How to make manufacturing charming again? It is everything, everywhere, all at once

A literature review on the perceptions of manufacturing

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About this policy brief

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Contents

Executive summary

This report presents insights into how manufacturing is perceived, the factors shaping this perception, and how this perception has evolved in the last decade. The findings draw upon a systematic review of academic, grey and policy literature across seven countries: the United Kingdom (the UK), Canada, Germany, Singapore, South Korea, Switzerland and the United States (the US).

The report is the main output of the InterAct-funded project "How to make manufacturing charming again? It is everything, everywhere, all at once". The aim of the report is to support InterAct research on the future of manufacturing on an international scale by providing insights into attitudes to manufacturing and industrial strategies, and how manufacturing is discussed in other countries, particularly where digital technologies have been adopted.

The intricate relationship between industrial policy and public perceptions of manufacturing

Public policy both shapes and is shaped by public perceptions, and manufacturing is no different when it comes to this dynamic interplay. The global fragmentation of production, which became a sustained and increasing trend in the 1980s, contributed to the misleading idea that manufacturing was a low-value-added activity and thus not important for countries' economic and social growth. This narrative has been compounded by the waning interest in "industrial policy" within policy spheres and mainstream academia since the late 1970s. Both factors have contributed to undermining the perception of manufacturing as a high-value economic driver. For example, a survey[1] conducted in the UK in 2012 found that 74% of the 1,452 survey participants believed that manufacturing jobs would be the first to be offshored.

However, the landscape has shifted notably in the last decade, particularly following pivotal global events like the 2008/9 Global Financial Crisis, subsequent pandemic challenges, and the inflation crisis. These events have prompted broader acknowledgement of the imperative role of government participation in boosting the manufacturing sectors. Despite hesitation among governments to explicitly champion "industrial policy" in contemporary political discourse, manufacturing often features prominently in discussions surrounding industrial and innovation strategies.

Countries that have massively outsourced and allowed severe deindustrialisation of their productive structure, such as the UK and US, are trying to reverse such a trend.[2] For instance, the UK's recently unveiled Advanced Manufacturing Plan showcases this renewed commitment, underscoring the pivotal role of manufacturing in driving the national economy.

[1] De Waal J. R. (2012). Public views on the economic state of Britain. yougov.co.uk

[2] Pisano, G. P. and Shih, W. C. (2009). Restoring American Competitiveness. *Harvard Business Review*, 87(7/8): 114–125.

Perceptions of manufacturing across countries and over time

One of the potential – and most detrimental – impacts of a negative image of manufacturing is the lack of a labour pool for manufacturing firms to tap into, especially skilled and high-skilled labour. Therefore, as research suggests, it is paramount to understand and address the attitudes of the general public – most notably young people and students – towards the industry of "making things".

Key findings from the review of perceptions of manufacturing among the public include the following:

- *The image of manufacturing has been very poor among the British public, but it has improved in the last decade*. In 2001 the British public knew very little about manufacturing and believed the country could grow without it. However, in 2023, 93% of the public believes that the manufacturing industry is essential to growth and resilience. In 2018[3] only one out of five parents suggested manufacturing as a prospective career for their child, while in 2022[4] two out of five parents suggested the industry as a potential career for their child. A similar trend was observed in the US, where the perception of manufacturing has also become more positive in the last decade.[5]
- *Young populations are the least attracted to manufacturing*. Teenagers (aged 10–12) and young adults (aged 14–19) across countries (including the UK) believe that the industry is male-dominated, not well paid and repetitive, and this trend has remained relatively stable over time.
- *Perceptions of manufacturing tend to be more positive in Germany and the US than in the UK*. German and US residents are the most likely (75%) to perceive manufacturing as having significant importance in their country's economy, considering it "very attractive". This is in contrast to the UK, where only 40% of residents perceive manufacturing as offering good job opportunities.

The review also revealed some factors that may help to build a more positive perception of manufacturing and make it more attractive as a career path; these include providing more information or improving aspects such as:

- education about manufacturing careers among primary and secondary school students;
- the role of high skills, innovation, creativity and technology in manufacturing;
- pay, benefits, job security and stability compared to other industries;
- wellbeing and job flexibility compared to other industries;
- the diversity of the sector across different roles;
- the visibility of manufacturing role models of under-represented groups; and
- showcasing the role of manufacturing in society and the economy, such as its pivotal role during the COVID-19 pandemic.

[3] Make UK (2018). Why does manufacturing matter to the British public? makeuk.org

[4] Make UK (2023). Perceptions Vs Reality Report 2023, p. 10.

[5] Deloitte – Manufacturing Institute (2022). Competing for Talent: Recasting Perceptions of Manufacturing.

Manufacturing in public policy

Terms and definitions of manufacturing

As previously discussed, how manufacturing is addressed in industrial and innovation policy influences public perceptions of manufacturing. Based on a review of 68 strategies and initiatives, we found that terms such as "advanced manufacturing" are increasingly used to highlight the high-tech nature of this industry. For instance, the Five-Year Strategic Plan of Next Generation Manufacturing Canada (NGen) describes manufacturing and advanced manufacturing as follows:

> *If manufacturing is the business of making things, advanced manufacturing involves the use of leading-edge technologies and techniques to grow that business, by solving problems and making things – often new things – for customers, in significantly better ways.*[6]

Variations of advanced manufacturing, such as "advanced low-carbon manufacturing" and "advanced materials and manufacturing", are prevalent in UK strategies. Similarly, the terms "sustainable manufacturing" and "net-zero manufacturing" are found in Singapore's Research, Innovation & Enterprise 2025 Plan. Other terms commonly used across the seven countries examined include smart and digital manufacturing, Industry 4.0 and production.

The role of manufacturing in society and the economy

National strategies portray manufacturing as a key driver of economic growth, exports, productivity, research and innovation, regional development and inclusion. For example, Singapore's Minister of State for Trade and Industry referred to manufacturing as the "bedrock" of Singapore's economy.[7]

On the contribution of manufacturing to innovation, the US MForesight report highlights its crucial role in translating research into profit or, in other words, "capturing the gains from new manufacturing technologies".[8] In Switzerland having a manufacturing value added share that is among the highest in the industrialised world (25%) is also recognised as a key driver of innovation, and the country is seen as "the most effective worldwide in transforming innovation investment into results".[9]

Recognising the important role of manufacturing, countries such as Canada, Germany, Korea and Singapore have established targets to increase the participation of this sector in their economies. One of the most common metrics used for these targets is manufacturing value added shares, and a frequent target is to sustain or increase these shares to a level around 20% and 30%.

[6] ISEDC (2021). Canada's Biomanufacturing and Life Sciences Strategy; NGen (2023). Five-Year Strategic Plan; NGen (2021). Careers of the Future.

[7] Ministry of Trade and Industry Singapore (2023). Speech by Minister of State for Trade and Industry Alvin Tan at Ministry of Trade and Industry's committee of supply debate 2023.

[8] MForesight (2018). Manufacturing Prosperity, p. 7.

[9] Switzerland Global Enterprise (2020). Advanced Manufacturing in Switzerland. Factsheet.

Gender disparities in manufacturing

The manufacturing sector is predominantly male-dominated, especially in high-tech industries and advanced economies. For instance, in the UK, women account for 26% of the manufacturing workforce, and their representation is even lower in high-tech sectors such as automotive and aerospace. A similar pattern is observed in the other countries analysed, where female representation in the manufacturing sector ranges between 27% in Germany, 29% in Canada, South Korea, Switzerland and the US, and 37% in Singapore.

Despite this clear under-representation of women, gender inequalities are rarely addressed in industrial and innovation strategies. Of the 68 strategies and initiatives examined, only 15 address gender inequalities and all have a narrow scope. In terms of imagery, overall gender balance or use of gender-neutral images was found.

Megatrends and perceptions of manufacturing

In the industrial and innovation strategies of the countries analysed, environmental sustainability and the digitalisation of manufacturing remain top priorities. However, the impacts of the COVID-19 pandemic and geopolitical tensions have resulted in an increasing emphasis on resilience, national security, the reconfiguration of value chains and technological sovereignty.

Changes in priorities, and the ongoing focus on digitalisation and environmental sustainability, have changed how manufacturing is described. For instance, Canada's Careers of the Future initiative describes advanced manufacturing enterprises as follows:

> *Advanced manufacturing enterprises don't just assemble or make things; they use cutting edge technologies, business and engineering know-how, software, data analytics, and artificial intelligence to solve problems – and address some of the world's most pressing challenges.*[10]

These transformations have broadened the scope of activities and value chain segments discussed within manufacturing. Notably, there is a growing emphasis on areas such as design and recycling in various national strategies. In addition, services are increasingly integrated with manufacturing.

The strategies reviewed also highlight the interconnection between the green and digital transition. The role of digital technologies in improving energy and materials efficiency is emphasised. Examples include smart energy systems, energy-efficient ICT systems and the use of sensors to monitor CO_2 emissions. This was confirmed by the participants of the international roundtable, who emphasised the potential of these trends to reinforce one another, but they clarified that this is not always the case.

Skills gaps and labour shortages are issues frequently covered in industrial and innovation strategies. Key themes discussed in this area include: the deskilling of workers as a result of the automation of tasks; how technological change and sustainability concerns are creating the need for reskilling and upskilling employees; the ageing population and the related labour shortage; and the need to enhance diversity and inclusion in manufacturing.

With the manufacturing sector facing skills shortages, countries have launched initiatives to attract young professionals and ensure that perceptions of manufacturing align with the transformations occurring in this sector. These initiatives encompass a range of activities, from

[10] https://www.careersofthefuture.ca/

providing information about “modern manufacturing” to young people and parents, showcasing role models, career opportunities, and offering advice on pursuing a career in manufacturing.

Final reflections and actionable insights

This report has shed light on the changing perceptions of manufacturing while stressing the imperative role of industrial innovation policy in shaping these perceptions. It underscores the pivotal role of manufacturing in economic growth, innovation, regional development and social inclusion, and the relevance of initiatives to showcase the evolving nature of manufacturing in the context of digital and green transformations.

This review also suggests directions for future research and initiatives to improve public perceptions of manufacturing:

i. **Systematic collection of data** (yearly or every 2 years) about how the general public perceives manufacturing, including age, gender, education, sub-sectors and regional breakdowns, and the role of the digital and green transformations in shaping perceptions.
ii. **Leveraging the manufacturing observatory**, outlined in the UK Advanced Manufacturing Plan, to constantly monitor policy developments across different contexts. This includes ongoing examination of how manufacturing and related terminologies are defined and portrayed within these policy documents.
iii. **Setting measurable targets and initiatives aimed at enhancing diversity in manufacturing**. As discussed in the report, increasing diversity would attract younger demographics and unlock the talent of under-represented groups.
iv. **Providing education and career information about manufacturing from the early education stages**. In the comparator countries examined, governments and industry associations are working with education institutions to raise awareness about manufacturing and its varied career prospects, aiming to dispel misconceptions and nurture interest among students.

1. Introduction

Manufacturing is witnessing a renaissance. Policy-makers, academics and international organisations have seen a renewed interest in the role that manufacturing plays in our economies. The global fragmentation of production, which became a sustained and increasing trend in the 1980s, contributed to the idea that manufacturing was a low-value-added activity and thus not important for countries' economic and social growth. However, a few decades later, countries that massively outsourced and allowed a severe deindustrialisation of their productive structure, for example, the UK and US, are paying the consequences and trying to reverse such a trend.[11] In fact, in recent years, and especially after the global financial crisis (GFC henceforth), it became more apparent that manufacturing constitutes a critical backbone of countries' growth and sustained development.

Against this backdrop, it became clearer that the narrative around the decreased importance of manufacturing for the economy has been a mistake. Outsourcing dynamics, servicification and the idea that "services are now more important than manufacturing" have dominated for the last three decades. In both academic and practice circles in the UK, there have been conversations suggesting that we need to change how manufacturing is discussed. There is a strong argument that misconceptions are resulting in manufacturing struggling to attract skilled workers and, at least until some years ago, not receiving enough attention from policy-makers.

This report presents insights into how manufacturing is perceived in the UK and internationally, including strategies, attitudes, roles and skills. By reporting our systematic literature review, we intend to explore trends, changes and perspectives influencing the perception of manufacturing, stressing the misconceptions around the decreasing relevance of the industry in countries' economic and social growth. Although this is, surely, a real trend that has characterised the productive structure of various economies, it is also true that there is an often-overlooked interdependent relationship between manufacturing and high-value-adding tradable services.

Following this introduction, we present findings from a systematic review of: (i) academic and grey literature on the perception of manufacturing among the general public; (ii) surveys on

[11] Pisano, G. P. and Shih, W. C. (2009). Restoring American competitiveness. *Harvard Business Review*, 87(7/8): 114–125.

public perceptions of manufacturing; and (iii) policy documents across seven countries, the UK, the US, Canada, Germany, Singapore, Switzerland and South Korea. This analysis, designed to capture the perceptions of manufacturing among policy-makers, was based on the review of 68 strategies and initiatives related to manufacturing published between 2018 and 2023. Wherever documents were not available in English, automated translations were used to conduct the analysis. Documents studied included: (i) research, innovation and industrial plans and strategies; (ii) digital manufacturing initiatives; (iii) skills development programmes; (iv) white papers; and (v) technology foresight studies.[12] See Appendix A for the full list of strategies and initiatives consulted.

The systematic review adopts a gender perspective. Although a comprehensive analysis of gender disparities is outside the scope of this research, this report confirms the insufficient attention paid to gender disparities in industrial and innovation policies.

As a final robustness check, we discussed and validated preliminary findings in an online roundtable with the participation of seven actors from multilateral organisations: the United Nations Industrial Development Organization (UNIDO), the United Nations Conference on Trade and Development (UNCTAD), the International Monetary Fund (IMF), the United Nations Economic Commission for Latin America and the Caribbean (ECLAC) and the Organisation for Economic Co-operation and Development (OECD).

The report is organised as follows. Section 2 introduces historical and economic definitions of manufacturing. Section 3 discusses the perceptions of the general public, both in the UK and internationally, building on an analysis of academic literature and on surveys conducted in different countries. Section 4 introduces the policy document analysis conducted across seven countries and the emergence of three megatrends. Section 5 discusses the three megatrends, while Section 6 provides insights from an international roundtable conducted as a "reality check" of our study. Section 7 concludes and puts forward some policy implications.

