Building Scenarios for the Future of Manufacturing

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Abstract Forecasting future scenarios is an approach that enables companies, governments, and countries to interpolate the most important trends unfolding in a certain context to help tackle the uncertainties of a world that is changing ever more rapidly. The future outlook can be influenced by many different variables and it is reasonable to consider different possible scenarios. This chapter briefly describes the scenarios discussed and validated by the National Cluster of Intelligent Factories as some of the most promising to influence and change production systems. The work is based on the analysis of various trends from economic, social, technological, and environmental dimensions that have been clustered. The expected influence on the manufacturing sector has been discussed and validated with the support of a group of experts.

Keywords Future scenarios · Consumption trends · Electric mobility · Circular economy · Digital economy

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1 Introduction

Future scenarios can be forecasted to enable companies, governments and countries to interpolate the most important trends unfolding the external environment to tackle the uncertainties of a world that is changing ever more rapidly (Amer et al., 2013). Scenario planning is used to support public policy decisions and industrial policy in various contexts using qualitative methods to gather the approval of industry experts and quantitative methods to forecast phenomena based on the interpretation of historical data (Georghiou, 2008).

It is important to create different scenarios, taking into account a number of dimensions, namely economic, social, technological, environmental trends, as sources of possible changes to have a vision of the future based on causal relationships between exogenous and endogenous variables with the aid of experts from various fields or with the use of forecasting methods.

The pandemic has further accelerated sudden changes, while the crisis linked to the Russia-Ukraine war likewise has a profound impact on energy scenarios, the supply of materials and production supply chains, as well as an impact in terms of outlets for specific sectors. In this context, it becomes even more important, beyond the individual trends, to understand the possible interactions between current and forecast changes, and develop potential future scenarios that can serve as a reference for manufacturing's development.

The creation of future scenarios facilitates the ability to set up strategies to deal with ongoing changes and can give a country or its manufacturing system a competitive edge. In addition, if informed by appropriate industrial policy actions that intervene at the national and regional level, this ability is a starting point for the future.

Herein, a mixed approach has been applied while starting from statistical data on exogenous trends. A group of experts from the Cluster for Intelligent Factories has been involved through focus groups with an iterative method to support the following phases:

- Clustering the exogenous trends for defining the scenarios: experts have been involved in order to analyse exogenous trends (political, economic, social, technological and environmental) and to group them in six macro areas.
- Brainstorming and definition of the impact of these trends on manufacturing in terms of new methods and technologies necessary to face them. Having in mind a time horizon of 5 to 10 years, this has brought the focus group to create six scenarios.
- Upon these scenarios, the focus group Identified opportunities arising for the future in terms of research and development useful for the definition of the Cluster Strategic Action Lines.

The roadmapping group of the Cluster has managed to involvement of the experts along the six scenario definition taking into consideration their expertise. Both experts from academia and industry have been involved with brainstorming sessions and interviews.

Six scenarios are presented in this chapter, focusing on relevant topics such as electric mobility, new consumption models, circular economy, knowledge management, digital economy, and climate change. Each scenario is introduced with its current context and possible future evolutions. Then the impacts on manufacturing and action lines are outlined to support the preparation and adjustment of manufacturing strategies.

2 Scenario 1: Electric Mobility: A Supply Chain Challenge

In 2019 more than 2.1 million electric cars have been sold worldwide, outperforming 2018—which was already a record year—for a grand total of 7.2 million electric cars (which also includes plug-in hybrid electric vehicles).

While accounting for only 2.6% of global car sales and approx. 1% of the global car installed base in 2019, electric cars are recording a 40% year-on-year increase (IEA, 2020). With the advancement of new technologies in vehicle, bus and truck electrification and their growing market, electric vehicles are expanding significantly. In recent years, ambitious policy interventions have been key to stimulating the launch of electric vehicles in the main markets.

Moreover, the 2019 indications of a shift from direct subsidies to more systemic approach, based on regulatory measures on zero-emission vehicles and new fuel economy standards, provided clear signals to the automotive industry and consumers that an economically sustainable transition can be achieved in the medium to long term, also with the help of governments.

