution to your transformational capabilities	*Q5*: Still following up with the third question, as a **catalyst for industrial transformation** (e.g., digital/green/green digital technology) and still focusing on your manufacturing operations, which sector from the five ones do you select? *Answer options*: ①: No opinion ②: Manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers (e.g., for mobility) ③: Manufacture of machinery and equipment (e.g., for automation) ④: Manufacture of fabricated metal products (e.g., for tooling) ⑤ Manufacture of chemicals and chemical products (e.g., for treatment) ⑥: Manufacture of chemicals and chemical products (e.g., for treatment) ⑦: Another industry (thank you for being specific and telling me the reason why in the text field below)

Individual Results

ANSWER CHOICES		RESPONSES	
No opinion		0.00%	0
Manufacture of transport equipment with a focus on motor vehicles, trailers and semi-trailers (e.g., for mobility)		23.53%	4
Manufacture of machinery and equipment (e.g., for automation)		47.06%	8
Manufacture of fabricated metal products (e.g., for tooling)		5.88%	1
Manufacture of chemicals and chemical products (e.g., for treatment)		11.76%	2
Manufacture of food products and beverages (e.g., for substitution)		5.88%	1
Another industry (thank you for being specific and telling me the reason why in the text field below)	Responses	5.88%	1
TOTAL			17

Research Question	Covered Sections of My Master's Thesis	Addressed Topics in My Master's Thesis	Questions for the Online Quantitative Survey
RQ 3: Considering the identified vertical sector, what existing/emerging technologies and innovations are worth being considered? • From the digital technology perspective.	5.1	Technologies with smart manufacturing levers	*Q6*: Assuming that the German machinery and equipment manufacturing industry is instrumental in the success of connected, responsive, and flexible manufacturing operations by reorienting its value proposition with a multi-pronged strategy geared toward hardware, software, automation/robotics and service/application offerings integration, this integrated approach enables new business opportunities for your organisation. *Answer options*: ①: Strongly Agree ②: Agree ③: Undecided ④: Disagree ⑥: Strongly Disagree ⑦: No opinion

Individual Results

ANSWER CHOICES	RESPONSES	
Strongly Agree	17.65%	3
Agree	64.71%	11
Undecided	5.88%	1
Disagree	5.88%	1
Strongly Disagree	0.00%	0
No opinion	5.88%	1
TOTAL		**17**

Research Question	Covered Sections of My Master's Thesis	Addressed Topics in My Master's Thesis	Questions for the Online Quantitative Survey
RQ 3: Considering the identified vertical sector, what existing/emerging technologies and innovations are worth being considered? • From the digital technology perspective.	5.1	Technologies with smart manufacturing levers	*Q7*: Following on from the previous question, the success of your digitalisation toward smart, effective, and efficient manufacturing operations resides in a still-to-be-defined equilibrium between industrial internet of things, automation/robotics, data analytics, artificial intelligence with machine learning, and apps. *Answer options:* ①: Strongly agree ②: Agree ③: Disagree ④: Strongly disagree ⑤: Need to reflect on it ⑥: No opinion

Individual Results

ANSWER CHOICES	RESPONSES	
Strongly Agree	17.65%	3
Agree	47.06%	8
Disagree	17.65%	3
Strongly disagree	0.00%	0
Need to reflect on it	5.88%	1
No opinion	11.76%	2
TOTAL		17

Research Question	**Covered Sections of My Master's Thesis**	**Addressed Topics in My Master's Thesis**	**Questions for the Online Quantitative Survey**
RQ 3: Considering the identified vertical sector, what existing/emerging technologies and innovations are worth being considered? • From the green technology perspective.	5.2	Technologies with immediate decarbonisation levers	*Q8*: Assuming that the German machinery and equipment sector is key to accelerate the decarbonisation of other industries, I have identified in my research four technically and economically accessible technologies with immediate decarbonisation levers: 1.) Heat optimisation and waste heat recovery, 2.) Electrical & mechanical efficiency, 3.) Energy management systems, and 4.) Heating, ventilation, and air conditioning (HVAC). Based on your operational needs and your own experience, which technology, taken individually or combined, currently contributes the most to your organisation's greenhouse gas emissions reduction objectives? *Answer options*: ①: No opinion ②: Heat optimisation and waste heat recovery alone [referred to as 1] ③: Electrical & mechanical efficiency alone [referred to as 2] ④: Energy management systems alone [referred to as 3] ⑤: Heating, ventilation, and air conditioning (HVAC) alone [referred to as 4] ⑥: Combination of 1 + 2 ⑦: Combination of 1 + 3 ⑧: Combination of 2 + 3 ⑨: Combination of 1 + 2 + 3 ⑩: Combination of 1 + 2 + 3 + 4 ⑪: From the German machinery and equipment sector: different technology [referred to as 5] (thanks for being specific and telling me why in the text field below) ⑫: From another sector: different technology [referred to as 6] (thanks for being specific and telling me why in the text field below)