[12] Key themes analysed included: (i) the terms used to refer to manufacturing and industrial policy; (ii) value chain segments included in how manufacturing is defined; (iii) national priorities; (iv) how the contribution of manufacturing to the economy and society is portrayed; (v) key challenges and opportunities addressed; and (vi) whether and how strategies and initiatives address gender gaps and the representation of different genders in the imagery they use.

2. Definitions of manufacturing

Manufacturing is a multifaceted topic, and its definition and dynamics have evolved over time, especially in recent years. Considered for a long time to be the backbone of every country aiming for economic growth and structural transformation, more recently – in the 1980/90s – manufacturing has been considered less important, even detrimental, to a country's growth, which should be based more on services as GDP increases. In the last decade the advance of new digital production technologies, as well as urgent matters such as climate change and the pandemic (2020 and 2021) have called for the role of manufacturing to be reconsidered, in addition to the role that industrial policy can play in revitalising manufacturing across countries. Indeed, it became clear that manufacturing affects every aspect of our lives, and governments should act to reinforce production capabilities that may be critical to face environmental, health and inequality challenges.

Transformations of manufacturing have involved new technologies, an increase in supply chain complexity, as well as a higher demand for sustainability for both products and processes; also, evolutions in regulations, skills and the labour market generally are affecting changes in manufacturing. One of the most critical transformations of the manufacturing sector has been digitalisation, which is deeply transforming the sector, with products and processes moving from traditional/mechanical to advanced/digitalised practices. Also, its role within the complex industrial ecosystem has evolved, and the interconnected industrial activities have expanded, changing the boundaries and actors of manufacturing activities.[13] Nowadays, the idea of manufacturing can encompass anything from the old-style factory floor industrial production to the futuristic idea of a smart factory where there are no workers and digital machines can make everything alone, once programmed. Yet, the reality lies somewhere between these two ideas, and its complexity, coupled with the multitude of industrial activities and sectors associated with manufacturing, impedes the formulation of a singular and concise definition thereof. The rest of this section provides an overview of the different meanings of manufacturing across time, and across countries (Section 2.1), and of the complexity around its classification and conceptualisation in economics, and consequently in the policy-making sphere (Section 2.2).

[13] Szalavetz, A. (2022). The digitalisation of manufacturing and blurring industry boundaries. *CIRP Journal of Manufacturing Science and Technology*, 37: 332–343.

2.1 What does *manufacturing* mean?

Going back to basic definitions, the *Collins Dictionary* defines the verb "to manufacture" as making in a factory, usually in large quantities; the Cambridge University Press dictionary similarly defines manufacturing as the business of producing goods in large numbers. These definitions embed the two concepts of making and doing it in large quantities, the latter being an important point of differentiation from artisanal production. Yet, no definition discusses the type of product and/or technology that is normally associated with manufacturing. A more encompassing definition from the UN reports that, traditionally, manufacturing has been characterised by "the process of physical or chemical transformation of materials, substances, or components into new products".[14] As general as such definitions sound, it is clear how the definition of manufacturing can change widely depending on a number of factors and historical facts. For example, the industrialisation process (i.e. the art of making goods) has been diverse across countries, with consequences for the collective imaginations of different people. Countries that industrialised in the 19th and first half of the 20th century, where big plants of automotive and steel production dominated the scene with large, noisy and often unhealthy conditions, are likely to have a different idea of manufacturing to countries such as Ireland and Singapore, where the focus on high-value-adding segments of specific value chains (e.g., pharmaceutical, ICT, aerospace) allowed to avoid the phase of old industrialisation. In the UK, similarly to the first case, old textile factories are part of history books and the collective image, influencing the perception of manufacturing even today.

Different experiences across countries are also influencing how manufacturing is changing; for example, in South Korea and Japan, where technological adoption and digitalisation have been faster than in other countries (looking at the number of industrial robots per 10,000 people in 2020, Japan has 390, South Korea 932 and the UK 101),[15] manufacturing importance is reflected in high share of GDP and national employment figures. The relentless pace of technological change and digitalisation is propelling the sector towards further evolution, rendering the conceptualisation of the industry even more challenging. In recent years, considerable attention and effort have been directed towards an array of digital technologies, notably the "internet of things", "big data" and cloud computing, as well as advanced robotics, artificial intelligence, visualisation technologies and 3D printing. The transformation of the manufacturing sector has resulted in different countries employing a range of similar and interconnected terms in innovation policies and academic literature to describe the "digitalisation of manufacturing", such as "smart manufacturing", "digital

[14] United Nations (2008). https://unstats.un.org/unsd/classifications/Econ/Detail/EN/27/C

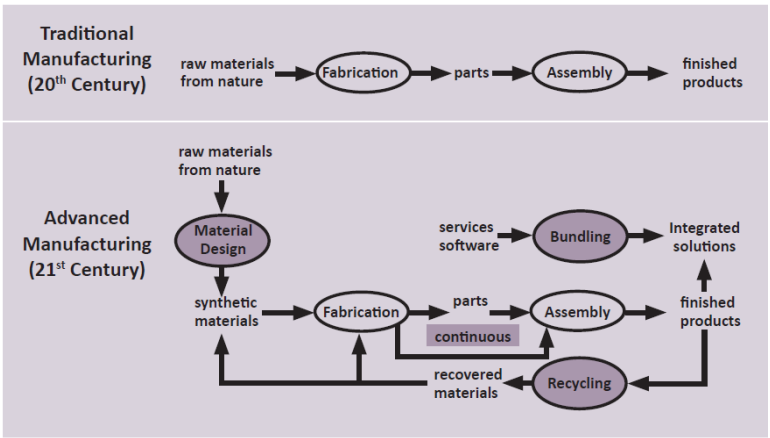
[15] As the only G7 country – the UK has a robot density below the world average of 126, ranking 24th (IFR, 2021).

manufacturing", "'industrial internet", "smart factories", "cloud manufacturing", "Industry 4.0", and more.[16]

Other definitions include the expanding scope of the manufacturing value chain, encompassing activities within the factory, production functions, material transformation, assembly and supply processes, as well as product development and delivery. For instance, in 1983 the International Academy for Production Engineering (CIRP) recognised the interrelated industrial activities, defining manufacturing as "a series of interrelated activities and operations involving the design, materials selection, planning, manufacturing production, quality assurance, management and marketing of the products of the manufacturing industries."

It has been recognised that the evolution of the manufacturing industry in the 21st century, from traditional to advanced manufacturing, requires the incorporation of new forms of factory input, production stages and industrial processes in material transformation activities.[17] The key differences include bundling products with embedded software and services software, designing synthetic materials, and recycling and reusing materials for more sustainable products.

Figure 1. *Production process in transition, between traditional and advanced manufacturing*



Source: De Weck and Reed, 2014.

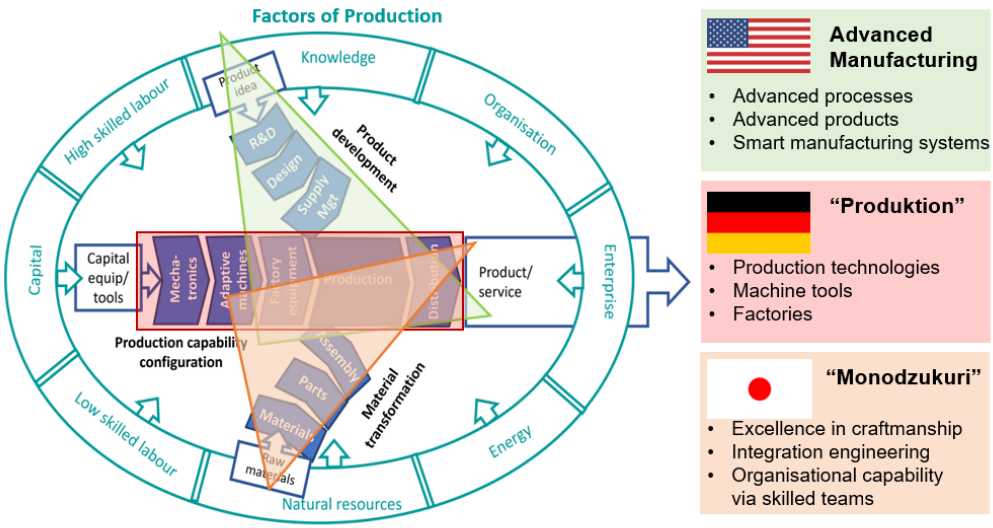
[16] NSTC, 2022.

[17] De Weck, Olivier L. and Darci Reed (2014). Trends in Advanced Manufacturing Technology Innovation. In: Locke, R. M. and Wellhausen, R. L. (eds), *Production in the Innovation Economy*. Cambridge, MA.

This viewpoint was furthered by the UK Department for Business, Innovation & Skills (2010),[18] stating that manufacturing was "[often perceived as merely production – the process of transforming raw materials and semifinished products either into new more complex goods or for final sale to consumers … production is often only one aspect of the manufacturing process or…] [the] value chain comprising [production and] a number of other vitally important functions: research, design & development of products and services, production, logistics & distribution, sales & marketing, after sales services."

In order to clarify the intricate and multifaceted nature of "manufacturing", Figure 2 presents an integrated conceptualisation framework, which offers insights into the various terminologies and emphases found among different nations. At its core, manufacturing revolves around factory-based production activities, with a multitude of factors influencing production. These factors encompass knowledge, organisation, entrepreneurship, natural resources, energy, labour and capital. Diverse economies capture value from different aspects along the value chain, resulting in distinct terminologies and emphases within the manufacturing ecosystem.

Figure 2. *Examples of manufacturing concepts*



Source: O'Sullivan (2013).[19]

One perspective of manufacturing sees it as a "product development and delivery" process, where the product concept is the central focus. In this context, production aims to translate

[18] BIS (2010). Manufacturing in the UK: An economic analysis of the sector. BIS Economics Paper No. 10A.

[19] Figure adapted from a presentation on the report: O'Sullivan, E. and Mitchell, N. (2013). International approaches to understanding the future of manufacturing. Available at: service.gov.uk

knowledge into tangible products or services, following stages such as research, design and development, and supply chain management. An example of this perspective is embodied in the concept of “advanced manufacturing”, as exemplified by the US national manufacturing strategy. This concept concentrates on advanced processes, products and intelligent manufacturing systems, with the emphasis that advancements in manufacturing can boost productivity, address environmental challenges and generate new, high-quality employment opportunities.[20]

Moreover, manufacturing is intricately intertwined with the concept of “production capability”, particularly in economies characterised by high wages. This association becomes particularly pronounced when capital-intensive tools or machinery play an integral role in the manufacturing process. An example is Germany’s manufacturing strategy, which frequently employs the term “*produktion*" to underscore its emphasis on the nation’s comparative advantage in producing high-quality and competitive manufactured goods. This strategic orientation relies heavily on sophisticated production technologies, precision machine tools and the efficient functioning of industrial facilities. Notably, Germany’s latest industrial strategy incorporates measures aimed at modernising instruments for safeguarding technological sovereignty.[21]

A final example comes from Japan, where manufacturing frequently adopts the perspective of a “material transformation and assembly/supply” process, emphasising the conversion of raw materials into assembly-ready components. An illustrative term representing this perspective is “*monodzukuri”*, a Japanese concept that translates into “production” or “the art of making things”. At its core, *monodzukuri* embodies a philosophical approach centred on the pursuit of excellence in craftsmanship, the seamless integration of engineering principles and the cultivation of organisational capabilities through skilled teams. *Monodzukuri* is believed to have not only significantly contributed to Japanese culture and industry but also played a pivotal role in enhancing the quality of life for the Japanese populace.[22]

[20] Executive Office (2022). National Strategy for Advanced Manufacturing, p. 1.

[21] BMWi (2019). Made in Germany: Industrial Strategy 2030. Germany, Federal Ministry for Economic Affairs and Energy (BMWi).

22 METI. (2023). Overview of Manufacturing Industry.

2.2 Manufacturing in economic policy

Definitions of manufacturing are hotly debated in the realm of economics and industrial policy. A comprehensive review of diverse manufacturing definitions is available in the report *Inside the Black Box of Manufacturing*.[23] As stated in the report, "manufacturing is not a single cog in the economy, but an industrial system comprising many interrelated cogs and activities". This systemic complexity, along with the constant technological advancements, underscores the dynamic and intricate nature of the manufacturing sector, making it imperative to consider a multitude of perspectives and definitions in the study of this vital industry.

Within the economic discipline, a critical aspect of the "perception of manufacturing" deals with its supposed "decrease of importance" across advanced economies. In national statistics, manufacturing went from being the first economic sector, both as contributor to GDP and as source of employment, to a residual role. Country national statistics measure manufacturing output as the sum of all production-based activities; for example, in the common ISIC classification, section C incorporates all manufacturing sectors from class 10 (2-digits) to class 32. By looking at the share of manufacturing output in different countries, there are some differences, for example 9.9% in the UK, 11.4% in the US, or higher shares, as in Germany (21.2%) and Switzerland (18.7%).[24]

Therefore, although in some countries the manufacturing decline has been severe (e.g. the UK and US), data on manufacturing output is strongly underestimated across countries, mainly because official statistics fail to include the important role of manufacturing-based activities in services, especially high-value-added business services. Indeed, there are strong production and skills complementarities between, for example, manufacturing and high-value-adding ICT services and R&D activities. Despite R&D activities mainly being accounted for as business services – a trend that became common after the increasing external outsourcing of such activities to other firms – it is widely recognised that they require a manufacturing base to continue the innovation and technology diffusion process.[25]

A final – critical – point is related to the perception of manufacturing in the policy and political discourse. Historically, manufacturing has been associated with industrial policy, intended as a government effort to modify countries' specialisation in different policy instruments, with the

[23] Hauge, J. and O'Sullivan, E. (2019). *Inside the black box of manufacturing: Conceptualising and counting manufacturing in the economy*. Cambridge: University of Cambridge Engineering Department.

[24] 2019 data. OECD Stan data.