Italian car manufacturers are also working on electric vehicles and related technologies to meet an exponentially growing demand. In Italy, there is a significant ecosystem of both electrical component and power electronics manufacturers, relying on the expertise of many product design and engineering hubs. The role of machinery manufacturing companies in the industrial production of components — already providing manufacturing solutions to the electric mobility industry—is also significant.

Major structural interventions are required on several fronts to facilitate the transition to electric mobility:

- Development of adequate infrastructure for electric car charging with investments for a smart grid and for postponing charging to night-time when energy demand and prices are lower.
- There is a need to grow the ecosystem of the production of lithium-ion cells and their reuse, as well as the recovery and recycling of batteries in Italy, since these account for an important part of CO_2 emissions related to the manufacture of electric cars, a gap which is recovered during their use.

In particular, investments are required in treatment plants for the re-purposing, reuse for static uses and material recycling of batteries from various applications.

- Investment in electric motors, which represent a significant part of the mobility electrification scenario and require major investments to ensure, on the one hand, ever-increasing performance together with weight reduction and, on the other, the implementation of circular economy solutions that allow the reuse of functions and materials (some of which are among Europe's critical materials such as permanent magnets).
- Review of the production chain and relationships between manufacturers and component suppliers due to the technological shift.

To understand the potential effects on the automotive value chain, it is worth noting that 50% of the industrial cost of an electric car is not present in a traditional internal combustion engine car. And the effects are not limited to the powertrain, but also extend to the body, chassis and interior.

An average of 6.2 h of labour are required to assemble the engine and transmission of internal combustion engine cars. In the case of plug-in hybrid cars, the number of hours increases to 9.2, since the electric motor and batteries must also be assembled. On the other hand, for a full electric car, the number of hours decreases to 3.7, i.e. 40% less, because the engine and transmission are simpler.

Therefore it is necessary, at the Italian level, to organize and orient academic and industrial expertise, coordinating stakeholders like researchers, design and product engineering companies, industries (automotive, electrical and electronic component, chemicals and SW development excellences), utilities and transport companies, in order to "work as a system" and facilitate the creation of supply chains aimed firstly at the development and production of electric vehicles fully made in Italy. The contribution to the country's GDP and industrial resilience that this sector represents is given by the 100 billion turnover of the automotive supply chain (including lower tiers suppliers), 258,000 workers, with a worker multiplication factor equal to 3, and 3.9 billion investments in the industrial sphere that should be oriented by national industrial policy precisely towards the production of electric vehicle components.

In terms of current supply chains, electric is a fast-growing sector even though, as mentioned, figures compared to traditional cars are still very much on the low side for now.

Therefore, the traditional car business cannot be excluded from the equation, as this will still be the main market for at least another decade. Italy is well positioned as a country working together in a networked system, especially regarding automotive components.

Moreover, it is necessary to monitor the development of electric mobility since this may not be the end point but simply a stage in the transition to more environmentally friendly mobility, where the combination of hydrogen with electric, for example, could be the solution for industrial vehicles.

The expected impact of the scenario on R&D activities is associated with the observation that investments in electric mobility are yielding results in the short term. Still, structural interventions are essential, potentially leading to significant transformations in the medium to long term. These interventions can help minimize the inherent national dependence on those controlling the necessary raw materials during this transition.

This scenario should be studied from the point of view of the following action lines:

- LI2: Industrial sustainability,
- LI4: High-efficiency manufacturing,
- LI5: Innovative production processes,
- LI7: Digital platforms, modelling, AI, security.

3 Scenario 2: New Consumption Models

Before the Covid-19 pandemic, 30–40% of luxury goods sales were generated by consumers passing through airports and abroad. However, with the restrictions on travel and movements during lockdown, global tourist spending has halved, while domestic luxury purchases have doubled.

Generally speaking, there are consumption models that are changing radically and prevailing over others. One of these is the luxury market in China, where last year sales increased by 48%, sitting at around 350 billion yuan ($54 billion), bolstered by domestic consumption due to a reduction in overseas travel (and hence purchases).

