D.T1.1.2 – Foresight Scenario and challenges for innovation 4.0 supporting schemes (Part 1)

Version 1
09 2018

Part 1 - Foresight Study

Abstract

The present foresight study includes regional analyses and scenarios that aimed at anticipating opportunities and risks for innovations in the fields of additive manufacturing and resource efficient advanced manufacturing technologies. It will allow to formulate requirements in order to suggest efficient supporting measures for each for the regions involved in the AMiCE project.
The motivation of this deliverable is to support the project partners to gain insights about the potential benefits of additive manufacturing technologies and the specific opportunities and applications that are currently entailed for the upcoming market and technology projections.
The process for developing this document started by analysing the current reality of each of these regions, focusing on their manufacturing capacity, innovation potential and regional priorities as included in the strategies for smart specialisation.
This analysis was followed by a benchmark assessment for both technologies, additive manufacturing and circular economy principles, at a global and Central European scale. A basis for discussing the main drivers and barriers of both technologies was then set and subsequently linked to the current reality of the regions. As a result, specific divers and barriers were identified for each region.
During this process, several interviews with the tandem partners (research-oriented and business supporting organizations) as well as experts in the field of additive manufacturing and circular economy were carried out. This iterative process allowed to identify specific challenges and opportunities for each of the regions at the short, mid, and long term. The potential of the regions and their main shortcomings were considered in order to come up with feasible actions and activities.
The outcome of the present document will enable project partners to better support and assess the needs of their members, particularly SMEs, when defining the strategy that will contribute to adoption of these new technologies. Additionally, this deliverable will contribute to identify and shape the relevant contents to be presented in the online environment, according to different audiences and following the strategy tailored from this foresight study.

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Abbreviations

ABBREVIATION	DEFINITION
AM	Additive Manufacturing
a.o.	among others
CAT	Catalonia
CIRC	Circular Economy
CZ	Czech Republic
DE	Germany
EC	European Commission
EU	European Union
I(C)T	Information (and Communication) Technology
IT	Italy
OEM(s)	Original Equipment Manufacturer(s)
PL	Poland
R&D	Research and Development
RIS3	Research and Innovation Strategies for Smart Specialisation
RTO(s)	Research and Technology Organisation(s)
SME(s)	Small & Medium sized Enterprise(s)
SK	Slovakia
3DP	3d-printing

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1. Context and motivation

Advanced manufacturing technologies are changing the mindset of companies towards the way they manufacture products. Their adoption allows shortening value chains into collaborative and more localised approaches, increasing sustainability.

Additive manufacturing (AM), which is commonly known as 3d-printing (3DP), is the most promising advanced manufacturing technology since it brings new types of products to the market and reinvents existing ones while improving manufacturing efficiency [1]. The AM process uses almost the exact amount of material needed, saving costs and generating less waste. This enhanced approach in resource efficiency maximises the "value" of materials retained within the economy, in accordance with the goal of circular economy (CIRC) [2]. This might be achieved by designing and building products and assets to be more durable, and to be repaired, refurbished, reused and disassembled. In this aspect, AM technologies can support CIRC by improving resource efficiency, enabling more efficient manufacturing systems, integrating new materials, implementing new manufacturing processes and adopting new business models [3].

Thus, the aim of this foresight study in the framework of the AMiCE project is to analyse the status of AM technologies and CIRC measures in Central Europe. This will allow identifying opportunities and risks in the deployment of these technologies for the regions involved to further tailor actions that foster their adoption. Although this document is mainly addressed to SMEs, all players in the whole value chain might be benefited as well (from material suppliers, designers, agents for product & technology development, distributors, and ultimately customers).

Due to its weight in Central Europe, the focus of this deliverable is on manufacturing industries. At EU level, manufacturing now represents about 15 percent of total EU value added and 15 percent of its total employment. Specifically, in Central Europe, manufacturing added value is above 20 percent of total value added. Although the manufacturing's share of added value is only 15 percent, it accounts for 64 percent of all EU business R&D. This shows the great innovation potential of the region in manufacturing [1]. However, Central Europe is characterised by considerable lagging behind in the indicator "governmental orders of technologically advanced products" (127th position), driven by several socio-economic factors [4][1].

The rate of adoption of AM technologies in Europe is relatively slow, especially compared to the North American region. The efforts in Europe have been mainly focused on multi-material 3DP and laser-based AM, with naval and industrial parts manufacturing being the main sectors of applications.

Nevertheless, there has been an increase in funding for AM in other sectors such as the automotive. Horizon 2020 has funded 27 AM projects with €113 million, an increase of 70 percent with respect to the previous programme (2007-2013) [5].

The broadening of sectors and market applications for AM technologies together with the implementation of CIRC measures could potentially support Central Europe in the challenges related to increase global competitiveness and resource's availability. [6] Resource efficient AM technologies can play a key role in positioning Europe at a leading position in competitiveness.

At present, the adoption of CIRC measures in the EU framework presents high levels of variation within Member States. As it will be further analysed, this is especially relevant in Central Europe due to geographic, environmental, economic, or social factors. It has been recognized by European authorities that a greater harmonization is needed among European legislation and best practices down to the municipal and inter-municipal levels [2].

Although CIRC covers all aspects of economic activity (from resource extraction through production, storage and consumption, ending with disposal or ideally recycling) the avoidance of waste and designing for reuse, dismantling and recycling enabled by AM technologies are prioritized and analysed in this foresight study.

[1] This indicator evaluates how the public sector can stimulate development of domestic enterprise environment through demands for technologically advanced products.

2. 3DP: a growing market with a promising future

The technology of AM is capable of creating objects from 3D data by joining many kinds of materials on a layer-by-layer process. The “*additive*” nature of the process is what distinguishes the technology from the traditional subtractive manufacturing methods. The potential implications of additive manufacturing are recognized worldwide across different industries. The nature of the technological process enables to produce high-end or unique products that were not possible with conventional technologies, in a more resource efficient way. This disruptive technology will influence many processes in production, supply chain, design, logistics, CIRC, and consumer behaviour as well. The next sections address the current market situation of the technology and the projections made according to its potential.

2.1. Market assessment

The technologies for AM can be applied in many industrial sectors. The market can be segmented on the basis of the type of technology, material, and application. At a global level, industrial machinery is the dominating sector, as it is presented in Figure 1 [7] [8]:

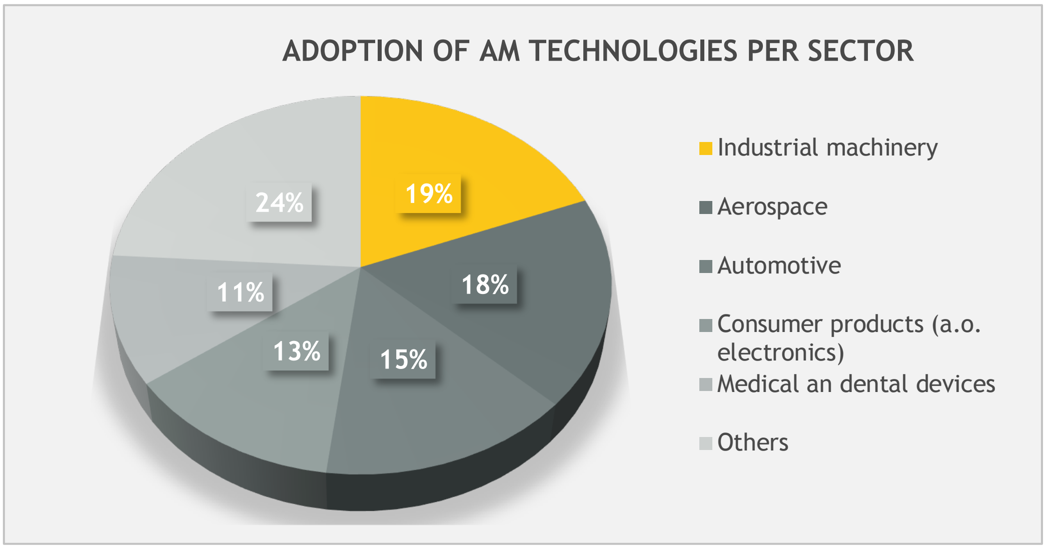

Figure 1. Main sectors of application of AM technologies in 2016 [8].

Other markets might appear in the future as more advances are made on the technology, but nowadays AM technologies have the following capabilities and effects on manufacturing:

- **Industrial Machinery:** 3D printers are already replacing some conventional machines since the technology allows producing cheaper tools in less time because of the shorter lead time. Tools for production and special machine parts are the main application.
- **Aerospace:** Geometrically complex and lightweight parts can be designed and produced, allowing to have fewer stocks and sometimes faster and cheaper to produce. For instance, Airbus or General Electric Aviation are already large customers for 3D printed parts.
- **Automotive:** The use is especially in prototype construction, pre-production and design of complex parts.
- **Consumer products** (a.o. electronics): This type of industry relies on individually adapted products, especially in consumer electronics. Thus, several types of devices can be built such as micro-electromechanical systems, microwave circuits fabricated on paper substrates, radio frequency identification devices inside solid metallic objects (RFID), polymer based, and three-dimensional grippers among others. These 3d-printed devices present improved properties with respect being manufactured by conventional technologies, such as: a) being easier to adapt to certain specific

development processes; b) accelerate the design process; c) allow the functional integration of a number of different electronic devices in just one product; and d) allow making functional prototype and spare products on demand.

- **Medical and dental devices**: In this area, AM technologies are especially suitable for the implementation of complex geometries that could be customized and otherwise impossible to build by conventional technologies. Dental technology is the pioneer in 3D printed parts and is becoming increasingly established in the market. In the medical sector, AM allows assembling complex parts in a shorter period of time. The current technologies allow producing hips, knees, hearing devices, digital prostheses, etc. The manufacturing process can be digitalised, which allows to easy reproduce properties. A European Report clearly shows that 3D printed medical applications, either in dental or in prosthesis applications, is achieving a huge part of the market, more than 13 percent, showing that 3D structures are almost feasible by the pure technical point of view [9] [10].This is a part of the "Tailored Medicine" concept that nowadays drives the scientific applications on biomaterials. Indeed, European countries are moving on this path with different speeds, looking to different aspects. The Belgian Health Care Knowledge Center – KCE published in 2018 a deep analysis on the 3D applications in Medical Devices highlighting not only the technical challenges but also the medical, the economic and the legal [11].It is foreseen that in the next 10 years the AM industry will continue at steadily high growth rate, with CAGR ranging from 18 percent (Academics & Education) to 36 percent (Medical prosthetic devices). The fastest growing segments are all related to medical applications, including medical and dental (27.3 percent), medical and dental diagnostic and treatment (28.2 percent), for medical prosthetic devices (36.4 percent) [9] [10] [12].

A survey by Ernst&Young conducted among 900 companies (Figure 2) shows that the polymer industry is the leading application area worldwide, followed by the automotive and aerospace sectors in almost the same share as industrial machinery, pharma and medical (health) and consumer products (electronic devices) [13]. The greatest share of the polymer industry from this source is likely to come from cross-cutting applications in different sectors.

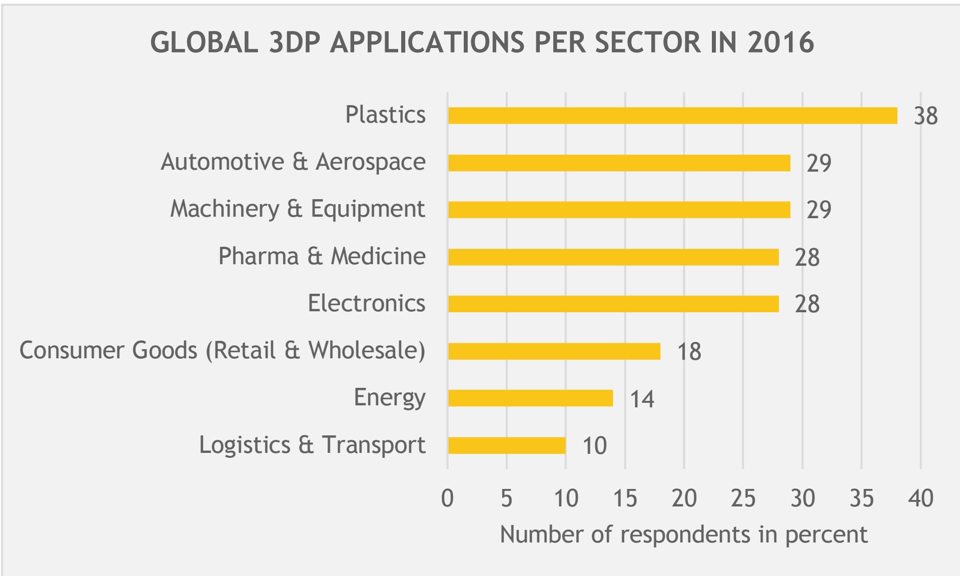

Figure 2. Main sectors of application for 3DP technologies [13].

These statistics also show that logistics, transport and energy industries are currently represented worldwide with the smallest proportion of AM applications.

Beyond the type of sector in which these technologies can be used, the level of adoption and their application also show the current reach of the technology's capabilities. At a global level, AM is mainly applied for the proof of concept of products (34 percent) followed by prototyping (23 percent) and non-mass production (22 percent) (Figure 3). This trend is in accordance with the main sectors in which AM has found the greatest deployment: customized units in which economy of scale is not relevant or it is overshadowed by the enhanced performance offered by the technology (as in the aerospace or luxury automotive sectors).

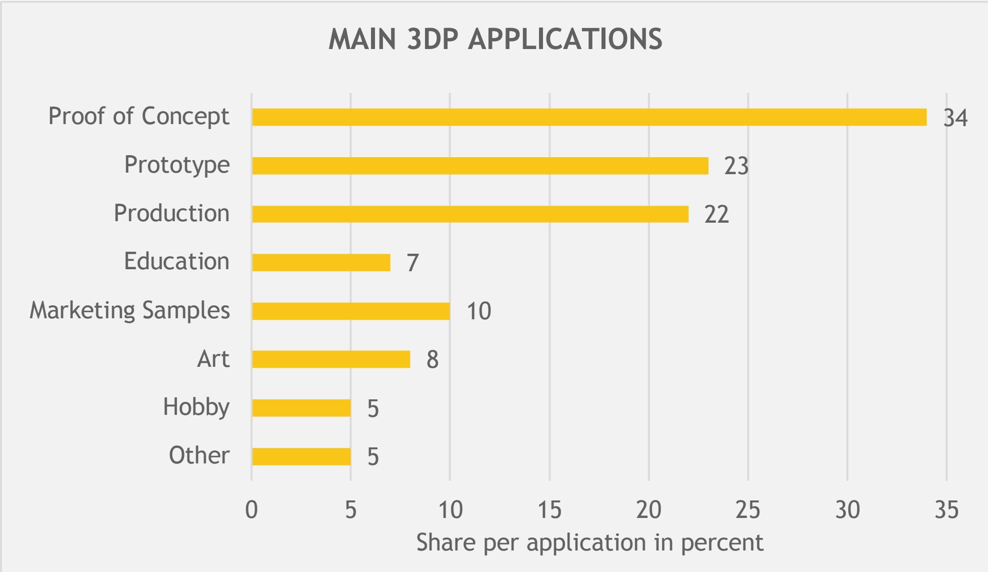

Figure 3. Main 3DP applications at a global level [14].

Despite the strong global competition (mostly from Israel, the United States and Japan in polymer and hybrid manufacturing, and from China in bioprinting), Europe is considered a major hub for AM technologies.
The share in applications is slightly different from those presented in Figure 3, and the technology is mainly used for R&D (26 percent), design (17 percent) and production (14 percent), driven by the role of SMEs in which high speed, reliable and low-cost prototypes are needed [14].
On a global scale Europe is the current leader of metallic AM and selective laser melting as well as leading in the AM community in the biomedical sector [15].
The annual growth rate for investment in AM has been 29 percent over the past five years, compared to an average of 9.7 percent for global investment growth in traditional machines [8]. Among the application sectors, aerospace, automotive, and medical industries are expected to account for 51 percent of the market at a global level by 2025, reflecting the promising future ahead for these industries. For the same period, the automotive industry is expected to become a US$4.30 billion global business (€3.7 billion) [16]. The aerospace and medical sectors are projected to grow at a Compound Annual Growth Rate (CAGR) of 22.3 percent and 15 percent respectively [17].
In Europe, the market is growing at a rate of 17 percent due to rising consumption, mainly driven in Germany, France and the Netherlands. The end-user markets of materials are growing steadily, with a CAGR of 20 percent until 2025, especially in the manufacturing and industrial sectors [17].
The medical and aerospace sectors have been key in the increased penetration in Europe. Here the combined spending on 3DP technologies will experience a five-year CAGR of 15.3 percent with revenues reaching US$7,4 billion (€6.3 billion) in 2022 [18]. In 2017, Western Europe delivered 83 percent of total European 3DP revenues and is likely to remain the largest contributor in Europe, with a CAGR of 14.4 percent until 2022. However, Central and Eastern Europe will be the fastest-growing region, with a CAGR of 19.1 percent for the same period.
As mentioned above, both waste generation and resource utilisation are addressed through AM technologies. Regarding both concepts, the current situation in Europe has been a result of legislation and regulation. On the one hand, 5 billion tonnes of raw materials were consumed in 2012, out of which 80 percent (4 billion tonnes) came from virgin materials and only 20 percent (1 billion tonnes) came from secondary raw materials recovered from the waste stream. On the other hand, approximately 2.5 billion tonnes of waste were generated in the same year, out of which 42 percent went to landfill [19]. To tackle this, the EU proposed the CIRC Package with the following targets:

- No more than 10 percent of municipal waste should be sent to landfill;
- a ban on the landfilling of separately collected waste;
- and 65 percent of municipal waste to be re-used or recycled.

Green or circular economy has been identified by the EC as one main area of important job creation potential [2]. In 2014, 3.9 million people were already employed in CIRC sectos in the EU-28 with theirn involvement in different activities related to CIRC (Figure 4) [20].

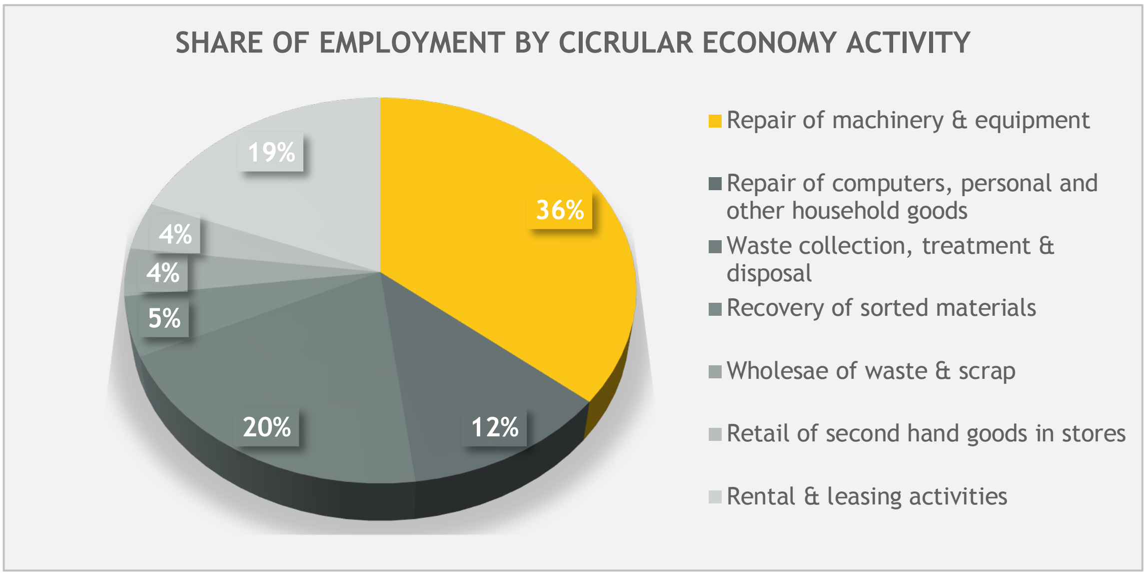

Figure 4 Distribution of employment by circular economy activity across EU28 in 2012 [21].

The performance of Member States in waste generation and waste management can be seen in Figure 5. The goal is to achieve the largest share of municipal solid waste recycled and the lowest waste generated per capita. The countries of the regions of AMiCE partners showed different behaviour:

- Germany has only met part of the challenge since it attains high levels of recycling but without reducing waste generation.
- Italy remains at moderate levels of waste generation and waste management although far away from goal targets.
- Slovakia, Poland, and the Czech Republic presented a similar behaviour, with an average of 300 kg of waste generated per capita and 15 to 25 percent of waste recycled.

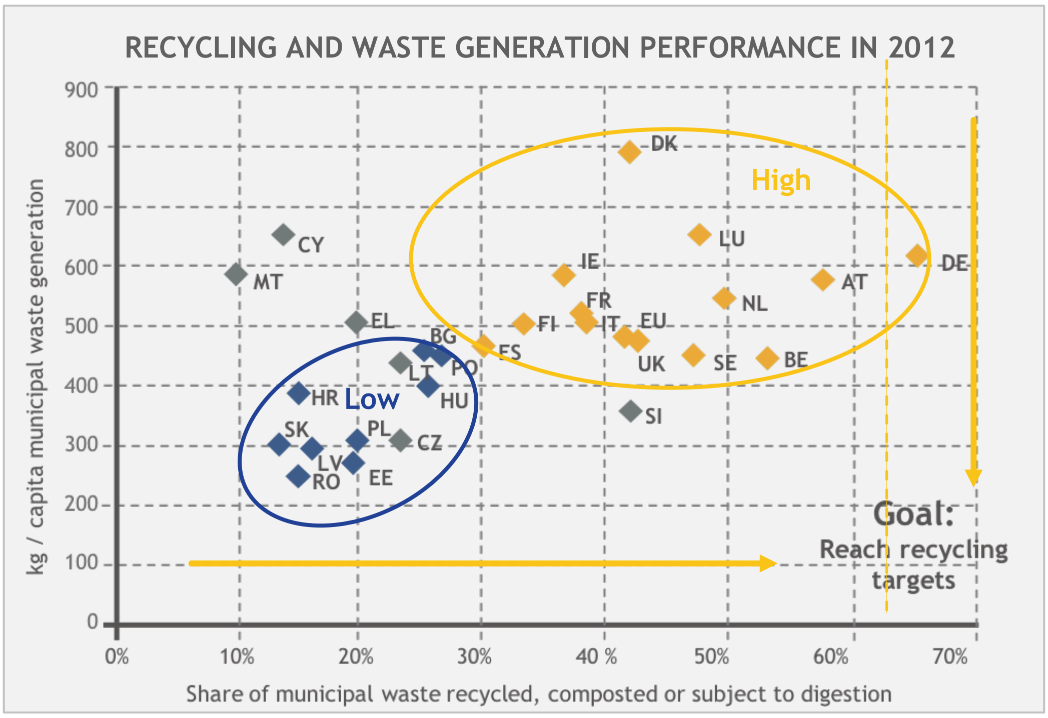

Figure 5 . Country performance in waste generation and recycling [21].

The spread of CIRC practices and technologies will depend on how citizens and industry are willing to change conventional mindset and engage alternative forms of consumption and manufacturing.
In Germany, several sectors are considered to have high levels of remanufacturing (this is understood as the product in which faulty or old components have been substituted, and which is sold with the same guarantees as a new product). Among these sectors we can include: aerospace; automotive; heavy duty and off-road equipment; electronic and electrical equipment; as well as machinery and medical equipment [2]. The adoption of AM technologies in these sectors could significantly contribute to CIRC by increasing **material** savings in production and consume phases of a product (by enhancing performance). During early production phases, reduced material inputs would decrease handling costs along with shorter supply chains. As for the use phases of products, lightweight components enable energy consumption to be reduced. According to Despeisse and Ford (2015), around US$113-370 billion (€95-320 billion) and US$56-219 billion (€50-190 billion) could be saved by 2025 for production and consumption respectively [3].[2]

2.2. Benchmark report

At a global and European level, there have been several reports analysing the acceptance of AM technologies and their effects in the economy and society at the short, medium, and long term. The companies that are aware of the opportunities offered by the technology and the challenges that must be faced for their adoption show a different acceptance level according to the region analysed (Figure 6).

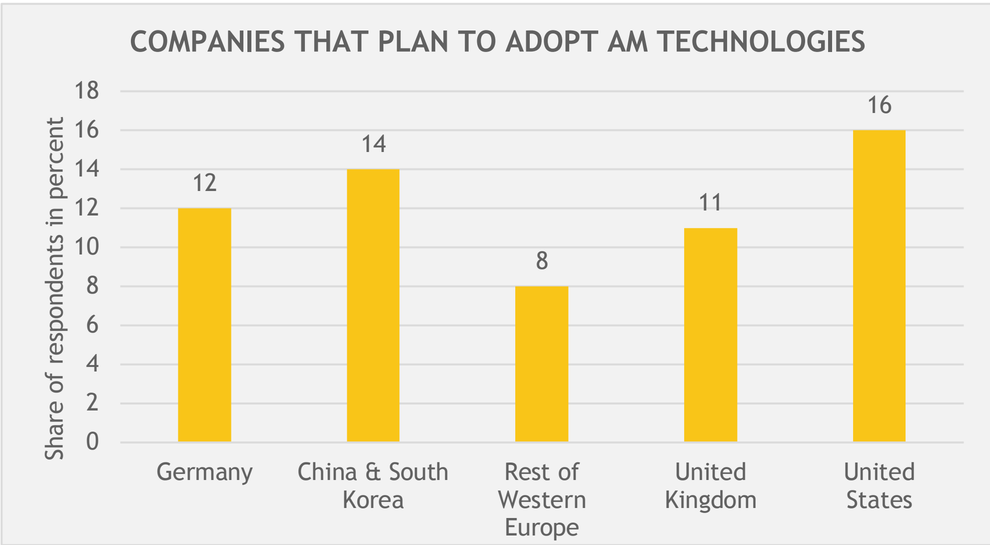

Figure 6. Acceptance level of AM technologies in different regions of world [22].

In terms of adoption, Germany is at forefront, followed by China, South Korea, and Western Europe.

[2] Material savings are related to the fact that the exact amount of material can be used. Energy savings are related to the fact that components with enhanced performance can be produced. For example, heat exchangers might be better produced (with a complex geometry, better suited for cooling), with an improved efficiency during consumption/use, and hence more energy efficient (other examples can be found for turbines, etc.).