[25] Ciriaci, D., Montresor, S. and Palma, D. (2015). Do KIBS make manufacturing more innovative? An empirical investigation of four European countries. *Technological Forecasting and Social Change*, 95: 135–151.

aim of “picking winners”, favouring certain industries and firms that would contribute to economic growth in the country. This government attitude has been strongly opposed since the 1980s, when “government failures” were argued to be bigger than “market failure”; thus, there was more scope to give the market the freedom to operate.[26] This approach, also known as the ”Washington Consensus’”, has been very persuasive, especially in the US and UK, to the point that while the term “industrial policy” has often been substituted with “innovation strategy”, the concept behind it has barely changed.[27] In recent years, especially after the GFC and – even more so – the pandemic and inflation crisis, it has become more widely accepted that government intervention targeting specific manufacturing sectors[28] is not only part of the policy practice but also once again part of the academic and policy discourse.

3. Public perception of manufacturing

In this section we explore the perception of manufacturing among the public. The growth of services in value added and employment, in the last 3 decades, has changed the industrial make-up in the UK, lessening the importance and appeal of manufacturing, with increasing competition from emerging markets.

The rapid growth of the financial sector and the increase in salaries offered by different types of financial actors meant that the newest generations of graduates in engineering, physics and chemistry have been opting for finance rather than industry jobs.[29] These changes are reflected in national statistics and employment figures.[30] Contrary to some perceptions, manufacturing is also the most productive sector of the economy, and it is where most of the private R&D investments take place (see Raijic and Bailey 2020;[31] Research & Development spending[32]). Although most of the negative perceptions about manufacturing do not have an

[26] Wade (2017). The American paradox: ideology of free markets and the hidden practice of directional thrust. *Cambridge Journal of Economics*.

[27] Chang, H.J. and Andreoni, A. (2020). Industrial policy in the 21st century. *Development and Change*.

[28] One of the most critical examples is the recent US policy agenda targeting the semiconductor industry. See Atkinson (2023). https://itif.org/publications/2023/07/17/export-controls-shrink-global-markets-us-semiconductors-need-to-survive/

[29] Beverland M., Nielsen B. and Pryce V. (2015). Redesigning Manufacturing. Reimagining the business of Making in the UK. England: Palgrave Macmillan, p. 13.

[30] Make UK (2023). Perceptions Vs Reality Report 2023. makeuk.org

[31] Rajic I. and Bailey D. (2020). Manufacturing and Brexit. The UK in a Changing Europe Report. p. 4, ukandeu.ac.uk

[32] Panjwani A. (2023). Research & Development spending. House of Commons Library, United Kingdom, 11 September 2023, pp.14 –25, more at parliament.uk

empirical basis, what people think matters. We used academic tools to review surveys from the general public, both in the UK and internationally.

Key findings from the academic and policy documents reveal that:

- The image of manufacturing has been very poor, but it is not set in stone: while in 2001 the British public knew very little about manufacturing and believed the country could grow without it, in 2023 93% believe that the industry is essential to growth and resilience.
- Teenagers (aged 10–12) and young adults (aged 14–19) across countries (including the UK) believe that the industry is male-dominated, not well paid and repetitive, and this trend has remained relatively stable over time.
- German and US residents are the most likely (75%) to perceive manufacturing as having significant importance in their country's economy, considering it "very attractive", which is in sharp contrast with the UK (~40%), who viewed manufacturing as offering good job opportunities.

We draw the majority of our evidence from surveys conducted by governments, industry associations and consultancy firms, as the perceptions of manufacturing has not been a rich field in academic studies. The analysis is based on an examination of surveys conducted across several countries, including the UK (Section 3.1) and Canada, the US, Germany and Switzerland (Section 3.2). By comparing these surveys, we evaluate the similarities and differences in the perceptions of these nations, aiming to observe trends and specific features of public attitudes towards manufacturing. However, it is crucial to acknowledge that this analysis primarily has an informative function because of the inherent variations in sample sizes across these surveys and the composition of the sample population.

The academic articles that address the perceived problem with the industry, either directly or indirectly, are few, with most focusing on the US market. We conducted a systematic literature review drawing articles from *Google Scholar* and *Scopus* using a combination of keywords such as "perception of manufacturing", "attitudes towards manufacturing" or "public perception of manufacturing",[33] with each returning around 24 articles, which is an extremely low number. Across these articles, the perception of manufacturing was discussed with reference to the

[33] The use and combination of keywords were drawn from the funder's research call and agreed by the members of the team; for consistency, we also based our search on the Livesey report (2013). Different combinations have been tested.

ageing workforce in manufacturing,[34] the role of manufacturing in national systems of innovation, and manufacturing strategy (mainly in management journals that do not address the perception of the public).[35]

3.1 Public perception of manufacturing: a UK perspective

In this section we aim to provide an overview of the public perception of manufacturing in the UK, gathering both academic and policy evidence. One of the potential – and most detrimental – impacts of a negative image of manufacturing is the lack of a labour pool for manufacturing firms to tap into, especially skilled and high-skilled labour.[36] Therefore, as the research suggests, the attitudes of the general public – most notably young people and students – towards the industry of "*making things"* is paramount to understanding and addressing it.[37]

One of the most comprehensive evidence-based reports is found in the Livesey report of 2013,[38] where the author addresses the public image of manufacturing in the UK. The report collates academic and survey-led evidence from the early 2000s to 2012. The key takeaways are as follows:

- Adults over 18 years of age have a relatively positive attitudes towards manufacturing, but the importance of the industry is destined to decline, and the industry will not have a prominent role in the economy in the next 20 years – starting from the aftermath of the financial crisis in 2008.
- Younger (aged 10–19) survey respondents have a more negative view of manufacturing; they see the industry as dull, boring, repetitive, factory-based and male-dominated, with little possibility to travel.
- The image of manufacturing is solidifying over time because the people that the industry seeks to attract, and which it needs – young people and university graduates – view it negatively.

[34] Thun, J. H., Größler, A. and Miczka, S. (2007). The impact of the demographic transition on manufacturing: Effects of an ageing workforce in German industrial firms. *Journal of Manufacturing Technology Management*, 18(8): 985–999.

[35] Livesey F. (2013). Public images of manufacturing in the UK: the current situation and future prospects. Foresight, Government Office for Science, p. 10.

[36] Perini S., Oliveira M., Costa J., Kiritsis D., Hansen P. H. K., Skevi A., Sziget H. and Taisch M., (2014). Attracting Young Talents to Manufacturing: A Holistic Approach. Chapter in Advances in Production Management Systems. Springer.

[37] Beverland M., Nielsen B. and Pryce V. (2015). Op. cit. p. 13.

[38] Livesey F. (2013). Op. cit.

One of the first and most direct surveys on the perception of manufacturing and engineering was conducted in 2001 by Ipsos MORI.[39] The survey produced a striking result: 70% of children aged between 10 and 16 did not know what manufacturing was and 40% believed the industry was just for men.

Next, a survey carried out by YouGov in 2012, involving 1,452 adults from the general public, on attitudes to manufacturing in the UK, and discussed in Livesey (2013),[40] revealed that the public has a "nuanced view of manufacturing". The participants also agreed that the industry is high-tech-intensive; however, 74% believed that manufacturing jobs are the first to be offshored. Older respondents (55+) believed that the UK needs a strong manufacturing sector, while the 18–34 age cohort believed that the UK can grow without it. This is an interesting result, which may unravel the deindustrialisation narrative that the economy will be service-based and manufacturing will not assume the same central role in the future. Another striking difference between older and younger participants was the attitudes towards a career in manufacturing: while the former would encourage their children to work in the industry (31%), the latter would not (34%).

Similar results can be found in a survey administered by Engineering UK[41] in 2009/10 on public attitudes towards engineering, where just 15% of students between the age of 15 and 17 believed a career in manufacturing to be well paid and saw a potential career in the industry. Differences are tangible across locations too. While London was the region with the most negative attitudes towards manufacturing, the East showed the opposite tendency.

Another survey carried out by YouGov[42] in 2012, involving 1,748 adults in the UK, investigated the role of manufacturing in growth models. A total of 55% of the sample believed that manufacturing was (and still is) one of the most important industries for boosting economic growth in the short term. Less positive responses were collected on the role of manufacturing in 20 years' time. When respondents were asked if they believed the UK would be among the world's top 10 manufacturers, 63% disagreed, and this perception did not change over time.

[39] Market research company based in London.

[40] MENTION LIVESEY HERE?

[41] Engineering UK 2009/10 – report. engineeringuk.com

[42] De Waal J. R. (2012). Public views on the economic state of Britain. yougov.co.uk

What stands out from these surveys, administered between 2001 and 2013, is that the image of manufacturing was perceived as quite negative, subject to offshoring, "male-dominated" and an unlikely career for teenagers to consider in the future. However, the image of the industry is not set in stone – it can change. For instance, the pandemic has highlighted the frailty of supply chains and production networks in withstanding the pressures of lockdowns and other safety protocols, including product and workforce shortages (Kapoor et al. 2021[43]), reinforcing how dependent we are on the manufacturing industry. Recent surveys on the perceptions of manufacturing[44] have detected this change, showing how public opinion is more positive towards manufacturing. However, there is room for improvement, and new technological trends can boost the industry's attractiveness (see Box 3).

More positive perceptions were gathered by Make UK, a British manufacturers' organisation that since 2018 has published two waves of surveys on the perceptions and importance of manufacturing in the UK. The first round, in 2018,[45] revealed that 79% of the British public wanted more emphasis to be placed on manufacturing in government policies, especially after Brexit and the challenges arising from the UK's exit from the EU (see Rajic and Bailey 2020[46]). However, only one out of five parents suggested manufacturing as a prospective career for their child, and the numbers are lower for those with daughters. The views from the 2018 survey highlight an improvement in the general perceptions of manufacturing; however, when it comes to the industry image for younger generations, views collected in the past 2 decades show a similar trend. The reality is that the industry is home to very high-skilled and highly paid jobs, but this image has failed to materialise.

In 2022,[47] 4 years after the last survey, Make UK revealed that 93% of the British public believe that manufacturing is important for UK prosperity, and two out of five parents would suggest the industry as a potential career for their child. This is a notable improvement from the last wave. A third of participants said that they had not even seen one manufacturing story in the news or a media outlet. The public recognises the importance of manufacturing for the country's economic fabric and that a resilient industry is needed to face challenges such as Brexit, the pandemic and geopolitical turmoil.

[43] Kapoor, K., Bigdeli, A. Z., Dwivedi, Y. K. and Raman, R. (2021). How is COVID-19 altering the manufacturing landscape? A literature review of imminent challenges and management interventions. *Annals Operation Res*. Nov. 2021, 17: 1–33.

[44] Make UK (2023). Perceptions Vs Reality Report 2023. makeuk.org

[45] Make UK (2018). Why does manufacturing matter to the British public? makeuk.org

[46] Rajic, I. and Bailey, D. (2020). Op. cit.

[47] Make UK (2023). Op. cit. p. 10.

The views recorded by Make UK echo those presented by the InterAct survey in 2023,[48] which has been administered to 2,107 members of the public. According to the findings, over 80% have recognised the key role of manufacturing in the UK's reputation and supply chains, and 30% said they had not seen or read anything about UK manufacturing in the media. While participants were quite positive about manufacturing, they were sceptical about job quality. Only 21% believed that manufacturing can be high skilled, with 60% believing that jobs are repetitive and the industry does not offer high salaries, benefits or sufficient job flexibility. Additionally, the survey identified the top five expectations of individuals engaged in manufacturing roles, including comparable pay and benefits (90%), wellbeing and flexibility (90%), a clean and safe environment (89%), contractual stability and security (89%) and an employer that values its employees' voices (87%). The study also suggests that increasing female and minority representation in leadership positions (58%) would enhance innovation in the sector.

3.2 Public perception of manufacturing: international comparison

This section aims to provide insights into the public perception of the manufacturing sector across countries. Detailed information regarding the survey methods and demographics of respondents can be found in the respective reports.

This section reviews the three main findings to have emerged from the analysis on perceptions of manufacturing across countries:

• Divergent opinions on manufacturing exist across nations, age groups and genders, including aspects such as the image of manufacturing, its attractiveness as a future career, its importance in the national economy and its capacity for innovation.
• There has been a shift in perception and expectations regarding employment in the manufacturing sector, particularly among the younger generations.
• Manufacturing is generally perceived as a sector that acknowledges the contemporary challenges brought about by global trends, such as supply chain disruption and the shortage of a skilled workforce, and it is oriented towards future advancements through digitalisation and new technologies.

[48] Interact. Perceptions of manufacturing – survey findings infographics. Interact-hub.org

3.2.1 Divergent perception of manufacturing across countries

The study conducted by Chargeurs – Institut Choiseul (2018)[49] underscores that Germans exhibit a particularly strong attraction towards manufacturing. In this study Germans were the most likely (75%) to perceive manufacturing as having significant importance in their country's economy. Moreover, when assessing the sector's attractiveness for those entering the labour market, 55% of German respondents considered it "very attractive", contrasting sharply with Americans (35%), who viewed manufacturing as offering good job opportunities. This favourable perspective in Germany can be attributed to the sector's crucial role in the national economy and a deeply ingrained appreciation of apprenticeship-based training, which offers robust pathways to employment. The comparative study conducted by Chargeurs – Institut Choiseul (2018) reveals that Germans are most inclined to regard manufacturing as a vital component of their economy (75%), demonstrating a positive view of its integration in their national activity. In contrast, countries such as Canada and the UK face a more pronounced and persistent negative image of manufacturing. Similar to the surveys reviewed for the UK, the public associates words such as "repetitive", "dull", "boring" and "male-dominated" (see also InterAct, 2023) with manufacturing, but at the same time they recognise the central role of the industry in supporting and promoting economic growth.