Partly thanks to pop-up stores used by brands to sell directly on social media, the Chinese market has increased purchases from overseas, encouraged by a much lower tax rate than on the Chinese portals (namely 9% compared to 40–50%). The winners from this trend were not just the big Italian luxury brands, but niche brands, too, since anyone who managed to communicate effectively through the right channels during lockdown enjoyed a real surge in sales (McKinsey, 2021).

This surge has contributed to the doubling of China's total share of the global luxury market in 2020, going from about 11% in 2019 to 20% in 2020, with an additional increase forecast by 2025. A drop in international tourism contributed to two- or even three-figure increases in the rate of domestic luxury goods spending for some brands. Growth rates varied wildly across the different regions, brands and categories.

When it comes to engines fuelling the birth of new consumption models, generation Z and millennial consumers are expected to continue spending on luxury goods and customized products as almost three quarters of them say that they will increase or maintain current spending levels on these kinds of goods. Consumer online shopping behaviour has changed for good, having overcome the obstacles of recent years (i.e. digitalization).

Moreover, most brands feel that the online penetration of luxury goods (including omnichannel retail) will reach 20–25% within three years. Between 2019 and 2020, e-commerce has grown by at least 50% in Europe and China, as well as in the United States, according to McKinsey.

In the second quarter of 2020, Farfetch sales were up almost 75% on the previous year, hitting a turnover of $365 million. Brands like Nike and Louis Vuitton have seen an increase in online sales, which they attribute partially to the customization of the shopping experience delivered across all sales channels. To achieve this, fashion brands are defining new customer experience solutions blending of AI and other technologies. This also needs to be backed by adequate design and production systems to provide the luxury or customized goods demanded by the market.

Social shopping can be a channel to support the luxury market and product customization, while the presence of increasingly environmentally conscious and concerned consumers prompts a change in the type of offering, which must be based on traceable and environmentally friendly products.

This scenario can represent a driving force for Made in Italy manufacturing in various sectors and opens up new challenges linked to the need to have production systems in place that allow companies to increase their product customization capacity, and cater to the demands of some geographical regions, both by defining products specifically tailored to their needs, and by offering product configuration systems that are interfaced with the production systems.

As for technological development, the potential of the Internet of Actions (IoA) will enable companies to review their offerings, facilitating the sensory experience linked to the purchase of certain products, delivering a new customer experience in store and online thanks to the development of vision systems and virtual and augmented reality.

While the growth of the social component at the sales and loyalty stage opens up a challenge when it is implemented through multichannels, at the same time it also presents an opportunity since it gives companies access to huge amounts of data about customer preferences, attitudes and needs, allowing them to predict and understand the demand for the design of new product generation and related manufacture increasingly tailored to customer requirements.

The expected impact of the scenario on R&D activities is linked to the ongoing evolution of new consumption models. Urgent interventions are needed in the short term to support design and manufacturing activities with new models and methods.

This scenario should be studied from the point of view of the following action lines:

Ll1: Personalized production,

LI5: Innovative production processes,

LI6: Evolving and resilient production,

LI7: Digital platforms, modelling, AI, security.