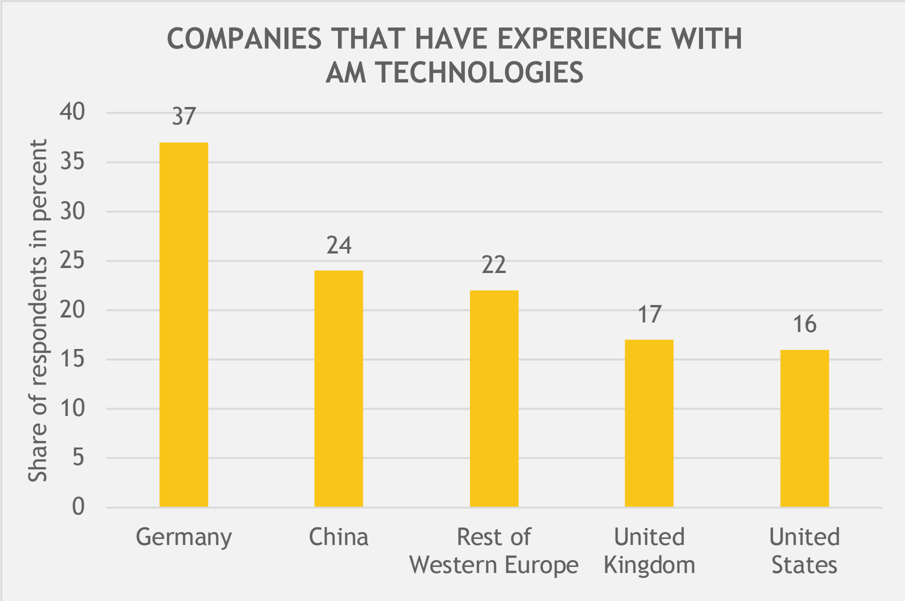

Figure 7. Share of companies already having experience in AM technologies per region [23].

In this context, industries relying on aerospace and medical technology have the largest total investment volume. The automotive, consumer goods and industrial machinery represent only a small fraction of the investments. It should be noted that a higher investment does not necessarily mean higher production since AM is to large extent used for prototyping.

Focusing on Central Europe, the region covers an area of over one million square kilometres with 146 million people inhabiting this area (Figure 8). Nine European states are part of the region including Austria, Croatia, the Czech Republic, Hungary, Poland, Slovakia and Slovenia. Furthermore, several regions from Germany (including Saxony) and Italy (including, Liguria) [24].

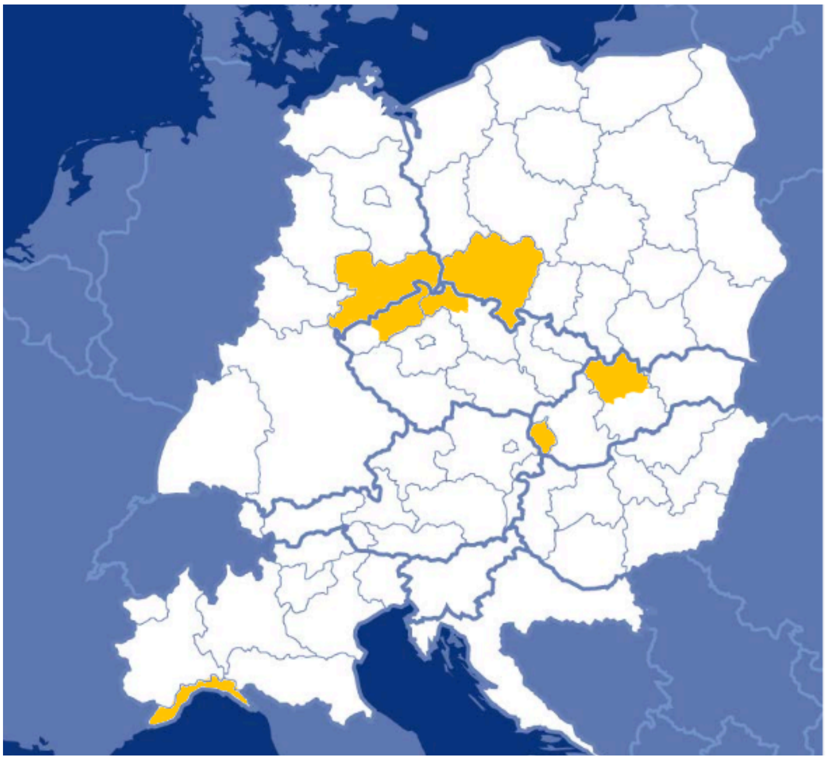

Figure 8. Regions of Central Europe under consideration in this foresight study [25].

The regions under study in the AMiCE project are listed as follows:

- Saxony (Germany)
- Liberec & Ustí region (Czech Republic)
- Bratislava & Žilina (Slovakia)
- Lower Silesia (Poland)
- Liguria (Italy)

The following sections address the economic context of each of the regions under consideration, in order to set the basis for further analysis in the adoption of these kind of technologies in the regions under analysis (economic facts and regional priorities). The analysis will also consider the role of CIRC. The information presented in the next sections was obtained from different sources (e.g. websites, reports, journals, articles, etc.) and also from the different interviews carried out with the partners of AMiCE (R&D experts and business-supporting entities).

For all the sectors involved in adopting AM technologies, the Circular Economy Action Plan of the EC comprises various legislative proposals and measures in the areas of production (product design and production processes), consumption and waste management, as well as concrete targets for creating an ambitious long-term roadmap for waste management and recycling in Europe [2]. AM technologies enable the eco-design by delivering products made with fewer resources, using recycled and renewable resources and avoiding hazardous materials, as well as with components that are lasting longer and easier to maintain, repair, upgrade and recycle [26].

2.2.1. Saxony (Germany)

Germany is the largest national economy in Europe and the fourth-largest by nominal Gross Domestic Product (GDP) in the world covering an area of 357,021 square kilometres with 82.7 million inhabitants [27]. In 2017 the GDP growth rate was 2.2 percent and the GDP per capita accounted for €39,649 which is well above European average [27]. 69 percent of the GDP was formed by services and 26 percent by the industry [27]. The country is known as successful global player and stable economy. The exports are driven by highly innovative SMEs known as the “Mittelstand” which account for 99.6 percent of all companies [28]. 63 percent of all employees contributing to social security in Germany were employed by SMEs in 2016 [29].

Within the manufacturing industry, which employs about 7.2 million [30], the following sectors are identified: industrial machinery, automotive, the chemical industry, energy technology, electrical engineering, electronics, metal production and processing, food and beverages, shipbuilding and textiles.

The German federal state of **Saxony** is the sixth most populous region in the country, with 4.084 million inhabitants in 2016 and a surface area of 18,416 square km [31]. The regional innovation scoreboard of the EC ranks Saxony as a strong innovator [32]. In 2017, the regional GDP grew about 1.4 percent [31]. It is the second highest economic growth among all German federal states. The GDP for last year grew to €121.7 billion - accounting for about 3.7 percent of the German GDP, where 55 percent were contributed by the Saxon industry [33].

Table 1 shows the main manufacturing sectors as well as their contribution to the Saxon industrial turnover and the employment in 2017.

Table 1. Number of employees and the share of industrial turnover per sector Saxony [34] [35].

SECTOR	SHARE OF SALES [PERCENT]	EMPLOYEES IN MANUFACTURING	EMPLOYMENT SHARE IN SAXONY [PERCENT]
Automotive	27.0	44,154	2.8
Metal production	13.0	62,540	4.0
Industrial machinery	12.6	39,175	2.5

Electrical engineering/ microelectronics	11.6	39,423	2.5

Furthermore, the textile as well as the plastic and metal industries are important pillars of the Saxon industry.
The main export partner of Saxony in 2017 was China followed by the U.S. but the export partners from the European Union accounted in total for 58 percent. The Czech Republic and Poland are main import partners followed again by the U.S. and China [36]. On the or hand, at a national level the USA, France, the Netherlands and China are the main trade partners [37].
The Smart Specialization Strategy in Germany is divided in a national strategy and specific strategies for each federal state. At a national level, the priorities of the German Federal Government are based on five pillars [38]:

- Priority tasks for future, including digital economy and society, sustainable management and energy, innovative working environment, healthy life, intelligent mobility and civil security.
- Better transfer at regional, national and international level.
- High innovation dynamics of the German economy and particularly for SME support.
- Improved frame in terms of securing skilled labour, innovation financing and other social, technical and legal prerequisites.

Among the thematic fields that were prioritised in the specific regional **RIS3 strategy document for Saxony** are key topics like environment and resources, mobility, energy, health and digital communication. These topics are addressed by key technologies defined as Saxony's regional smart specialization priorities [38]:

- ICT and digital communication
- Microelectronics including organic and polymer electronics
- Photonics
- Nanotechnology
- Biotechnology
- New materials
- Advanced production technologies

The evaluation report on innovation policy sees a good impact on these innovation strategies. Due to a funding policy that is not targeting specific sectors, but supports cross-sectoral projects, new infrastructures have been developed. On the other hand, the impact is not easy to evaluate since this approach is very broad. Undercapitalisation and the lack of skilled people in certain areas is the main risk for innovation in Saxony.
Whereas on the other hand a well-developed research infrastructure, state of the art equipment, and a well embedded Saxon research in the international context are proof of the high potential of the region. Companies in the region furthermore state that students bring knowledge and experience on new technologies into the companies and the funding scheme works.
In 2017, Germany was the leading country within the EU in the adoption of AM technologies with 8.4 percent of all global 3d printer instalments [39]. It is a leading industrial nation and its level of expertise in AM is reflected in the high level of applications of Patent Cooperation Treaty (PCT) patent families. The entrepreneurial landscape is medium-sized and, in addition to companies specializing in AM, also has traditional mechanical engineering companies. The existing initiative 'Mittelstand 4.0 — Digital Production and Work Processes' supports SMEs in digitising, networking and introducing Industry 4.0 applications to their business. The overall goal is to raise awareness of the technical and economic challenges of digitisation and it supports the development of secure digital solutions and processes. The development of new business concepts and cross-company networks are supported through incentives. [29].
Saxony has a very strong manufacturing sector with a long lasting industrial (Cars e.g. Audi originated in Saxony, many important inventions) and innovative tradition. The handicraft and manufacturing sector which is crucial for innovation activities is very strong. Furthermore, Saxony offers a strong funding infrastructure (automotive, aerospace, IT, semiconductor). More than 80 percent of Saxon enterprises are

SMEs which is both an advantage and also one of the main obstacles. It leads to high innovation potential due to the flexibility of SMEs, but since SMEs are working with bigger companies that operate outside of Saxony (Automotive mainly) in Western Germany the created value or capitalisation is also outside of Saxony. Saxony has been referred to as a cheap workbench which is lowering the speed of innovation.
The potential of Saxony is based on a well-developed research infrastructure and state of the art equipment. Saxon research is well embedded in international research and students bring knowledge and experience on new technologies into the companies. Saxony's extraordinary innovative power made the region a European pioneer in the area of AM technologies. The regions researchers and entrepreneurs play an important and leading role in developing intelligent solutions [38]. Unique knowledge and selling points exist in resource- and energy-efficient production technologies, industrial structural lightweight construction, fibre-reinforced lightweight construction and the development of new and existing materials. The German leadership position of existing know-how in advanced production systems is reflected in the amount of applications for patents. Due to a high representation of Fraunhofer Institutes the share of patent applications for Saxony is far above average in Germany [40].
Traditionally, there are very strong links between university and non-university research institutions and SMEs in Saxony. This 'infrastructure' serves as the basis for the development and implementation of advanced manufacturing technologies in Saxony. Currently there are some technology centres existing in Saxony that rely on 3DP. Those centres produce mainly prototypes for their own companies but also receive orders from other regional companies that lack the technology. Internationally renowned 3P companies work together with Saxon companies or buy them directly [41].
Even though Germany has not established an Eco-innovation Action Plan as yet (it is under development), the country has the fourth highest eco-innovation performance in the EU [42]. The German Federal Environment Agency is currently running a project in order to provide the German Government with a scientific basis for setting up the national Eco-innovation Action Plan. The CIRC concept has been increasingly included into other political programs and objectives at a national level. Several national developments like the establishment of the German Material Efficiency Agency or the introduction of the new "German Resource Efficiency Programme (ProgRess)" in 2012 have been milestones and driving forces for resource efficiency and eco-innovation [43].
In a regional context the focus of Saxon companies lays primarily on recycling as one of the most visible and easier to adress parts of CIRC. Addressed are mostly glass and packaging materials. In this business the yearly turnover accounts for €1.37 billion. Apart from that there are companies actively using AM companies that bring CIRC into the process by e.g. reusing powder. Overall the integration of CIRC principles is usually driven by cost reduction rather than environmental concerns.
The greatest potential for CIRC adoption is seen predominantly in the manufacturing sector (automotive, aerospace, mechanical engineering, ICT, semiconductors, food, textile, packaging).
Several clusters have working groups dedicated to CIRC such as CLEANTECH Initiative Ostdeutschland (CIO), and the Energy Saxony Cluster. Green Ventures Germany serves as a partnership forum for companies interested in environmental and energy technologies and attracts SMEs for the topic. The event in of 2017 was hosted in Leipzig.

2.2.2. Liberec & Usti regions (Czech Republic)

The Czech Republic has developed its position as a quality manufacturing base that is competitive among the more cost-competitive countries in Central, Eastern, and Western Europe [44]. Its economy is ranked 20th among the EU members. In 2017, the GDP per capita was estimated to €18,193, below the European average (€29,200) [45]. The most important trade partners for the country belong to Central Europe, with one third of Czech exports is linked to the German economy. More than half of all exports go to Central European countries, from which the country imports around 50 percent [46]. The manufacturing industries contribute to 45 percent of the national GDP and account for 75 percent of all exports. The main sector is the automotive sector, which is ranked as the 6th largest in the EU, representing 25 percent of total industrial production and 25 percent of total Czech exports. This segment is characterized by large businesses, which

make up about 95 percent. The remaining significant sectors are electronics and electrical engineering, machinery, and electrical equipment [30]. Another important sector especially in terms of AM technologies is the medical sector.
As by June 2018, the unemployment rate in the Czech Republic was the lowest among all European member states [47]. In 2017, the manufacturing sector employed around 38 percent [48] of the population currently living in Czech Republic (Table 2).

Table 2. Number of employees and enterprises & manufacturing output share per sector in the Czech Republic [49] [50] [51] [50].

SECTOR	EMPLOYEES IN MANUFACTURING	NUMBER OF ENTERPRISES	MANUFACTURING OUTPUT SHARE [PERCENT]
Automotive	166,836		More than 20
Electrical and Electronics	146,040	15,000	More than 13
Mechanical engineering	126,359		

The Czech Republic is above the global average with 93 robots per 10,000 manufacturing workers according to the International Federation of Robotics.
The regional innovation scoreboard of the EC ranks the Czech Republic as a moderate innovator [32]. Among the knowledge domains that were defined in the RIS3 for the purpose of smart specialization under the conditions existing in the Czech Republic, advanced manufacturing technologies is one major point. Furthermore, advanced materials, nanotechnology, micro- and nanoelectronics, photonics as well as industrial biotechnology were identified. Prospective areas of specialization that were defined in the RIS3 document are [44]:

- Mechanical Engineering, Energy Industry and Metallurgy
- Electronics and Electrical Engineering and ICT
- Manufacture of Transport Equipment
- Medicinal Products, Biotechnologies, Medical Devices, Life Sciences.

The main mechanism of support are grants that stimulate companies to innovate, where the expenditure on R&D during 2015 reached 1.95% of the national GDP [52]. But in general, there is a positive development of the Czech economy. The Czech industry is no longer only manufacturer but now on the way to become an innovator. The innovation trend is increasing because global companies such as Siemens and Bosch are supporting the build-up of R&D centres in the country. Other than in the past 10 years big capital companies decide to now do R&D activities on-site. Apart from investing in own research departments they also promote and support close collaborations with Research and Technology Organisations (RTOs). Due to this changing trend the innovation level of SMEs is improving with shares of sales revenues from innovative products reaching 27.4 percent compared to 30.4 percent of large enterprises [49]. In General, experts see a high potential innovation in the country for the coming years. The opportunities are driven by the available capital that companies have to invest in automation and industry 4.0 and their change of mindset towards a more global landscape. One reason to invest in automation is also to overcome identified barriers such as the compensation of the lack of human resources.
The continuing digitalization, automation and development of advanced production technologies, and subsequent change in production chains brings opportunities for the major manufacturing sectors in the country. Identified threats on the other hand include the high cost of intellectual property protection in Europe as well as an expected lower use of non-specialized-workforce due to new skillsets necessary for advanced manufacturing technologies [44]. Only about two to three percent of Czech companies currently use digital technologies on a large scale. Industry 4.0 and subsequent advanced manufacturing technologies bring many opportunities and challenges that need to be addressed by industry and policy equally [30].

Nonetheless, the Czech industry is on the process to become a leader for the development, application and production of 3DP solutions in Central and Eastern Europe. The high level of industrialization is supporting the breakthrough of the technology in many areas. So far AM technologies have been used predominantly for prototyping. In the future, however, more components in the production process will come from 3D printers. More than 50 percent of large manufacturing companies already use the technology or plan to do so in the next five years.[3] The 3DP technology is an important instrument to ensure Czech competitiveness, reduce production costs and react faster to new customer requests. The Czech manufacturing industry is globally among the top countries in the use and introduction of AM technologies. Czech 3D printer developer Prusa Research in Prague is among the best performing in the world. The Prusa i3 melt-coating printer is said to be the most widely used 3D printer in the world. Although, the main use of the printer is not found in the industry but for hobby or research related purposes [53].

So far, AM is largely used in Czech mechanical engineering to meet individual customer requirements and in consumer goods production. The main sector with a high prospect to adopt AM technologies broadly is the automotive sector. Other sectors include construction and the health sector (life science) (for example dental parts), biotechnologies and electronics. For SMEs the focus lays on different kinds of applications but mostly medical parts because there AM adds value. However, there are still barriers to overcome in the Czech Republic such as lacking know-how, unsuitable material and high investment and operating costs. The latter affect mainly small companies. This is where regional open workshops (service providers specialized in AM) mostly located near technical universities step in [53]. These aspects will be analysed in further sections.

In comparison to western European countries eco-innovation and CIRC are still emerging areas but with constantly rising importance and interest from industry and public. [54] For the public the topic is relatively new and there is still no understanding of what the concept is about. For both public and industry, the topic is too time intensive. The main sector in which CIRC has the greatest potential was identified by regional partners as the automotive sector since it is a very local and over a long-time stabile sector. In terms of CIRC measures and practices, the Czech Republic has increased in ten years its recycling rate from under 10 to 70 percent for general packaging.

2.2.3. Bratislava & Žilina (Slovakia)

The Slovak Republic is a small and very open economy that ranked 22nd among the EU members. It benefits from an advantageous geographical location at the crossroads of Central Europe. [32] The top manufacturing industries in the country are the production of cars, video displays, vehicle parts, broadcasting equipment, and rubber tires (Table 3). [30]

The main economic sectors that show high potential for AM technology adoption as well as their shares for employment, enterprise and revenue within the manufacturing industry are listed in Table 3.

Table 3. Number of companies per sector and activity in Slovakia [55]

SECTOR	EMPLOYEE SHARE [PERCENT]	NUMBER OF ENTERPRISES	ENTERPRISE SHARE [PERCENT]	TOTAL REVENUE SHARE [PERCENT]
Automotive	18.0	150	5.0	30.5
Mechanical engineering	9.8	212	7.7	5.7
Electrical engineering	10.9	217	7.5	10.6

[3] Material savings are related to the fact that the exact amount of material can be used. Energy savings are related to the fact that components with enhanced performance can be produced. For example, heat exchangers might be better produced (with a complex geometry, better suited for cooling), with an improved efficiency during consumption/use, and hence more energy efficient (other examples can be found for turbines, etc.).

Medical/ Life science	188

The industry of advanced manufacturing technologies is growing fast, especially in the automotive sector in which is the world leader per capita (concentrated in the western and northern regions of the country). [56] The Automotive sector employs 129,000 people directly (VW, PSA Peugeot, KIA, Tier 1 suppliers) and 250,000 people indirectly and per year Slovak manufacturers produce 1 million cars. Tier 1-2 suppliers export their products to plants located all around Europe as well as to overseas locations [57].
The GDP Growth in 2017 was 3.3 percent and a sustained and steady growth is forecasted for the Slovak Republic throughout the next 5 years due to a favourable outlook for the Eurozone (Slovak GDP growth of roughly 3.7 and 3.9 percent in 2018 and 2019) [58]. The three main export partners - with around 40 percent of all exports going to - are all Central European countries (Germany, Czech Republic and Poland). Germany and Czech Republic also are the main partners from which Slovakia imports approx. 30 percent of its goods [59].
In Slovakia the share of currently employed people sums up to 93.9 percent and among those 36 percent were employed in the industrial sector in 2017 [60].
Other sources considering a different extent of the mechanical engineering sector state an employment rate of 33 percent of industry workers distributed in 735 companies, greatly supported by the automotive sector (74 percent corresponds to automotive OEMs and suppliers). The country has a strong tradition in mechanical engineering. There is also a variety of other industrial segments in demand of production capacities: machinery and equipment (12 percent), basic metal & fabricated metal products (13 percent), and other transport vehicles (1 percent). The metalworking industry includes 396 enterprises, which employ around 29,600 workers that are skilled in different conventional methods: CNC machining, turning, welding, cutting, forging, metal surface treatment, stamping [61]. The automotive industry, as the strongest branch of mechanical engineering, is mostly concentrated in the regions of Western Slovakia. The region of Žilina concentrates 66 percent of the regional share in mechanical engineering while Bratislava region accounts for 41 percent.
Although no statistical data on the medical sector is available (which is probably due to the fact that it is included in different cross-cutting sectors), it is seen as having the highest added value.
Regions that are interesting for AM adoption are the Bratislava and Žilina Region with most of the R&D expenditures concentrated mainly in the Bratislava Region, where 42 percent of total expenditures were allocated in 2015 [62]. Bratislava and the eastern regions are also the part of Slovakia were most companies are located. Especially the automotive sector is strong there as well as the mechanical engineering sector that collaborates with many engineering facilities from the region. The Žilina Region is second with the highest increase of R&D expenditures (compared to 2007) [62].
Slovakia belongs to the group of moderate innovators [32]. The innovation level is increasing for several years now. Both industry and RTOs are investing more into innovative research.
Due to the small size of the country, the concept of smart specialization although existing in a formal regional dimension implementation is very limited therefore remains mainly at national level [4]. Due to the limited resources and capacities, the strategy concentrates on a limited number of priorities which are defined based on strengths and international specialization. Three basic groups of thematic priorities were developed: R&D priorities, technological priorities, and social priorities.

The ICT sector is a big booster for the development of new technologies and tools. Slovakia thrives on local tech talents, stemming from local engineering schools like the Slovak University of Technology in Bratislava. Major tech companies including AT&T, Lenovo, and Dell, which all have offices in Bratislava and benefit from locally generated knowledge and human resources [63].

The areas of economic specialization were those related to automotive and mechanical engineering industries, consumer electronic and electrical equipment, ICT and services, production and processing of iron and steel. The prospective areas of specialization defined were automation, robotics and digital technology; processing and increasing the value of light metals and their alloys; production and processing of plastics; creative industry; increasing the value of domestic raw material base. By this manner, the country officially launched and implemented the RIS3 and the concept of intelligent industry in 2016. The RIS3 document identified three key industry sectors [4]:

- **Materials research and nanotechnology** including new materials (especially lightweight structural materials and composites, organic materials, steel and special materials) and surface treatment and diagnosis system for applications in the field of the Slovak economic specialization.
- **Information and communication technologies** including communication systems, technological process management systems, as well as data mining services and processing of large databases and the safe use of ICT including web technologies and cloud solutions.
- **Biomedicine and biotechnologies** including new diagnostic and therapeutic approaches for cancer, heart disease, blood vessels and brain, endocrine and metabolic disorders, infectious diseases and allergies. In the field of the biotechnology the focus is on pharmacological and industrial biotechnologies.

The technological priorities also include advanced manufacturing technologies and certain aspects of circular economy through resource efficiency [4]:

- Industrial technologies encompassing automation, control, robotics, as well as the technology for forming, cutting and joining of new metallic and non-metallic materials and composites, logistic technologies, processing technologies for polymers, wood and products thereof. Increasing the value of domestic raw material base.
- Effective usable energy sources for reducing energy intensity, emission reduction program ALEGRO, smart grid technology, the safety of nuclear power plants, etc.).
- Environment, agriculture, and food security including advanced technologies and practices in agriculture and food production to ensure the sufficiency of quality food production.

The societal priorities are the aging population and quality of life; multiethnicity, social inclusion and poverty problems; and employment of young people in the changing conditions [4].

In general, no big progress has been identified in the deployment of those RIS3 priorities. Overall, Slovakia lacks behind other regions in this area. Experts talk about being one to two years behind other EU countries. For Industry 4.0 there was a more concrete plan drafted, but finally the government decided not to implement it. Action plans exists for many areas to distribute and attract funding but so far those haven't been implemented due to financial reasons. In Slovakia the most important mechanisms of support are governmental incentives and support through European funds. There is a lot research infrastructure, e.g. universities as well as an overall huge HR demand from companies, but they lack experts. SMEs strive to employ skilled people and have the capacity to pay accordingly but the overall lack of skilled people especially in technical fields hits the SMEs harder than larger enterprises. This development has been noticed already in the past.

CIRC is gaining visibility on the policy discourse in Slovakia and some framework conditions are in the making that facilitate the progress such as the ones in waste management policy. However, to date, there is no national policy outlining a coherent approach towards eco-innovation and CIRC.

2.2.4. Lower Silesia (Poland)

The economy of Poland is ranked 9th among the EU members with a GDP growth of 4.6 percent in 2017. The Polish industry employs around 32 percent of all Polish labour force and contributes around 28 percent to the national GDP [64]. The Polish manufacturing industry which is the 6th largest in the EU identifies the following sectors [30].

- Automotive: The automotive sector accounts for 8 percent of the GDP, generates 13 percent of Polish exports, and accounts for 10 percent of all manufacturing industry employees.
- Food and beverages
- Metal products

- Rubber and plastic
- Coke and refined petroleum products
- Chemicals and chemical products
- Electrical equipment
- Non-metallic mineral products
- Basic metal products
- Miscellaneous machinery and equipment
- Furniture

Poland is rich in minerals and one of the world's biggest producers of hard and brown coal, copper, zinc, lead, sulphur, rock salt and construction minerals. Mining has a long tradition in Poland and especially in the regions of Lower and Upper Silesia it is an important sector [65] [66].