Considering the gender perspective that we adopt in this study, we looked at whether countries reported any insights into gender differences. Surveys in countries such as Canada and Germany address the gender differences in perceptions more directly. For instance, the Ngen – Abacus Data Survey (2021)[50] found a repeated trend of female respondents being more negative towards manufacturing.[51] The structural under-representation of women within the industry might reinforce this perception.[52] This viewpoint persists, as highlighted by the InterAct survey (2023), where 66% of respondents asserted that the manufacturing industry must enhance its efforts to recruit women and individuals from minority backgrounds. Moreover, responses concerning the potential for a successful career for women within manufacturing reveal disparities. The Chargeurs – Institut Choiseul (2018) survey found that Americans (72%) believe the sector offers favourable conditions for an engaging professional

[49] Chargeurs – Institut Choiseul (2018). Compared Perception of Industry in France, Germany, Japan and the United States. choiseul-france.com

[50] Ngen – Abacus Data Survey (2021) at abacusdata.ca

[51] This divergence is commonly linked to the perception of manufacturing as a "male-dominated" industry, a notion supported by a report from the Council for Industry and Higher Education (2011).

[52] For instance, the percentage of women among the UK's engineering professionals is less than 10%, compared to 26% in Sweden. For the UK, see also Castañeda-Navarrete J. (2023). Women in manufacturing: the case for a gender-transformative digitalisation. Cambridge Industrial Innovation Policy, University of Cambridge. InterAct. available at interact-hub.org

life for women, while opinions in Germany were most contrasting (43%). This low rate, however, is explained by the fact that a large number of respondents in Germany consider manufacturing to be no different to other sectors in this regard. A similar trend can be detected in the UK. Surveys conducted since 2001, reported in Livesey (2013), reveal that students across secondary and higher education believe that manufacturing is male-dominated.

3.2.2 Shifting perceptions

In the Deloitte-Manufacturing Institute (2017)[53] study, US respondents held the manufacturing industry in high regard, with 83% of respondents believing that the industry is important to the nation's economic prosperity. The survey also revealed that manufacturing was ranked as the third most important industry in terms of supporting job growth at the community level, after technology and the healthcare sector.

In the case of the US, we were also able to retrieve a few academic studies investigating the public attitudes of students by stressing the role of higher education in enhancing student perceptions of pursuing a career in manufacturing (see also Box 2). For instance, Lynch et al. (2019)[54] employed a qualitative approach to gather information about the perception, satisfaction, motivation and knowledge of the manufacturing process across Generation Z industrial engineering students in the US. The background and motivation of the study stem from the importance of the manufacturing industry in the US economy, the misperceptions surrounding manufacturing as a career choice, and the skills gap existing as a result of retiring *baby boomers* and a shortage of skilled workers in manufacturing. The results show that 37.5% of the students (21 out of 56) had little to no knowledge about manufacturing processes before taking the solidification processes course (e.g. courses in nanotechnology and specialised manufacturing processes). About 60.7% (34 out of 56) reported having some basic knowledge, and only 1.8% (1 out of 56) stated that they had a strong knowledge base of manufacturing processes prior to taking the course. The students were asked about their perceptions of working in manufacturing before and after taking the solidification processes course. Prior to taking the course, around 41% of the students (23 out of 56) stated that they would not have considered a career in manufacturing. However, after completing the course, the number of students who would consider a career in manufacturing increased significantly, to 49 out of 56. This demonstrates a notable increase of 28.5% in the students' willingness to consider a career in manufacturing after completing the solidification processes course (e.g.

[53] Deloitte – Manufacturing Institute (2017). A Look Ahead: How Modern Manufacturers Can Create Positive Perceptions with the US Public

[54] Lynch, P. C., Wilck, J. and Gaughan, E. (2019, June). Changing the manufacturing perception of millennial and generation Z engineering students. In *2019 ASEE Annual Conference & Exposition*.

additional lectures for nanotechnology and other manufacturing processes). Furthermore, all 56 students (100%) agreed that, after taking the solidification processes course, they now believe it is important for industrial engineering students to have a strong understanding of manufacturing processes.

Here, the findings echo Strimel et al. (2020),[55] who discuss the challenges faced by manufacturing firms in the US in hiring qualified employees despite a considerable number of available jobs (~340,000 in 2016). The research shows that familiarity with the manufacturing field positively influences opinions about pursuing careers in manufacturing. In Bosman et al. (2021),[56] the authors suggest that exposing pre-service science, technology, engineering and mathematics (STEM) teachers to manufacturing could impact how they influence their K-12 (i.e. primary and secondary school students) students' perceptions of manufacturing careers. The idea is that they could better educate students about manufacturing careers, which could help with the many challenges facing the manufacturing workforce, including the ageing US workforce and rapid technological advancements, which are common to many industrialised and labour-intensive countries such as China, India and Germany (see Box 1 for a review of the ManuSkills Five Pillars Learning and Teaching project).

[55] Strimel, G. J., Krause, L., Bosman, L., Serban, S. and Harrell, S. (2020). The Next Generation for Manufacturing Competitiveness? Investigating the Influence of Industry-Driven Outreach on Children Career Perceptions. *Journal for STEM Education Research*, 3: 232–258.

[56] Bosman, L., Strimel, G. J. and Krause, L. (2021). The role of higher education in establishing career perceptions related to manufacturing: An exploratory study. *Industry and Higher Education*, 35(6): 736–745.

***Box 1**. The ManuSkills Five Pillars*

ManuSkills is a learning and teaching framework aimed at addressing the misperceptions of primary and secondary school students about manufacturing. More importantly, the framework aims to tackle the skills shortages in the aftermath of the financial crisis.

Their argument is based around the STEM (science, technology, engineering and mathematics) leaking pipeline. This translates into the generalis

ed disinterest of young students (i.e. both primary and secondary schools) in STEM and the disillusionment of young adults at universities, leading to drop-outs. In fact, an analysis of the whole student life cycle shows that the perception and feeling of youngsters towards STEM is fundamental to forming and stimulating their possible future involvement in the manufacturing world.

The core of the experiment runs across five pillars, in which students are put in contact with manufacturers, they use interactive manufacturing software to solve real-life challenges, and student hubs are created for the creation and design of new products to make pupils aware of the kinds of skills needed.

ManuSkills: the experiment, target group and learning objectives

Crucial to this approach is the concept of experimenting to increase awareness of learning manufacturing skills: videos, games, animations and hands-on experiments in a gamified manner.

Students: across the10–12 (teenagers) and 14–16 (young adults) age cohorts, the ages when students usually choose their curricula.
Teenagers: to drive and support an increase in their awareness and interest in manufacturing.
Young adults: to drive and support an increase in their awareness, interest and application of manufacturing, which represent the three different levels of communication and perception needed to efficiently involve the two target groups. These levels are inspired by Bloom's taxonomy of learning objectives, which refers to a classification of the different objectives that can be set for students to define learning objectives.

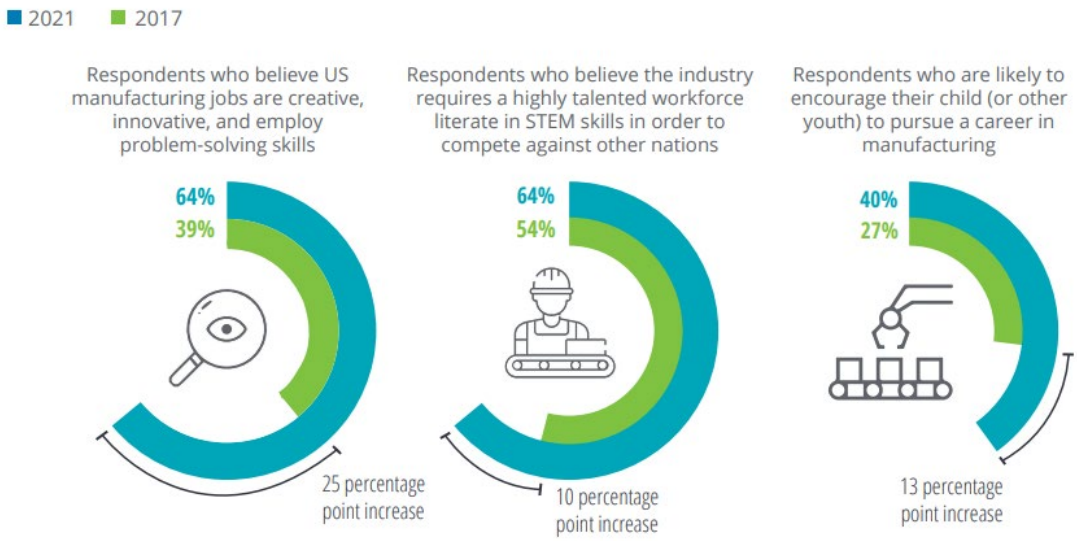
ManuSkills: the Five Pillars

1. *Interaction with the experiment*: ICT platforms to deliver games, simulations and quizzes.
2. *Interaction with real companies*: this is essential to engage talent with real-life situations and problems to solve; this stimulates interesting and innovative ideas based on student feedback, for example, online interactions between students and manufacturing engineers.
3. *Social networks:* young talent should be involved by leveraging innovative distribution channels such as social media. Examples are the collection of feedback from students by means of social network features and the creation of forums for the discussion of specific manufacturing themes.
4. *Challenges and making real products:* this is based on real scenario-based challenges by creating incubators to allow students to prototype their ideas.
5. *Career management and skills orientation:* this is the pillar that supports the four pillars listed above. It is crucial for students to participate in online career fairs and have the chance to showcase their work.

Source: Perini, S., Oliveira, M., Costa, J., Kiritsis, D., Hansen, P. H. K., Skevi, A., Sziget, H. and Taisch, M. (2014). Attracting Young Talents to Manufacturing: A Holistic Approach. Chapter in *Advances in Production Management Systems*. Springer
The project is currently taking place in five companies across Denmark, the UK, Italy, Austria and France. For more information, visit portal.effra.eu.

An interesting study across time was conducted by Deloitte and the Manufacturing Institute (2022)[57]; it reveals a significantly improved perception of manufacturing among the American public in 2021 compared to 2017. Notably, 25% more respondents believed that manufacturing jobs are “innovative” and “creative”, and 13% more expressed a willingness to encourage their children to pursue careers in the industry. The study also underscores that the COVID-19 pandemic played a role in generating positive perceptions of US manufacturing, as the sector was seen as pivotal in producing PPE and ventilators and sustaining jobs during the crisis.

Figure 3. *Perceptions about manufacturing jobs between 2021 and 2017*



Source: Deloitte analysis of the 2017 and 2022 US perception of manufacturing study data.

In addition, a survey by digital manufacturer Proto Labs (2017) in the US highlighted a distinct generational shift. Millennials exhibited a heightened appreciation of manufacturing as a high-tech career choice, with 37% recognising this aspect – significantly surpassing Generation Xers (27%) and baby boomers (23%). Furthermore, 49% of millennials surveyed acknowledged the indispensability of engineering skills in today’s manufacturing landscape, compared to a modest 41% of baby boomers.

Despite the positive shift in perception in the US, in Switzerland the opposite has occurred. The Deloitte study (2018)[58] underscored that the nation’s economy has transitioned towards

[57] Deloitte – Manufacturing Institute (2022). Competing for Talent: Recasting Perceptions of Manufacturing.

[58] Deloitte (2018). Motivated, Optimistic but Training Neglected.

a more service-oriented and knowledge-intensive model as a result of technological advancements. This shift has driven substantial job growth in the service sector but limited growth in the manufacturing sector, leading 65% of Swiss mechanical and electrical engineering (MEM) companies to perceive other sectors, particularly banking and insurance, to be more attractive and adept at attracting talent. The Deloitte study (2018) highlighted that there are marked differences in motivating factors between age groups, with job security and stability being a priority for those under 35, while clear definitions of responsibilities are crucial for those aged 35–44. Competent leadership becomes a top priority for those aged 45–54, and seeing a purpose in the job takes precedence for individuals above 55.

3.2.3 Future opportunities and challenges

Examining the future of manufacturing, the studies reveal a notable degree of optimism among the general public. The Chargeurs – Institut Choiseul study (2018) revealed that over half of the respondents in each surveyed country believe that the manufacturing sector is geared towards the future. Specifically, both Americans (52%) and Germans (55%) expressed confidence in the industry's resilience and its ability to address future challenges.

The Deloitte study (2018) also pointed to a strengthening outlook on manufacturing among Americans. Nearly 41% of respondents expressed a belief in the industry's long-term growth, marking a significant increase from 2014, when only 29% held this belief. Looking ahead, respondents unanimously recognised a critical future challenge for manufacturing: the shortage of skilled labour, primarily driven by skills gaps. The study also highlighted that a significant proportion of Americans (45%) believe that school systems are falling short in exposing children to the manufacturing industry, contributing to the skilled labour shortage.

The manufacturing workforce survey conducted in Canada (2019)[59] highlighted several obstacles that must be addressed to revitalise the workforce. These obstacles include insufficient engagement and training among Canada's youth, talent mobility barriers, underutilised demographics, and a lack of career support and incentives.

[59] Canadian Manufacturers & Exporters (2019). We're Hiring: Manufacturing Workforce Survey Report.

4. Perceptions of manufacturing across policy-makers

This section presents the findings of a systematic analysis of the perceptions of manufacturing in policy-making across seven countries. The analysis is based on the review of 68 strategies and initiatives related to manufacturing spanning the period of publication from 2018 to 2023. These include: (i) research, innovation and industrial plans and strategies; (ii) digital manufacturing initiatives; (iii) skills development programmes; (iv) white papers; and (v) technology foresight studies (see Appendix A for the full list of strategies and initiatives consulted). Strategies in German and Korean were analysed using automated translations into English. This analysis was completed with expert advice from national and international academics and practitioners in industrial innovation policy.

The countries selected for this comparative analysis were:[60] the UK, Canada, Germany, Singapore, South Korea, Switzerland and the US. These are all advanced countries but with diverse trajectories in the role that manufacturing has played in their economies over time. Historically, manufacturing has served as a cornerstone of the economy in some of these nations, such as Germany and South Korea. In contrast, in others, such as the UK and US, manufacturing experienced a significant decline in participation in the economy between the 1970s and early 2000s.[61]

Commonalities and differences are observed in how manufacturing is discussed in policy documents and the terms used to refer to this sector. For example, terms such as “advanced manufacturing” feature prominently in innovation strategies across most of the countries. The US and Canada use the term “advanced manufacturing” in their policy documents to highlight the high-tech nature of this industry. For instance, the Five-Year Strategic Plan of Next Generation Manufacturing Canada (NGen) describes manufacturing and advanced manufacturing as follows:

> *If manufacturing is the business of making things, advanced manufacturing involves the use of leading-edge technologies and techniques to grow that business, by solving*

[60] Countries were selected during an ad hoc call in accordance with the funder for this project, InterAct.