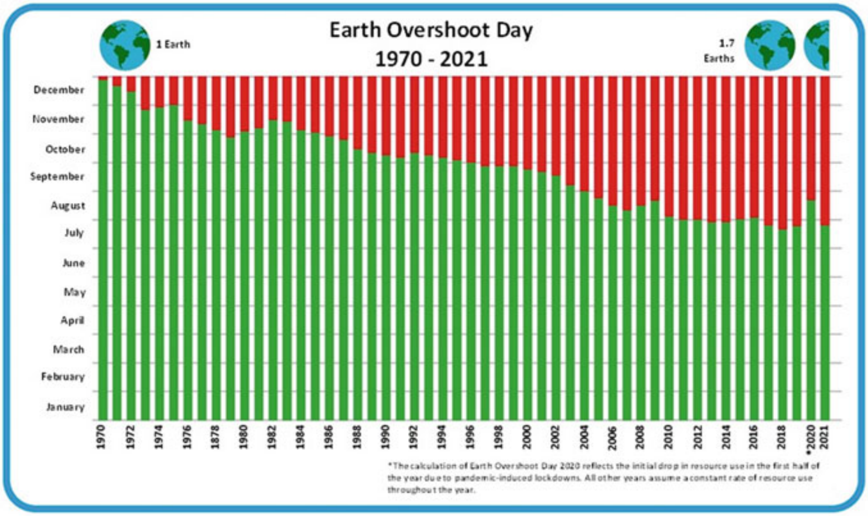

Fig. 1 Earth Overshooting day

4 Scenario 3: Circular Economy

Relentless population growth over the last two centuries (from 1 billion in 1800 to 7.9 billion in 2022) has led to a progressive increase in the demand for natural resources, which includes raw materials, water, energy and arable land, as highlighted by “overshoot day” calculations (Fig. 1).

This value measures humanity’s environmental footprint and the ability of the Earth—both at the global level and with reference to individual nations—to regenerate the resources consumed over 365 days, including in terms of its ability to absorb emissions released into the atmosphere.

Over the last 50 years, the overshoot day has fallen progressively earlier, meaning that humans are consuming resources quicker than the Earth can regenerate them. The increase in demand for these resources puts a lot of pressure on the environment and, at this rate, material consumption worldwide is expected to increase roughly eightfold by the end of 2050.

Another important trend that adds to the pressure on the environment is the increase in urbanization, which entails an increase in the use of raw materials for construction, such as roads, bridges, dams, sewers, and the need to step up transport systems.

In addition, the rapid shift in the global scenario characterized by crises—such as the COVID-19 pandemic, socioeconomic conflicts, and raw material and energy shortages—has exposed the fragility of our current linear system. There are loud calls to “rebuild better” with a green recovery—thus repairing the impacts of the pandemic and including the climate crisis—as documented by the recent Recovery Plan for Europe budget.

Consequently, it is necessary to improve how resources are being handled currently to identify opportunities for greater wealth for people, while still employing environmentally responsible practices.

This shift is based on the circular economy concept (MacArthur 2015) that considers factors capable of reducing waste and monitoring the consumption of resources more closely. The circular economy reduces the need for new raw materials, instead reusing product functions and existing materials. This practice that can be implemented by rethinking the function of the product in a closed loop.

This extends the life of resources and includes strategies such as reuse, repair, regeneration, recycling and reducing overall negative effects of manufacturing activities on the environment, which call for a thorough overhaul of companies' activities.

The circular economy not only brings challenges for companies, it also allows them to obtain economic, environmental and social benefits, such as giving impetus to innovation and economic growth, increased resilience and competitiveness, reduced pressure on the environment, optimized availability of raw materials, and job creation.

In addition, consumers can buy long lasting products that save money, are innovative, and capable of improving quality of life. Embracing circular economy systems and strategies thus entails macro- and micro-level changes.

At the micro level, companies need to rethink and redesign their production processes to use renewable sources of energy and materials, extend the products' life, create sharing platforms, reuse and regenerate products or components, and rethink products as services.

At the macro level, the European Union sponsored the Circular Economy Action Plan in 2015 to prompt countries to invest in the circular economy area and monitor investments through the Circular Economy Monitoring Framework. This tool is used to analyse and compare the various countries in terms of circular economy.

Figure 2, for example, features a Sankey diagram of material flows in the European Union and the circular material use rate, or circularity rate, namely the amount of material recycled and fed back into the economy.

Both the Sankey diagram and the circularity rate are part of the EU circular economy monitoring framework (Fig. 2). The purpose of a circular economy is to retain the value of products, materials and resources for as long as possible, integrating them back into the production loop once they reach the end of their life cycle, minimizing the waste generation.

Materials like biomass, metals, minerals and fossil fuels are extracted from the environment to make products or produce energy. At the end of their life cycle, products can be recycled, incinerated or discarded as residual waste. These material flows are a core component—effectively the only component—of the circular economy. The fewer products are discarded and the more recycled, the fewer materials are extracted, for the sustainability of society and the environment.