The country identified **prospective and essential technologies** that should be supported and developed; specially to give those branched push and opportunity to strengthen their competitiveness:

- Aviation industry: To increase the dynamic development and requirements in the product environment as well as competitiveness [67].
- Automation, Robotics and Measuring Technology: Here, the government is banking on technology that will generate the greatest profit in the next 20 years. It is about identifying development trends and trends, ensuring the safety of robots and their systems [68].
- Technologies of automated and robotized production cells and lines.
- Rehabilitation robot technologies.
- Autonomous mobile robots for internal transport application technology.
- Non-invasive measurement and diagnostic techniques.
- Sensors in distributed systems of pollution monitoring and of natural hazards warning-
- Measurement systems integrated into technological processes·

Within the framework of the national research programs, **modern material technologies** are the focus of ongoing research and the European Union [69]:

- Technologies of construction materials.
- Technologies of photonic and nano-electronic materials.
- Technologies of functional materials and materials with designed properties.
- Non-waste material technologies and technologies of biodegradable engineering materials.
- Technologies of materials for storage and transmission of energy.

The Polish manufacturing sector is closely linked to the German one since it is associated to many supply chains (predominantly in the automotive sector). Therefore, the current instable outlook of German exports poses also risks to the Polish manufacturing sector [70].
Poland is a moderate innovator [32] but behind the EU average when it comes to implementing Industry 4.0 principles since the developments and adoption are showing only slow progress. Only 22 robots are available per 10,000 industry employees and the fourth lowest overall innovation index score in the EU poses a threat to the competitiveness [30].
Since successful scientific projects usually end up being not implemented due to a lack of knowledge-to-industry transfer mechanisms, the innovation potential is not fully used. Furthermore, permanent emigration of the scientific staff as well as large foreign competition in the area of technology pose threats that Polish policy needs to address [71].
The smart specialization priorities that were defined in the RIS3 document are listed below (among them, CIRC and AM technologies are included) [71]:

- **Healthy Society**: New medical and medicinal products and manufacturing technologies; diseases diagnosis and advanced therapy methods.
- **Circular economy**: Technologies of acquisition, processing and use of natural resources, reducing their consumption and re-use of secondary raw materials as materials or energy sources.

- **Bio-economy**: Innovative biotechnological technologies and products in agri-food, forestry, chemical and environmental engineering.
- **Innovative technologies and industrial processes**: Focus on advanced materials, sensors and their networks, ICT application, printed, organic and flexible electronics, automation and robotics, photonics, creative technologies and innovative marine technologies.
- **Sustainable energy**: Smart and energy efficient construction, high efficiency, low-emission and integrated circuits of manufacturing, storage, transmission and distribution of energy (smart grid), and sustainable transport solutions.

At regional level, Lower Silesia is an automotive industry region, a leading manufacturer of porcelain, crystal, pharmaceutical and electronic products, as well as an important road, rail, air and waterway transportation hub. According to the latest available Eurostat data for 2010, the share of employment in industry accounted for 34 percent of total regional employment. Two of the most important branches of economy are the automotive and electro-mechanical sectors, followed by the manufacturing of white goods, IT, and pharmaceutical sectors [72]. According to the information provided by partners, Table 4 presents the share of companies per manufacturing sector.

Table 4. Average trend of share of companies in the manufacturing sector in Lower Silesia [73].

SECTOR	ENTERPRISE SHARE IN THE MANUFACTURING INDUSTRY [PERCENT]
Automotive	13.5
Mechanical engineering	34.5
IT	19.5
Food processing	7.0
Electronics	9.5
Chemical and Pharma	9.5
Business process outsourcing	6.5

Although CIRC is a regional priority there are still many obstacles to overcome especially since the concept is very new in Poland. Currently regional authorities are just involved in one or two projects (small and local initiatives). For now, no clear prognosis can be made whether the national and regional governments will include specific strategies.

In general, Poland is still far from implementation and information about projects have not yet been included neither in operational nor in funding programs. Since the automotive sector involves many big players and is an important sector in the country, CIRC is prognosed to be a hot topic for the future. Furthermore, growing potential is seen for home appliances. So far there are no clusters in Poland that address the principles of CIRC.

2.2.5. Liguria (Italy)

Italy is the 3rd largest economy in the eurozone and a moderate innovator [32]. In 2017 the GDP per capita accounted for €26,338 which is slightly above the European average [74]. 66 percent of the GDP was formed by services and 21 percent by the industry [75]. 78 percent of all employees in Italy were employed by SMEs which were represented with a share of 99.9 percent in the Italian enterprise landscape in 2017 [76].

Liguria is a coastal region in the North-Western part of the country that has an area of 5,416 km^2 and a population of about 1.6 million inhabitants. In 2016, GDP PPS per capita was equal to €31,400 which is above both the Italian (€ 28,200) and the European (€ 29,200) average [77].
Liguria is a moderate innovator but, between 2011 and 2017, the Regional Innovation Index showed an increase for 4.1 points (one of the best performances among Italian regions) [32] [77]. The main factors that lead to this increase are SMEs innovating in-house (normalised value equals to 0.24 in 2011 and 0.41 in 2017) and product/process innovations (normalised value equals to 0.30 in 2011 and 0.42 in 2017).
The main weaknesses, which also apply to other Italian regions, are related to the R&D expenditure in business (1 percent below the Italian average; 26 percent below the one for Europe) and EPO patent applications (9 percent below the Italian average; 29 percent below the one for European).
Smart Specialization Strategy in Italy consists of a National and Regional Strategies. The National Strategy focuses on 5 priority areas (1- Agrifood, 2- Strategic production chains, 3- Maritime technologies, 4- Smart health, 5- Culture, creativity, and tourism) [78], while Regional Strategies on 12 areas of specialization, thus generating potential coordination problems [79].

The Ligurian region identified **three areas of specialization**:

- **Maritime technologies** and innovative solutions for shipbuilding, naval repair, boating and refitting, including materials and components, energy efficiency, environmental impact reduction, safety, e-Maritime solutions. - Protection and enhancement of the marine - coastal environment: including marine weather modelling, marine biotechnology, emergency management and green port. - Logistics, security and automation in port areas.
- **Health and life science** including technologies to support public health and assist disability and ageing. Innovative medicines and therapeutic approaches, diagnostic systems, rehabilitation and assistance technologies, and biomaterials.
- **Safety and quality of life** including energy, environment and socio-economic sustainable territorial development strategy. Smart mobility, Smart environment, Factories of the future (advanced automation), or Intelligent Factories (being co-founder of the related National Technological Cluster), territorial safety and monitoring.

Table 5 presents a summary of the number of companies and employees per sector and activity by 2018.

Table 5. Number of companies per sector and activity in Liguria region [80].

SECTOR	ACTIVITY	NUMBER OF COMPANIES	EMPLOYEES IN MANUFACTURING
Maritime	Shipyards	129	1648
	Recreational staff	286	1347
	Repair and maintenance of ships and pleasure boats	495	2343
	Boat storage	255	1976
Mechanical engineering	Repair and maintenance of general-purpose machines	85	437
	Manufacture of internal combustion engines (including marine engines)	56	276
	Manufacture of instruments for navigation, hydrology, geophysics and meteorology	24	126

ICT	Software production (focus on manufacturing)	588	3397
Industrial	Installation of motors, generators and electric transformers	9	35
	Installation of electrical and electronic devices	86	369
	Installation of measurement, control, test and navigation instruments	25	321

Given the manufacturing character of the region, the deployment of AM technologies is of particular interest. AM systems for maritime technologies, for life sciences and health, environment and energy, sustainable mobility and transport are the main technology areas in which the region has a specific competitive advantage [77]. In health technologies AM is applied by corporates like Esaote (Genova) that use it for prototyping purposes in ultrasonic construction as well as Spes Medica (Genova) that uses it as instrument to study and create a new mock-up of the transcranic sensors for signal recording. In dental applications SMEs like Mectron (Carasco, Genova) explore the feasibility of dental and piezoelectric applications while SMEs outside the Liguria region (BTK –Bioteconline – Vicenza) decided to support the University of Genova shared PhD Programs dedicated to developing new 3D printing zirconia based dental apparatus. An interesting application of image analysis and big data application on 3DP medical structure has also been created by Camelot (Genova), a former spin off now to be considered as a SME.
The basic elements to be fostered are the research and development of new materials and design methods and tools that could exploit all the advantages of this new type of production. Many companies in the region are focusing efforts in collaboration with the Ligurian research system. There is a strong concentration of IT companies in the region which are investing and developing new software platforms for the world of AM that can represent an advanced supply chain support with considerable potential for growth and development. At national level, the combination of firm capabilities and public infrastructure is allowing the North of Italy to respond to the challenges of new digital manufacturing, given their competitive advantage in high-medium technology areas. Italian AM is a fast-growing sector, with top notch companies specialized in the aerospace and energy business [81].
The Region indeed may rely upon one of the technological excellence in metal sintering, welding and also printing like the Italian Institute of Welding - IIS, part of the International Welding Association. IIS has an operative agreement with University of Genova dedicated to promote and develop either the research activity either the technological transfer to innovation with the surrounding industrial scenario. Liguria indeed may also take advantage by the Italian Institute of Technology – IIT that has its headquarter in Genova. This is a top Scientific and Technological institute that has deep and wide competences in material science and 3D printing throughout its scientific and technical facilities.
As for the energy sector, the Liguria region hosts the headquarter of Ansaldo Energia, which produces turbines for big plants to be sold worldwide. At the current state-of-the-art, Ansaldo is actually employing metal AM technology to repair turbine parts (after 25khours functioning) to basically double the achievable lifetime of such components. As for the marine sector, AM is actually still considered as a “Rapid Prototyping” technology rather than a production technology. Nonetheless, current efforts within the industrial and the academic community are focused towards the investigation of AM potential for the production of low-scale test components (e.g. for water tunnel tests). As for the industry and incomes connected to luxury yacht and yacht design, mostly located around the La Spezia area, AM is currently employed in order to provide scaled models of components characterized by rather complex geometries (e.g. hulls), which are still produced by highly skilled manual workers (even for what concerns proof-of-concept prototypes). It is interesting to underline that, within the La Spezia area, come Start-ups have been recently established, whose aim is to provide AM services tailored to the very peculiar requirements of the yacht industry.

It should be given relevance to the Italian Technology Cluster “Intelligent Factories”: the “Italian Technology Cluster Intelligent Factories – CFI” is an association that includes large and medium-small companies, universities and research centres, company associations and other stakeholders active in the advanced manufacturing sector. The Liguria Regional Government is co-founder of this cluster since 2012 and they will keep on aligning their S3 to its action plan. The CFI association is recognized by MIUR as a driver of sustainable economic growth in all the regions of the national economic system, as it fosters the innovation. and specialization of Italian manufacturing systems. The mission aims to increase the competitiveness of the Italian manufacturing industry through the design and implementation of a number of research projects for the development of the new enabling technologies, to maintain and develop advanced skills in Italian manufacturing, to increase Italian companies’ access to national and international funds and improve their return on investment in research projects, to support entrepreneurship and company growth through the involvement of private investors.

The vision is to propose, develop and implement a national strategy based on research and innovation aimed at the development and application of innovative technologies in order to strengthen the competitiveness of advanced manufacturing in the international industrial context.

Concerning the main figures, the high-tech manufacturing companies in Italy are 61.189 (over 389.317 in total), the production value €327 bilion (over €864 billion in total), 1.384.000 employees (over 4.137.000 in total), accounting for 10m percent of the domestic V.A. sector (over 32 percent in total), as reported by EUROSTAT in 2015.

All entities expressing a specific interest on the issue of Manufacturing and Smart Factory can join the Association. The following can be CFI members:

- Representatives of Universities and public and private research bodies;
- Enterprises, subdivided into large and small/medium enterprises, according to the classification adopted by the European Union;
- Other public or private organizations interested on the matter of Intelligent Factory.

Membership for Industrial Member is open to industrial and trade enterprises and to business service centres operating in the Manufacturing and Intelligent Factory sector. Public and private research bodies, research institutes, and public and private Universities operating in the Manufacturing and Intelligent Factory sector can join as Research Member. Membership is furthermore open to unions, entrepreneurial associations, non-governmental organizations and other stakeholders operating in the Manufacturing and Intelligent Factory sector. Regional (Liguria) members include organizations nominated by the regions that have formalized a Programme Agreement with MIUR about the Intelligent Factory themes, as required by the call for the development of national technology clusters issued by MIUR on 30 May 2012, or that have at a later date formally finalized their accession to the Programme Agreement.

One of the valuable output of CFI is the “Roadmap for research and innovation” which has involved the collaboration of companies, universities, research institutions, and associations, represents CFI’s vision of the themes to be addressed through appropriate research and innovation actions for ensuring the maintenance and strengthening of Italian industrial leadership in the manufacturing sector. The Roadmap, a regularly updated strategic document that is prepared taking into account all the European roadmaps and the S3 documents - Smart Specialization Strategies of the Regions participating in the Cluster - is the result of intense work by the CFI Roadmapping Group, which carries out research work to identify visions and strategies for the Italian manufacturing sector. The Roadmap identifies the development macro scenarios (Lines of Intervention) within which the manufacturing sector should plan specific research and innovation activities for the coming years. For each Line of Intervention, the CFI has set up a Technical-Scientific Thematic Group (GTTS) which represents the organizational modality chosen for integrating the visions,

plans and actions of the industrial and academic members and for identifying the paths of technology development.
The CFI (GTTS) represents the operational modality that the Cluster Intelligent Factories has chosen in order to integrate the visions, plans and actions of its industrial and academic members. Their role is to turn into reality the strategic suggestions of the CFI's Roadmap for Research and Innovation, promote the analysis of the current state of science and of the industrial sector, monitor current projects and existing infrastructure, define paths of technology development by specifying research priorities and their level of technological maturity. For every Line of Intervention related to the research themes laid out by the Roadmap (link) a specific GTTS has been set up, coordinated by a Steering Committee consisting of representatives of the Research Institutions/Universities and of the CFI member companies. The fundamental role of the Steering Committees is to guide CFI's roadmapping activity, promote the thematic development and specialization of the research lines, including with the involvement of Cluster members, and coordinate the production of technical documents by the GTTS with the supervision of the Cluster's Technical Scientific Committee.

Specifically, with respect to the AMiCE project, the intervention line Strategies, Methods and Tools for Industrial Sustainability aims to research and execute strategies, methods and tools capable of implementing sustainable production processes– from the standpoint of the environment, the economy and the community – that are less dependent on the outside for the supply of key production resources or that are negatively affected by the regulations in force. Those systems will need to be consistent with the evolution of markets and enabling technologies, using technology as competitive boost. Priority research actions in this area mainly concern: new solutions for the reduction of polluting and/or noxious emissions in manufacturing processes; methods and techniques for the strategic evaluation of product-process according to a vision of Life Cycle Engineering; technologies and processes for the reuse, re-manufacturing and recycling of products, components and materials at the end of the lifecycle or coming from maintenance processes; systems and methods to measure and implement "Sustainable Supply Chains" or "Closed-Loop Supply Chains" clearly involving AM technologies. At date the coordination of this intervention line is provided by University of Genova and Liguria.

In this frame, CFI proposed and developed with the Minister of Economic Development, **The Lighthouse Plant Club (LHP-Club),** bringing together all the Technology Cluster Intelligent Factories – CFI companies involved in the design and construction of Lighthouse Plants on the basis of research and development projects launched specifically to support this type of factory. The Lighthouse Plant is a production plant based completely on 4.0 Industry technology, built from scratch or thoroughly restructured, that complies with requirements laid out in the regulations for participation in the Lighthouse Plant project (link). It is a plant that evolves through the years and is destined to become a national and international point of reference for the feasibility of paths of technological development.
Companies participating in the design and construction of the plant can register in the Lighthouse Club (LH-Club), which carries out activities of promotion and dissemination of the plants in national and international delegations, promoting them as best practice or case studies for applied research.
The first Italian Light House Plant is in Liguria (Ansaldo Energia) which will be visited during the third partner meeting in Genova. Within this large €14 million Research and Innovation action a specific sub-project on 'hot gas component repairing by using additive manufacturing technologies' has been proposed and accepted, leading to one of the first national application of real industrial case working on CIRC and AM technologies for turbine blades maintenance, repair and substitution (the process will be presented to AMiCE partners during the third partner meeting). The sub project is going to be developed together with Italian Institute of Welding (IIS) and University of Genova (GeAM joint lab). The IIS will be visited during the third partner meeting in Genova too.

Last but not least, the government (Minister of Economic Development) is launching a national research and innovation plan aiming to set and develop "Competence Centres" on different topics. The topic "safety, security of critical infrastructures" has been assigned to Genova in a joint public-private partnership of large and SMEs, coordinated by National Council of Research. As a further witness of the active role played by the Chamber of Commerce in the "innovation regional eco-system", Genova CCI is supporting this Centre, putting into synergy its competences in technology transfer and as EEN Network partner.

In the circular economy framework, in the Ligurian Region the Municipality of Genoa and AMIU - the Municipal Urban Health Enterprise have created in 2015 Liguria Circular, the permanent forum of circular economy in Liguria aiming to promote and manage circular economy initiatives in the Liguria territory. Private companies, individual professionals, government agencies, associations, university departments and research centres joined the Liguria Circular forum starting from 2014. The main partners of Liguria Circular are the Genova Smart city association, the Regional innovation center for Energy and Environment, TICASS - Tecnologie Innovative per il Controllo Ambientale e lo Sviluppo Sostenibile, the Interuniversity Centre for the Development of Sustainabe Product (CESISP - University of Genova) and Confindustria Genova, association representing manufacturing and service companies. The activity of the Forum is sub-divided in four circular thematic labs: food waste reduction, built environment, sustainable products, waste as a resource. Additive manufacturing and resource efficient advanced manufacturing technologies can be considered as a part of the sustainable products circ lab.

2.3. Market projections

The global market volume of AM technologies has been experiencing a steady increase during the last years and is expected to boost in the next years (Figure 9). This market volume includes the main players of the whole value chain: sales of AM systems (i.e. 3D printers), related services and materials. In the year 2023, the market is forecasted to value €7.7 billion.

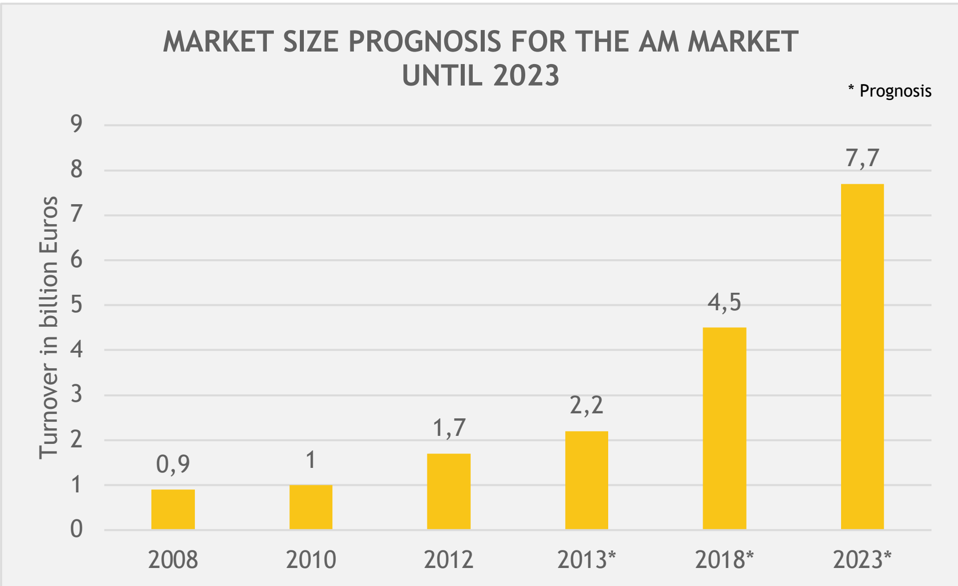

Figure 9. The trend of 3DP market and until 2023 [82].

Over the next five years, investments on AM systems are expected to increase with a growth rate of 29 percent compared to an average growth rate of 9.7 percent in traditional machines [83]. An alternative scenario forecasts that investment in 3DP will double after five years while conventional technologies will decrease by a third after 10 years [84].

Taking a look at the type of industry, the global market will be dominated by the aerospace sector (Figure 10). This sector will experience the greatest increase, with a value of around €9.59 billion in 2030. In the medical sector, an equivalent percentage increase is expected, followed by the automotive and industrial sectors with a similar increase of about 80 to 85 percent.

In Europe, the AM of car interior components, machine and airline parts, manufacturing moulds, implants and surgical planning tools, food, textiles, home decoration products and houses have been recognized as key emerging application areas relevant to European industry, although the value chains involved are still at an early stage in most of the cases.

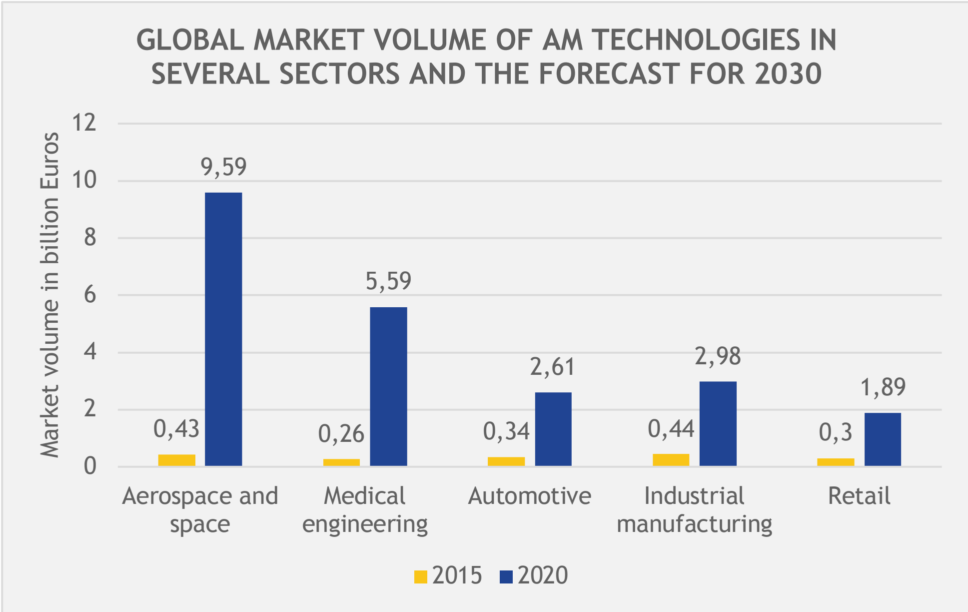

Figure 10. Global market volume of AM technologies and forecast for 2030 [85].

Thus, there is no doubt that all market projections agree on the fact that the future of manufacturing includes integrating AM into the traditional value chain in order to fully optimize and streamline the production [86]. Some experts expect that in the next one or two decades about half of all manufacturing products will be produced with 3D printers [8]. These technologies will start to increasingly dominate markets of labour intensive, complex shaped and of customized products, as it is shown in the forecast of Figure 10 [8]. Once the current barriers limiting mass production are overcome, as it will be further discussed, the current projections might end up being in some cases conservative.

As for CIRC, the projections for Europe are not less optimistic, since the technologies associated could bring an increase in GDP by 6.7 percent, and a reduction in CO_2 emissions by 25 percent by 2030 [87]. This would translate to a net economic benefit of €1.8 trillion euros by 2030 [88].

The European market is wasteful in its model of value creation disposal. In 2012, the average European used 16 metric tons of materials and only 5 percent of the original raw material value is recovered. This means that on average, Europe uses materials only once.

Employment will significantly increase by adopting CIRC measures, largely because of the lower prices expected across sectors and to the labour intensity of recycling activities and higher-skilled jobs in remanufacturing. Today, materials and components constitute 40 to 60 percent of the total cost base of manufacturing in Europe and 60 percent is imported [89]. In the CIRC scenario, the use of raw primary materials would drop as sum as 32 percent by 2030 and 53 percent by 2050 [88].

The transition to CIRC would involve considerable costs, estimated to be €108 billion at European scale (such as R&D and asset investments, stranded investments, subsidy payments to promote market penetration of new products, and public expenditure for digital infrastructure) [87]. It remains to be assessed to what extent these costs are additional relative to other development scenarios (e.g. establishing a digital single market, energy union) and to what extent they could act as a stimulus.

2.4. Market drivers and barriers

The transition to an economy that includes AM technologies in their manufacturing activities as well as CIRC principles will entail large and complex efforts associated with major opportunities, in which different drivers and barriers are the first aspects to be analysed. The next sections address these aspects at global, national, and regional level.

2.4.1. Market drivers:

By means of AM technologies, the manufacturing industry is able to increase their creativity by concentrating efforts on functionality instead of manufacturability issues, giving the capabilities for freeform fabrication. According to a recent survey (Figure 11), the main priority for using these technologies in Europe is for the acceleration of product development (25 percent), followed closely by customization (21 percent). This is in accordance with the dominating industries of aerospace and medical sectors, which are not limited by cost and economy of scale (section 2.1).

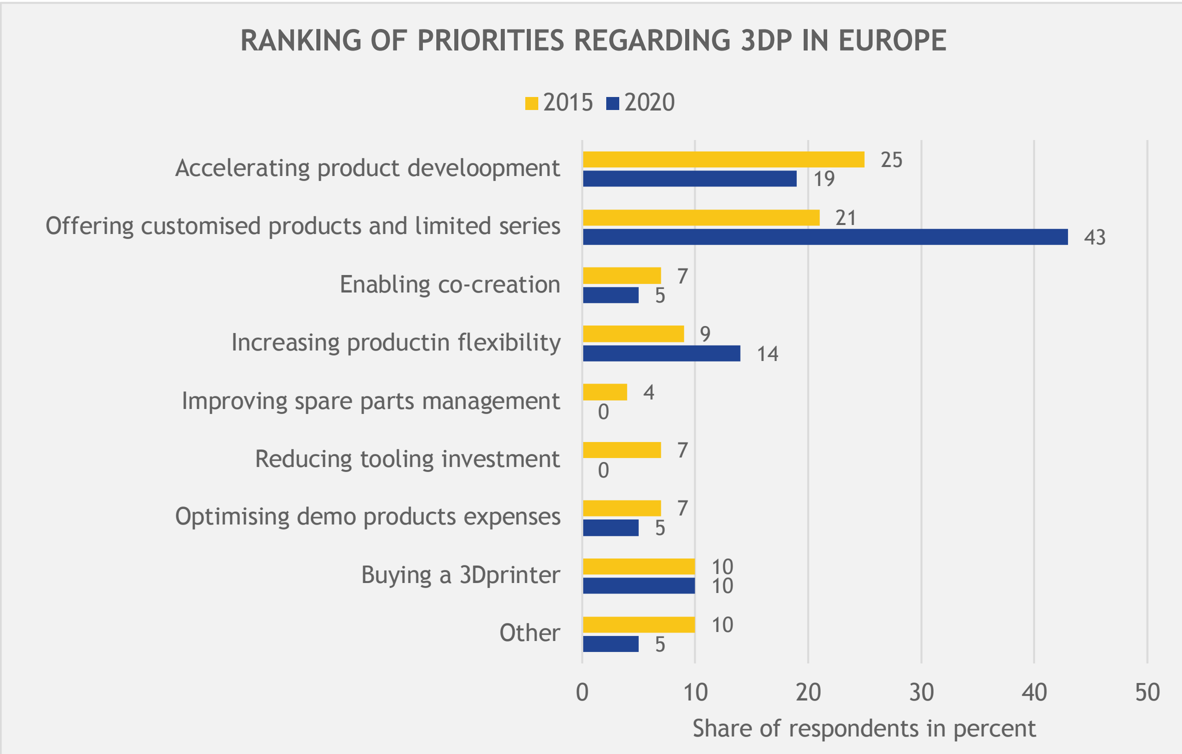

Figure 11. Current main priorities when adopting AM technologies in Europe and by 2020 [90].