[61] Kitson, M. and Michie, J. (2014). The Deindustrial Revolution: The Rise & Fall of UK Manufacturing, 1870-2010. Working Papers wp459, Centre for Business Research, University of Cambridge.

problems and making things – often new things – for customers, in significantly better ways.[62]

In the US, the National Strategy for Advanced Manufacturing defines this sector as "the innovation of improved methods for manufacturing existing products, and the production of new products enabled by advanced technologies".[63]

Variations of advanced manufacturing, such as "advanced low-carbon manufacturing"[64] and "advanced materials and manufacturing" are prevalent in UK strategies.[65] Similarly, the terms "sustainable manufacturing" and "net-zero manufacturing" are found in Singapore's Research, Innovation & Enterprise 2025 Plan.[66] Other terms commonly used across the seven countries examined include: smart and digital manufacturing, Industry 4.0 and production.

The rest of the section discusses our analysis of the 68 policy documents, focusing on:

- national priorities;
- how the contribution of manufacturing to economy and society is portrayed;
- key challenges and opportunities addressed; and
- whether and how strategies and initiatives address gender gaps and the representation of different genders in the imagery they use.

[62] NGen (2023). Five-Year Strategic Plan, p. 4.

[63] Executive Office (2022). National Strategy for Advanced Manufacturing, p. 2.

[64] Innovate UK (2023). Materials and manufacturing vision 2050.

[65] BEIS (2021). UK Innovation Strategy.

[66] National Research Foundation Singapore (2020). Research, Innovation & Enterprise 2025 Plan.

4.1 Perceptions of manufacturing in national strategies

Governments often shy away from explicitly discussing "industrial policy" in contemporary political discourse; however, manufacturing is usually addressed in industrial and innovation strategies. Variations across countries and over time are observed regarding how the role of industrial policy is portrayed. For instance, the 2017 UK Industrial Strategy stated, in the foreword by the Prime Minister: “At its heart it epitomises my belief in a strong and strategic state that intervenes decisively wherever it can make a difference.”[67]

In comparison, the German National Industrial Strategy 2030 presents a somewhat conflicting and neoliberal standpoint:

> *The means of choice to achieve the goals are rooted in a market economy, private sector and responsible approach. State activity can only come into question as an exception, temporarily, and only in cases of fundamental importance once all other options have proven to be inadequate*.[68]

> *Industrial policy strategies are experiencing a renaissance in many parts of the world. Hardly a successful country exists that relies exclusively and without exception on market forces to manage the tasks at hand*.[69]

4.1.1 Role of manufacturing in the economy and society

National strategies portray manufacturing as a key driver of economic growth, exports, productivity, research and innovation, regional development and inclusion. For example, Singapore’s Minister of State for Trade and Industry referred to manufacturing as the “bedrock” of Singapore’s economy.[70]

On the contribution of manufacturing to innovation, the US MForesight report highlights its crucial role in translating research into profit or, in other words, “capturing the gains from new manufacturing technologies”.[71] In Switzerland, having a manufacturing value added share that is among the highest in the industrialised world (25%) is also recognised as a key driver of

[67] HM Government (2017). Industrial strategy, p. 4.

[68] BMWi (2019). National Industrial Strategy 2030. Strategic guidelines for a German and European industrial policy, p. 4.

[69] BMWi (2019). Op. cit., p. 8.

[70] Ministry of Trade and Industry Singapore (2023). Speech by Minister of State for Trade and Industry, Alvin Tan, at the Ministry of Trade and Industry’s committee of supply debate 2023.

[71] MForesight (2018). Manufacturing Prosperity, p. 7.

innovation, and the country is recognised as “the most effective worldwide in transforming innovation investment into results”.[72]

National strategies also underscore the vital role of manufacturing in strengthening national resilience, industrial and technological sovereignty, and overall national security. This is particularly the case in countries such as Germany, Korea and the US. Notably, the role of manufacturing in national security has gained heightened prominence since 2018, coinciding with escalating geopolitical tensions.

The United States 2018 Strategy for American Leadership in Advanced Manufacturing is a good example of a comprehensive portrayal of the contribution of manufacturing to the economy and society:

> *Manufacturing plays a vital role in almost every sector of the U.S. economy, stretching from aerospace to pharmaceuticals and beyond. Advanced manufacturing—which includes both new manufacturing methods and production of new products enabled by innovation—is an engine of America’s economic power and a pillar of its national security. Advances in manufacturing enable the economy to continuously improve as new technologies and innovations increase productivity, enable new products, and create entirely new industries.*[73]
>
> *Manufacturing is among the highest paying sectors of the economy, and has a broad impact on jobs in other sectors. For example, one study found that the job-multiplier effect increases significantly for advanced manufacturing technologies, with every technology-intensive manufacturing job supporting at least four other jobs.*[74]
>
> *The growth of advanced manufacturing requires advances in technology-based infrastructure. Technological innovation is closely tied to manufacturing capability*.[75]

On the multiplier effect of manufacturing, Singapore’s Research, Innovation & Enterprise 2025 Plan states that for every S$1 million of value add generated by the manufacturing sector, a

[72] Switzerland Global Enterprise (2020). Advanced Manufacturing in Switzerland. Factsheet.

[73] Executive Office (2018). Strategy for American Leadership in Advanced Manufacturing, p. 1.

[74] Executive Office (2018). Op. cit., p. 3.

[75] Executive Office (2018). Op. cit., p. 4.

corresponding S$0.28 million is produced in the rest of the economy, particularly in knowledge-intensive services.[76]

In the US, the MxD[77] Strategic Investment Plan 2023–2025 also highlights the role of manufacturing in regional development and inclusion:

> *Manufacturing is the main economic engine and primary employer in around 500 U.S. counties today, and in those communities, the industry employs a broader-than-average swath of the overall population and does so more inclusively. Our analysis suggests that reviving manufacturing could add up to 1.5 million jobs, particularly among middle-skill workers, which would help recalibrate the U.S. labor market and bolster the middle class.*
>
> *Many government officials are also acutely aware that the decline of the U.S. manufacturing industry has contributed to rising inequality and hurt the country's global competitiveness. They see the revitalization of manufacturing as imperative for sustainable and inclusive growth and are set to commit significant public capital to that end.*[78]

Recognising the important role of manufacturing, countries such as Canada, Germany, Korea and Singapore have established targets to increase the participation of this sector in their economies. As described in Table 1, one of the most popular metrics used for these targets is manufacturing value added shares, and a popular target is to sustain or increase these shares to around 20% and 30%.

Table 1. *Examples of manufacturing targets*

Country	Metric	Target	Timeframe	Source
Canada	Sales Exports	Increase by 50%	2030	Canada's Economic Strategy Tables: Advanced Manufacturing

[76] National Research Foundation (2020). Research, Innovation and Enterprise 2025 Plan.

[77] ManufacturingxDigital is one of the 15 Manufacturing USA Institutes. https://www.manufacturingusa.com/institutes

[78] MxD (2023). MxD Strategic Investment Plan 2023–2025, p. 17

Germany	Value added shares	Increase to 25%	2030	BMWi (2019). Industrial Strategy 2030
Korea	Value added shares	Increase to 30%	2030	MOTIE (2019). Manufacturing Industry Renaissance Vision and Strategy
Singapore	Current value Value added shares	Grow by 50% Sustain levels around 20%	2030	EDB (2021). Manufacturing 2030

4.1.2 New challenges and priorities

In the industrial and innovation strategies of the countries analysed, climate change action (or environmental sustainability) and the digitalisation of manufacturing remain top priorities. However, the impacts of the COVID-19 pandemic and geopolitical tensions have resulted in an increasing emphasis on resilience, national security, the reconfiguration of value chains and technological sovereignty (including data and critical materials). For example, Germany's Future Research and Innovation Strategy states:

> *We regard our technological and digital sovereignty in Germany and Europe as a guiding principle in our industrial, digital and innovation policy and want to strengthen it in the long term. To this end, we are deepening existing or establishing resilient new partnerships with our value partners transatlantic space, the G7, the OECD and countries of the so-called Global South. The development of a vibrant European open source ecosystem will play a central role in this (…) Technological and digital sovereignty also includes the requirement and the ability to cooperatively (help) shape key technologies. Norms and standards play an important role in this.*[79]

Other common priorities include skills gaps, the related labour shortages and ageing populations. Noteworthy differences among the countries analysed include: Canada and the UK's focus on productivity growth; Korea's concerns about deepening inequalities and focus on the convergence between manufacturing and service industries; and the revitalisation of US manufacturing. On the latter point, the US National Strategy for Advanced Manufacturing states:

[79] BMBF (2023). Future Research and Innovation Strategy, pp. 59–60. (Automated translation using Google translate from German to English.)

> *The United States remains a leader in advanced technologies; however, production and employment in several high-technology manufacturing industries have fallen sharply in the 21st century. To address global competition, the United States has taken steps to revitalize the manufacturing sector, increase the resilience of U.S. supply chains and national security, invest in R&D, and train Americans for jobs of the future*.[80]

Table 2 summarises the main priorities identified from the national industrial and innovation strategies and initiatives of the seven countries examined. These correspond to central "themes" identified in the rationale, challenges and opportunities addressed in strategies and initiatives. Interestingly, among the different priorities, sustainability, digitalisation and skills are mentioned in all seven countries and will be discussed in-depth in Section 5.

Changes in priorities, and the ongoing focus on digitalisation and environmental sustainability, have changed how manufacturing is described. For instance, Canada's Careers of the Future initiative describes advanced manufacturing enterprises as follows:

> *Advanced manufacturing enterprises don't just assemble or make things; they use cutting edge technologies, business and engineering know-how, software, data analytics, and artificial intelligence to solve problems – and address some of the world's most pressing challenges*.[81]

These transformations have broadened the scope of activities and value chain segments discussed within manufacturing. Notably, there is a growing emphasis on areas like design and recycling in various national strategies, including Germany's Digital Strategy 2025,[82] Korea's K-design Innovation Strategy[83] and the UK's Materials and Manufacturing Vision 2050[84] and Design in Innovation Strategy, 2020–2024.[85] In addition, services are increasingly integrated with manufacturing. For instance, Germany's Digital Strategy 2025 discusses the blurring boundaries between manufacturing and services:

[80] Executive Office (2022). National Strategy for Advanced Manufacturing, p. 1.

[81] https://www.careersofthefuture.ca/

[82] DE.Digital (2016). Digital Strategy 2025.

[83] MOTIE (2023). K-design Innovation Strategy.

[84] Innovate UK (2023). Materials and manufacturing vision 2050.

[85] Innovate UK (2020). Design in innovation strategy, 2020–2024.

With Industry 4.0, both our notion of manufacturing and its design will change. The distinction between manufacturing and services will become less important, and global manufacturing competition will also be digitally driven or based on ICT.[86]

Similarly, the US Strategy for American Leadership in Advanced Manufacturing states:

Rapid advances in technology in combination with economic forces are changing the ways products and services are conceived, designed, made, distributed, and supported. Manufacturing can no longer be considered separate from the value chain—the system of R&D, product design, software development and integration, and lifecycle service activities performed to deliver a valuable product or service to market.[87]

In terms of priority manufacturing sectors or industries, some of the most prominent ones include: food and beverages, automotive, chemicals, pharmaceuticals, aerospace, biomanufacturing, biotechnology, and microelectronics and semiconductors (Table 3). The food and beverages sector stands out as the only one present across all seven countries.

Table 2. *Main priorities and challenges addressed in industrial and innovation strategies and initiatives*

Challenge/priority	Canada	Germany	Korea	Singapore	Switzerland	United Kingdom	United States
Climate change/ sustainability	✓	✓	✓	✓	✓	✓	✓
Digitalisation	✓	✓	✓	✓	✓	✓	✓
Skills gaps/labour shortages	✓	✓	✓	✓	✓	✓	✓
Resilience	✓	✓	✓	✓		✓	✓
Ageing society	✓	✓	✓	✓		✓	
Technology regulations	✓	✓		✓	✓	✓	
National security		✓	✓		✓	✓	✓
Productivity growth	✓			✓	✓	✓	
Reconfiguration of value chains/change of world order		✓	✓	✓	✓		
Technological sovereignty (including data and critical materials)		✓	✓				✓
Convergence between manufacturing and service industries			✓	✓			✓
Deindustrialisation					✓		✓
Increasing inequalities			✓		✓		✓

Source: Authors, based on the review of industrial and innovation strategies and initiatives (see list in Appendix A).

[86] DE.Digital (2016). Digital Strategy 2025. p. 41.

[87] Executive Office (2018). Strategy for American Leadership in Advanced Manufacturing, p. 1.

Table 3. Priority manufacturing sectors in industrial and innovation strategies and initiatives

Sector/industry	Canada	Germany	Korea	Singapore	Switzerland	United Kingdom	United States
Food and beverages	✓	✓	✓	✓	✓	✓	✓
Automotive	✓	✓	✓		✓	✓	✓
Biomanufacturing	✓	✓	✓	✓	✓	✓	✓
Pharmaceuticals		✓	✓	✓	✓	✓	✓
Chemicals		✓	✓	✓	✓	✓	
Microelectronics and semiconductors		✓	✓	✓	✓	✓	✓
Aerospace	✓	✓		✓		✓	
Biotechnology		✓	✓	✓	✓	✓	✓
Electronics		✓	✓	✓	✓		
Garments and textiles			✓	✓	✓	✓	
Batteries		✓	✓		✓	✓	✓
Machinery and equipment		✓	✓	✓	✓	✓	
Rubber and plastics/ sustainable plastics			✓		✓	✓	
Defence			✓			✓	✓
Mechanical engineering		✓			✓	✓	
Precision engineering				✓	✓	✓	
Displays			✓		✓		✓

Source: Authors. based on the review of industrial and innovation strategies and initiatives and expert advice (see list in Appendix A).