While this scenario may therefore represent an opportunity to increase companies' resilience and competitiveness, at the same time it also poses a challenge for Italian manufacturing—on the one hand, there is the opportunity to reap benefits from a circular system (i.e. reduced production costs, increased resilience, job creation,

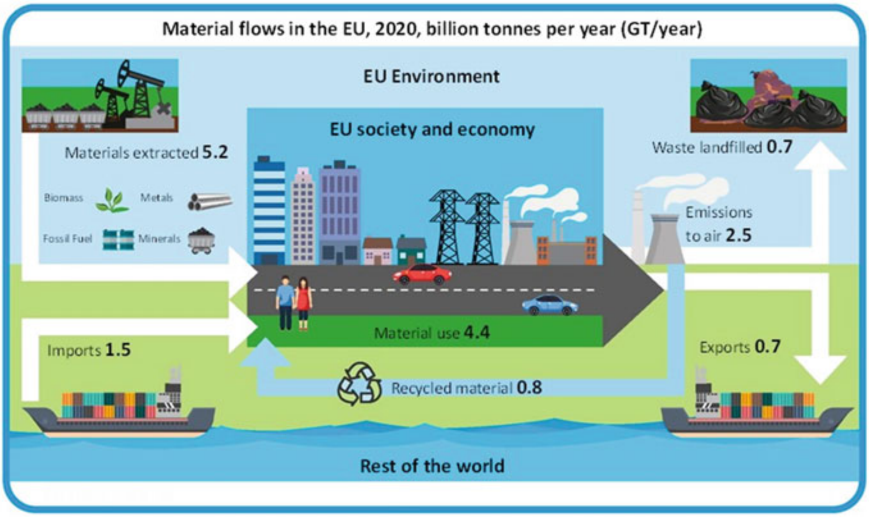

Fig. 2 Material flows in EU, 2020 (bln ton per year)

benefits for both the environment and quality of life); on the other, this change calls for financial and structural efforts with serious impacts on products, processes, governance and the supply chain, such as:

- Impacts on products/processes: Products play a crucial role in the economy, serving the needs of society, and helping build individuals' identity. Designing products better, extending their service life and changing their role within the system will be crucial for developing a circular economy. Moreover, research into new technologies and equipment for the circular economy can help improve production processes and is a major opportunity for Italy and Europe. This translates into an improvement in efficiency and a new capacity to reuse, repair and regenerate products, components and relevant functions.
- Impacts on strategies: The adoption of a circular economy approach calls for companies to transition from linear production to business models that allow them to design and produce goods intended for extended use, disassembly, reuse and recycling. In addition to an impact on companies' business models, this change may also entail sourcing new competencies and skills.
- Impacts on the supply chain: supply chains allow for coordination with partners adopting environmentally conscious practices. This coordination becomes a key factor in achieving a successful circular economy as supply chains also allow companies to align in terms of environmental and social goals. Circular supply chains entail new approaches to design that incorporate the concept of extended service life, reuse/recycling processes, and collection, re-manufacturing and resale activities.

The expected impact of the scenario on R&D activities is significant, given the ongoing implementation of various circular economy initiatives that are making a powerful short-term impact. Planned investments in R&D are mainly focused on the medium term in several directions. The focus is on enhancing processes like recovery, recycling, re-manufacturing, aiming not only for sustainability but also for efficiency with the support of emerging technologies.

This scenario should be studied from the point of view of the following action lines:

- LI2: Industrial sustainability,
- LI4: High-efficiency manufacturing,
- LI5: Innovative production processes,
- LI7: Digital platforms, modelling, AI, security

5 Scenario 4: Knowledge Management and Internet of Actions

The rapid and pervasive spread of the Internet, digitalization, and cyber-physical systems (CPS) is clearing the path for a novel technological transformation facilitated by the Internet of Things (IoT). In addition, manufacturing is becoming more data and knowledge-intensive (Grigorescu, 2020), thus enabling remote monitoring and interactions for the stakeholders, including managers, operators, and customers.

One development scenario that is progressively solidifying involves the concept of the Internet of Actions (IoA) as a solution. IoA enables entities to share not only data but even sensations and actions thanks to state-of-the-art smart sensors and actuators (Forbes, 2020).