Individual Results

ANSWER CHOICES	RESPONSES	
No opinion	0.00%	0
Heat optimisation and waste heat recovery alone [referred to as 1]	17.65%	3
Electrical & mechanical efficiency alone [referred to as 2]	11.76%	2
Energy management systems alone [referred to as 3]	5.88%	1
Heating, ventilation, and air conditioning (HVAC) alone [referred to as 4]	0.00%	0
Combination of 1 + 2	5.88%	1
Combination of 1 + 3	11.76%	2
Combination of 2 + 3	5.88%	1
Combination of 1 + 2 + 3	0.00%	0
Combination of 1 + 2 + 3 + 4	41.18%	7
From the German machinery and equipment sector: different technology [referred to as 5] (thanks for being specific and telling me why in the text field below)	0.00%	0
From another sector: different technology [referred to as 6] (thanks for being specific and telling me why in the text field below)	0.00%	0
TOTAL		**17**

Comments (0)

Research Question	**Covered Sections of My Master's Thesis**	**Addressed Topics in My Master's Thesis**	**Questions for the Online Quantitative Survey**
RQ 3: Considering the identified vertical sector, what existing/emerging technologies and innovations are worth being considered? • From the green technology perspective.	5.2	Technologies with potential decarbonisation levers	*Q9*: Assuming that the German machinery and equipment sector is key to accelerate the decarbonisation of other industries, I have identified in my research three not yet fully technically and economically accessible technologies with potential decarbonisation levers: 1.) Carbon capture, utilisation, and storage (CCUS), 2.) Fuel substitutes, 3.) Green hydrogen as feedstock. Based on your operational needs and your own knowledge, which technology, taken individually or combined, would/shall contribute the most to your organisation's greenhouse gas emissions reduction objectives? *Answer options*: ①: No opinion ②: Carbon capture, utilisation, and storage (CCUS) alone [referred to as 1] ③: Fuel substitutes alone [referred to as 2] ④: Green hydrogen as feedstock alone [referred to as 3] ⑤: Combination of 1 + 2 ⑥: Combination of 1 + 3 ⑦: Combination of 2 + 3 ⑧: Combination of 1 + 2 +3 ⑨: From the German machinery and equipment sector: different technology [referred to as 4] (thanks for being specific and telling me why in the text field below) ⑩: From another sector: different technology [referred to as 5] (thanks for being specific and telling me why in the text field below)

Individual Results

ANSWER CHOICES	RESPONSES	
No opinion	5.88%	1
Carbon capture, utilisation, and storage (CCUS) alone [referred to as 1]	5.88%	1
Fuel substitutes alone [referred to as 2]	11.76%	2
Green hydrogen as feedstock alone [referred to as 3]	17.65%	3
Combination of 1 + 2	5.88%	1
Combination of 1 + 3	17.65%	3
Combination of 2 + 3	5.88%	1
Combination of 1 + 2 + 3	29.41%	5
From the German machinery and equipment sector: different technology [referred to as 4] (thanks for being specific and telling me why in the text field below)	0.00%	0
From another sector: different technology [referred to as 5] (thanks for being specific and telling me why in the text field below)	0.00%	0
TOTAL		17

Comments (0)

Research Question	**Covered Sections of My Master's Thesis**	**Addressed Topics in My Master's Thesis**	**Questions for the Online Quantitative Survey**
RQ 3: Considering the identified vertical sector, what existing/promising technologies and innovations are worth being considered? • From a combined perspective (green digital technology).	5.3	Technologies with product carbon footprint levers	*Q10*: With climate protection being a top priority at European and national governmental levels, ecosystem-based solutions from the German machinery and equipment manufacturing industry embracing green digital technology can effectively contribute to make carbon-neutral product manufacture happen across many and various sectors of the manufacturing industry. Within the next 12-24 months, there will be a rising need for green digital technology such as solutions dealing with product carbon footprint traceability and transparency that will help your organisation reach its carbon neutrality objectives. *Answer options*: ①: Strongly agree ②: Agree ③: Disagree ④: Strongly disagree ⑤: Green digital technology could be an option but its technical and market readiness levels are still unclear ⑥: Green digital technology is not on our radar (thanks for specifying why not and which technology is rather on your radar in the text field below)

Individual Results

ANSWER CHOICES	RESPONSES	
No opinion	0.00%	0
Not likely	17.65%	3
Somewhat likely	47.06%	8
Very likely	35.29%	6
Green digital technology could be an option but its technical and market readiness levels are not advanced enough	0.00%	0
Green digital technology is not on our radar (thanks for specifying why not and which technology is rather on your radar in the text field below)	0.00%	0
TOTAL		**17**