4.1.3 Gender balance

The manufacturing sector is predominantly male-dominated, especially in high-tech industries and advanced economies.[88] For instance, in the UK women account for 26% of the manufacturing working force, and their representation is even lower in high-tech sectors such as automotive and aerospace.[89] A similar pattern is observed in the other countries analysed, where women's representation in the manufacturing sector ranges between 27% in Germany, 29% in Canada, South Korea, Switzerland and the US, and 37% in Singapore.[90]

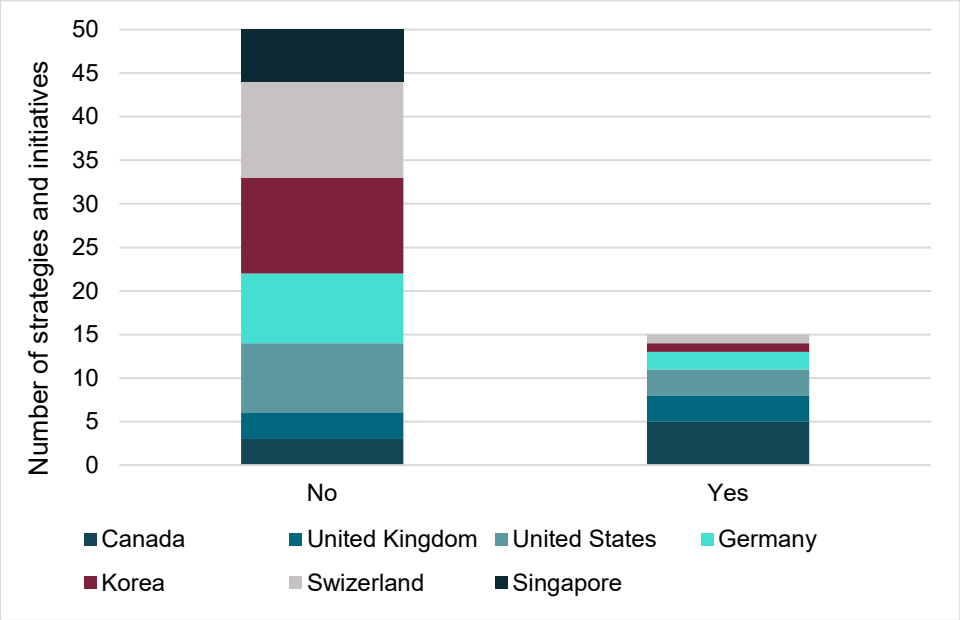
Despite this clear under-representation of women, gender inequalities are rarely addressed in industrial and innovation strategies. Of the 68 strategies and initiatives examined, only 15 address gender inequalities (Figure 4) and all of them have a narrow scope.

[88] UNIDO (2019). Inclusive and sustainable industrial development: the gender dimension. Vienna. UNIDO.

[89] Castañeda-Navarrete, J. (2023). Women in manufacturing: the case for a gender-transformative digitalisation. Cambridge Industrial Innovation Policy, University of Cambridge. InterAct.

[90] ILOSTAT. Employment by sex and economic activity (thousands) – Annual. Data corresponds to 2022.

Figure 4. *Discussion of gender inequalities in industrial and innovation strategies and initiatives*



Source: Authors, based on the review of industrial and innovation strategies and initiatives (see references list in Appendix A).

In Canada the emphasis is on enhancing women's participation in the labour market.[91,92] In Germany the Future Research and Innovation Strategy[93] addresses inequalities in leading research positions and professorships, while the Skilled Workforce Strategy[94] addresses the lower participation of women in the labour market, explaining this as result of gendered disparities in unpaid care work. In Korea the SME Manufacturing Innovation Strategy[95] mentions gender differences in career breaks.

In the UK references to gender inequalities are present in various strategies: the 2017 Industrial Strategy[96] highlights pay gaps and disparities in science, technology, engineering and mathematics (STEM) fields; the 2020 Research and Development Roadmap[97] mentions gaps in access to finance; and the 2021 Innovation Strategy[98] discusses gaps in patent activity.

[91] NRC (2020). NRC Strategic Plan 2019–2024.

[92] Conference Board of Canada (2020). Rising Skills: Digital Upskilling for Advanced Manufacturing Workplaces.

[93] BMBF (2023). Future Research and Innovation Strategy.

[94] Bundesregierung (2022). Skilled Workforce Strategy.

[95] MITE (2020). SME manufacturing innovation strategy.

[96] BEIS (2017). Industrial strategy.

[97] BEIS (2020). UK Research and Development Roadmap.

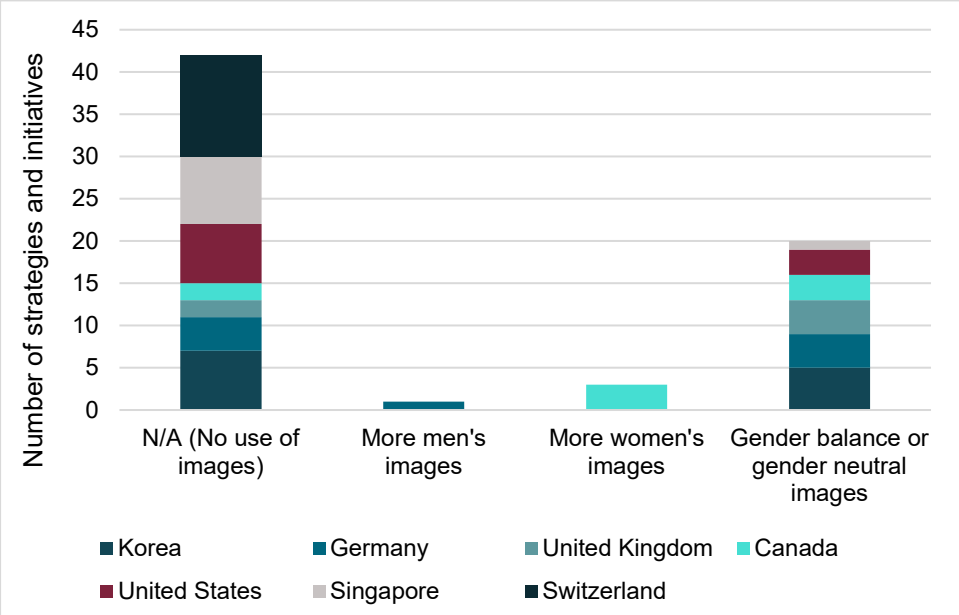
[98] BEIS (2021). UK Innovation Strategy.

In the US mentions of gender gaps in STEM fields and workforce participation appear in the Strategy for American Leadership in Advanced Manufacturing[99] and the National Strategy for Advanced Manufacturing.[100] Additionally, the CHIPS and Science Act discusses women's underrepresentation in STEM fields and gender-based harassment.[101]

Despite the absence of a systematic approach, some progress has been observed in terms of awareness and commitment to reducing gender inequalities. For example, Germany's Future Research and Innovation Strategy has set a target of increasing the proportion of women in professorships from 27% in 2021 to 30% by 2025.[102]

In terms of imagery, overall gender balance or the use of gender-neutral images was evident (Figure 5). However, there are some exceptions. The German Digital Strategy 2025[103] predominantly uses men's images, while in Canada, two strategies and one initiative use more women's images.[104]

Figure 5. *Use of gender images in industrial and innovation strategies and initiatives*



Source: Authors, based on the review of industrial and innovation strategies and initiatives (see references list in Appendix A).

[99] Executive Office (2018). Strategy for American Leadership in Advanced Manufacturing.

[100] Executive Office (2022). National Strategy for Advanced Manufacturing.

[101] The White House (2022). CHIPS and Science Act. Fact Sheet.

[102] BMBF (2023). Future Research and Innovation Strategy.

[103] DE.Digital (2016). Digital Strategy 2025.

[104] ISEDC (2021). Canada's Biomanufacturing and Life Sciences Strategy; NGen (2023). Five-Year Strategic Plan; NGen (2021). Careers of the Future.

5. Megatrends

This section presents findings derived from the review of the main themes discussed in the policy discourse (Table 2); the findings encompass three key megatrends: (i) environmental sustainability and climate change action; (ii) digitalisation; and (iii) skills and the future of work. The term mega-trend is not new, yet it has recently been used to describe the transformative forces that are shaping the manufacturing sector at the global level[105].

The themes identified from the policy review are indicative: a comprehensive examination of the priorities within these megatrends would have required a more in-depth study. This would have entailed reviewing research agendas in major research organisations across the seven countries examined, and decentralised skills programmes, as well as analysing the budget allocated to each of these areas, rather than analysing references to these topics in strategies and initiatives.

It is also important to stress that climate change policies are also the result of international cooperation (e.g. COP28) and multilateral settings between countries and lead companies (e.g. ISO 14001 and the Maersk Carbon Pact[106]). The priorities outlined in this section are also informed by expert advice from national and international experts in industrial innovation policy. We acknowledge these contributions at the beginning of this report.

5.1. Sustainability

Growing concerns about the impact of industrial and household activity on climate change are broadening the focus of industrial and innovation strategies. These strategies have extended their scope beyond production and research to tackle design and recycling activities and the extraction of critical materials. Key priority technology areas include: new materials, such as sustainable or low-carbon, lightweight materials and biomaterials; recycling technologies; energy-efficiency systems; fuel cells; and zero-emission transportation systems, such as electric and hydrogen-powered vehicles (Table 4).

[105] Hauge, J. (2023). *The Future of the Factory: How Megatrends are Changing Industrialization*. Oxford University Press.
[106] For more information, see Gentile, E., Lema, R., Rabellotti, R. and Ribaudo, D. (2023). Greening Global Value Chains: A Conceptual Framework for Policy Action. In *Global Value Chain Development Report: Resilient and Sustainable GVCs in Turbulent Times* (pp. 228–260). World Trade Organization (WTO).

Table 4. Priority technology areas related in sustainable manufacturing

Technology areas	Canada	Germany	Korea	Singapore	Switzerland	United Kingdom	United States
Materials (sustainable/ low-carbon, lightweight, biomaterials, etc.)	✓	✓	✓	✓	✓	✓	✓
Recycling technologies		✓	✓	✓	✓	✓	✓
Zero-emission transportation (electric, hydrogen)	✓	✓	✓	✓	✓	✓	✓
Energy-efficiency systems		✓		✓	✓	✓	✓
Battery technologies and systems	✓	✓			✓	✓	✓
Carbon capture, utilisation and storage (CCUS)		✓		✓	✓	✓	✓
Fuel cells	✓	✓			✓	✓	✓
Superconductivity technology		✓					✓

Source: Authors, based on the review of industrial and innovation strategies and initiatives and expert advice (see list in Appendix A).

5.2 Digitalisation

The digital transformation in manufacturing is portrayed in industrial and innovation strategies as an ongoing trend that is changing people's lives and creating opportunities for businesses to increase their productivity and competitiveness. Yet, strategies acknowledge that governments, education institutions and industries are not keeping up with training the skilled workers required. Skills development strategies emphasise the transformation driven by digitalisation and the shift towards more technology-focused roles in this sector.

Table 5 presents technology areas related to digitalisation that are prioritised in industrial and innovation strategies and initiatives across the seven countries analysed. Top technology priority areas include artificial intelligence (AI), cyber security, big data and advanced data analysis, robotics, autonomous systems, distributed ledgers, interoperability, the internet of things (IoT) and industrial internet of things (IIoT), and quantum technologies.

The strategies reviewed also highlight the interconnection between the green and digital transitions; the role of digital technologies in improving energy and materials efficiency is emphasised. Examples include smart energy systems, energy-efficient ICT systems and the use of sensors to monitor CO_2 emissions.

Table 5. Priority technology areas in digital manufacturing

Technology areas	Canada	Germany	Korea	Singapore	Switzerland	United Kingdom	United States
AI	✓	✓	✓	✓	✓	✓	✓
Cyber security	✓	✓	✓	✓	✓	✓	✓
Big data/advanced data analysis	✓	✓	✓	✓	✓	✓	
Robotics	✓	✓	✓	✓	✓	✓	✓
Autonomous systems	✓	✓	✓	✓	✓	✓	✓
Distributed ledgers	✓	✓	✓		✓		✓
Interoperability (regulatory framework, standards and integration)		✓	✓	✓	✓	✓	
IoT/IIoT	✓	✓	✓	✓	✓	✓	
Quantum technologies (sensors, computers, quantum-based imaging)	✓	✓	✓		✓	✓	
Additive manufacturing	✓	✓		✓	✓	✓	✓
Bioinformatics	✓		✓		✓	✓	
Co-bots	✓		✓		✓		✓
Digital twins	✓	✓	✓	✓	✓	✓	✓
High-performance computing	✓	✓			✓	✓	
Cloud computing			✓	✓	✓		✓
Materials	✓	✓		✓	✓	✓	
Microelectronics		✓	✓	✓	✓	✓	
Nanotechnology	✓	✓		✓	✓		
Photonics		✓			✓	✓	
Virtual and augmented reality	✓	✓		✓		✓	
Digital threading	✓						
Metal additives	✓						
Power electronics		✓					
Printable and wearable electronics	✓			✓	✓		
Sensor and actuator systems		✓		✓	✓	✓	
5G			✓	✓			✓

Source: Authors, based on the review of industrial and innovation strategies and initiatives and expert advice (see list in Appendix A).

5.3 Skills and the future of work

As highlighted in the discussion of challenges and priorities, skills gaps and labour shortages are issues that are frequently covered in industrial and innovation strategies. Key themes discussed in this area include: the deskilling of workers as a result of the automation of tasks; how technological change and sustainability concerns are creating the need for reskilling and upskilling employees; the ageing population and the related labour shortage; and the need to enhance diversity and inclusion in manufacturing (Table 6).

Table 6. *Skills themes discussed in industrial and innovation strategies and initiatives*

Themes	Canada	Germany	Korea	Singapore	Switzerland	United Kingdom	United States
Deskilling/reskilling/ upskilling	✓	✓	✓	✓	✓	✓	
Diversity and inclusion	✓	✓			✓	✓	✓
Lifelong learning	✓	✓		✓	✓		
Ageing populations	✓	✓		✓			
Technological change	✓			✓	✓		
Further training specialist shortage		✓		✓	✓		
Mismatch between supply and demand of skills		✓	✓		✓		
New forms of organisation of work		✓		✓	✓		
Increasing inequality			✓				

Source: Authors, based on the review of industrial and innovation strategies and initiatives and expert advice (see list in Appendix A).