These priorities answer to several drivers, which are analysed in more detail as follows [91] [92] [93]:

- **The time-to-market of a product is significantly shortened:**

Since the time for prototyping is reduced, the costs associated with this stage decrease as well (e.g. conventional prototypes made of clay are labour intensive and time consuming), which allows to accelerate product development. It is estimated that 85 to 95 percent of costs and time can be saved in the creation of prototypes with AM [84].

- **The printing of complex geometries and customized products becomes possible by the freeform fabrication capabilities:**

The construction of parts and components with a structure resembling nature forms becomes feasible, otherwise impossible to build with conventional methods. This offers the possibility to produce components with optimum designs for an enhanced performance (e.g. in the automotive and aerospace sectors this often means an increased efficiency and hence reduced CO_2 emissions).[4] Another improvement is the single construction of functionally integrated parts, which results in production processes that are more resource efficient by combining lower energy consumption and higher quality to reduce rejection rates.

- **Increased energy and resource efficiency:**

AM technologies are able to build parts and components using almost the exact amount of material needed. Thus, the waste generated is minimum. Moreover, by-products can be directly reused as a material input for production. Unlike conventional manufacturing processes (such as casting and CNC machining), these technologies are more energy efficient since the use of cutting fluids and chips is avoided. AM is most competitive when the traditional production method involves many steps, for example combining machining, laser welding and wire eroding.

- **Production is brought closer to consumer:**

The single construction of functionally integrated parts allows eliminating fixed asset tooling and assembly/joining steps, which shortens the whole value chain. This entails having less actors, stages and interactions involved. The product manufacturing is hence brought closer to consumption, in an on-demand approach, in which the need of stocking is eliminated, and inventory costs are cut-off. In this framework, revenue flow is improved as products are paid for prior to being manufactured. The interaction between local consumers and producers is also improved by the customization capabilities, in which small batch production is possible at more affordable prices. For all these reasons, transportation and logistics costs within the supply chain are reduced and hence the associated CO_2 emissions. These factors enable companies to re-shore their production, leading to a potential revival of manufacturing jobs in Europe [1].

- **Automation:**

These technologies have fewer humans involved, resulting in lower costs due to human errors and hence a greatest capability for automation and integration into Industry 4.0. Lower labour costs for assembly, coordinating processes, and transport and intermediaries also become possible.

Sustainability drivers and the role of Circular Economy:

Although AM technologies are recognized for being resource and energy efficient as commented above, there are various benefits accompanying their implementation in manufacturing [3]:

- **Product and process design:**

As commented above, the mechanical performance and durability of components and parts are improved since an optimised design becomes feasible (e.g. resembling nature forms). In many cases, this entails an enhanced performance with an increased efficiency in terms of the material & energy required (e.g. a better distribution of heat in certain components might entail an enhanced energy efficiency).

- **Material processing:**

A significant amount of energy is consumed during the refining and processing of metal ores in preparation for raw material for conventional manufacturing. The obtaining of metallic powders for powder-based AM technologies requires significantly less energy than the established processes [94].

- **Repair, remanufacturing, and maintaining:**

The ability to repair creates incentives for companies to adopt service-based business models. In-situ repair of damaged components becomes possible, extending the operational life of components.

- **Recycling:**

Closing the loop through recycling can be achieved at various stages and scales in AM. The recovery of valuable materials becomes easier in 3D printed parts since it can be planned from the early phases of design. In-situ recycling systems have the potential to be linked to AM system, diverting material from waste streams into new applications (e.g. the Multijet Fusion Systems by HP is characterised by three stations, one for recycling material). The highest value recovery possible is achieved locally during the manufacturing process when the unused material is reclaimed.

[4] Connected to the statements on page 1

There will be opportunities for SMEs operating in the waste management, materials recycling and remanufacturing sectors to benefit from the transition to CIRC. Enabling factors were identified by Arup in their report "*The Circular Economy in the Built Environment*" (2016) [95]:

- Education.
- Awareness and communication: through training, cross-industry collaborations and sector networks, case studies, information sharing.
- Policy and regulation: there is a role for governments to raise awareness, address real barriers and to overcome them and facilitate information availability in support of business.
- Technology and innovation advances.
- Collaboration among actors across the value chain.

Overall, many types of factors are driving the adoption of CIRC technologies [96]:

- Political: national and EU policies and directives;
- Economic: scarcity of raw materials & price volatility, resource efficiency;
- Social: sharing economy, collaborative consumption, urbanisation, population growth;
- Technological: digitalization, internet of things, new separation technologies, valorisation technologies
- Environmental: sustainability, climate change.

2.4.2. Drivers per region in Central Europe:

In the context of the AMiCE project, the tandem partners of the consortium (business-supporting entities and R&D partners) were consulted during several interviews in order to identify and analyse the drivers and obstacles for adopting AM and circular economy measures in their region, as a consequence of their economic situation and reality in terms of innovation. The results are described as follows.

2.4.2.1. Saxony (Germany)

Given its strong manufacturing character, the adoption in AM technologies in Saxony is strongly driven by the demands of OEMs to increase speed of manufacturing, produce lightweight components that could integrate new functionalities and properties, customisable and able to be connected to the IoT. Large corporations see in AM technologies the opportunity to redesign themselves and produce their own spare parts, decreasing their dependence on external suppliers.
Considering the main manufacturing sectors in the region, automotive and medical are seen as the most promising areas. Metal laser sintering is the predominant technology, mainly for prototyping and small batches, in which customisation is sought. The parts that are not available for retrofitting or repairing are produced through these technologies as well. Public actions or funding programs are not seen as a consequence for adopting AM technologies but more a result of a demand from OEMs, as commented above.
In the framework of CIRC, the main reasons for adopting these measures rely on the legal regulation from the EU or the national government and the potential saving of costs. Brand image and reputation is increasingly gaining importance in companies. Many companies in Saxony perceive that adopting CIRC measures will be a key aspect for keeping clients and attracting new ones. [97]

2.4.2.2. Liberec & Ustí regions (Czech Republic)

Even though the automotive industry is the most promising sector for AM technologies in the Czech Republic, others such as construction and medical applications (e.g. dental parts) are gaining importance. The SMEs that produce 3D printed parts (service bureaus or production, see Table 11 in section 3) focus on different kinds of applications but medical attracts most of the attention since it delivers the highest added value. Despite this, automotive sector suppliers are the dominant application area. For instance, the Technical University of Liberec (TUL) in the Liberec region has doubled their AM capacity in only two years, being all activities connected to the automotive sector. The same situation can be found in Usti region and the rest

of the country, although at different levels. According to partners, the main drivers are related to increasing the productivity of companies, reducing production cost, and coming up with new products into the market. The 3DP of polymers is the most used technology in the region, followed by other materials such as ceramics, glass, and special fibres. Prototyping, manufacturing of small batches, and R&D are seen as the main application areas.
According to a recent survey made by Ernst&Young, the main key benefits for the region are the lower manufacturing costs, the speed of low-turnover item production and the adaption of products to customer needs. This is in accordance with the feedback received from partners. The same survey showed that 56 percent of companies already use or plan to use AM technologies within 5 years and 38 percent of companies consider lack of know-how to be one of the greatest obstacles to introducing AM technologies [98].
The same survey showed the next figures among the companies already using AM [98]:

- 49 percent of companies say the greatest benefit of 3DP is lower manufacturing costs. Other benefits are faster production of low-turnover items (46 percent), adaption of products to customer requirements (38 percent), increased manufacturing efficiency (24 percent).
- 68 percent of companies predict 3DP will have some degree of impact on their business model.
- 72 percent of companies have plans to print from metal within 5 years.
- 64 percent of companies plan to use 3DP to manufacture products in the next 5 years.
- 73 percent of companies currently use 3DP to manufacture prototypes / for research and development purpose.
- 65 percent of companies already working with 3DP technology own their own 3D printer.

The adoption of AM technologies in the Czech Republic responds to the demand of the market rather than being a consequence of public actions or funding programs. The manufacturing companies in the country see AM as a major factor for remaining competitive, by introducing new types of products into the market or improving the existing ones.
In the framework of CIRC, the main reason for adoption is the pursue of health. The recycling industry and the recovering of raw materials from waste is already very well developed, in accordance with EU directives. The waste is separated at both household and industrial level. The bio-electronics and automotive industries are engaged in the adoption, and the environmental legislation is favourable. Since the culture of CIRC is perceived as an economical issue, it is mainly addressed by large companies, although for SMEs there is a highly dependence on the type of sector. Most of the drive comes from OEMs and customers.

2.4.2.3. Bratislava & Žilina (Slovakia)

The most important reason for companies to adopt AM technologies is the prospect of saving costs. Furthermore, increasing productivity and effectivity as well as the demand that is expressed from OEMs or clients are also driving the adoption. Slovak companies mainly use AM technologies in the prototyping stage.
One of the main drivers for CIRC could be the automotive industry since it is one of the main industries in Slovakia. An incentives framework to promote innovation among companies and academics could foster adoption as well. In this sense, innovation vouchers to financially support companies launched in 2013 already showed some success but the support scheme is very instable since the calls are open only from time to time not all year long.
Unlike other regions, in-house and industrial recycling practices are not carried out regularly for what public awareness is needed in the first place. The environmental implementation is regarded a challenge for the whole country, with poor waste management performance, low recycling rates and a strong dependence on land filling [99]. Moreover, improving water management policy is also a major concern. A combination of funding schemes on EU level and the willingness of locals to offer new services might subsequently aid to spread the adoption of CIRC practices. In order to get Slovak companies engaged in the topic, regional and national authorities should make information available and foster adoption. A major driver for the country is the rich natural environment and biodiversity.

2.4.2.4. Lower Silesia (Poland)

Wroclaw has a very strong research centre in the region focusing on AM technologies, the biggest in the country (CAMT - Centre for Advanced Manufacturing Technologies), which has fostered the adoption in the region. The centre cooperates with companies. The manufacturing industry in the region is strong, which is a general driver for AM and other advanced manufacturing technologies, being also further supported by strong academia and business organizations. Polish universities focus on AM for the aerospace sector, directly manufacturing parts and components. Fused deposition modelling (FDM) is the most widely used technology, followed by SLM, which are mainly used for prototyping and customisation for final parts.
In the framework of CIRC, although it is a regional priority, EU's directives have been the main driver for adopting measures in Polish industries. The country set a waste management regulation in 2012 to satisfy the EC and aimed for spreading waste segregation along the country and to facilitate waste recovery, recycling, and reprocessing [100]. "Green Parks of Entrepreneurship" is one of the projects implemented by the Environmental Partnership Foundation as a part of the Clean Business Program, which helps small and medium sized enterprises to introduce pro-ecological changes inside and around the company [101].

2.4.2.5. Liguria (Italy)

Due to the strong manufacturing sector in Liguria, the GDP of the region is highly dependent on industry, in which engineering and highly complex products are produced and sold at high costs (especially to aerospace and medical sectors). The AM technologies enable companies in the region to manufacture more complex parts and components that otherwise would be impossible to produce with conventional techniques. Thus, technologies such as metal laser sintering allow manufacturing steel and titanium customised parts with complex geometries.
Since the preservation of natural capital is one of the main levers of economic development in Italy, CIRC has been recognized as the strategy for passing from "necessity" (efficiency in the use of resources, rational management of waste) to an "opportunity", by designing products in order to use what is now destined to be waste as a resource for a new production cycle. This perception has been gaining attention among industry in the region, which see that resource lifecycle management and product service system allow recapturing value in materials for saving costs. The Industry 4.0 Plan adopted by the Italian Government through their RIS3 strategy could be an opportunity to accompany the transition to a circular economy, both by supporting investments in research and development, and innovative technologies, and by encouraging the diffusion of systems based on collection and analysis of large amounts of data.
One of the instruments for implementing policies on CIRC is the National Action Plan on Sustainable Production and Consumption (PAN SCP). The plan is formed by 6 areas of intervention (SMEs, production chains and districts, agriculture and agro-industrial chains, constructions and living, tourism, organized distribution, sustainable consumption and behaviour) [102]. Specific lines of action for each area are also provided in order to integrate the various aspects of sustainability in the whole value chain: [102]

- Elimination of environmental impact incompatible with the self-regenerative capacity of natural systems;
- Counteract climate change;
- Closing the material production-consumption cycles;
- Elimination of waste (energy, water, food);
- Increasing efficiency in the use of resources, and
- Reducing waste and pollution.

The Ministry for the Environment and for the Protection of the Territory and the Sea set up suitable indicators to measure and monitor the circularity of the economy and the efficient use of resources at macro-, meso- and micro-level [102].

2.4.2.6. Catalonia (Spain)

This region will be also subjected to analysis since it is part of the consortium and exerts the role of expert, having successfully adopted AM technologies in their industrial ecosystem during the last years. Nowadays is considered an international and recognized region to which the other partners could look up to.
Boasted by its solid industrial base and diversified industrial ecosystem, the region is becoming one of the best-equipped industrial application technology hubs in the world. This transition has been fostered by global companies such as Hewlett Packard with its global 3DP business centralized in the city of Sant Cugat and RICOH and REWNISHAW [103].
In general, the main drivers for adopting AM technologies in Catalonia were of economic nature. Other factors are related production – namely the optimised use of resources and energy and the opportunity to be able to produce customised products with less time effort. Technological improvements like lightweighting and more complex structures or manufacturing of products with less components can furthermore be seen as drivers for AM. The design stages in AM can help improving the technologies downstream in terms of process and the introduction of products into the market is eased, avoiding the need of investment in massive production tools (product development). The medical sector, with a strong base in the region, perceives multi-material printing as one of the main advantages. There is a trend in which printable devices made by these technologies will be able to deliver customized doses, this technological improvement is the second drive for adoption.
AM technologies can improve materials, products, and processes with a greater efficiency. The time for building is currently shorter in some cases, and in the future, this is expected to be improved. The role of large companies in adopting AM has driving many SMEs to start adopting these technologies as well, having an encouraging effect upon others. The Catalan market includes big players such as Siemens, General Electric, General Motors, Airbus and Boeing which are heavily investing in the R&D of AM technologies. The commitment of these big players has accelerated adoption as well as the growth of consultancies that offer support for analysis of new business opportunities. Back in 2007 there were around 10 companies working with AM and nowadays there are counted by hundreds. Furthermore, the amount of software providers and service bureaus increased immensely as a consequence of market stimulation. Ten years ago, there were 3 service providers, and now there more than 20 companies, some of them very small and other medium, employing about 20 workers. They focus mainly on local companies (Spanish and some European).

2.4.3. Market barriers

Despite the increase of AM technologies in some market segments during the last years, such as in the aerospace and health sectors, these technologies are facing several barriers that are impeding their full deployment. The biggest barriers come from the legal aspects related to the quality analysis of the products and the regulatory affairs bodies. Engineers and designers often perceive AM technologies only for rapid prototyping and not suitable for direct component and product manufacture. Thus, lack of knowledge and ‘cold feet’ are regarded to be the most important hurdles for their adoption. There are other barriers which can be economic, technological, and environmental [8] [92]:

Economic barriers:

- Required investment and operating costs and services are still too high, especially for manufacturing goods that are not characterised by customisation and small batch size production.
- The cost of raw materials is high since the market is characterised by a few suppliers with monopoly pricing power.
- The Intellectual Property might be compromised since AM relies on digital manufacturing and data exchange might be subjected to illegal copies and unwanted exchange of information.
- SMEs often have problems with the access to finance, administrative burdens, lack of technical skills and greater vulnerability to the supply and demand of products and services.

Technological barriers:

- The speed of AM processes is still relatively low, and high-speed production is not feasible for the moment.
- CAD tools lack of more complex design possibilities and the possibilities of AM are far for being exhausted.
- CAD tools need to be upgraded in order to be more user-friendly.
- The printing area is limited by size in most of the technologies, with restriction in multi-colour and multi-material printing.
- Quality of 3D printed products falls short in some cases, compromising user acceptance.
- The current technologies cannot embed functionality into components and product.
- Lack of skilled designers and engineers.

Sustainability barriers and the role of CIRC:
In the framework of CIRC measures, the uptake of remanufacturing also faces several barriers, such as the lack of technical information on third party products, the lack of clarity over what remanufacturing entails and whether is considered 'waste processing' or not, together with the poor design approach that currently exists for remanufacturing [2]. Other barriers for adopting AM are listed as follows:

- AM technologies are energy intensive, which are directly related to environmental impacts. In case this energy demand is covered with fossil fuels, the ecological footprint becomes significant.
- During 3DP fine dust pollution and nano-particles are emitted.
- Even though waste generated from the raw materials is greatly reduced, most technologies use material for supporting the structures, which ends up being a waste if it's not recycled and/or recovered.
- Some of the materials used in AM contain volatile organic compounds (VOCs), solvents, and the process might generate waste water (e.g. post-processing and finishing).
- There are still high requirements on the material quality and purity, which limit the number of by-products that can be recycled.

The transition to CIRC requires setting a new mind-set in cross-industry and technological collaboration in the whole value chain, with new governance models and regulation schemes.
The wide application of these technologies in manufacturing activities is particularly affected by the still not favourable economies of scale and the limited economic viability for mass production. However, recent technological advances indicate that high speed and thus mass production will eventually become a reality. A detailed analysis of the current manufacturing cost and evaluation of expected improvements reveals a cost reduction potential of about 60 percent in the next 5 years and another 30 percent within the next 10 years [104].

2.4.4. Barriers per region in Central Europe:

Some of the drivers for adopting these technologies entail also barriers and obstacles, since many actors and participants in the whole value chain might end up being affected. For example, the local 3DP of components and parts could affect export flows worldwide, especially in the automotive sector. In this sense, Germany is the originator of five of the ten largest bilateral automotive flows worldwide, with the UK, France, the US and China as its largest export destinations. This type of scenarios and others affecting the regions in Central Europe are analysed in the next sections.

2.4.4.1. Saxony (Germany)

The companies in the region face several financial problems when trying to adopt new technologies and, in many cases, they don't know how AM technologies could fit into their industrial activity. The traditional mindset of engineering in many of these companies has to be changed before adoption starts to be taken under consideration.

Table 6 Specific (regional) barriers for AM adoption per sector in Saxony

Sector	Specific (regional) barriers
Automotive & general	▪ Structure of supply chain of the OEM (Original Equipment Manufacturer) ▪ Certification of processes - Qualitative and legal requirements ▪ Printing processes are reworked by the companies to fulfil their requirements of the manufactured product ▪ Digital process needs to be designed continuously - Challenges in ERP interfaces ▪ Product manufactured in diamond - Small batch production ▪ Companies hope for "just-in time" production and use of several materials in one process ▪ Specifications regarding certificates are missing - No overview on who or what needs to be certified
Mechanical Engineering & general	▪ Vision and technological possibilities must be connected ▪ Lack of technological know how ▪ Material waste in general and within the support structure ▪ Monitoring/ Maintenance contracts of machines - e.g. FDM technology has higher requirements than SLS processes ▪ Downstream working steps/ processes – time requirements ▪ Health risks caused by micro-particles
Electrical & Electronics	▪ Current technology can just produce novel forms and cannot embed micro ▪ electronics
Medical	▪ The same like general part
Aerospace & general	▪ Political challenges - clear structure of requirements are hard to break through ▪ Process speed - 3D print needs longer within different working steps ▪ Qualitative comparable end product to conventional technologies ▪ Precision/ repeatability ▪ Availability of materials ▪ Limitation of material/ colour variability ▪ Introduction of new products - political/ legal frame - monopoly position
Textile	▪ The same like general part

The barriers for the broad adoption of CIRC principles can be usually found in a lack of legislation: [105]

- existing legislations that lead to the on-going focus on virgin raw materials due to the lack of pricing in of externalities;
- legislations that hinder the uptake of recycling markets or the development of markets for secondary raw materials;
- legislations that make waste generation preferable compared to industrial symbiosis, internal loops or resource efficient production.

2.4.4.2. Liberec & Usti regions (Czech Republic)

The main obstacles that pose a threat to a long-term positive development of the Czech industry in terms of innovation is the lack of human resources in innovative sectors such as in the field of advanced manufacturing. In many cases, highly educated people leave the country and many Universities are suffering from lacking interest of students in technical fields/ engineering. Many students put their focus more on business (management) and social studies. Companies that want to innovate and therefore need to employ

young and skilled professionals are pressured by that development. Furthermore, the quality of education is varying a lot. Many small private universities give diplomas for a low price showing low quality.
According to a recent survey made by the University of Prague and Ernst&Young, the main barrier of adoption in the Czech Republic is the lack of know-how (38 percent), followed by technological barriers/unsuitable material (35 percent), high investment costs (28 percent), and high operating costs (20 percent) [98]. The latter affects mainly small companies. This is where regional open workshops (service providers specialized in AM), mostly located near technical universities, step in. [53].
As it is the understanding of the regional tandem of the AMiCE consortium the following specific challenges can be mentioned for the predefined sectors.

Table 7 Specific (regional) barriers for AM adoption per sector in Liberec & Ustí

Sector	Specific (regional) barriers
Automotive	▪ Cost (production) ▪ Productivity (slow productivity) ▪ Merging (dissolving) of SME with large companies after reaching specific milestone in their relevant industry
Mechanical Engineering	▪ Uncertainty about mechanical properties of the products and their performance ▪ Durability / lifetime of the products ▪ Lack of knowledge about the available opportunities/solution
Electrical & Electronic	▪ Lack of suitable (conductive) materials in the AM ▪ Variety of materials
Medical	▪ Technical (mechanical, chemical, bio-compatibility) ▪ Long time required to certify these products for use with health-related

As for adopting CIRC measures, the main barriers are at policy level. The absence of targeted funding for eco-innovation and CIRC prevent the fast adoption of these concepts in a broader sense. Other barriers include the following aspects [49] [51]:

- Weak outcomes and results of Czech R&D activities.
- High dependence of the Czech Republic's economic development on the activities of foreign-owned companies that only use the Czech Republic as a manufacturing base, strategic decisions for future investments are made outside of the Czech Republic - especially SMEs are affected.
- R&D policy and funding framework remains fragmented and R&D funding is stagnating.
- Limited cooperation between academia and business.
- Low level of entrepreneurship and inadequate performance of the endogenous entrepreneurial sector.
- Lacking human resources in R&D.
- Lack of legal enforcement and incentives.

2.4.4.3. Bratislava & Žilina (Slovakia)

In terms of innovation as a whole, Slovak companies face different challenges [106]:

- Attracting new customers.
- Introduction of new product(s) to the market.
- Motivation of employees for innovations.
- Development of the company´s innovation management model.
- Development of collaboration with universities and Slovak Academy of Sciences.
- Establishment of innovation workshops.
- Development of a specific innovation room for generation of new ideas.
- Establishment of own R&D / technology centre.
- Elimination of complexity in relations with suppliers.

- Development of collaboration with start-ups.

Specifically, for adopting AM technologies, several barriers have been identified [106]:

- Different levels of preparation of Slovak companies for introduction of intelligent industry to practical production, which results in a non-homogeneous ecosystem.
- The potential impact on the further development of human resources is unknown.
- As in other regions, companies face financing and investment issues.
- Some universities and research institutions are not flexible to market changes.
- Lack of skilled workforce.

The main barriers to CIRC that were identified are the following [107]:

- Economic and financial barriers i.e. a lack of financial resources and high costs of innovation
- Lack of market demand for innovation and low level of public awareness on this topic
- Regulatory and policy framework for innovation, which is highly fragmented and insufficient to promote environmentally friendly behaviour
- Almost non-existent cooperation between academia and industry due to the fact that industry has a low level of confidence in the quality of services offered by universities and research institutes

2.4.4.4. Lower Silesia (Poland)

The main barriers for adopting AM technologies are economic. Since unemployment in the region is very low, companies found difficulties in hiring skilled personnel. The SMEs, which represent a large share of manufacturing industries, focus mainly on their everyday business and can't hardly put resources on the process of adopting new technologies. Poland has a high dependency on the German industry and also on the German innovation process.

Table 8 Specific (regional) barriers for AM adoption per sector in Lower Silesia

Sector	Specific (regional) barriers
Automotive	▪ Speed of AM process ▪ Limited printing area prevents the manufacturing of some parts ▪ Acceptance of products by costumers
Automotive/ Mechanical Engineering/ Electrical & Electronic	▪ Lack of technical know-how ▪ Traditional mindset of designers and engineers ▪ (Non-existent) cooperation between academia and industry ▪ Lack of data libraries ▪ Lack of human resources in innovative sectors ▪ Designs may be easily changed/ tailored by manufacturers due to 3D scanning technologies – design protection legislation has to change ▪ Difficulty to attract new customers ▪ High operating costs
Medical	▪ Lack of data libraries ▪ Availability of materials ▪ Restrictions in multi-colour and multi-material printing ▪ Acceptance of products (e.g. 3D-printed implants, organs) ▪ Lack of standards and regulations
Aerospace	▪ Limited printing area prevents the manufacturing of some parts ▪ Acceptance of products by costumers ▪ Restrictions in multi-material printing ▪ Traditional mindset of designers and engineers ▪ (Non-existent) cooperation between academia and industry ▪ Availability of materials
Mining [108]	▪ Product safety and quality must be proven.