Comments (0)

Research Question	**Covered Sections of My Master's Thesis**	**Addressed Topics in My Master's Thesis**	**Questions for the Online Quantitative Survey**
RQ 4: What results on the fossil fuel energy dependency reduction and energy efficiency gains have already been delivered to date and how impactful and measurable are they for the identified vertical sector of the German manufacturing industry?	6	Fossil fuel energy dependency reduction and energy efficiency gains	*Q11*: Now, I would like to turn this question to the online survey participants, who work in the machinery and equipment sector with at least some manufacturing operations in Germany (the point being that I have targeted the German manufacturing industry and its top 5 heavyweights from a gross value-added perspective as per the third question of the online survey). What results on the fossil fuel energy dependency reduction and energy efficiency gains have already been delivered to date? *Answer options*: ①: No opinion ②: I could not objectively answer the question ③: None ④: Isolated ⑤: Reproducible [referred to as 3] ⑥: Recurrent [referred to as 4] ⑦: If your answer has been either 3 or 4, has digital innovation/technology played an active role? - Yes - No (thanks for being specific on another type of active innovation/technology and tell me why in the text field below)

Individual Results (answered: 13, skipped: 4)

Block 1

	NO OPINION	I COULD NOT OBJECTIVELY ANSWER THE QUESTION	NONE	ISOLATED	REPRODUCIBLE [REFERRED TO AS 3]	RECURRENT [REFERRED TO AS 4]	TOTAL
Answers	15.38% 2	38.46% 5	7.69% 1	7.69% 1	30.77% 4	0.00% 0	13

Block 2

	BLOCK 1, 3 OR 4 SELECTED: DIGITAL INNOVATION/TECHNOLOGY HAS PLAYED AN ACTIVE ROLE	BLOCK 1, 3 OR 4 SELECTED: DIGITAL INNOVATION/TECHNOLOGY HAS NOT PLAYED AN ACTIVE ROLE (THANKS FOR BEING SPECIFIC ON ANOTHER TYPE OF ACTIVE INNOVATION/TECHNOLOGY AND TELL ME WHY IN THE TEXT FIELD BELOW)	TOTAL
Answers	50.00% 1	50.00% 1	2

Comments (0)

Research Question	**Covered Sections of My Master's Thesis**	**Addressed Topics in My Master's Thesis**	**Questions for the Online Quantitative Survey**
RQ 4: What results on the fossil fuel energy dependency reduction and energy efficiency gains have already been delivered to date and how impactful and measurable are they for the identified vertical sector of the German manufacturing industry?	6	Impacts and measurements of the fossil fuel energy dependency reduction and energy efficiency gains	*Q12*: Following up with the previous question, how impactful and measurable are the results on the fossil fuel energy dependency reduction and energy efficiency gains? *Answer options*: ①: I could not objectively answer the question ②: No opinion ③: No impact and measurability ④: Low impact and measurability ⑤: Moderate impact and measurability [referred to as 3] ⑥: High impact and measurability [referred to as 4] ⑦: If your answer was either 3 or 4, what did benefit the most from them (several possible options)? - a: Strengthen your competitiveness - b: Improve your brand perception from a sustainability standpoint - c: Emphasise customer's loyalty and trust - d: Motivate your human capital to push ahead - e: Other (thanks for being specific in the text field below)

Individual Results

Block 1

	I COULD NOT OBJECTIVELY ANSWER THE QUESTION	NO OPINION	NO IMPACT AND MEASURABILITY	LOW IMPACT AND MEASURABILITY	MODERATE IMPACT AND MEASURABILITY [REFERRED TO AS 3]	HIGH IMPACT AND MEASURABILITY [REFERRED TO AS 4]	TOTAL
Answers	38.46% 5	7.69% 1	0.00% 0	7.69% 1	30.77% 4	15.38% 2	13

Block 2

	BLOCK 1, 3 OR 4 SELECTED: WHAT DID BENEFIT THE MOST (SEVERAL POSSIBLE OPTIONS)?	A: STRENGTHEN YOUR COMPETITIVENESS	B: IMPROVE YOUR BRAND PERCEPTION FROM A SUSTAINABILITY STANDPOINT	C: EMPHASISE CUSTOMER'S LOYALTY AND TRUST	D: MOTIVATE YOUR HUMAN CAPITAL TO PUSH AHEAD	E: OTHER (THANKS FOR BEING SPECIFIC IN THE TEXT FIELD BELOW)	TOTAL
Answers	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1

Comments (0)

Appendix E (Survey Screenshot)