The strategies of both Germany and Korea discuss the paradox of unemployment and labour shortages because of a mismatch between the supply and demand of skills. The Korean New Deal[107] also discusses the risks associated with rapid changes in the demand and supply of skills and how some workers are being left behind. In Germany the Future Research and Innovation Strategy[108] highlights changes in the organisation of work, while the Skilled Labour Strategy stresses the shortage of further training specialists:

> *With the associated need for skills and further training, the demand for specialists in information and communication technology as well as for specialists for the further training of employees is increasing. Bottlenecks are becoming increasingly apparent in these areas in the coming years (…) The associated specialist paradox, i.e. the increasing simultaneity of a shortage of skilled workers in some sectors and regions and job cuts in other sectors and regions will continue to increase in the future. So, while jobs are being cut as a result of the accelerated structural change, this is also the reason why skilled workers are desperately needed elsewhere and completely new jobs are also being created.*[109]

Table 7 summarises the main priority skills areas referred to in the strategies and initiatives reviewed.

[107] Government of the Republic of Korea (2020). Korean New Deal.

[108] BMBF (2023). Future Research and Innovation Strategy. Berlin.

[109] BMAS (2022). *Skilled Workforce Strategy*. Berlin. (Automated translation using Google translate from German to English.)

Table 7. Priority skills areas in industrial and innovation strategies and initiatives

Skills	Canada	Germany	Korea	Singapore	Switzerland	United Kingdom	United States
Digital							
Data mining/analysis	✓	✓	✓	✓	✓	✓	
AI (machine learning, deep learning, etc.)		✓	✓	✓	✓	✓	✓
Additive manufacturing	✓	✓		✓	✓		✓
Cyber security	✓	✓		✓	✓		✓
Robotics	✓	✓	✓	✓	✓		✓
Automation programming	✓	✓		✓	✓		✓
Coding/software development		✓	✓	✓	✓		✓
IIoT/IoT		✓	✓	✓	✓		✓
Network architecture	✓			✓	✓		
Advanced materials		✓		✓	✓		
Blockchain			✓	✓			✓
Cloud systems				✓	✓		
Computer-aided design		✓			✓	✓	✓
E-commerce and digital marketing		✓		✓	✓		
Data centre facilities management				✓			
Innovation management		✓	✓				
Precision engineering		✓		✓	✓		
Preventive maintenance		✓		✓			✓
Quantum information processing		✓	✓		✓		
Radio frequency engineering				✓			
Repair and maintain autonomous systems	✓						
Semiconductors (systems design)			✓				
Green/sustainability							
Energy management	✓	✓		✓	✓		
Circular manufacturing	✓	✓			✓		
Energy, resource circularity and decarbonisation		✓		✓	✓		
Net-zero processes	✓	✓			✓		
Sustainability management		✓		✓	✓		
Sustainable finance		✓		✓			
Other							
STEM training		✓			✓	✓	✓
Critical/creative thinking		✓			✓	✓	
Leadership	✓				✓	✓	
Planning and management	✓			✓	✓		
Entrepreneurship		✓			✓		
Social and emotional	✓				✓		
Customer behaviour analysis				✓			
Customer experience management				✓			

Skills	Canada	Germany	Korea	Singapore	Switzerland	United Kingdom	United States
Foresight						✓	
Product development				✓			
Quality management				✓			

Source: Authors, based on the review of industrial and innovation strategies and initiatives and expert advice (see list in Appendix A).

With the manufacturing sector facing skills shortages, countries have launched initiatives to attract young professionals and ensure that perceptions of manufacturing align with the transformations occurring in the sector. These initiatives encompass a range of activities, from providing information about "modern manufacturing" to young people and parents, to showcasing role models, career opportunities, and offering advice on pursuing a career in manufacturing. Box 2 presents examples of how Canada and the US are changing perceptions of manufacturing and working to attract and develop the skills of the next generation of manufacturers.

Box 2. *Changing perceptions of manufacturing*

Canada: Careers of the Future

Careers of the Future is an initiative with the objective of empowering and informing young Canadians about the advanced manufacturing sector. This initiative offers a comprehensive range of activities aimed at providing insights into advanced manufacturing technologies and career prospects (Your Future Career). It showcases young and inspirational individuals who are actively contributing to the manufacturing sector in its "Meet the Changemakers" series. For those aged between 15 and 18 who are preparing for post-secondary education, and who aspire to join the advanced manufacturing field, the initiative hosts the "Manufacturing the Future Contest", an essay contest encouraging young people to articulate their desire to pursue a career in the sector.

Careers of the Future is led by Next Generation Manufacturing (NGen) and supported by funding from the Government of Canada's Innovation Superclusters Initiative and contributions from NGen members. NGen is a not-for-profit organisation dedicated to building world-leading advanced manufacturing capabilities in Canada.

Source: NGen (2023). Careers of the Future.

United States: Pathways to Manufacturing Careers

Manufacturing USA, a network of institutes dedicated to advanced manufacturing, collaborates with industry, academic organisations and public entities to raise awareness about careers in advanced manufacturing and to develop the skills of the current and future workforce. Key initiatives include the following:

- *Manufacturing Day (MFG Day)*, held on the first Friday in October, is aimed at showcasing the world of advanced manufacturing to students, parents and the public. It is described as "manufacturing's biggest annual opportunity to inspire the next generation, positively shift perceptions about our industry, and build the foundation for the manufacturing workforce of the future". While the Manufacturing Institute takes the lead in organising this event, partner organisations and manufacturers are encouraged to host their own MFG Day events. The Manufacturing Institute provides a marketing toolkit for this purpose.

- *Women Make Awards* recognise women gamechangers working in the manufacturing industry who exemplify leadership within their companies. It encourages award winners to mentor and support the next generation of female talent to pursue modern manufacturing careers.

- *Modern Makers* features diverse individuals, nominated by the Manufacturing USA institutes, who contribute to the Manufacturing USA ecosystem. This section includes stories ranging from college students to executives who work at manufacturing innovation institutes and member companies.

- *Pathways to manufacturing careers*. On the websites of the Manufacturing USA network, opportunities in the manufacturing sector are highlighted. This includes information about the number of job postings, salaries, relevant skills and training courses.

Source: Manufacturing USA (2023). Manufacturing Day 2023; ARM Institute (2023). Robotics Career; Manufacturing Institute (2023). Women Make Awards.

Box 3. *The perception of digital technologies, robots and automation systems in the UK*

The changing perception of manufacturing may be positively associated with new technological trends that, through direct applications in the industry, can make it more appealing to younger generations. The perception of technologies such as industrial digital technologies and robots contributes to the perception of manufacturing.

The perception of DMTs

Marinescu et al. (2022) investigated the public perception of digital manufacturing technologies (DMTs, see also Table 5) in the UK. Understanding public attitudes to DMTs can aid effective support to education and policy-making around the issue.

The analysis included data from 134 participants (61% female, 39% male), all older than 18 (52% aged between 21 and 39), with 66 % of them holding a university degree (undergraduate and postgraduate).

Their findings suggest that there is a moderately positive perception of DMTs. Participants also agreed that larger companies can benefit more than small companies, particularly when it comes to DMTs as a means to improve accessibility practices. A negative perception of personal data management and concerns related to privacy and job security were also evident. Participants expressed concerns about how the introduction of DMTs, particularly AI, could minimise the need for human workers.

As shown in Sections 3.1 and 3.2., one of the biggest problems with the image of manufacturing is the (perceived) lack of job flexibility. DMTs might be useful in tackling the issue. Digital technologies have the potential to enhance work flexibility and quality of life, and it is therefore paramount to highlight digitalisation as an attractive factor that can potentially improve workers' wellbeing and job flexibility in manufacturing.

Source: Marinescu, A., Argyle, E. M., Duvnjak, J., Wilson, M. L., Lawson, G., Sharples, S., Hubbard E. and Justham, L. (2023). The future of manufacturing: Utopia or dystopia? Human Factors and Ergonomics in Manufacturing & Service Industries, 33(2): 184–200.

The perception of robots

In 2014 the Department for Business, Innovation and Skills administered a survey to understand Public Attitudes to Science in the UK. The 428 adult participants were asked to have conversations with their friends and family about robots – defined as machines that can make their own decisions. The findings revealed that the understanding of robots tends to reflect media coverage on the topic, and only two out of ten people had heard or read something about the use of robotic technology. In this instance the gender imbalance also stands out: men are more likely to have read or heard something about robots. For younger cohorts (16–24), gender differences are less evident.

The use of robots in manufacturing is relatively well known, yet very few people surveyed knew that robots can be used in healthcare and education. The most trusted use of robotics is in the agriculture sector, specifically to "monitor the condition of food crops and apply water or pesticide as needed" (72%,) followed by "to fly unmanned planes in search and rescue missions" (57%).

The image is positive when robots substitute humans in dangerous or difficult activities such as space exploration and for military purposes (similar results are reported for the EU, see Eurobarometer, European Commission, 2012)

Source: Castell S., Charlotn A., Clemence M., Pettigrew N., Pope S., Quigley A., Navin Shah J. and Silman T. (2014). Public Attitudes to Science 2014. March 2014. Department for Business, Innovation & Skills.

6. Megatrends and policy: “a reality check”

The systematic literature review confirmed that the three megatrends discussed – digitalisation, sustainability and skills – are attracting attention in the policy documents of the countries considered in the analysis (the US, the UK, Singapore, Switzerland, Canada, South Korea and Germany). To complete our study on the “perceptions of manufacturing”, we organised a roundtable[110] with major international organisations to provide a “reality check” for our analysis and to include other critical insights from stakeholders working in the international policy context. The roundtable had seven participants from UNIDO, UNCTAD, IMF, OECD and ECLAC. The roundtable was organised around four guiding questions: (i) *How do you perceive the role of digitalisation and decarbonisation in transforming manufacturing?* (ii) *What are the key advantages and challenges associated with this transformation?* (iii) *How are these transformations changing the perception of manufacturing among policy-makers and the public?* (iv) *Are these transformations changing the gender balance in manufacturing? If so, how?*

Overall, the roundtable confirmed that the new trends discussed in Section 5 have been attracting increasing attention, both in advanced and emerging economies. The discussion also introduced new elements to complement the “perceptions of manufacturing” at the policy-making level. We summarised these insights into four main points: (i) megatrend interrelations; (ii) the disconnection between policy hype around digitalisation and reality at firm level; (iii) the impact on gender; and (iv) the interrelation between manufacturing and services

First, the relevance of megatrends depends upon not only the novelty in each megatrend but also their interrelation. Specifically, this entails: (i) the relation between digitalisation and sustainability, for example, in the case that a higher adoption rate of digital technologies has the potential to reduce emissions (e.g. through predictive

[110] The roundtable lasted 1 hour, 15 minutes; it was conducted remotely via Zoom on 25 October 2023.

maintenance, production control, quick and remote proof of concept of products during the design phase); and (ii) the relation between these two megatrends (i.e., digitalization and sustainability) and the different skills required by firms engaging in one or both trends. The megatrend on skills is deeply connected to both digitalisation and sustainability, since they have a direct impact on the different skills sets required by firms. However, the discussion around skills – one participant argued – cannot be disentangled from the technology considered. For example, the skills and capabilities required to implement fully automated robotic cells are quite different from those required to set up and maintain technologies. Technologies have different impacts on the skills they require, and they tend to differ across firms, sectors and countries, also because of the different production capability levels in the use of different technologies. Another critical point regarding the relation between such megatrends is that digitalisation and sustainability have the potential to reinforce each other, but this is not always the case. *Green can be digital, and digital can be green*, but it depends. For example, the recent focus on semiconductors, which are critical to both digitalisation tools and sustainability industries, overlooks the amount of waste produced by the sector – one participant argued. Another example comes from new AI applications and the huge number of emissions required to train AI models.[111]

Two final points should be made. On the one hand, considering each megatrend and the relationships between them, they are contributing to the emergence of new industries and renewed supply chains. Different from what has been argued in recent years, namely, that new technologies would favour near-shoring, friend-shoring, and so on, one participant argued that such new supply chains are reinforcing existing cluster and ecosystem dynamics, for example, in China and South-East Asia.[112] On the other hand, one participant mentioned that digitalisation and sustainability are also perceived differently because their objective is different. The main driver of digitalisation lies in firms' potential to increase productivity (also considering how

[111] Researchers at the University of Massachusetts, Amherst, found that the training process for a single AI model can emit more than 626,000 pounds of carbon dioxide. That is about the same number of greenhouse gas emissions as 62.6 gasoline-powered passenger vehicles driven for a year. See: Strubell, E., Ganesh, A. and McCallum, A. (2019). Energy and policy considerations for deep learning in NLP. *arXiv preprint arXiv:1906.02243*.
[112] One participant mentioned that even when there have been attempts to relocate industrial production, as in the example of the Adidas factory, they failed and remained bounded to the ecosystem where they have been operating for the past decade/s. See: https://edition.cnn.com/2019/11/12/business/adidas-speedfactory-plants-closing/index.html

innovation around digital technologies leads to so-called Schumpeterian rents[113]); sustainability, on the other hand, is not a source of productivity – it can lead, in the short term, to increased productivity challenges, as it can be more expensive. Unlike digitalisation, sustainability gives a direction – to policy and firms – for learning and innovation. Related to this point, there is an interesting policy related element to consider, which regards the different 'weight' that trends have when government level funding is considered. In 2021, across OECD countries, only 3% of industrial strategies funding was channelled to programs targeting digitalisation; for sustainability the figure is 15%[114]. This figure could potentially point to the fact that while there is a big emphasis on digitalisation, government action focuses more on sustainability. On skills the quantification is more complex, since funding can be very high in some countries (e.g., in France where industrial strategies for skills is around 35% - in 2021), and low in other countries (e.g., in Denmark) where, instead, there are measures that subsidise workers directly for reskilling/training purposes.