	▪ International and local suppliers must have the capability and desire to enable in-situ production. ▪ Lower cost and/or higher speed of production necessary. ▪ AM remains relatively unproven for precision-engineered parts. ▪ Metal and multi-material printing must reach production speed.
General	Business-related ▪ Lacking knowledge on how AM can fit to industrial activity – companies rely on pilot demonstrators ▪ Human-robot cooperation and cyber-security ▪ Universities and research institutions are not flexible to market changes ▪ Varying quality of education ▪ SME´s vulnerability to supply & demand of products & services ▪ Introduction of new products to the market ▪ High investment cost/ lack of cash-flow ▪ Lack of knowledge on funding schemes Technology related ▪ Surface quality of product ▪ Accuracy of product ▪ Consistency of quality and reliability of product

Although CIRC is a regional priority there are still many obstacles to overcome. With an Eco-Innovation Score of 59, the country ranks at position 26 among all other EU countries. The high cost of implementation, difficult access to capital, uncertain return on investment and the weak system of economic and fiscal incentives encouraging eco-innovation are the main barriers. Furthermore, insufficient knowledge on potential economic benefits from the implementation of CIRC prevent the broad adoption. National sources that drive the implementation of eco-innovative ideas apart from EU funding include operational and national priority programs, as well as national regulations [109].

2.4.4.5. Liguria (Italy)

There is a significant lack of awareness and know-how in the companies of the region when trying to adopt AM technologies. Particularly for micro-companies, they are not aware on the financing opportunities. As a result of the lack of awareness and know-how, companies cannot find a business model that fits their needs and strongly rely on pilot demonstrators in order to understand how the technology would fit their needs. Specific barriers for the sectors under investigation in Liguria have been identified by partners:

Table 9 Specific (regional) barriers for AM adoption per sector in Liguria

Sector	Specific (regional) barriers
Medical	▪ Lack of technical know-how ▪ Availability of materials ▪ Acceptance of products (e.g. implants)
Mechanical Engineering	▪ Traditional mindset of designers and engineers ▪ Weak outcome of R&D activities ▪ Availability of materials ▪ Accuracy of product
Aerospace and Energy	▪ Speed of AM process
Marine	▪ Lack of technical know-how ▪ Varying quality of education ▪ User-friendliness of CAD tools/ lack of complexity of CAD tools ▪ Limited printing area prevents the manufacturing of some designs ▪ Surface quality of product

	▪ Accuracy of product
Cross Field	▪ (Non-existent) cooperation between academia and industry ▪ Lacking/ slow development of collaborations with start-ups ▪ Universities and research institutions are not flexible to market changes ▪ Lack of data libraries ▪ Lack of human resources in innovative sectors ▪ Lack of interest of students in technical fields ▪ Vulnerable to supply & demand of products and services ▪ Market knowledge: Introduction of new products to the market ▪ Lack of knowledge on funding schemes ▪ Rapid obsolescence: lack of knowledge of services IPR ▪ Many designs won't be covered by patents ▪ Potential for a large number of new ▪ infringing parties ▪ Border detention is less effective since products don't cross borders ▪ Designs may be easily changed/ tailored by manufacturers due to 3D scanning technologies – design protection legislation has to change ▪ Encryption efforts make detection of potential infringement difficult ▪ High costs for patents

The following are the main barriers and main opportunities for the transition to a CIRC for the Commission for Productive Activities. One of the main barriers is an incomplete legislative framework and, in some cases, contradictory. In fact, it is evident that an essential precondition for industrial investments is the existence of a stable, clear regulatory framework and consistency.
The main critical issues concern:

- The conflict still unresolved between the Reach Regulation and the relevant legislation on waste recovery;
- The clear demarcation between waste and by-products. A renewed legislation constitutes an element essential for the launch of industrial initiatives based on the re-use of materials which at present are considered waste;
- The legislation concerning the End of Waste.

The following issues constitute further obstacles to the affirmation of a CIRC:

- The low diffusion of the culture of eco-design, a key element of the development of CIRC, as it is able to generate on one side strong demand for secondary raw materials, on the other hand to project on the whole life cycle of future products the positive effects of CIRC.
- The lack of knowledge of the contribution that the application of the CIRC is strongly influenced by the identification and quantification and therefore prevention of the processes that directly and/or indirectly create accumulations of matter and/or energy.
- Low diffusion of companies specialized in energy saving services (Energy Service Company or ESCo), to be connected also with the scarce supply training in this sector;
- The theme of value chains is particularly delicate, especially in the sectors not yet structured or for specific types of waste/by-products (e.g. waste Agribusinesses). In this sense, the missed matching between supply and demand is highlighted as a problem, resulting in a waste of potential.
- Financial/economic aspects: In particular in relation to the building and infrastructure sectors, we highlight the significant costs (especially initial) associated to the equipment and technologies necessary for the reuse interventions of the selective demolition materials for in-situ transformation of various materials.

- The difficulty in using economic resources: access to finance by companies and institutions must be facilitated; to this extent, it is necessary to make the reference scenario clearer and more stable.
- Scarcity of culture, collaboration and knowledge: a country like Italy, based on small and medium-sized businesses must work hard on networks and on the creation of collaborations and transparency of information.
- Difficulty, given the rigidity of procurement rules, to develop forms of local contracts for the maintenance of watercourses, roads, etc. with payment mainly in kind (who carries out the maintenance repays his work with the use of wood material that derives from cleaning).

Other barriers are represented by consumption patterns:
- Purchase choices not attentive to the quality of the products and their traceability but also conditioned by the lowest price;
- Consolidated methods of not repairing products but replacing them with new ones;
- Lack of propensity to consider products as shareable services;
- Poor exploitation and quantification of the economic return linked to the overview that characterizes the CIRC chain.
- In terms of opportunities concerning the transition to CIRC, the possibility to create new supply chains or to integrate existing ones with the occasion to stimulate the development of emerging industries with high growth potential is highlighted.

2.4.4.6. Catalonia (Spain)

The adoption of CIRC principles has not been deployed as much as AM technologies, although great advances have been made during the last years. The Catalan government launched "*Catalunya Circular*" on the 9th of May 2018 in Barcelona. This initiative has already gathered around 20 member organizations. Its aim is to become a central point of reference for CIRC in Catalonia. The main functions of Catalunya Circular include the formation of a collaborative structure, exchange of information on funding and opportunities, generate knowledge, and evaluate the progress in the region
According to partners, the mainstream adoption of CIRC measures in the region is facing several barriers, in which the following aspects are included:
- SMEs are lacking knowledge about the existence of certain funding programs.
- Co-financing is very limited.
- SMEs usually don't have enough staff to justify the effort of personnel to learn about CIRC measures and how to implement them.
- In case SMEs use funding for certain small-scale projects, when it comes to the implementation of the results after the project is completed, they found that the additional funding is not available.

In general, CIRC measures are not directly related to the core business of SMEs. In most occasions, SMEs are only willing to invest in CIRC when the solution is directly linked to their core business. This raises the need of having incentives for co-finance implementation. Large companies have enough resources to overcome these obstacles and can make commitments easier.
Nowadays, principles of CIRC are not included in any legislation (neither national nor regional).

3. Ecosystem of key players

Even though the development of AM technologies is becoming increasingly more widespread, it is still concentrated in specific regions around the world, as it is shown in Figure 12 for **all kinds of players**.

REGION	KEY PLAYERS OF THE AM COMMUNITY	
United States	▪ ExOne ▪ Stratasys ▪ Protolabs	▪ 3D Systems ▪ HP ▪
Central Europe	▪ Renishaw ▪ Materialise ▪ Conceptlaser	▪ Realizer ▪ Fraunhofer ▪ EOS
Japan	▪ OPMLab	▪ Matsuura
Catalonia	▪ CIM-UPC ▪ Eurecat ▪ Avinent	▪ Leitat ▪ Renishaw ▪ Ricoh

Figure 12. The main hubs for AM development [22].

The main key players in the United States, as presented in Figure 12, focus their activity in developing AM systems (3D printers), except for Protolabs, which focuses on rapid prototyping services. All manufacturers of 3D printers also relate their activities to material supply and development. In Europe, manufacturers of AM systems are also key in the technology development, as in the case of Renishaw, Realizer, EOS, and Conceptlaser. Materialise focuses its activities on prototyping and knowledge services, the latter being also offered by Fraunhofer. In Japan, both OPMLab and Matsuura offer 3D printers based on laser sintering. As for Catalonia, all key players, except for Renishaw, are knowledge and service providers.
The most widely used technologies and their relative shares are shown in Figure 13, in which the results of a global survey from 2018 are presented as the proportion of survey participants per type of technology.

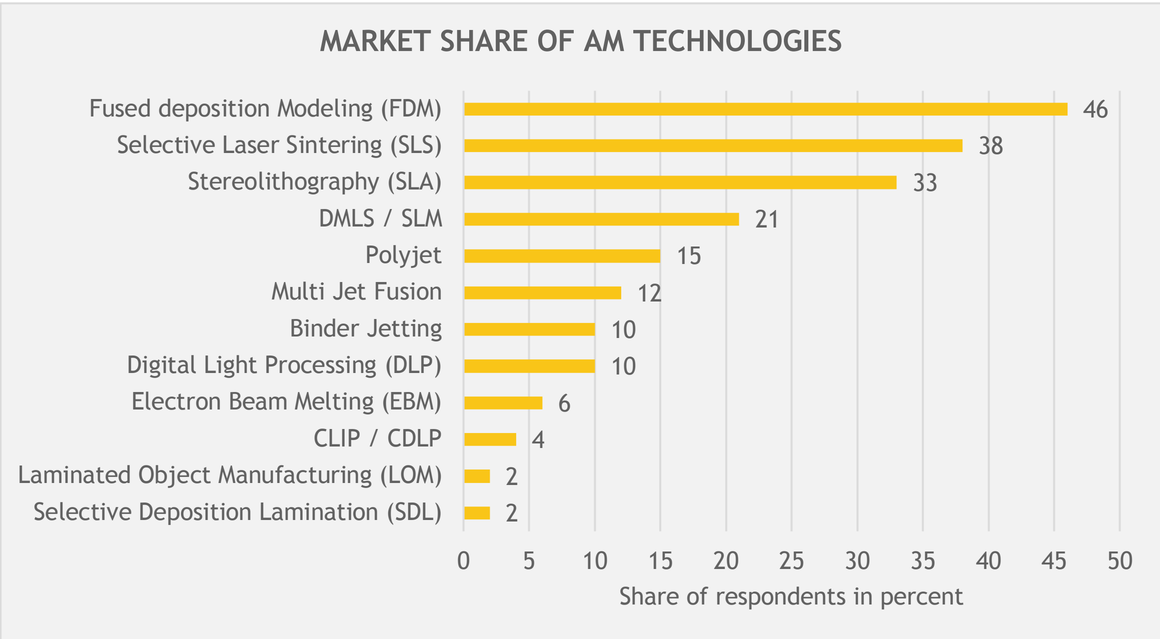

Figure 13. Market share of AM technologies [110] .

Fused deposition modelling (FDM) was the most popular technology among participants (46 percent), followed by selective laser sintering (SLS) and stereolithography (SLA), which presented 38 percent and 36 percent respectively. FDM is mostly used for product development, prototyping and manufacturing processes and is known to be popular in different types of companies, from automotive (BMW, Hyundai, Lamborghini) to consumer goods manufacturing (Black and Decker, Dial, Nestle). These results are in accordance with the main applications shown in Figure 3. Moreover, FDM printers are among the cheapest options for companies that are planning to adapt these technologies in their business activity. As for SLS, it is especially suitable for industries that need only small batches of printed components in high quality materials or prototyping, such as in the aerospace industry (e.g. 3D printed titanium inserts for use in spacecraft). AM has made a breakthrough in these sectors, by enabling aerospace companies to create complex components previously impossible with traditional techniques. As for SLA, it is the oldest technique and is recognized for being especially suitable for prototyping in different kind of industries, from medical to manufacturing, in which in some cases the final product can be built as well.

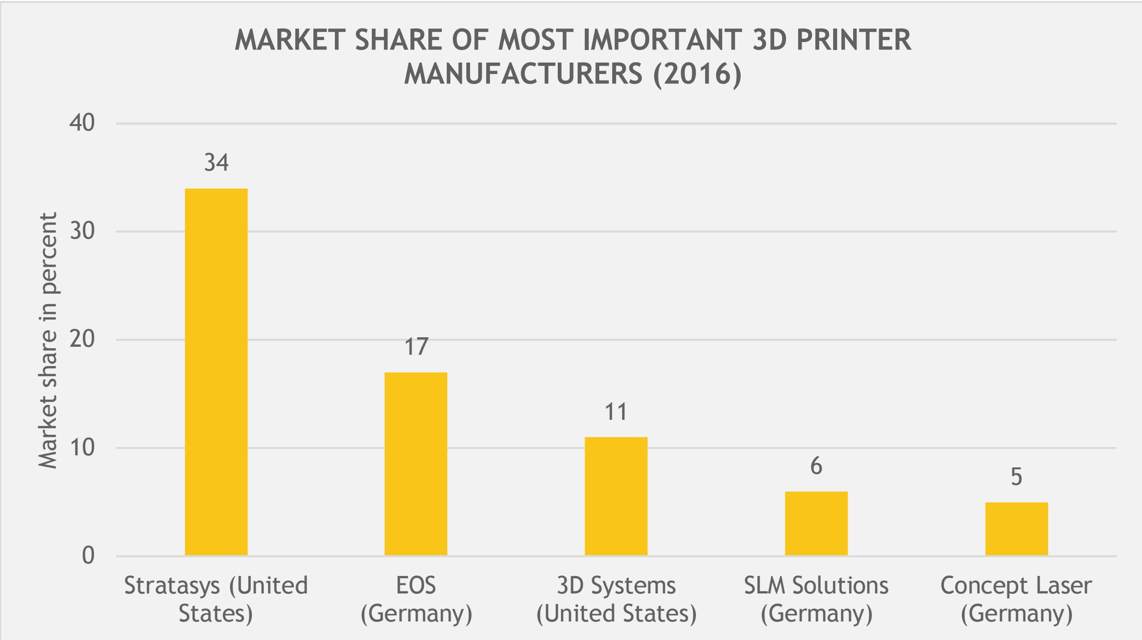

Figure 14. Market share of manufacturers of 3DP systems as by 2016 [111].

There are several key players from the whole value chain, which can be integrated by 5 areas (Table 10)

Table 10. Main actors of the AM value chain [104].

AREA OF THE VALUE CHAIN	DESCRIPTION	KEY PLAYERS
Material providers	It includes metal powder (e.g. steel, titanium alloys) for powder-based technologies (e.g. PBF, SLS) but also polymers such as polyamide (PA11, PA12) for other technologies (e.g. SLM). Photopolymer resins for SLA are also included in this category. Although input materials were usually sold by systems providers, several independent manufacturers have appeared in Europe, China, and the United States, fostered by the expiration of patents and the sought of new properties.	▪ Höganäs ▪ TLS Technik ▪ Sandvik ▪ EOS ▪ Arcam ▪ Solvay ▪ Concept Laser ▪ ExOne, Renishaw
Manufacturers of 3DP systems	They have the greatest range of activities since they can not only provide the AM machines and the materials needed, but also technical consulting. They have the greatest range of activities since they can not only provide the AM machines and the materials needed, but also software and technical consulting. They are characterized by a low level of vertical integration. The supplier base for AM machines is dominated by German suppliers. [112] The market share of the main manufacturers is shown in Figure 14. As it can be seen, Stratasys has the highest share of market with 34 percent followed by the German manufacturer EOS with 17 percent and SLM Solutions with 6 percent. The main technologies of Stratasys are FDM and PolyJet, which is in accordance with the results shown in Figure 13.	▪ 3D Systems (Market cap of $1.4 billion, the company covers with its products the sectors of manufacturing, design and engineering, 3D scanning, and healthcare). ▪ ExOne (Market cap of $103.69 million, ExOne's printers range from production printers, prototyping printers, and research and education printers based on binder jetting technology). ▪ HP Inc. (Market cap of $36.14 billion, machines are based on Multi Jet Fusion technology for polymers and is expecting to enter the 3DP metal market). ▪ Nano Dimension (Market cap of $26.63 million, focuses on 3D electronics printing and nanotechnology-based ink products using their DragonFly 2020 3D printer). ▪ Stratasys (Market cap of $1.07 billion, key patents in FDM, Polyjet and WMD). ▪ SLM Solutions group AG (Market cap of EU $624.9 million, focus is on industrial design and rapid manufacturing while producing and distributing SLM systems).

		▪ Voxeljet (Market cap of $66.22 million, manufacturer of 3DP systems for industrial applications mainly in powder binder jetting). ▪ Sisma (IT, their AM machines are applicable to different sectors, but specialize in jewellery). ▪ CONCEPTLASER (DE, Supplier of machines with different kinds of metals).
Software developers	Among software developers, a difference is made between process control and enhancement). The first one is usually provided by the manufacturers of AM machines while the second one might be offered by specialized companies for support generation and design optimisation (3D modelling software, slicers & 3D Printer Hosts).	The main key players for process control software are those for AM systems while those for process enhancement (from modelling to sculpting and customising) there are various companies offering tools for 3D modelling software: ▪ 3D Slash, TinkerCAD, FreeCAD,SketchUP, 123Design, Blender, SolidWorks And for slicer & 3D Printer Hosts: ▪ NetFabb, Repetier, Simplify3D, Slic3r, Ultimaker Cura Currently there are several options in the market for software solutions.
Knowledge & service providers	It aims at giving support to end customers and it can be carried out by specialized research centres, systems manufacturers, software developers and/or 3DP bureaus.	▪ Materialise NV (Market cap of $588.26 million, provides software solutions and 3DP services to the industry). ▪ 3d Systems, Sculpteo, Stratasys, 3D Hubs, HP, GE, Markforged, GPI Prototype & Manufacturing Service, Voodoo manufacturing, Groupe George, Voxel8, Wiivv wearables
Production	It might be carried out by large OEMs, contract manufacturer/ service provider and specialized part manufacturer. It is not normally done by the manufacturers of 3DP systems.	▪ Organovo (Market cap of $26.63 million, it uses 3D bioprinting technology for 3DP functional human tissues in close collaboration with biopharmaceutical companies). ▪ ProtoLabs (Market cap of $3.22 billion, specialized in rapid prototyping using SLA, SLS, and DMLS. Is the leader in assisting developers, designers, and engineers towards moving from prototyping to low-volume production)

End users	Industries from the sectors of automotive and motorcycle; machinery, metallurgy and capital goods; healthcare and medical equipment; pharmaceutical; construction; food; circular economy; fashion; home.	From big corporations to small start-ups, plenty companies are currently using AM technologies: ▪ General Electric, Boeing, Ford, Nike, American Pearl, DIY Rockets, Hasbro, Hershey's, MakieLab, Matter.io

In Central Europe, the key players (according to AMiCE partners input) are distributed unevenly (Table 11):

Table 11 Key Players of AM technologies in Central Europe.

AREA OF THE VALUE CHAIN	SAXONY (DE)	CZECH REPUBLIC	SLOVAKIA	LIGURIA (IT)	LOWER SILESIA (PL)
Material providers	▪ GS-Pro GmbH	▪ Protocom s.r.o.	▪ 3Dimenzia & Polymer Institute of SAS ▪ STU Bratislava		▪ 2B3D Advanced 3dimensional technology solutions ▪ 3LIAN
Manufacturers of 3DP systems	▪ EOS ▪ facts42morrow GmbH	▪ Prusa Research ▪ Protocom s.r.o.	▪ 3Dimenzia		▪ HBOT 3D ▪ 3LIAN
Software developers	▪ PROCIM Xperts GmbH ▪ Symate GmbH ▪ Casonex GmBH ▪ Monkey Works	▪ Materialise ▪ Protocom s.r.o.			▪ 3YOURMIND
Knowledge & service providers	▪ Symate GmbH ▪ Berufsakademie Sachsen ▪ Staatliche Studienakademie Bautzen	▪ Materialise ▪ Protocom s.r.o.	▪ FabLab ▪ Creative Point ▪ LAB.café	▪ Astrati Genova ▪ Superfici La Spezia ▪ Lab2share Chiavari	▪ 3LIAN ▪ Materialise

	▪ Fraunhofer-Kunststoffzentrum Oberlausitz ▪ POLYSAX ▪ Bildungszentrum Kunststoffe GmbH			▪ Puntoexedesign ▪ Italian Institute of Welding (GeAM joint lab) ▪ FabLab ▪ IIT	
Production	▪ Casonex GmbH ▪ NRU GmbH ▪ formKONZEPT Sporbert ▪ 3D MicroPrint GmbH ▪ IdeeGO GmbH ▪ third-layer GmbH ▪ DAVOSCAN GmbH ▪ Der SL PROFI ▪ Kunz Engineering GmbH ▪ soft trim seating sts GmbH ▪ Rapidobject GmbH ▪ PTZ-Prototypenzentrum GmbH ▪ Ingenieur-Büro für Maschinenbau Wolfgang Anders ▪ VG Kunststofftechnik GmbH	▪ Protocom s.r.o.	▪ Volkswagen ▪ Tvaroch ▪ Biovoxel ▪ CEIT Biomedical	▪ Ansaldo Energia ▪ Superfici La Spezia ▪ Lab2share Chiavari ▪ Italian Institute of Welding (GeAM joint lab) ▪ IIT	▪ 3dl.tech Sp. z o.o ▪ 2B3D Advanced 3dimensional technology solutions ▪ 01Prototyp ▪ 3DFactor ▪ 3LIAN ▪ LTS Poland ▪ Strefa usług 3D ▪ Materialise
End users	▪ Monkey Works ▪ SEs Solutions GmbH ▪ Siemens AG, Division Power and Gas - Turbinenwerk Görlitz ▪ Städtisches Klinikum Görlitz	▪ Škoda auto ▪ eta ▪ AEG ▪ BMW ▪ Vaillant	▪ CEIT Biomedical ▪ KINAZO DESIGN ▪ Anima Technika ▪ Volkswagen	▪ Ansaldo Energia ▪ Esaote ▪ Spes Medica ▪ IIS ▪ IIT	▪ Autoliv ▪ Bosch ▪ Whirlpool ▪ UTC

- Wirbelsäulenzentrum Ostsachsen
- Sachsen Dental

4. Forthcoming added value applications

According to experts, the greatest potential for further development and use of AM technologies at a global scale lies in the areas of aerospace (including defence), medical and health devices, automotive, robotics, drone, IoT devices and the mould industry (Figure 15)**Error! Reference source not found.** [84]. This is accordance with the market projections presented in the past sections, in which **aerospace and health industries** have the greatest weight of potential, especially at the short term. Both industries are less limited by cost and mass-production, and the customization capabilities of the freeform fabrication allows producing parts and components whose performance justifies their currently added cost.

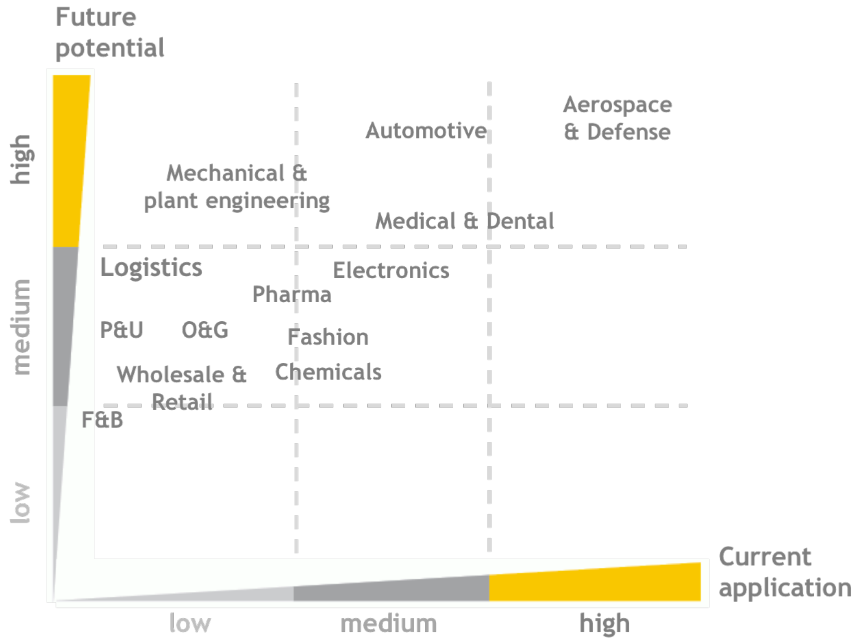

Figure 15. Current application and future potential of AM by type of industry [113].

The cost development in additive metal production worldwide, including both the direct and indirect costs, is expected to decrease to 1.1€/cm^3 in 2023 (Figure 16). [114] According to the source, the celerity of the "printing process", purchase cost of the machine, share of machine monitoring, machine utilization, costs for the raw material (metal powder) as well as the post-processing effort are all going to be improved in order to make this happen. This is of special relevance to Europe since it's the current leader in metal AM. This forecast shows that industries would be able to overcome in many cases the economic barriers that are currently presented in many sectors and which are impeding mainstream adoption. This aspect, together with customisation, are believed to completely disrupt traditional manufacturing in several industry sectors in Europe.

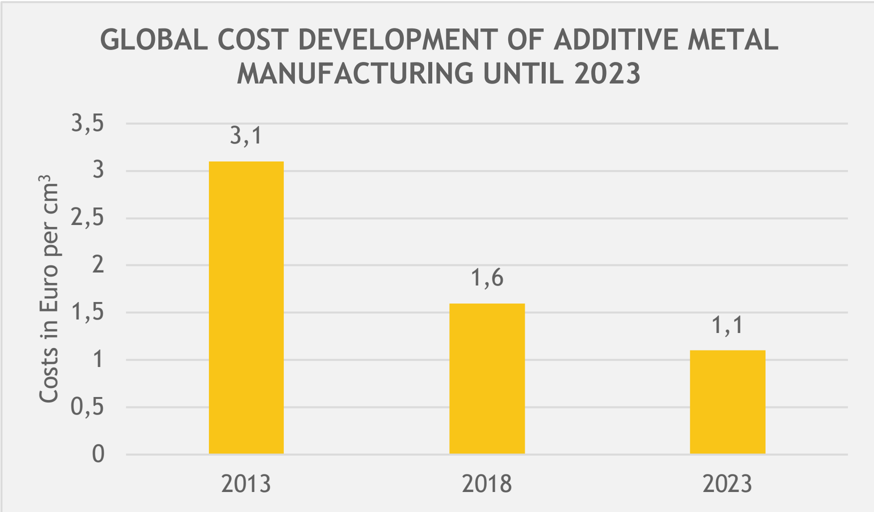

Figure 16. Forecast for cost development in additive metal production [114].