Effective IoA systems will necessitate the precise replication of sensations to generate interactive and adaptive (re)actions by humans and devices (Xu, 2021). Above all, the development and exploitation of sensors and actuators will play a pivotal role in establishing a remote sense of presence and facilitating accurate and safe remote actions (Javaid, 2021). Devices employed in IoA architectures will need to manage interactions with both the environment and human beings.

Factories provide an ideal testing environment for investigating and developing suitable IoA systems since factories already incorporate many of the underlying technologies that drive IoA. Subsequently, IoA systems can be extended to other domains. For instance, IoA enables operators in industrial plants, even when situated at substantial distances from one another, to exchange data, information, and actions, thus ensuring that all operators have the same vision and perception. Complete remote support and maintenance can offer relevant advantages (Silvestri, 2020), particularly where there is a shortage of local specialized workers and when it becomes imperative to operate in intrinsically hazardous or unsafe environments, such as during a lockdown.

This scenario would enable the manufacturing sector to devise strategies for achieving comprehensive remote support and maintenance for manufacturing facilities. Digital technology can effectively support operators to impact the real world with actions generated in a mixed-reality environment (Seiger, 2021). In the long term, once the technology is more mature, applications can be extended to many other unstructured environments, such as the home, entertainment, shopping processes, inspection and exploration.

This scenario entails the development of IoA devices and systems with processors, sensors and actuators, while further developing and integrating various enabling technologies, such as augmented and virtual reality (AR/VR), High-Performance Computing, Cloud and Fog Computing, Cyber-physical production systems, Big Data Analytics, ultrafast communication infrastructure and standards, AI, data archiving, sensors and monitoring, wearable devices and actuator technologies (Tolio, 2019).

More specifically, in the Italian context—characterized by many small- and medium-sized enterprises (SME) facing challenges in adapting to the digital transformation of products, processes and technologies—manufacturing companies will have to address complex production phenomena using solutions based on expertise, wherein the operator may play a central role. Consequently, it is equally crucial to strategically invest in these enabling technologies to support user-centred activities (e.g. operator training and maintenance support through feedback and visual, auditory and tactile interactions) together with the development of digital twin models incorporating appropriate semantics and ontological representations of information and knowledge in support of the reuse of expertise (Terkaj, 2024).

This scenario offers opportunities to SMEs that market products globally, especially durable assets and capital goods, ensuring their capability for remote maintenance and assistance. The IoA approach is also founded on the possibility of operating physically from anywhere worldwide while centralizing product and process knowledge in specific locations, with Italy potentially being one of these.

The expected impact of the scenario on R&D activities is intertwined with the ongoing development of effective knowledge management systems, which, in the short term, require an enhanced ability to interact with operators and consumers. Significant investments need to be strategically scheduled in the medium to long term, particularly in the fields of sensors, actuators and cybersecurity.

This scenario should be analysed considering the following action lines:

- LI1: Personalized production.
- LI3: Enhancing human resources in factories.
- LI6: Evolving and resilient production.
- LI7: Digital platforms, modelling, AI, security.

6 Scenario 5: Digital Economy

In the contemporary economic landscape, which is increasingly interconnected and complex, businesses operate on a global scale whereby digital platforms enable consumers and enterprises to virtually interact and share information, meet customer needs, and improve their ability to manage company processes. Therefore, stakeholders in the digital platform economy can swiftly create new products and services that cater for consumer preferences and habits. They can also create entirely new offerings by reconfiguring innovative products and services based on information acquired through these platforms (McKinsey, 2020). KPMG estimates that turnover linked to the platform economy will go from 7 thousand billion dollars made in 2018 to over 60 thousand billion by 2025 (KPMG, 2019).

In business models founded on the platform concept, the sale of products and services is integrated—in a transparent way for the user—thanks to the provision of value-added services (shared design, product configuration, maintenance, insurance, after-sales support), offering modular solutions, which leverage the combined offering of different operators who are often in different areas of business, but who are seen as a single entity by the company client/end consumer.

Notably, the progressive implementation of the platform economy through digital technologies (such as sensor-based systems, Internet of Things, Big Data, AI) has been one of the distinctive traits of companies that have thrived during the crisis. On this note, several hi-tech companies have exploited digital platforms as a core part of their business model to go from design to rapid remote prototyping, to handling maintenance and product sales, and have managed to meet market demands even when the presence of operators on site could not be guaranteed.