Second, the roundtable participants agreed that there is a "disconnect" between how such megatrends are portrayed in most policy documents and the firm level context (i.e. the environment where such discussions should be reflected), in both advanced and emerging economies. Discussed as big forces that are changing the socio-economic structure of countries, digitalisation and sustainability are often more present in policy documents than in firms' priorities. Therefore – the discussion proceeds – there is an imbalance between the "digital is coming" and "sustainability is coming" and the fact that they are not happening and there is no clarity about who should fund such shifts (i.e. technological and sustainability ones). This is a critical point, given the cost (of purchasing the technology and adapting it to the existing production environment through training and reorganising production) that both technology adoption and green manufacturing entail. In addition – the roundtable participants argued – it is important to consider that costs differ across countries; for

[113] The theory centres around the idea that organisations and individuals that introduce new products or services to the market can benefit from a temporary period of monopoly, earning a rental fee from their innovation. Such a monopolistic period is critical to the innovation process itself. See: Antonelli, C. and Gehringer, A. (2017). Technological change, rent and income inequalities: A Schumpeterian approach. *Technological Forecasting and Social Change*, 115: 85–98.

[114] See QUIS (Quantifying Industrial Strategies), OECD, https://www.oecd.org/industry/industrial-policy-and-strategies/quantifying-industrial-strategies/. We are grateful to Guy Lalanne for pointing at this body of work around the effort to quantify industrial strategies at OECD.

example, emerging economies tend to be market takers rather than technology makers, since a small number of countries are leading the innovation/patenting process around digitalisation and sustainability technologies. Discussing the differences across countries, two main points emerged. First, and interestingly, talking about the differences across countries, one participant argued that, in reality, the return of industrial policy and manufacturing to the centre of the policy agenda has been triggered by geopolitical factors (e.g. the rise of China) rather than by digitalisation and sustainability trends. He mentioned that manufacturing is still seen in the "old way" by policy-makers. Second, it has been argued that, although it became more common to have a science and innovation policy, in both emerging and developed economies this actually may constitute a problem and more emphasis should be placed on manufacturing policy.

Third, the impact of megatrends on gender was discussed by three participants, among whom there was a gender equality expert. She commented that the three megatrends are impacting gender, yet not necessarily in the desired direction (i.e. decreasing the gender gap). She reported that, following historical trends and what happened during the previous industrial revolutions, every time a sector becomes more sophisticated, it tends to lose women. As reported by our analysis, gender disparities are not sufficiently considered in most major economies, and it was confirmed during the roundtable that more attention should be paid to decision-making roles and R&D positions, since these occupations are highly gender-unbalanced. One participant also reported that there is – especially, yet not exclusively, in developing countries – a wide gap concerning graduation in STEM subjects; even where the share of STEM female graduates is high (e.g. in the MENA region), there is no correlation between this figure and the labour market, signalling that there is a strong bias and stereotypes. For example, in the UK women account for 70% of administrative and secretarial occupations but only 9% of skilled trades and 23% of process, plant and machine operatives. Thus, digital automation of administrative and secretarial tasks is more likely to impact women than automation of machine operative tasks.[115]

[115] Castañeda-Navarrete, J. (2023). Women in manufacturing: the case for a gender-transformative digitalisation. Cambridge Industrial Innovation Policy, University of Cambridge. InterAct.

Fourth, the interrelation between manufacturing and services, discussed throughout the rest of the report, is strengthened by the megatrends. For example, the increasing relevance of services (in policy and academic circles) is highly related to the digitalisation of services that are strongly impacting work dynamics, especially in non-tradable services. Another example comes from the fact that new sectors are emerging as part of the digitalisation and sustainability megatrends; yet most of these are classified into services, even when they rely heavily on the manufacturing sector.

To conclude, the roundtable participants mentioned that perceptions of manufacturing at the policy-making level are characterised by an intrinsic heterogeneity, which depends on a number of contextual factors that change the perspective of digitalisation, sustainability and skills challenges. These factors are country-specific, as well as industry-, technology- and firm-specific.

7. Conclusions

In this report we have analysed and provided insights into perceptions of manufacturing from both the general public and policy-makers from seven countries: the UK, the US, Singapore, South Korea, Switzerland, Germany, and Canada. We started by revising the definition, in economic and linguistic terms, of the word “manufacturing” and how this might vary across countries. We contributed to the debate around deindustrialisation, shedding light on misconceptions around the importance of manufacturing in today’s modern economies for both economic and social growth. This systematic literature review was conducted to provide a coherent summary – from both academia and practice – of “perceptions of manufacturing”. This project supports InterAct research around the future of manufacturing on an international scale, by providing insights into attitudes to *manufacturing* and *industrial strategies*, and how manufacturing is discussed in other countries, particularly where digital technologies have been adopted. In this review we have focused on attitudes, roles, skills and language across countries in order to provide the tools and insights to change how we talk about manufacturing.

The report focused on the perceptions of the general public and policy-makers across seven countries: the UK, the US, Canada, Germany, Singapore, Switzerland and South Korea. These countries were selected in accordance with InterAct (which funded the project) because of the important role that manufacturing plays, or has played, in their economies and their contribution to global manufacturing. Additionally, following InterAct call guidelines, the selection of countries was informed by the extent to which digital technologies have been adopted in these countries.

The first step we took to understand the perceptions of manufacturing was to detail the different meanings and words (i.e. the language) associated with the concept from the general public and economic and policy experts. The outsourcing trend that took hold in the 1970s, which became dominant in the 1980/90s, has significantly impacted perceptions of manufacturing. On the one hand, it fuelled the misbelief that manufacturing processes could be outsourced seamlessly without incurring any drawbacks. On the other hand, it contributed to the emergence and, in certain industries, dominance of fragmented and increasingly complex supply chains where value is distributed unevenly. The analysis conducted on surveys across different countries indicates stark differences across both countries and time, pointing to a change in perceptions of manufacturing and a resurgence of industrial strategies. Survey perceptions are mainly about how people perceive manufacturing in their economy and the likelihood of working in the sector, often across age groups. Very rarely was data

disaggregated at gender level, despite women being systematically under-represented in the manufacturing sector. The review of industrial strategies points to the renaissance of manufacturing at policy-making level; we suggest that, in the past 5 years, countries' industrial strategies have discussed manufacturing mostly in relation to three main trends: digitalisation, sustainability and the changing landscape around skills. These megatrends were then unpacked into different sectors, and the technologies and challenges discussed in more detail in different countries.

We can draw three main conclusions from this study:

- First, manufacturing has experienced a renaissance since the global financial crisis and the COVID-19 pandemic. This is confirmed by how public perceptions are (slowly) changing to encapsulate a higher consideration of the role of manufacturing. For example, a survey conducted in the UK in 2012 found that 74% of the 1,452 survey participants believed that manufacturing jobs would be the first to be offshored. In 2023, however, 93% of the public believes that the industry is essential to growth and resilience.
- Second, such a revival is mainly focused on megatrends that are both changing and characterising the new role that manufacturing can have in driving these changes and supporting countries' growth and resilience. Within this new role, definitions matter, as manufacturing means different things in different countries based on historical, social and sectoral characteristics and strengths of different productive structures. Based on a review of 68 strategies and initiatives, we found that terms such as "advanced manufacturing" are increasingly used to highlight the high-tech nature of this industry.
- Third, there is a high degree of heterogeneity in terms of how digitalisation is perceived across countries and sectors; it is critical to unpack this in future studies. In the industrial and innovation strategies of the countries analysed, environmental sustainability, digitalisation of manufacturing and skills remain top priorities. However, the impacts of the COVID-19 pandemic and geopolitical tensions have resulted in an increasing emphasis on resilience, national security, the reconfiguration of value chains and technological sovereignty.

This review suggests directions for future work, at both academic and policy levels. First and foremost, more data is required to inform perceptions of manufacturing and their changes across time. More tools are needed to discuss manufacturing more consistently and effectively in order to challenge the misconceptions that result in manufacturing struggling to become an

attractive industry and a priority at policy-making level. Specifically, systematic collection of data (yearly or every 2 years) about how the general public perceives manufacturing, focusing on age, gender, education and a detailed examination of how perceptions change across sectors, would provide consistent data for the UK. Also, as our review suggests, there are megatrends and interdependencies between them; it would be key to understand how the general public perceives changes in the manufacturing sector brought about, for example, by the climate change emergency or the digitalisation process that is redesigning some sectors at the intersection between manufacturing and services. It would also be interesting to understand whether such megatrends and their interdependencies are shaping the attractiveness of manufacturing. For example, is a job in a plant that manufactures solar panels more attractive, since the sector is critical to increasing reliance on renewable energy sources? In understanding such dynamics it is relevant to consider also that there may be different layers of perceptions on manufacturing that may require to change; for example, the perception of young people that would need to decide about a career/degree, making clear that there are a broad spectrum of activities that take place in manufacturing, both within and beyond engineering; also perceptions at the policy making level with reference to the ways in which government classify sectors and what is defined as manufacturing. Such different layers may require different wording and different, combined, efforts. A final recommendation would be to consider the different meanings, especially across countries, of words such as manufacturing, sectors, advanced manufacturing and engineering: definitions and labelling of critical concepts are a precondition to engaging in a broader understanding of the changing perceptions of manufacturing.

Appendix A. List of industrial innovation strategies and initiatives reviewed

1. A*STAR (2023).The Future of Manufacturing.
2. BMBF (2023). Future Research and Innovation Strategy.
3. BMWi (2019). Industrial Strategy 2030.
4. BMWi (2020). Charter for Work and Learning in Industry 4.0.
5. BMWK (2023). Funding concept to support the industry initiative "Manufacturing-X".
6. Bundesregierung (2022). Skilled Workforce Strategy.
7. Canada NRC (2020). NRC Strategic Plan 2019–2024.
8. Canada Conference Board of Canada (2020). Rising Skills: Digital Upskilling for Advanced Manufacturing Workplaces.
9. Canada ISEDC (2021). Canada's Biomanufacturing and Life Sciences Strategy.
10. Canada NGen. AMP UP.
11. DE.Digital (2016). Digital Strategy 2025.
12. Department for Business and Trade (2023). Advanced Manufacturing Plan.
13. Department for Business, Energy and Industrial Strategy, BEIS (2017). Industrial strategy and Sector Deals.
14. Department for Business, Energy and Industrial Strategy, BEIS (2020). UK Research and Development Roadmap.
15. Department for Business, Energy and Industrial Strategy, BEIS (2021). UK Innovation Strategy.
16. Department for Science, Innovation and Technology (2023). National semiconductor strategy.
17. Economic Development Board Singapore (2022). New Growth Strategies to Drive Advanced Manufacturing Across Five Sectors in Singapore. Press Release.
18. Enterprise Singapore, Workforce Singapore, SkillsFuture Singapore (2023). Supply Chain Management Jobs.
19. ETH Board (2022). Strategic Plan 2025–2028.
20. ETH Board. Strategic action areas for 2021–2024.
21. Executive Office (2018). Strategy for American Leadership in Advanced Manufacturing.
22. Executive Office (2022). National Strategy for Advanced Manufacturing.
23. Germany’s Federal Ministry for Economic Affairs and Climate Action. Gemacht für was Großes: Das Fachkräfte-Potenzial wecken
24. Germany’s Federal Ministry for Economic Affairs and Climate Action. National Hydrogen Strategy.
25. Government of Canada (2018). Economic Strategy Tables: Advanced Manufacturing
26. Government of Canada (2023). Future Skills Centre.
27. Government of the Republic of Korea (2020). Korean New Deal.

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32. Manpower Group – DMDII (2019). Digital manufacturing & design job roles taxonomy.
33. Manufacturing USA. Manufacturing Workforce Development.
34. MForesight (2018). Manufacturing Prosperity.
35. MForesight (2019). Reclaiming America's Leadership in Advanced Manufacturing.
36. Ministry of Education of Korea. K-MOOC.
37. Ministry of Education of Korea. National lifelong learning portal.
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39. Ministry of Trade and Industry Singapore (2016). Transformation Maps 2025.
40. Ministry of Trade, Industry and Energy, MOTIE and Korea Institute of Science & Technology Evaluation and Planning, KISTEP (2022). 6th Science and Technology Foresight (2022).
41. Ministry of Trade, Industry and Energy, MOTIE (2019). Manufacturing Industry Renaissance Vision and Strategy.
42. Ministry of Trade, Industry and Energy, MOTIE (2020). SME manufacturing innovation strategy.
43. Ministry of Trade, Industry and Energy, MOTIE (2023). 3rd Basic Plan on Intelligent Robots. Notice No. 2019-523.
44. Ministry of Trade, Industry and Energy, MOTIE (2023). First Basic Plan for Nurturing National Strategic Industries (2023–2027).
45. Ministry of Trade, Industry and Energy, MOTIE (2023). K-design Innovation Strategy.
46. Ministry of Trade, Industry and Energy, MOTIE (2023). Pan-ministerial strategy for export growth.
47. Ministry of Trade, Industry and Energy, MOTIE (2023). Super Gap Project for Industrial Transformation.
48. MxD (2023). MxD Strategic Investment Plan 2023–2025.
49. National Research Foundation Singapore (2020). Research, Innovation & Enterprise 2025 Plan.
50. NGen (2023). Careers of the Future.
51. NGen (2023). Five-Year Strategic Plan.
52. Platform Industrie 4.0 (2019). 2030 Vision for Industrie 4.0.
53. Prime Minister's Office Singapore (2022). Speech by DPM Heng Swee Keat at Opening of Industrial Transformation Asia-Pacific.
54. Research Council of the Platform Industrie 4.0 (2019). Key themes of Industrie 4.0.
55. SkillsFuture Singapore (2022). Skills demanded for the future economy.

56. State Secretariat for Education, Research and Innovation, SERI (2023). Swiss Roadmap for Research Infrastructures 2023.
57. State Secretariat for Education, Research and Innovation, SERI (2021). Federal ERI priorities 2021–2024.
58. State Secretariat for Education, Research and Innovation, SERI (2023). Swiss Roadmap for Research Infrastructures 2023.
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63. Switzerland Global Enterprise (2020). Advanced Manufacturing in Switzerland. Factsheet
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