According to a recent survey among German SMEs made by Fraunhofer IPA the role and adoption of AM technologies in production will change significantly throughout the next 10 years. (Figure 17) About 85 percent of SMEs state that at this moment AM plays no or a minor role in their production and only 3.5 percent of the SMEs see it as a major role or even a key technology. In five to ten years SMEs prognose s different picture with 35 percent and 21 percent, respectively. For 43 percent of all SMEs AM will be an established technology in production.

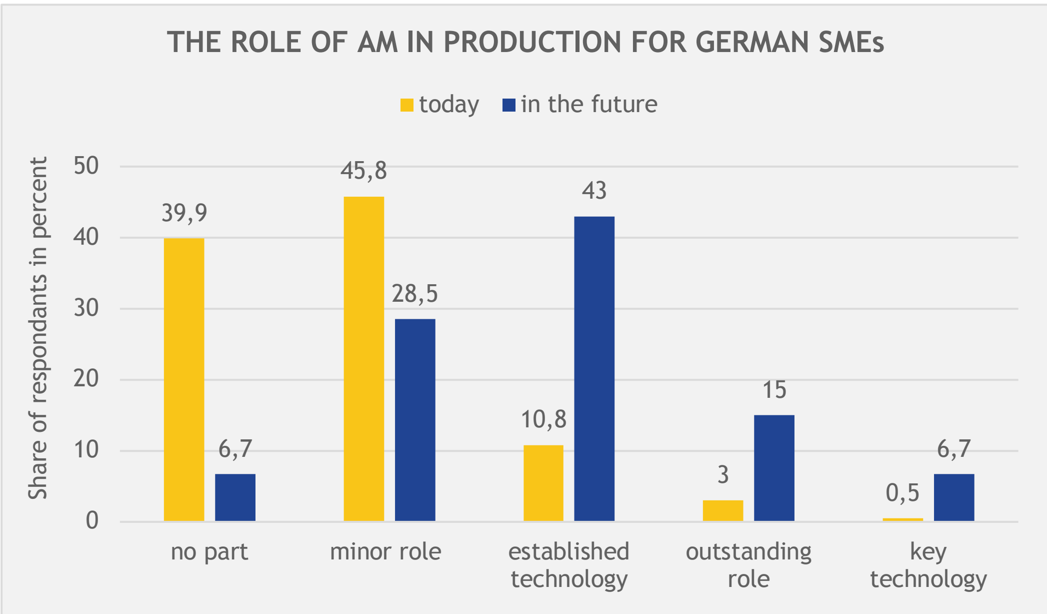

Figure 17. The current role of AM technologies in production and in 5 to 10 years [115].

According to the AM-MOTION Roadmap, several opportunities are offered by AM technologies: [116]

- In automation, digital twins & 4D printing, 3DP technologies can trigger a 4th industrial revolution & industry 4.0.
- Printing robots, real-time control & predictive maintenance can enable artificial intelligence in AM.
- Customisation and co-creation approaches can improve quality of life & inclusive societies.
- Recyclability in AM & resource efficiency might contribute to circular economy & better environment.
- By addressing specific patient-needs and bioprinting, personalised medicine and sustainable health.
- Skilled jobs, increased employment & entrepreneurship for developing a knowledge-based economy.

- Affordable solutions for energy in alignment with green mobility & low carbon economy.

In order to make profit of these opportunities, there are several challenges that should be addressed:

- Technology: new materials, better material quality and reliability, faster & cost-effective production and cyber implementation.
- Industrial access: to technology at lower cost, in particular for SMEs.
- Standardisation: industry and user engagement and certification.
- Education & training: appropriate modules for regular curricula and training on the job.
- Business: new and successful business models.
- IPR & financing: ensure protection and market opportunities.
- Smart specialisation: cross-regional cooperation in AM.

The cited document also suggested developing different products at the short, mid and large term for each sector considered relevant in AM technologies, considering the opportunities and challenges mentioned:

Table 12. Opportunities and challenges for AM technologies at the short, medium, and long term [116].

SECTOR	MAIN PRODUCTS GROUPS	HIGHLIGHTS
Medical	▪ Medical implants ▪ Living tissues & organs ▪ Assistive & prosthetic devices ▪ Surgical guides, tools & models ▪ Other customized products such as sport and orthopaedics parts. ▪ Dental products ▪ Pharmaceutical products such as drug delivery systems ▪ Food	▪ At the short term, modelling and design methods for interaction between materials and the development of novel biomaterials will attract most of attention. ▪ At medium term the integration of CE measures in the life cycle approach gain weight, together with drug testing structures and exoskeletons manufacturing. ▪ At the long term, organ bioprinting and the modelling of the whole body will be the main focus.
Aerospace	▪ Turbine and engine parts ▪ Small aircraft wings and fuselage and their components ▪ Cabin & cockpit parts ▪ Other complex parts such as bionic designs ▪ Components of large aircraft wings and fuselage ▪ Spare parts and repair ▪ Concept modelling, prototyping and advanced moulds ▪ Nice, low volume parts such as circuits and customised cabin applications ▪ Embedded electronics such as for structural health monitoring	▪ At the short term, main focus will be on the modelling and design on CFRP moulding and vibration dampening geometries. Simplified parts for aircrafts will be demonstrated as well as the development of multi-materials and their characterisation, integration and improved process manufacturing. ▪ At the medium term, complex and large parts will be addressed, together with quality-related aspects (e.g. reproducibility, surface finishing, inspection criteria)
Automotive	▪ Engine components ▪ Auxiliary means of production and supports ▪ Embedded electronics ▪ Concept modelling, prototyping and design ▪ Niche, low volume parts ▪ Spare parts & repair	▪ At short term, material and process related aspects will be addressed for spare parts and repair. Process reliability, monitoring, automation and standardisation for increased reproducibility are of importance. ▪ At the medium term, the focus will be on developing complex and large structures. Cost-effective printing assemblies and hybrid manufacturing will be the focus as well.

Consumer Goods & Electronics	▪ Wearables ▪ Household utensils ▪ Entertainment ▪ Sensors and antennas ▪ Basic electronic components ▪ Spare parts and repair ▪ Other electronics such as cooling devices and audio components. ▪ Packaging ▪ Art	▪ At the short term, activities aimed at enabling a better control of AM processes in manufacturing customised products. Promoting mass customisation and reduce post-processing steps will be also relevant. ▪ At the medium term, increasing product functionality and sustainability through hybrid manufacturing and industry 4.0 approaches.
Industrial Equipment & Tooling	▪ Mould inserts ▪ Subsea/deep sea industrial equipment ▪ Scientific & measurement instruments ▪ Tooling and guides ▪ Integrated electronics ▪ Industrial AM equipment ▪ Industrial AM software ▪ Spare parts and repair ▪ High performance tool materials	▪ At the short term, complex multi-material and multi-components will attract most of the attention. Hybrid manufacturing and standardisation will be of importance as well. ▪ At the medium term, the development of innovative cost-effective machines will be the main focus although novel manufacturing process for powder production and novel moulds for tooling will be importance as well. ▪ At the long term, expanding AM technologies towards nanoscale will capture the entire attention.
Construction	▪ Unconventional buildings (e.g. prototypes, decorative façades, art, design, heritage construction) ▪ Structural parts like bridges, floors, walls ▪ Low risk parts with complex shapes ▪ Special buildings (e.g. army, nuclear, disaster, army buildings, lunar base) ▪ Organic shaped complex	▪ At the short term, improving processing knowledge and availability of materials in this sector will be the main focus. Strategies towards standardisation and cost-effective printing equipment will be the focus as well. ▪ At the medium term, the integration with building integration modelling systems and multimaterial printing. ▪ At the long term, attaining high production rates in manufacturing process will be the main objective.

Energy	▪ Turbine parts ▪ Oil and gas industry products ▪ Renewable energy industry components (e.g. solar cells, wind turbines blades) ▪ Energy storage ▪ Electromechanical and 3D electronic components ▪ Floating platform components ▪ Concept modelling, prototyping and design ▪ Spare parts & repair	▪ At the short term, activities will focus on developing new materials with improved performances, including processes for multi-materials and demonstration of cost-effective methods. ▪ At the medium term, hybrid manufacturing, large structures and improving surface quality will be the main focus. ▪ At the long term, digital twin for enabling production of equivalent spare parts.

Other cross-cutting technical and non-technical actions among several sectors were also identified. Regarding the former, the next activities were highlighted in the cited roadmap:

- At the short term it is worth mentioning the need to develop an effective transition to an automatic model printing process, process monitoring & validation measures, and define the role of AM in circular economy.
- At the medium term, the set-up of a quality management system and the integration of AM technologies into existing industrial processing chains. The research and demonstration of 4D printing technologies and the convergence among Artificial Intelligence, robotics, sensing technologies and 3DP.
- At the long term, improving heat or light sources for AM equipment and the convergence between virtual reality and AM technologies.

As for non-technical issues:

- At the short term: promoting effective communication among AM technologies, AM specific training, innovative sustainable models, and safety issues.
- At the medium term promoting crowdsourcing solutions for design and manufacturing, create a European network for education and training, and effective IPR strategies.
- At the long term, the focus will be on promoting the creation of a sustainable IP framework.

The up-scaling of AM technologies has been also highlighted as a key challenge elsewhere [117]. This challenge is considered a driver for start-up development and regeneration of existing manufacturing sectors, as it is mentioned for several sectors in Table 12. Other cross-cutting challenges also mentioned in the cited document are the following:

- The shifting to industry 4.0 and digital factories by covering issues around digitalisation of production, complex production systems, networked manufacturing, and the transition to factories of the future.
- The adoption of clean technologies and circular economy measures, particularly resource and energy efficiency of the novel upcoming technologies. The need to reduce transportation costs and improve logistics, which is also seen as a threat to other sectors, as it will be addressed in detail in the following section.
- In the framework of this new wave of technologies, the development of new business models in manufacturing, enabling production customisation, individualism, service innovation, among others are also highlighted.
- Internationalisation of SMEs and reorganising supply chain management of OEMs, which has a significant impact on reshoring.
- In many documents industrial training is considered key in order to the workforce adapt to this transition.
- The need to develop and make pilot lines and laboratories more accessible is considered necessary for SMEs in order to ease adaptation. Bilateral approaches are no longer convenient, and “wider manufacturing communities” are needed for improving science-business cooperation (so research ideas arrive to the market in less time and more effectively).
- The access to funding also supposes a challenge to some European regions, which hinder adaptation.

These challenges could be adapted by region and according to their capabilities (e.g. regional reality, companies per manufacturing sector, strengths, potential, etc.) different measures can be tailored in order to adapt AM technologies and CE successfully, as it will be analysed in the next section.

Threats to traditional sectors:

As mentioned above, the adoption of AM entails a reconfiguration and shortening of the whole value chain, affecting several participants and agents involved such as in the logistic and transportation sector. These sectors currently represent a significant share of employment, as it is shown in Figure 18 for the countries of the regions of AMiCE.

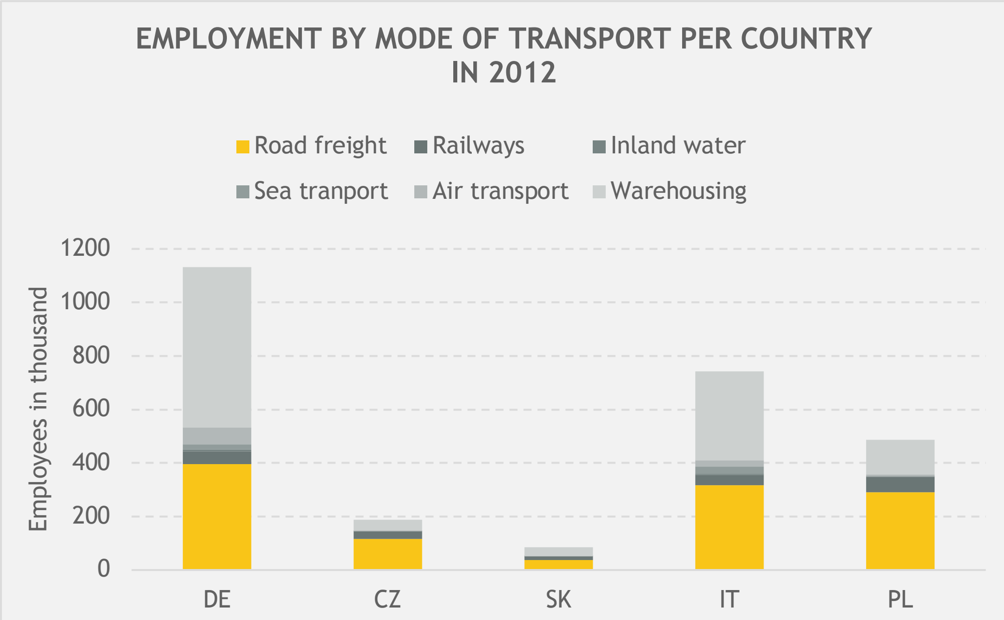

Figure 18. Data on employment in the transport sector [118].

For Germany and Italy, the warehousing is especially relevant, followed by road freight transport. The latter is the main employment mode in the resto of countries. These two sectors are likely to be affected by the AM adoption at the long term, once the transition towards customisation and mass production is enhanced. On the other hand, the positive effects of reshoring could counterbalance the loss of jobs in these sectors. Traditional logistics providers could also provide manufacturing services in order to counterbalance the loss of capabilities in the logistics and transportation sectors [119]. These effects will be considered when analysing the opportunities foreseen for each of these regions in the upcoming section.

5. Foresight for Central Europe

For developing this section, the regional reality for each AMiCE partner (as presented in section 2) was considered the basis of analysis. To do so, the main statistics regarding the number of companies and their share in employment were taking as the starting point, allowing to identify the regional potential and therefore the most important manufacturing sectors. For each of these sectors, the capabilities offered by AM technologies were analysed in depth together with the opportunities and challenges, as found in the literature [116] [119] [120] [121]. In order to come up with tailored opportunities for each partner, regional priorities, drivers, and barriers were considered in the analysis. These are presented in a timeline organized in short (1 to 3 years), mid (5 years) and long term (10 years) and following a structure in terms of intervention logic. The following tables present the results obtained,

5.1. Saxony (Germany)

Table 13. Most feasible and tangible opportunities in short, mid and long term in Saxony (DE).

SECTOR	SHORT TERM	MID TERM	LONG TERM	MAIN BACKGROUND AND MOST PROMISING POTENTIAL
Aerospace	▪ Develop or optimize modelling tools for process, material and topology optimisation ▪ Demonstration of simplified assembly of complex parts ▪ Quality and consistency of powder production ▪ New materials and processes and related characterization in the field of multi-functional materials, multi-materials and materials with highly improved functionality ▪ Develop processes and tools to manage graded materials ▪ Improved process with control mechanisms for improve quality of printed parts ▪ Research on material characterisation ▪ Optimisation of critical and unique component through 3DP	▪ Design strategies for the development of complex shaped structures ▪ Increased automation of repair processes through integration of AM and robotics ▪ Improved process control and reproducibility of nozzle-based AM techniques ▪ Production of larger airframe structures through AM technologies	▪ 3DP aircraft wing structure and large parts	▪ Strong IT sector to support software development ▪ A good technology transfer level from research to industry, ensuring innovation potential at early stage ▪ The development of advanced new materials and related technologies are considered a priority ▪ High level of expertise in materials science ▪ A strong aerospace cluster is located in Dresden, with a high level of core competences ▪ 3DP of complex parts is already a reality

Mechanical Engineering	▪ New design approaches and tools for assembly of complex multi-material and multi-component parts (▪ Design for reparation in 3DP ▪ Functional parts for prototyping, moulds and tooling ▪ Hybrid Manufacturing: introduction of AM processes into existing subtractive methods ▪ Standardization: material and product testing and process monitoring for improved quality control of manufactured parts ▪ Innovative strategies, technologies and processes increasing the dimensional and surface accuracy of final parts	▪ Innovative cost-effective machines (including robotic machines with artificial intelligence algorithms, multi- voxel machines etc.) enabling higher production rates ▪ Novel manufacturing processes increasing quality and consistency of powder production ▪ Novel tooling materials and moulds for AM processes (the same as above) ▪ Software for graded materials and density	▪ New equipment and technologies for expanding AM towards nanoscale ▪ Industrial 3DP using recycled materials	▪ Strong IT sector to support software development and innovation. It is also a regional priority, which will increase its role in the future ▪ 80 percent of SMEs are suppliers to large OEMs ▪ Large expertise in material science Advanced materials are a regional priority. ▪ The large network of Fraunhofer Institutes ensures a high level of research and technology transfer, together with the high level of innovation ▪ A plan on circular economy measures is under development. Its effects will likely be noted at long-term
Medical	▪ Modelling methods for interaction between materials and living tissue and design software for AM product customization and data management ▪ Novel biomaterials suitable for AM with focus on material	▪ Modelling methods and digital twin technologies for customized implants and medical devices and prediction of long-term clinical performance ▪ Smart products with improved functionalities	▪ Organ and complex tissues bioprinting ▪ Studying and modelling the whole body and its evolution over time, supported by 3D imaging and 3D prototyping, for optimized prostheses	▪ Strong IT sector to support software development and innovation ▪ The development of new materials are considered a priority ▪ Validation tasks could be supported at a large extent by

	variety and large production at lower costs ▪ Validation of mechanical and thermal properties of existing materials ▪ Viable processes for fabrication of 'smart scaffolds' and for construction of 3D biological and tissue models ▪ Vascularization and innervation of tissues through biofabrication ▪ Medical tools with improved performance ▪ Printing of hearing aid, dental and bone prostheses ▪ Personalized splints and orthopaedic braces	▪ Integration of life cycle approach in the health sector: AM pilots operating with closed loop recycling, reuse of precious materials, use of sustainable materials (including bio-based ones). ▪ Biological structures development for drug testing ▪ Personalized 3d-printed medicine ▪ Novel exoskeletons and protective gear ▪ Personalized glasses on head/skull 3D scan	▪ 3d-printers in all hospitals and pharmacies	the strong network of Fraunhofer Institutes and other research entities. ▪ Biotechnology is a priority, which will foster innovation in this field ▪ 3DP of customized parts such as dental and medical components is already a reality ▪ Nanotechnology is a priority, which will ease the development of smart and functional materials ▪ A plan on circular economy measures is under development, which will have effects on the sector ▪ Strong cluster of bio-technology located in Dresden BioinnovationsZentrum
Textile	▪ Develop new materials suitable for 3DP of textiles ▪ Optimize design and modelling tools to increase performance of 3d-printed technical textiles ▪ Prototypes and experimental products	▪ Develop 3d-printed textiles from biobased materials ▪ Functional or technical products ▪ Reduce from multi-stage to single process in 3DP of textiles towards obtaining near net-shape products (e.g. for the medical sector)	▪ Incorporate 3DP of textiles with conventional methods (hybrid manufacturing) ▪ Improve characteristics in terms of adhesion, stability, separation force and abrasion resistance of 3d-printed textiles	▪ Large tradition in technical textiles, especially lightweight ▪ Great research potential and technology transfer given the high level of innovation ▪ Strong IT sector

		▪ 3DP at nanoscale ▪ Development of nanoscale materials ▪ Develop materials withstanding high temperature processing	▪ 4d textile printing (embedded functionalities)	▪ Large number of companies with a big expertise in materials science ▪ Bio- and nanotechnology are considered priorities. Hence they are expected to be deployed in the upcoming years
Electrical & Electronics	▪ Convergence among custom design, electronics, smart/4D printing materials and artificial intelligence enabling better control of AM processes and quality and reliability of customized products ▪ Development of multi-material electronics ▪ Integrate new functionalities into product development (prototyping)	▪ Predictive, self-learning and holistic multi-physical modelling approaches for modelling AM processes leading to increased product functionality ▪ 3DP at nanoscale ▪ Development of nanoscale materials ▪ Develop materials withstanding high temperature processing ▪ Materials treatment for adhesion between parts and conductive materials ▪ Decrease post-processing steps ▪ Printability of non-flat surfaces with optimized design and functions	▪ Improving process sustainability through flexible and hybrid manufacturing and industry 4.0 approaches ▪ Bring down of production costs enabling mass production ▪	▪ Strong IT sector ▪ Development of advanced new materials and nanotechnology are priorities ▪ The region already has great expertise in material science ▪ Innovative actions are supported by the strong research network and the high level of technology transfer ▪ A plan on circular economy measures is under development, which will have effects on the sector ▪ Mass production at the long term will be facilitated by achieving goals at earlier stages

Automotive	▪ Improve modelling tools for materials processing ▪ Quality and consistency of powder production ▪ Increased process reliability and stability through in line control system, monitoring, automation and standardization ▪ Innovative solutions for higher production rates and cheaper systems ▪ Increase reproducibility of 3D printed automotive parts ▪ Fabrication of rare or discontinued parts	▪ Development and demonstrate strategies for cost- effective printing assemblies in one step ▪ Characterization of the behaviour of AM components in large assemblies and of large assemblies ▪ High-end personalized vehicles and customization of regular vehicles ▪ 3DP of engine components (Al, Ti alloys); embedded components such as sensors, single part control panels (polymers); hubcaps, tires, suspension springs, dashboards, seat frames.	▪ 3DP of body in white and body panels (frame, body, doors with Al alloys) ▪ Highly transformed value chains, especially in terms of suppliers and logistics (see threats)	▪ Strong IT sector, which will support modelling activities and software development ▪ Large expertise in material science and related technologies ▪ Automation and industry 4.0 are regional priorities ▪ Innovation and R&D activities are likely to be supported by the strong network of research institutes ▪ OEMs such as WV, BMW, operate in the region, with luxury brands ▪ Development of cost reduction strategies to be fostered by SMEs

5.2. Liberec & Usti regions (Czech Republic)

Table 14. Most feasible and tangible opportunities in short, mid and long term in Liberec & Usti regions (CZ).

SECTOR	SHORT TERM	MID TERM	LONG TERM	MAIN BACKGROUND AND MOST PROMISING POTENTIAL
Automotive	▪ Develop modelling tools for materials processing ▪ Powder production ▪ Increased process reliability and stability through in line control system, monitoring, automation ▪ Develop solutions for higher production rates and cheaper systems	▪ Development and demonstrate strategies for cost- effective printing of complex parts and assemblies in one step ▪ Characterization of the behaviour of AM components in large assemblies and of large assemblies	▪ 3DP of engine components (Al, Ti alloys); embedded components such as sensors, single part control panels (polymers); hubcaps, tires, suspension springs, dashboards, seat frames. ▪ -Increase reproducibility of 3D printed automotive parts ▪ 3DP of body in white and body panels (frame, body, doors with Al alloys)	▪ Strong IT sector, also included as regional priority ▪ Metallurgy is a regional priority as well ▪ The region already has expertise in Industry 4.0 ▪ The development of cost effective methods should be tackled as soon as possible in order to remain competitive ▪ OEMs will foster R&D activities at mid-to-long term ▪ Many SMEs are suppliers for large OEMS, with a great expertise in polymer (especially rubber) and metallurgical related products ▪ 3DP of large parts should be the main focus at the long term in order to remain competitive
Mechanical Engineering	▪ New design approaches and tools for assembly of complex	▪ Innovative cost-effective machines (including robotic	▪ Novel manufacturing processes increasing quality	▪ The strong ICT sector could support the development of

	multi-material and multi-component parts ▪ Hybrid Manufacturing: introduction of AM processes into existing workflow ▪ Innovative strategies, technologies and processes increasing the quality of final parts	machines with artificial intelligence algorithms, multi- voxel machines etc.) enabling higher production rates. ▪ Software for graded materials and density	and consistency of powder production ▪ Novel tooling materials and moulds for AM processes ▪	modelling and design software ▪ Innovative design approaches are already been developed in some OEM (e.g. Skoda) ▪ Advanced manufacturing, automation, robotic, metallurgy are priorities and therefore are expected to be developed and drive research activities
Medical	▪ Modelling methods for interaction between materials and living tissue and design software for AM product customization and data management ▪ Validation of mechanical and thermal properties of existing materials ▪ Viable processes for fabrication of ‘smart scaffolds’ and for construction of 3D biological and tissue models ▪ Vascularization and innervation of tissues through biofabrication	▪ Novel biomaterials suitable for AM with focus on material variety and large production at lower costs ▪ Modelling methods and digital twin technologies for customized implants and medical devices and prediction of long-term clinical performance ▪ Smart products with improved functionalities ▪ Biological structures development for drug testing ▪ Novel exoskeletons developed by AM	▪ Organ Bioprinting ▪ Studying and modelling the whole body and its evolution over time, supported by 3D imaging and 3D prototyping, for optimized prostheses ▪ Integration of life cycle approach in the health sector: AM pilots operating with closed loop recycling, reuse of precious materials, use of sustainable materials (including bio-based ones)	▪ The strong IT sector will support the development of modelling method and related software ▪ The medical sector is attracting much of the attention since it is seen as the one having the highest added value ▪ The research on new biomaterials is expected to be driven by biotechnology, which a priority ▪ The pharmaceutical sector is strong, 18 percent of the chemical industry ▪ The region has a large experience with collaborative robots

				▪ Bio-printing of organs is already a reality (success case in the next section), will is likely to be deployed in the future ▪ The adoption of circular economy measures are currently at early stages for which its effects will be probably be noted at long term
Electrical & Electronics	▪ Convergence among custom design, electronics, smart/4D printing materials and artificial intelligence enabling better control of AM processes and quality and reliability of customized products ▪ Development of multi-material electronics ▪ Mass customisation of products including co-creation and fabrication strategies ▪ Decrease post-processing steps ▪ Printability of non-flat surfaces with optimized design functions	▪ Predictive, self-learning and holistic multi-physical modelling approaches for modelling AM processes leading to increased product functionality	▪ Improving process sustainability through flexible and hybrid manufacturing and industry 4.0 approaches ▪ 3D capturing technologies ▪ Bring down production costs, enabling mass production	▪ Strong IT sector ▪ The great potential of customization is likely to drive the deployment at early stages ▪ The region as already a great expertise in Industry 4.0, which could support the actions at the short-term ▪ The field of electronics is already playing a big role in the region, apart from being a priority ▪ The main focus at the long term should be the reduction of costs in order to remain competitive

5.3. Bratislava & Žilina (Slovakia)

Table 15. Most feasible and tangible opportunities in short, mid and long term in Bratislava & Žilina (SK).