Similarly, in e-commerce, major retailers have exploited digital platforms—even platforms employing different data management models (some more centralized and rigid, others open and flexible to handle their processes)—to handle the above-mentioned processes.

Digital platforms supporting manufacturing processes must be conceived to provide a "digital" extension of functionalities to physical assets (Effra, 2020). In particular, services provided through digital platforms can aim to support:

- Collaboration during the engineering of manufacturing plants;
- Monitoring of manufacturing processes;
- Data analytics through advanced data science techniques;
- Manufacturing control based on interaction between different agents, including machine-to-machine communication;
- Introduction of machine self-learning capabilities;
- Simulation of manufacturing processes;
- Assistance to workers and engineers also with the support of virtual and augmented reality;
- Production planning, predictive and automated maintenance, etc.
- Digital integration of value chains (e.g. real-time or near-real-time sharing of production, distribution and sales data).

- Interoperability of decentralized processes and production systems.

These services can be offered by different providers in a multi-actor ecosystem, supporting processes both inside and outside the factory. The preconditions for improving digital platform development in Italian manufacturing contexts include the definition of agreements between providers, as well as between providers and manufacturers, on industrial communication interfaces and protocols, common data models and data interoperability and hence, on a broader scale, intercommunication and interoperability between platforms, ensuring an open approach.

This kind of model still has a margin for expansion in Italy and there are several challenges still to be tackled to study open solutions supporting process management, especially at the manufacturing system level. The opportunity to develop solutions that are federated between different providers is also promoted by the European Commission through the funding of various European projects (Gaia, 2022), and Italy's role is of paramount importance as an advocate for the interests of companies whose task, as either manufacturers or users of machinery, is to bring to light the user requirements of these platforms.

Some of the aspects that need to be worked on over the coming years to improve the digital economy for the manufacturing sector are:

- The possibility to connect to additional services according to the plug-and-play philosophy, considering the ecosystem of service providers, platform providers and manufacturing companies.
- Mechanisms for commercial or open-source provision of digital services through appropriate marketplaces.
- The modularity of platforms using standards such as RAMI4.0 or other standards.
- Data and information integration from and to legacy systems (hardware and software).
- The creation of trust systems that facilitate the exchange of information between companies.
- Definition of new semantics in support of interoperability.
- Specific requirements of different manufacturing sectors (process industry, consumer goods, capital machinery and equipment,…).

Platform-Based Manufacturing, then, clearly needs to focus not just on handling logistics, but also on the actual transformation processes. This completely changes supply chains and the way businesses deal with customers. Hence, new actors (managing the platforms) are expected to rise, while existing actors change their functions and how they operate. A radical change offering new market opportunities may be key for machinery manufacturers. In addition, these platforms are quick to go global, posing questions around country-level industrial strategy.

The expected impact of the scenario on R&D activities is related to the fact that digital platforms have a powerful short-term impact improving communication and collaboration across different decision levels in manufacturing. Indeed, they urge for investments in R&D in the medium term to support SMEs and technology providers in developing and implementing open solutions that facilitate communication between different actors.

This scenario should be studied from the point of view of the following action lines:

LI7: Digital platforms, modelling, AI, security.

7 Scenario 6: Climate Change

The global warming observed over the past 150 years is probably triggered by human activities, hence resulting in an anthropogenic greenhouse effect that adds to the natural greenhouse effect. With the industrial revolution, humankind has suddenly dumped millions of tonnes of carbon dioxide and other greenhouse gases into the atmosphere, causing a huge upsurge in the amount of CO_2 in the atmosphere (Enel, 2021).

The average temperature of the planet has increased by 1 degree on pre-industrial levels and, judging from the trend observed from 2000 to date, if no action is taken, this value is forecast to be as high as +1.5 °C by 2050. "Fire seasons" have become longer and more intense; from 1990 to date, every year there has been an increase in extreme weather events, such as cyclones and flooding, which are even hitting outside the periods of the year that would typically experience this kind of event in the past, and with increasingly devastating consequences (Enel, 2021).