SECTOR	SHORT TERM	MID TERM	LONG TERM	MAIN BACKGROUND AND MOST PROMISING POTENTIAL
Automotive	▪ Improve modelling tools for materials processing ▪ Quality and consistency of powder production	▪ Increase reproducibility of 3D printed automotive parts ▪ Increased process reliability and stability through in line control system, monitoring, automation and standardization ▪ Development of strategies for cost- effective 3DP of parts and assemblies in one step ▪ Develop characterization methods of AM components suitable for SMEs activities. ▪ 3DP of components (steel and lightweight metals); embedded components in polymers, especially rubber-based components (e.g. tires)	▪ Demonstrate the strategies developed at mid term for cost effective 3DP. ▪ 3DP of body in white and body panels (frame, body, doors with Al alloys) and other types of large parts ▪ Parts printing for EVs	▪ The IT sector is strong in the region ▪ The companies in the region have expertise in metal working and specialized in steel and other metallic alloys. ▪ R&D activities at the short term are hindered by the current lack of expertise. Most of research is performed outside of the country. ▪ Ensuring the quality of final parts should be the focus at mid term in order to SMEs to remain competitive ▪ Automation and robotics are priorities, and should be developed in the upcoming years ▪ In the strong supplier landscape of the region, their expertise in plastics (mainly rubber), steel, and other metallic alloys will play a

				significant role in 3DP of final parts. ▪ In order to remain competitive and keep with exports, cost effective methods should be implemented at the long term, together with strategies for 3DP in-house and the capabilities for manufacturing large assemblies.
Mechanical Engineering	▪ New design approaches and tools for assembly of complex multi-material and multi-component parts focusing on composites, steel, and light metal alloys ▪ Develop and strongly support Hybrid Manufacturing since they have a great expertise on conventional methods ▪ Standardization: material and product testing and process monitoring for improved quality control of manufactured parts ▪ Innovative strategies, technologies and processes increasing the dimensional	▪ Innovative cost-effective machines (including robotic machines with artificial intelligence algorithms, multi-voxel machines etc.) enabling higher production rates ▪ Novel manufacturing processes increasing quality and consistency of powder production especially for steel and light metal alloys. ▪ Novel tooling materials and moulds for AM processes ▪ Software for graded materials and density	▪ New equipment and technologies for expanding AM towards nanoscale ▪ All companies working have included hybrid manufacturing in their industrial activity, taking as a basis their strong and traditional mechanical engineering background.	▪ Strong IT sector ▪ The region has a strong expertise in metalworking related materials, which eases innovation activities at the short term. The same can be said for conventional methods. ▪ Surface treatment and diagnosis are considered priorities and therefore will likely play a significant role ▪ Manufacturing of machinery and equipment is traditional in the region and should meet with regional priorities in order to remain competitive

	and surface accuracy of final parts			▪ Nanotechnology could be deployed at the long term given its considered a priority
Medical	▪ Modelling methods for interaction between materials and living tissue and design software for AM product customization and data management ▪ Novel biomaterials suitable for AM with focus on material variety and large production at lower costs ▪ Validation of mechanical, thermal, and surface related properties of existing materials ▪ Develop viable processes for biofabrication and other of biological structures	▪ Modelling methods and digital twin technologies for customized implants and medical devices and prediction of long-term clinical performance ▪ Smart products with improved functionalities ▪ Biological structures development for drug testing ▪ Novel exoskeletons developed by AM	▪ Organ Bioprinting ▪ Studying and modelling the whole body and its evolution over time, supported by 3D imaging and 3D prototyping, for optimized prostheses ▪ Integration of life cycle approach and CE measures in the medical sector: recycling, reuse, and use of sustainable materials (including bio-materials).	▪ A strong IT sector and the prioritization on digital technologies will ease innovative activities at early stage ▪ There is a great expertise in materials, especially polymers, as well as in diagnosis activities ▪ Biotechnology is considered a priority, which will foster future developments. ▪ Customised implants, prostheses, organ bioprinting are already been developed (see success cases next section) ▪ Both nanotechnology and biomaterials are priorities, for which their joint development and implementation should be the focus ▪ The effects on CE measures will likely have an effect at the long term, given their potential late implementation

Electrical & Electronics	▪ Convergence among custom design, electronics, smart/4D printing materials and artificial intelligence enabling better control of AM processes and quality and reliability of customized products ▪ Development of multi-material electronics	▪ Predictive, self-learning and holistic multi-physical modelling approaches for modelling AM processes leading to increased product functionality ▪ Mass customisation of products including co-creation and fabrication strategies ▪ Decrease post-processing steps ▪ Develop 3D capturing technologies	▪ Improve process sustainability through flexible and hybrid manufacturing and industry 4.0 approaches	▪ A strong IT sector, together with both materials and nanotechnology as regional priorities, could foster early activities ▪ The electronics sector is huge in the region and composites are a priority, which will support multi-material development. ▪ Given their strong expertise in video displays, 3d capturing technologies could be deployed at the mid term ▪ Late activities should be completed by the deployment of regional priorities, specifically mechanical engineering, ICT, automation and digital technologies)

5.4. Lower Silesia (Poland)

Table 16. Most feasible and tangible opportunities in short, mid and long term in Lower Silesia (PL).

SECTOR	SHORT TERM	MID TERM	LONG TERM	MAIN BACKGROUND AND MOST PROMISING POTENTIAL
Automotive	▪ Develop innovative solutions for prototyping of parts and components ▪ Develop cost-effective strategies for customization of parts and components ▪ Increase reproducibility of 3D printed automotive parts ▪ 3d printer control and operation software ▪ Develop new materials that incorporate new functionalities such as sensors.	▪ Improve modelling tools for materials processing ▪ Increase process reliability and stability through in line control system, monitoring, automation and standardization ▪ Design strategies for the development of complex shaped parts and structures ▪ Demonstrate strategies for cost- effective printing during mass customisation ▪ Advanced and multi-material capable CAD software ▪ 3DP of engine components (Al, Ti alloys); embedded components such as sensors, single part control panels (polymers); hubcaps, tires, suspension springs, dashboards, seat frames. ▪ Obtaining industrially relevant larger certified build envelopes	▪ 3DP of body in white and body panels (frame, body, doors with Al alloys) and other large assemblies ▪ Characterization of the behaviour of AM components in large assemblies and of large assemblies	▪ ICT is a RIS3 priority and the IT sector will support the development of modelling methods and software ▪ Reproducibility and quality assurance should be a priority in the short and mid-term to remain competitive ▪ The strong supplier landscape is linked to German OEMs that will demand cost-effective parts ▪ Expertise in rubber, chemicals, metals, etc.) ▪ Prospective areas are measurement and diagnostic techniques that will be necessary to assemble large parts

		▪ Develop strategies that counterbalance the shortening of the supply chain by the deployment of mass customization in DE		
Mechanical Engineering	▪ Standardization: material and product testing and process monitoring for improved quality control of manufactured parts ▪ Innovative strategies, technologies and processes increasing the dimensional and surface accuracy of prototypes and customised components ▪ Novel tooling materials and moulds for AM processes	▪ Develop innovative design approaches and tools for assembly of complex multi-material and multi-component parts ▪ Innovative cost-effective machines (including robotic machines with artificial intelligence algorithms, multi-voxel machines etc.) enabling higher production rates ▪ Software for graded materials and density ▪ 3DP of final parts and components ▪ Hybrid Manufacturing: introduction of AM processes into existing workflow	▪ New equipment and technologies for expanding AM towards nanoscale ▪ Multi-material and big volume fabrication ▪ 3DP of motors and turbines and other large assemblies	▪ Measurement and diagnostic techniques as well as sensors that will be necessary for control quality of parts are prospective areas. ▪ Strong expertise in metals, chemicals and polymers will support novel materials for tooling and moulding. ▪ ICT is a RIS3 priority and the IT sector will support the development of modelling methods and software. ▪ Strong machinery and equipment sector and prospective area of robotics support cost-effective machine manufacturing ▪ Weak industry 4.0 leads to slow adoption of AM into existing manufacturing infrastructure

Medical	▪ Novel biomaterials suitable for AM with focus on material variety ▪ Personalized splints, orthopaedic braces, and other medical tools	▪ Advanced and multi-material capable CAD software for medical tools ▪ Modelling methods for interaction between materials and living tissue and design software for AM product customization and data management ▪ Modelling methods and digital twin technologies for customized implants and medical devices and prediction of long-term clinical performance ▪ Smart products with improved functionalities (▪ Biological structures development for drug testing, 3d printed personalized medicine and new organic and biomaterials ▪ Develop Cost-effective strategies for large production of medical parts	▪ Organ and complex tissues bioprinting ▪ Studying and modelling the whole body and its evolution over time, supported by 3D imaging and 3D prototyping, for optimized prostheses ▪ Implementation of cost-effective strategies in order to have 3d printers in all hospitals and pharmacies	▪ Measurement and diagnostic techniques as well as ICT necessary support whole-body-modelling ▪ ICT is a RIS3 priority and the IT sector will support the development of modelling methods and software. ▪ New medical products and functional materials are prospective areas and life science a priority in RIS3) ▪ There is already expertise on the manufacturing of medical tools, prosthesises etc.
Electrical & Electronics	▪ Development of multi-material electronics ▪ Decrease post-processing steps	▪ Convergence among custom design, electronics, smart/4D printing materials and artificial intelligence enabling better control of AM	▪ Improving process sustainability through flexible and hybrid manufacturing and industry 4.0 approaches ▪ 3D capturing technologies	▪ Development of ICT is a priority and should develop software at short term to tackle mass production at later stages

	▪ Small-scale customisation of simple products ▪ Develop design software from 3DP electronics to support mainstream electronics application.	processes and quality and reliability of customized products ▪ Predictive, self-learning and holistic multi-physical modelling approaches for modelling AM processes leading to increased product functionality ▪ Electronics integrated into 3d printed products ▪ Develop modelling software for nanosized scale 3DP	▪ Bring down the costs and enable mass production. ▪ Nanosized scale 3DP	▪ The great potential of customization is likely to drive the deployment at early stages ▪ The main focus at the long term should be the reduction of costs in order to remain competitive ▪ Printed, organic and flexible electronics are a smart specialization priority ▪ Improving process sustainability will be delayed due to late adoption of Industry 4.0 principles
Aerospace	▪ Quality and consistency of powder production ▪ Develop processes and tools to manage graded materials ▪ Improve quality of prototypes and customized parts ▪ Research on material characterisation ▪ Development of unique components through 3DP for final use	▪ Develop or optimize modelling tools for process, material and topology optimisation ▪ Demonstration of 3d printed parts during service ▪ Design strategies for the development of complex shaped structures ▪ Increased automation of repair processes through integration of AM and robotics ▪ Improve process control and reproducibility of 3d printed parts	▪ 3DP aircraft wing structure and multi-material large parts	▪ Development of advanced materials and technologies are priorities ▪ There is a strong existing expertise on materials. ▪ ICT is a RIS3 priority and the IT sector will develop modelling methods and software. ▪ Due to a slow research transfer demonstration of 3d printed parts only in mid term. ▪ Automation and robotics are prospective areas.

		▪ New materials and processes and related characterization in the field of multi-functional materials, multi-materials and materials with highly improved functionality		
Mining	▪ Quality and consistency of metal powder production ▪ Equipment and tool making ▪ Innovative strategies, technologies and processes increasing the dimensional and surface accuracy	▪ Develop innovative design approaches and tools for assembly of complex multi-material and multi-component parts ▪ New metal powder materials ▪ Improve process control and reproducibility of 3d printed parts	▪ Multi-material fabrication at production speed	▪ The region has a great expertise in this sector

5.5. Liguria (Italy)

Table 17. Most feasible and tangible opportunities in short, mid and long term in Liguria (IT).

SECTOR	SHORT TERM	MID TERM	LONG TERM	MAIN BACKGROUND AND MOST PROMISING POTENTIAL
Aerospace	▪ Develop or optimize modelling tools for process, material and topology optimisation ▪ Demonstration of simplified assembly of complex and low weight parts ▪ New materials and processes and related characterization in the field of multi-functional materials, multi-materials and materials with highly improved functionality	▪ Design strategies for the development of mass production of complex shaped structures ▪ Increased automation of repair processes through integration of AM and robotics ▪ 3DP of complex engine parts ▪ Manufacture of drones and their parts	▪ -Production of large airframe structures through AM technologies (e.g. aircraft wing structures) ▪ Printing on-demand parts/spares in space	▪ The region has a great expertise in this sector ▪ There is a strong IT sector, many companies concentrated in the region (> 500) which will likely foster software development and related tools from early stages) ▪ Customized and complex parts are already been manufactured for final use ▪ The region has an increasingly level of innovation, for which research activities could be fostered from early stages ▪ The repairing sector has a large share of industrial activities, together with engine manufacturing. Both activities should be the focus of innovation activities. ▪ Drones have already been constructed in the region (e.g. IPERDRONE) for which

				activities that could improve the related technology are a great opportunity
Marine [122] [123]	▪ Customized parts for ships that are produced as one-of-a-kind ▪ Develop strategies for raising awareness among the sector, especially for repairing and maintaining of ships ▪ Create communities that explore emerging technologies in the marine sector ▪ Explore and develop quality assurance and IPR measures to increase trust of the sector ▪ Develop and Improve product design in terms of customization and efficiency (e.g. by printing lightweight structures inspired by nature, structures to increase fuel efficiency by means of parts that are energy-optimized)	▪ Focus on innovation and product development with higher degree of co-creation with ship owners in order to fit specific needs and operational profiles of ships ▪ Development strategies for the production of casted items such as impellers, turbines, and pumps castings. ▪ 3DP of metal spare parts for turbines and propellers components ▪ Foster the use of metal cladding and/or cold spray in the repair and reproduction of obsolete parts ▪ Rebuild worn or damaged surfaces ▪ Repair parts and components on-site ▪ Develop rapid manufacturing of critical components and ensure certification of processes (e.g. material integrity tests)	▪ 3D printing of large components and assemblies (e.g tanks) ▪ Develop strategies for cost-effective 3DP of large structures (e.g. ships, hull sides with an embedded honeycomb structure) ▪ Development of new materials with integrated functionalities (4DP) ▪ Improved supply chain by producing parts and components on board or on site (ports)	▪ The marine sector is quite significant for the region, especially repairing and maintenance activities, for which AM technologies could have the greatest potential. ▪ Since there is still a lack of awareness, actions at early stages should be aimed at establishing an adequate framework for future development ▪ The expertise in materials and the inclusion of several cross-cutting technologies as priorities, will likely support the deployment of AM in the sector

Mechanical Engineering	▪ New design approaches and tools for assembly of complex multi-material and multi-component parts ▪ Hybrid Manufacturing: introduction of AM processes into existing workflow for engine production ▪ Introduction of AM processes for repairing and maintaining ▪ Standardization: material and product testing and process monitoring for improved quality control of manufactured parts ▪ Functional plastic and metal parts for prototyping, moulds, and tooling. ▪ Design for reparation	▪ Innovative cost-effective machines (focusing on repairing and maintaining machines ▪ Novel materials and technologies for engine manufacturing ▪ Software for graded materials and density	▪ Integration of robotics, automation, and digital technologies in repairing and maintaining machines in the framework of industry 4.0	▪ Strong IT sector in the region ▪ Parts and components are already been produced for prototyping and small batch production ▪ Diagnosis and repairing are among the main expertise
Automotive	▪ Improve modelling tools for materials processing ▪ Increased process reliability and stability through in line control system, monitoring, automation and standardization ▪ Develop innovative solutions for higher production rates and cheaper systems	▪ Development and demonstrate strategies for cost- effective printing of final parts and assemblies in one step ▪ 3DP of final part and components for high-end personalized vehicles ▪ 3DP of engine components	▪ 3DP of body in white and body panels (frame, body, doors with Al alloys) ▪ Characterization of behaviour of AM components in large assemblies ▪ Develop strategies to counteract highly transformed value chains, especially in terms of suppliers and logistics (see threats)	▪ Strong IT sector ▪ Development of new materials and components is considered a regional priority ▪ Prototypes are already manufactured and early activities should aim to make progress towards manufacturing of parts for final use, taking advantage of customization capabilities

	▪ Improve design and prototyping of parts and components ▪ Develop strategies for the fabrication of rare or discontinued parts ▪ Design strategies for the development of complex shaped structures	▪ Obtaining industrially relevant larger certified build envelopes		▪ At the long term, printing large assemblies and parts should be feasible in order to remain competitive
Energy	▪ Develop or optimize modelling tools for repairing of gas turbine blades ▪ New materials and processes and related characterization in the field of multi-functional materials, multi-materials and materials with highly improved functionality	▪ Design strategies for the development of mass production of complex shaped structures ▪ Increased automation of repair processes through integration of AM and robotics ▪ 3DP of some complex engine parts	▪ Printing on-demand parts/spares in space	▪ The region has a great expertise in this sector ▪ There is a strong manufacturer of energy production plants ▪ Repair parts in 3D printing are already been manufactured for final use ▪ The region has an increasingly level of innovation, for which research activities could be fostered from early stages ▪ activities that could improve the related technology are a great opportunity

For all sectors, CIRC measures should be included as a cross-cutting principle:

- At the short-term, recycling of plastics for 3DP should be the main focus since these materials have already reached, in many cases, a mature level in terms of being used for product development and small batches productions. This is especially relevant for aerospace, medical, and automotive sectors. The recycling at the end-of-life should be addressed at the design stage enabling remanufacturing.
- At the medium and long term, industrial 3DP, especially for the electric, electronics, and textile sectors, should be able to use recycled materials, ensuring a high performance.

Unlike AM technologies, partners in Central Europe lag behind the European average in respect to adopting CIRC principles. This was set clear during the roundup of interviews that were made with AMiCE partners. An exception should be made with Saxony and Liguria, in which a legal framework is under development, although it is soon still to monitor a progress of implementation. Thus, SMEs have not yet identified the opportunities of CIRC measures (as it was presented in the past sections).

The opportunities and challenges in CIRC for Central Europe can be hardly tailored per sector, since the topic is still under development. However, it is possible to present a series of measures and principles for the AMiCE consortium, as it is depicted in Figure 19.

As it can be seen, the main principles of CIRC are based on three pillars:

- Balance of renewable resources and stock management through new technologies (such as AM) that allow to extend the life of products through regeneration, substitutions (of parts and/or components), virtualisation from the design phase to make restoration more feasible. The role of AM in this first principle is essential.
- Optimise resource yields by maximising the reutilisation of products, components and materials at the highest utility before recycling. A strong interaction takes place between the consumer and the producer of goods and services.
- Minimize the effect of external negativities.

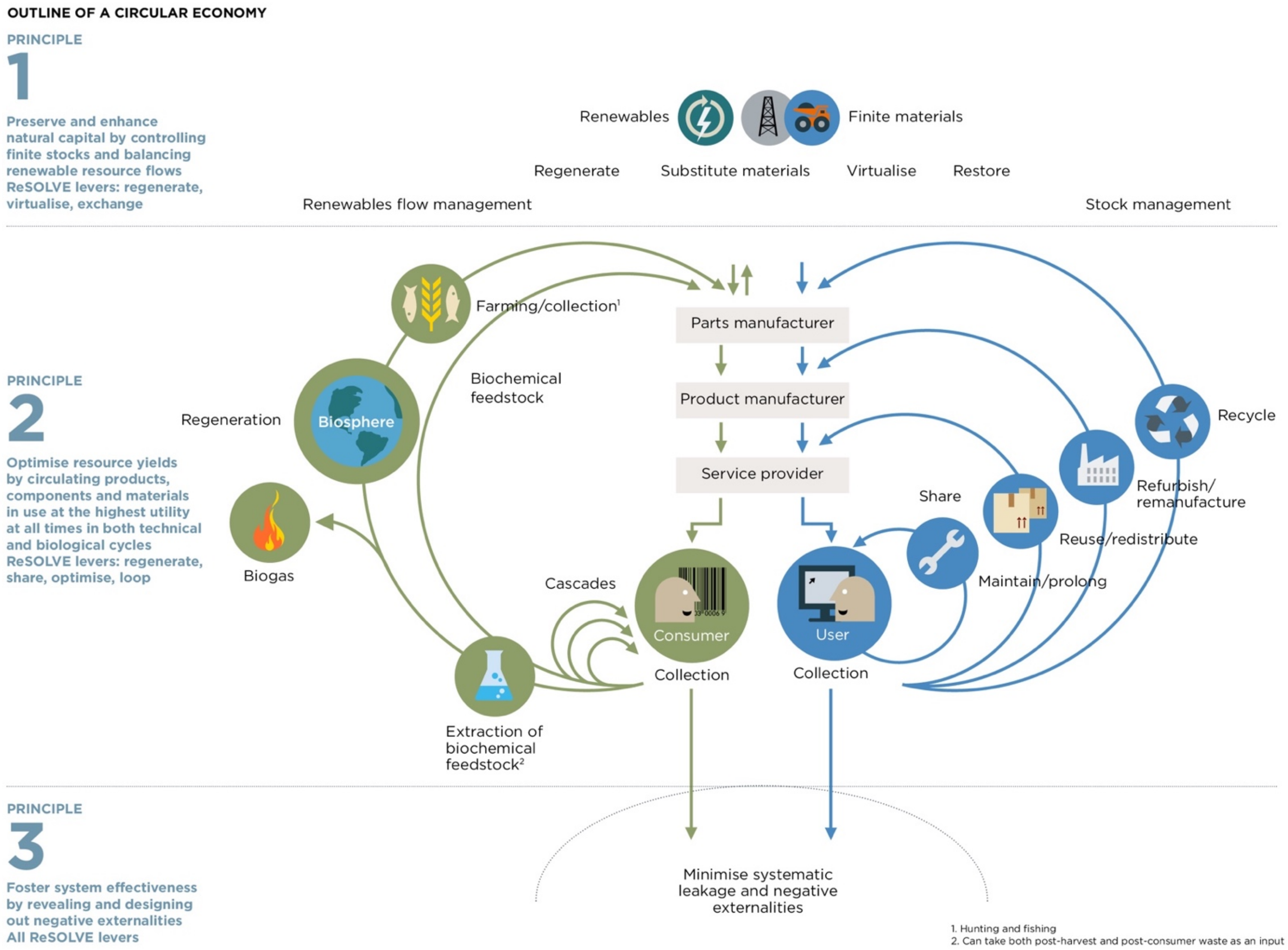

Figure 19. Cross-cutting opportunities of CIRC (Source: Ellen MacArthur Foundation).

Development of the intervention logic and evaluation criteria

The list of feasible actions and milestones for the next years presented in Tables 13 to 17 above can be related to the intervention logic suggested to successfully tailor a strategy for AM adoption. AMICE's intervention logic starts from analysing the currents needs of SMEs towards implementing new technologies and subsequently identifying the types of actions that are needed to fulfil those needs (e.g. specific knowledge, expertise, partners). During this process, a methodology for carrying out those actions is identified and performed (e.g. for attaining specific knowledge within an organization, the planning of selected events such as workshops might be useful). This methodology consists in several actions or activities that are aimed for connecting the actors, namely the SMEs (having needs) and the experts (RTOs) who have the expertise for fulfil them

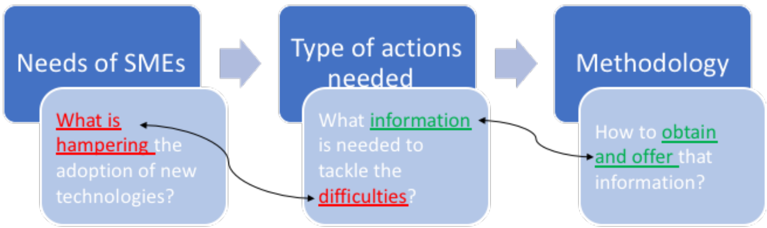

Figure 20. Intervention logic

The strategy is presented in the next deliverable D.T1.1.3 together with the evaluation criteria that will allow the consortium to assess the degree of success of the strategy.

Success cases in AM adoption:

The benefits of AM on a large scale will be achieved only if the broader supply chain adopts AM technology and experiences its benefits. In many cases, like in Saxony and Lower Silesian, this falls to large extent on SMEs. This type of companies, regardless the sector, experience different challenges when adopting innovative technologies. According to Martinsuo et al (2018), strategic and operative solutions are key solutions to overcome the main challenges, through the reassessment of manufacturing process and strategies [124].

Even when SMEs are aware of the technological advantages and capabilities of AM technologies, effective exploitation measure should be applied. The benefits of AM might be hampered by problems regarding planning, installation, and implementation stages [125]. It can be found in the literature that the main determining scenarios in AM adoption fall into the following categories [126]:

- Environmental context, in which external pressure (customers and competitive pressure), supplier support, and financial resources are included as the influencing main factors. SMEs should be aware that a continuous upgrade of their manufacturing and production equipment is mandatory in order to remain competitive in Europe. To do so, SMEs need to establish supportive relationships with technology vendors and RTOs, which facilitate new technology integration. The role of governments here is key, as they should provide efficient funding instruments in order to encourage technology adoption.
- Organizational context, in which organizational structure and culture, manufacturing strategy, HR practices, and top management are the main factors. The fewer layers of authority, the better the integration of AM in SMEs. The employees should be prepared and supported prior starting adoption, by means of education and training programs, which are regarded to consume 25 to 40 percent of the full cost of implementation [127]. A more flexibility-oriented organization and workforce development activities are also considered as key for easing a smooth adoption [128] [129].

- Technological context, in which perceived benefits and technology-in-use are included. The adoption of stand-alone technologies (e.g. in a single stage of the whole manufacturing process) can be planned and adopted easily at a lower level of management, whereas the adoption of integrated systems that affect the whole manufacturing process require the full involvement of all levels of management and decision makers in the organization.

The sector in which a company performs may of course impact the success of adoption and implementation. Depending on the extent of AM adoption, companies will need to make changes in their strategy in order to make profit of the advantages at each stage of the value chain.

Value chain	AM benefits	Requirements
Procurement	• Higher material cost but resource efficient • Lower capital to achieve economies of scale	• Choice of parts that are better suited to AM • Choice of specific technology • Use of service bureaus • Choice of AM materials
R&D and manufacturing	• Ease of concept modelling, rapid prototyping, and tooling • Weight reduction • Waste minimisation • Parts simplification • Complex-design products • Ease of product customisation • New product development	• Skilled manpower and digital technologies to run AM systems • Possibility of hybrid manufacturing • Post-processing activities • Quality check • Reduced machine changeover cost and effort • Change in recycling efforts
Delivery	• Reduced time-to-market • Optimized packaging based on prototypes	• Delivery adapted to production near the point of use • Smaller batch size deliveries
Marketing	• Customisation • Co-creation with customers • Benefits from premium products	• Pricing/promotion planning for superior and/or new products • Branding of "green" products
After sales service	• On-demand approach • Faster and customisable replacements	• Customer-facing executives with hands-on AM knowledge • Spares planning considering AM benefits and limitations

Figure 21. Strategic consideration and benefits for AM adoption across the whole value chain [130].