The greatest damage is being caused, above all, by the consumption of coal, oil and gas, which are responsible for most greenhouse gases. According to McKinsey's Global Energy Perspective 2019, fossil energy sources in 2019 accounted for 83% of total CO_2 emissions, while coal-fired electricity generation alone accounted for 36%26, although in 2020—as a result of the Covid-19 pandemic—emissions then plummeted (McKinsey, 2019).

It has been estimated that the current rate of CO_2 emissions from coal combustion is responsible for about one third of the 1 °C increase in annual average temperatures on pre-industrial levels, making it the number one source of emissions in human history. Oil is the second biggest source of emissions by far, having produced 12.54 billion tonnes of CO_2 in 2019 (86% of that produced by coal).

There is also a political issue surrounding fossil fuel at the moment, since the recent tensions over Ukraine could put 155 billion cubic metres a year of natural gas imports into Europe at risk—tensions due to Russia cutting supplies—amounting to 30% of Western Europe's annual gas demand (Rystad, 2020).

European gas markets have been plunged into great instability, gas stocks are at a five-year low, and international prices are highly volatile. These are just some data showing how important it is to define development scenarios based not just on renewable energy—wind, solar (thermal and photovoltaic), hydro, geothermal and biomass power—as a fundamental alternative to fossil fuels.

Their use enables a reduction not just in greenhouse gas emissions resulting from the generation and consumption of power, but also in our dependence on fossil fuel imports (especially gas and oil), hence improving Italy's position from the standpoint of energy resource procurement, a crucial point for the economy in general and an essential factor in manufacturing when it comes to competitiveness.

To achieve the ambitious EU-defined goal of renewable energy accounting for a 20% share of its energy mix, efforts thus also need to be stepped up in energy-related sectors in terms of production systems and innovative products. More specifically, some of the open challenges for manufacturing concern:

- Supporting the hydrogen value chain through the development of innovative technologies, such as the production of high-power-density, high-efficiency turbines, and processes for the use of combined heat and power fuel cells;
- Technologies for decarbonising of CO_2-emitting processes through the production of Carbon Capture, Utilization and Storage systems.
- Technologies and systems for fossil fuel conversion aimed at achieving efficient, environmentally neutral and flexible systems (to be better suited to compensate for the variability and uncertainty of renewable sources);
- Promoting greater efficiency in manufacturing plants that, for the same energy source, are capable of optimizing its use through appropriate resource and usage time management mechanisms, possibly with the implementation of demand response models for power usage management;
- Designing long-lasting products that use less power during their life cycle; environmentally and energy-efficient products;
- Developing technologies and products for the energy sector, such as components for wind turbines, mini wind generators, technologies for harnessing marine resources, advanced components for solar panels and production of biomass energy;
- New circular economy mechanisms for energy products, such as: recycling solar panels; strategies and technologies for the reuse of electrochemical energy storage systems; systems for the regeneration of electric/hybrid vehicle batteries, which can also be used to power infrastructure; development of technologies and techniques for the management of distributed storage/reserve capacity for power grid and private consumption ancillary services, exploiting electric and hybrid vehicle storage batteries;
- The promotion and development of end-use technologies is deemed necessary: these include fuel cell technologies, capable of operating at different temperatures and hence applicable to different sectors, from the mobility sector to stationary, industrial, residential and commercial applications, with high efficiencies.

Italy should invest in systems of this kind as they boost research excellence spanning from the laboratories of public bodies and universities to the industrial sphere. This will change the economy of whole regions, prompting the rise of new manufacturing hubs linked to new energy sources and more efficient use of energy. Moreover, a larger amount of green energy will be produced and supplied, which will probably see a scaling back of the strategic roles of some players in the supply of energy, such as the Middle East and Russia.

The expected impact of the scenario on R&D activities is predominantly linked to the necessity for investments in both structural and technological aspects, with a medium to long term impact.

This scenario should be studied from the point of view of the following action lines:

LI2: Industrial sustainability,

LI4: High-efficiency manufacturing,

LI5: Innovative production processes,

LI7: Digital platforms, modelling, AI, security.

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