Regarding our focus in Central Europe, many companies have already adopted AM technologies and CIRC measures successfully in their organizations, integrating effectively the factors of the different contexts mentioned above. In this sense, Table 18 presents a summary of relevant success cases in each region considered in the AMiCE project.

Table 18. Relevant success cases in the countries of AMiCE regions.

COUNTRY	TYPE OF CASE	DESCRIPTION
Germany	CIRC: New Method for the recycling rare earth from fluorescent waste	A new process for recovering strategic metals from florescent waste was developed by TU Bergakademie Freiberg in collaboration with the company the FNE Entsorgungsdienst Freiberg GmbH (a waste disposal services company) and NARVA Lichtquelle GmbH & Co. KG (a bulb manufacturing company). It is a real case of technology transfer in which hazardous luminescent waste substances from old smartphones, non-functional neon

		lights, separated computer screens can be recovered instead of being disposed. The “SepSelsea” methods allows isolating metals and recover phosphorus. It was developed from 2012 to 2014 and financially supported with funds from the SME Innovation Programme for process engineering of the Federal Ministry from Education and Research. [131]
Slovakia	AM: medical applications – extensive maxillofacial implant manufactured with AM	***Biomedical Engineering, s.r.o. is o***ne of the 3DP pioneers in Slovakia, established and successful company in the field of advanced manufacturing is company Biomedical Engineering. It was established as a spin-off organisation of the mother company CEIT a.s. and the Technical University of Košice. The team includes experts qualified in the field of biomedical engineering with close relations to scientific and academic environment. Biomedical Engineering develops new solutions with the focus on consulting, development and manufacturing in the field of 3DP. One of the company’s major achievements was 85.84 percent facial restoration- the most extensive maxillofacial implant manufactured applying the AM in the history of the industry. The patient suffered from an extensive defect in the facial area. Four various sources of anatomical data were used for the restoration, implanted in several development stages. Custom implant was made of titanium alloy and manufactured by the 3DP technology. [132]
Czech Republic	AM: Metal 3DP of automotive parts	Czech production tool maker Innomia develops the manufacturing processes that fabricate injection moulded plastic parts for Magna, an automotive component engineering and supply company. Magna found difficulties in optimizing the mould used in the injection moulding process since the material presented an uneven thermal conductivity, which end up producing imperfections. The company Innomia tackled the problem by 3DP a new insert using the direct metal laser sintering (DMLS) from EOS. The technology allowed producing an enhanced told with complex external and internal geometry that included a system of cooling channels that solve the problem with component deformation. Additionally, the productivity and speed of the production cycle was increased by 17 percent.
Poland[5]	AM: 3DP of fire engine’s manifold	The company Bocar (PL) manufactures fire engines with custom undercarriages and provides its customers with over 100 vehicles every year. It has over 25 years of experience in the production of specialized cars. The adoption of AM from 3DGENCE allowed the company to prepare a model which was identical to the real archetype, with the possibility of making changes at the design stage. By this manner, composites made of polymers could be manufactured at lower costs. Moreover, the process generated

[5] According to the tandem partners, a success case for Lower Silesian was not available. A reference case for another region of the same country was considered instead.

		less waste material, only 10 percent of the whole model weight. The company realised that the price of preparing a 3D printed model was significantly lower than producing it through the chill-moulding process. The checking of the functionality and durability of prototypes was also enabled after adopting AM technology.
Italy	IREOS – CIRC measures	This Italian company has been working for about 30 years in different services for the environment. It was founded by Prof. Stelio Munari of the University of Genoa. IREOS is an environmental consultancy that can also perform characterizations and analytical place enquiries, land and stratum reclamation in industrial and civil areas, reclamation from asbestos and from other dangerous substances on both industrial and civil plants and buildings; it manages and organizes waste recovery and/or disposal, different circular economy measures aimed at solving chemical problems related to hazardous waste.

6. Conclusions

- There is no doubt that AM technologies and circular economy have a bright future. Regardless the reference scenario, all market projections agree that they will play a significant role in economic development, especially for industrial manufacturing.
- AM is already widely used in strategic sectors such as aerospace, medical and automotive for accelerating product development. The next step is to naturally achieve a cost-effective mass production.
- To attain this, AM technologies still face several challenges, which should be considered as opportunities for the upcoming years.
- In order to remain competitive, Europe has to keep up in advancing towards an effective development and implementation of these technologies in key sectors.
- In this aspect, the role of SMEs is considered essential, since they are considered the gear assembly of Europe. They represent a large share in the economic activity in Central Europe, which is the focus region of this deliverable.
- The regions of Central Europe, specifically those considered in this study (Saxony, Liberec and Ustí, Lower Silesia, Bratislava and Zilina, and Liguria), are facing the adoption of AM technologies and CIRC measures unevenly.
- This is a consequence of several factors, all of them analysed in the present study. From the one hand, each region has different manufacturing sectors as main drivers of their economy.
- On the other hand, each region has different smart specialisation priorities, which results in a different approach when facing future adoption.
- Overall, there are several drivers for adoption, many of them shared by each of these regions, which at the same time imply different barriers that hinder a widespread implementation.
- The current status of the technology faces different challenges that should be taken as opportunities towards innovation. Central Europe could play a key role in contributing to position Europe as competitive hub in AM technologies if the challenges and opportunities offered by these technologies are tackled in a regional framework, in order to make it feasible.
- Considering the current reality of each region and the challenges/opportunities offered by AM technologies, we developed a foresight study that includes a list of feasible actions and milestones for the next years, considering the main manufacturing sectors of each region.
- To fulfil these actions, each of the regions should plan a strategy that would allow them to tackle these challenges and opportunities effectively, according to their current and future capabilities.
- The aim of the following deliverable is to present the strategy tailored for Central Europe in order to adopt successfully AM technologies. Furthermore, the scenarios for Central Europe will be presented.

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D.T1.1.2 - Foresight Scenario and challenges for innovation 4.0 supporting schemes (Part 2)

Version 1
09 2018

Part 2 - Foresight Scenarios

Abstract

The development of an action plan that highlights all actions that will be undertaken to connect the actors in Central Europe and beyond that area is critical for the success of the AMiCE project. Those actions include several activities towards achieving the objectives e.g. the organisation of events, dissemination actions, trainings, development of monitoring systems, marketing measures, analysis of specific sectors, etc. The action plan is tailored according to the foresight scenarios developed by the regions and the resulting scenarios for Central Europe.

The aim of this Part 2 of the deliverable is to present the scenarios that were developed for each of the regions in AMICE in a timeline of ten years from now. For their development, different working sessions were performed with the partners of the consortium as it is described below. These scenarios take into account the uncertainties of different factors affecting the implementation of new technologies by SMEs, namely additive manufacturing and circular economy principles, but comparable to other types of technologies as well. Therefore, this document can be taken as a reference.

The scenarios developed can be used for developing a strategy of support in the alliance and beyond the project's completion since the reality of the regions and their potential future is considered. These would allow the regions to be prepared by planning the actions necessary for successfully implement such activities in the action plan. These are presented in the next deliverable D.T1.1.3

Table of Contents

Abbreviations

ABBREVIATION	DEFINITION
AM	Additive Manufacturing
CIRC	Circular Economy
CZ	Czech Republic
DE	Germany
EC	European Commission
IT	Italy
OEM(s)	Original Equipment Manufacturer(s)
PL	Poland
R&D	Research and Development
RTO(s)	Research and Technology Organisation(s)
SME(s)	Small & Medium sized Enterprise(s)
SK	Slovakia
3DP	3d-printing

Tables

Figures

Part 2 - Foresight Scenarios

1. Method for developing the scenarios

For the development of the foresight scenarios for each region and the scenarios for whole Central Europe, the method followed the one used by Shell Company[1] (Table 1). It consisted of an interactive session with each regional tandem in which the next steps were followed:

Table 1 Steps for the foresight scenario development

	Step in foresight scenario development	Description
1	Formulation of the topic	A title that covers the essence of the challenge is defined: What are the major driving forces for the adoption of CIRC and AM by SMEs in Central Europe in 10 years?
2	Driving forces identification	Each tandem identifies the driving forces both currently already seen and those necessary for AM and CIRC for their region(s).
3	Clustering of change drivers	The clustering of the driving forces leads to a set of manageable key variables that will be the basis for the following exercises.
4	Ranking of variables in terms of importance and relative uncertainty or predictability	The identification of the most critical uncertainties is the goal of this exercise (compare annex). Those are seen as the forces with the greatest impact on the topic and will be the primary focus of the scenario creation process.
5	Development of scenarios	With a prioritisation technique four scenarios are created by using the two most critical uncertainties as the axis. The storyline of each scenario is created by including the other variables identified in step 3. Titles for the four scenarios are created which show the essence of the scenario.
6	Testing of scenarios	The testing relates to the inclusion of KPIs (in this case adoption by SMEs). Here the scenarios are also tested by looking at the current situation.

2. Driving forces identification and clustering for AM

In a collaboration between the tandem partners of each regions the main drivers for the adoption of AM technologies were identified. The clustering of those drivers is essential to allow the consortium to draw parallels between the regions. The combination and comprising of the information provided by the regional tandems serves as an overview for the driving forces for Central Europe. The overview is presented in **Figure 1**.

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Driving forces for the adoption of AM by SMEs

Value chain
- Available technological know-how (externally, not in-house)
- Sufficient regional and local players along value chain in the market

Knowledge Drivers
- Staff already experienced with AM
- Trained staff (AM related (academic) education)
- Expertise, innovation capacity

Mindset
- Innovative/ entrepreneurial mindset of CEO
- Openness for new technologies
- Innovative mindset of staff

Financial Support
- Policy instruments/ incentives
- Funding programs/ opportunities
- Investments in R&D and innovation (EU to local level)

Standardisation
- Development of standards for products manufactured with AM
- Certification of products

IPR legislation
- Legislative support for IP rights

Economic Drivers
- Reducing design/production costs
- New business models
- Increased productivity

Other Support
- Creation of synergies and collaborations
- Access to demonstrators
- Support for cost-modelling
- Service offers from specialised know-how providers
- Machine rentals to withstand the rapid obsolescence of tech

Advantages of technology
- Possibility of rapid prototyping/ tooling
- Increased speed of production
- Development and accessibility to new materials

Market demand
- Demand of the market(OEMs)
- Demand for repairing/ tooling

Product possibilities
- New product design possibilities
- New product functionalities or characteristics
- Increased possibility of customization
- Mass costumisation

Figure 1 Driving forces for the adoption of AM by SMEs in Central Europe

2.1.1. Foresight scenarios per region

Each tandem identified the most critical uncertainties which are the foundation for the creation of the foresight scenarios for each region. In this section we present the 4 scenarios per region that are based on those uncertainties. For each region the most important particularities, as discussed in the bilateral meetings are included in the specific scenarios. The graphs of uncertainty vs. importance and critical uncertainty #1 vs. critical uncertainty #2 that were created during the exercise are included in the annex.

2.1.1.1. Saxony

The Saxon tandem identified from all driving forces the *innovative mindset* and the *market demand for products with AM value proposition* as the most critical uncertainties.
The market demand is especially high in the field of lightweight structures, where AM offers many opportunities. But in general, the demand is not fully certain since it is very dependent on the technology and the different sectors. SMEs in forming and tooling will play a bigger role but a general view on the manufacturing sector is not possible.
Saxony in general has many entrepreneurial SMEs but still the innovative mindset is depending on all other factors regrading inhouse capacities and the market. A general statement about the Saxon SMEs in this field is not possible. In a further development those critical uncertainties were the basis to create the following four scenarios:

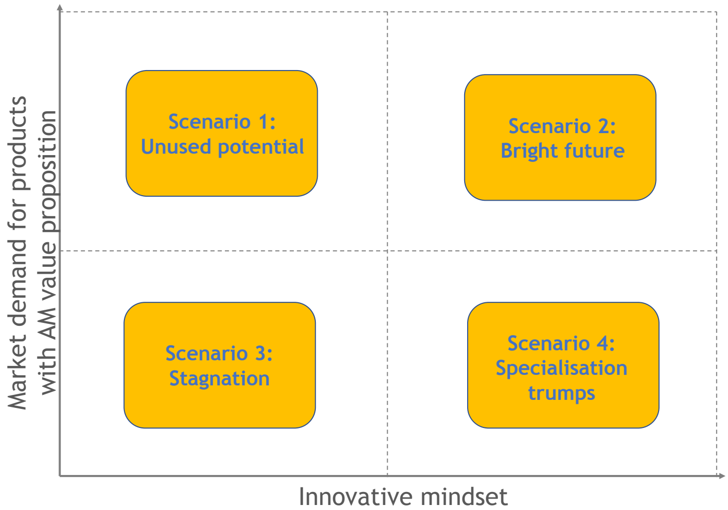

Figure 2 AM-scenario-matrix for Saxony

- **Scenario 1: Unused potential**

Many SMEs will lose their competitiveness among other market players due to their lacking innovative mindset. Adoption will happen to a certain extend since the market demands for it. But the main adopters will be start-ups or actors who are already established in the sector.

- **Scenario 2: Bright future (champion scenario)**

Due to a high market demand SMEs are encouraged to adopt AM technologies and their innovative mindset will allow SMEs to see the potential and use the opportunity for their organisation. The region of Saxony will grow and establish itself as a frontrunner also due to the well-established local value chain consisting of regional and international players that centralise knowledge and expertise. Adoption takes place to a high extent and is accelerated by the extensive in-house knowledge.

- **Scenario 3: Stagnation**

In a scenario that lacks an innovative mindset and market demand it is highly doubted that an adoption is going to take place although the product possibilities are proven, and in-house knowledge is to a certain extent already available.

- **Scenario 4: Specialisation trumps**

The lacking market demand through OEMs implies that SMEs will not adopt but their high innovative mindset might create opportunities for some of them even in this scenario. Major changes will be seen for niche players. The adoption of AM technologies will take place but only in niche markets. e.g. limited applications which are highly specialised.

2.1.1.2. Liberec and Usti

The most critical uncertainties in Liberec and Usti were identified by the tandem as the *market demand* and the *funding support*. Those two uncertainties were used to create the following 4 scenarios:

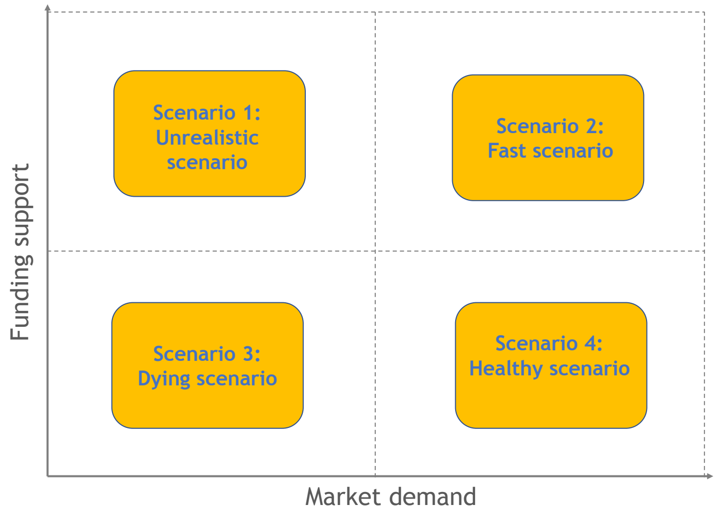

Figure 3 AM-scenario-matrix for Liberec and Usti

- **Scenario 1: Unrealistic Scenario**

The scenario of low market demand and high support schemes was identified as rather unrealistic. But in the case this scenario actually happens in 10 years the adoption of AM technologies in the process of Czech SMEs is very unlikely to happen since they are not obliged to by the market. Some supported companies may take the opportunity without market demand to try out the technology and the opportunities e.g. for new product development.

- **Scenario 2: Fast scenario**

Due to a high market demand and an elaborate set of funding opportunities the adoption through SMEs in development and production is very fast and progressive. Although it promises to be a rather safe scenario for SMEs this combination also offers risks. SMEs may adopt technologies that are not mature enough and won’t bring the economic feedback that is expected. A waste of resources needs to be avoided by adopting strategically to achieve realistic economic return.

- **Scenario 3: Dying scenario**

Scenario 3 shows a low market demand and no funding schemes that might support SMEs in the decision to innovate their processes. Here companies will not use the technologies since they don't see the need and lack resources to adopt.

- **Scenario 4: Healthy Scenario**

The Czech tandem foresees the fourth scenario as the healthiest one, companies will invest in the technology due to the market demand and because they see the economic drivers that the technology will offer in mid and long-term. Due to the lacking financial support some companies however won't have the opportunity to join the development and will end-up losing clients. This for many SMEs (especially micro and small companies) with limited resources and vision disruptive scenario will substantially change the present landscape of many industries.

2.1.1.3. Bratislava and Žilina

The regional tandem of Slovakia which covers the regions of Bratislava and Žilina foresees the following two driving forces as the most critical and uncertain: *market demand* and the *development of support schemes or the enactment of certain legislation*.
The market in Slovakia is dominated by the automotive industry which is the main market for SMEs that act as suppliers. Changes in this sector will affect a huge number of Slovakian SMEs. The lack of diversity of sectors is why the market demand is seen as uncertain. It is very dependent on external factors within Slovakia and the main export countries.
The development of support schemes or the enactment of certain legislation in Slovakia has proven to be slow and the existing support schemes are used only to a small extent since companies experienced extreme bureaucratic efforts and corruption. The scenarios are as follows:

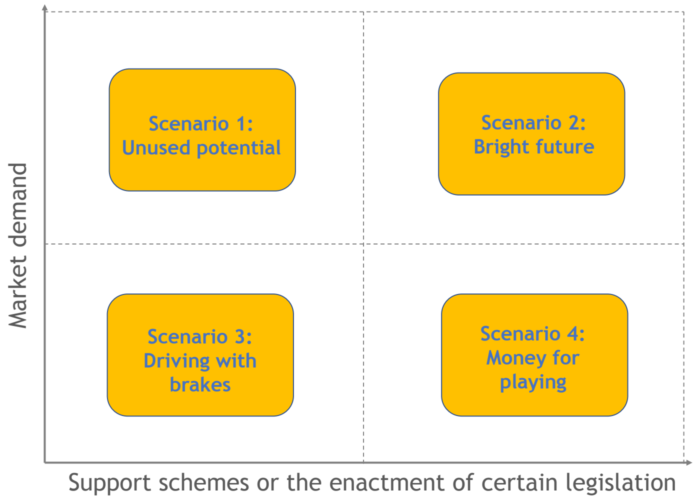

Figure 4 AM-scenario-matrix for Bratislava and Zilina

- **Scenario 1: Unused potential**

A high market demand will guarantee a fast take up of the technology which leads also to the adoption through SMEs. Some SMEs will be the losers of this scenario. These may lack an innovative mindset or more pressingly the resources, both capital and human - to be able to follow or even lead the development in their specific sector.

- **Scenario 2: Bright future (champion scenario)**

Due to the numerous opportunities to apply for funding SMEs in Bratislava and Žilina will have the money to buy the technologies and integrate them in their processes or even innovate their complete manufacturing process to become more efficient. The market is demanding and buying innovative products. The product possibilities and the advantages offered by the implemented technologies will be a big push for innovations (innovative products, new material combinations, functionalities) in the manufacturing sector and the protection of innovations will take place. This scenario is highly dependent on the development of funding structures. SMEs usually have negative experiences with public funding since corruption in involved entities is not a rare scenario.

- **Scenario 3: Driving with brakes**

The lacking demand through the market and lack of funding support will lead to the adoption of AM technologies only for prototyping, or some highly innovative niche markets. The adoption will not move forward to industrial-scale production. Especially micro and small SMEs will not be able to invest in the technologies due to lacking financial and human resources. Furthermore, the lacking innovative mindset will also keep SMEs from even looking into the possibilities that can be offered by AM technologies.

- **Scenario 4: Money for playing**

As the title implies, this scenario creates opportunities for innovative creative SMEs that use resources given through support schemes. Here it has to be considered that Slovak companies try to avoid funding schemes since corruption related to these funding schemes occurred in the past. Furthermore, SMEs usually fear the bureaucratic effort related to the application and submission process. Since the market doesn't demand for 3d printed products it will also lead a to a lot of unused potential to innovate whole industries.

2.1.1.4. Lower Silesia

In a collaborative effort the Polish tandem identified from all driving forces the *market demand* and the *standardisation for additive manufactured products* as the most critical uncertainties which lead in a further development to fours 4 scenarios.
The market demand in Lower Silesia is very difficult to forecast. The aerospace sector is very important in the region, but Lower Silesian SMEs are not really connected to the market as suppliers. Many SMEs are dependent on the mining sector which is a critical sector.
Standardisation and certification for additive manufactured products is especially in the Aerospace sector crucial. Without these standards OEMs in this sector will not buy the products. In general, the development process of standards is time-intensive and is influenced by external factors.

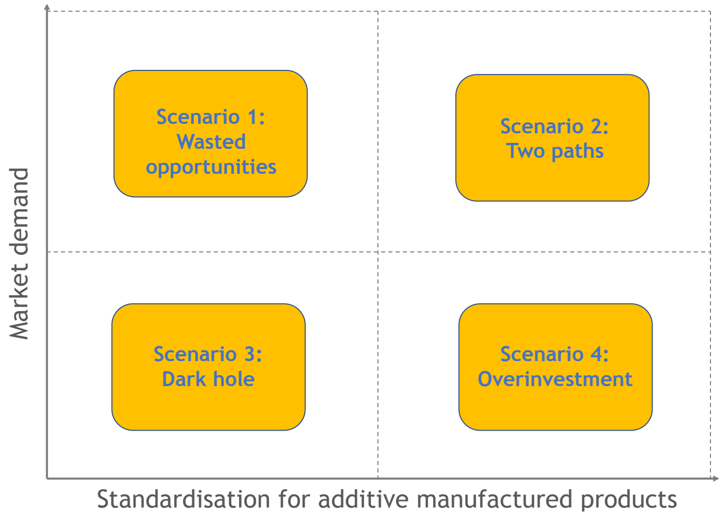

Figure 5 AM-scenario-matrix for Lower Silesia

- **Scenario 1: Wasted opportunities**

SMEs will push additive manufactured products into the market due to the high market demand for the products. But it is expected that many of those will fail due to high competition and because of the lack of standards. SMEs will need to fulfil the requirements of the OEMs that might vary significantly among company therefore they can only place products with a direct order placement otherwise they won`t be able to sell their products. For SMEs with products that don't rely on a certification or certain industrial wide standards the adoption might be high because of the market demand (e.g. home appliances).

- **Scenario 2: Two paths**

According to the tandem partners this scenario offers two paths for SMEs:

1. Due to a high market demand SMEs are encouraged to adopt AM technologies and already established companies will be able to grow their business. New business opportunities will occur and an increase in new companies and start-ups will be seen.
2. The second path foresees a risk for SMEs in the implementation of standards and certifications for products. Depending on the requirements that are formulated in the standards and the ability of SMEs to fulfil those the switch and investment into AM can be risky since the products cannot be placed in the market if they don't comply with the strict standards of the industry. This can lead to an increase in monetary issues (investments that don't pay out).

- **Scenario 3: Dark hole**

In a scenario that lacks both a demand through the market and standards (certification) for projects it is not expected that an adoption is going to take place. For Lower Silesia in this scenario no local change in the value chain is expected.

- **Scenario 4: Overinvestment**

Due to available standards and certification for 3D printed products SMEs will adopt the technologies and produce their products according to those standards. But a lacking market demand through OEMs will lead to the situation that many SMEs will have no possibility to actually find costumers. This wasted investment can be disruptive for many SMEs in Lower Silesia.

2.1.1.5. Liguria

Due to the unique expertise and knowledge about the current SME and AM situation in Liguria the Ligurian tandem was able to identify *funding programs* and *synergies* as the most critical and uncertain driving forces.
Synergies are seen as uncertain because of conflicting interests in sharing knowledge but are very important because these synergies are needed to access big funding schemes.
With a 10 percent success rate funding schemes in Liguria currently are not effective enough and not attractive for most SMEs. The following 4 scenarios have been developed as a result of this careful evaluation and final choice:

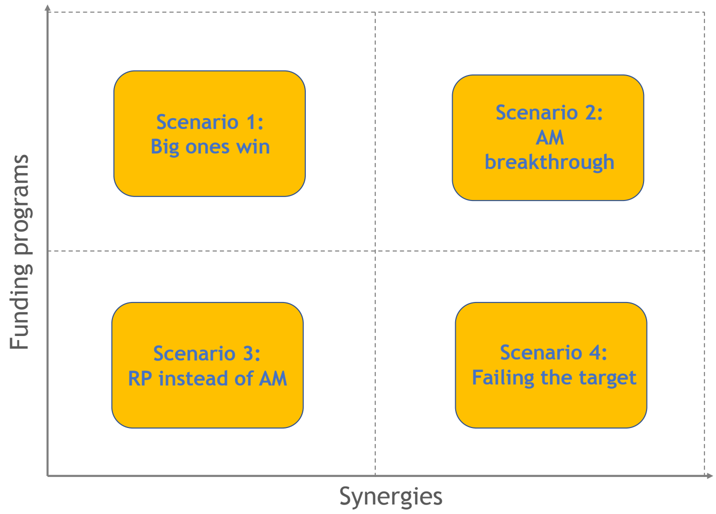

Figure 6 AM-scenario-matrix for Liguria

- **Scenario 1: Big ones win**

Without the creation of synergies only large companies and pre-existing cluster will be the ones to access funds and finally adopt to the technology.

- **Scenario 2: AM breakthrough**

Due to access of funding programs and the creation of synergies many SMEs will adopt AM in their everyday business. Furthermore, SME will provide particular services to other SMEs and also to larger companies.

- **Scenario 3: RP instead of AM**

This scenario shows that with no funding schemes and lacking synergies between SMEs, material or technology providers etc. AM technologies will be used to create proof-of-concept prototypes but won't find an implementation in the production lines.

- **Scenario 4: Failing the target**

SME will join forces but will not be able to access real funding, with exception of “high-tech” regions. Therefore, adoption will be visible but limited to a certain extent.

3. Driving forces identification for CIRC

The collaboration between the tandem partners of each regions also lead to the identification of the main drivers for the adoption of CIRC measures. These as well have been clustered according to their nature and further used to create scenarios in a next step. The combination and comprising of the information provided by the regional tandems serves as an overview for the driving forces for Central Europe. The overview is presented in Figure 7Figure 7 Driving forces for the adoption of CIRC by SMEs in Central Europe

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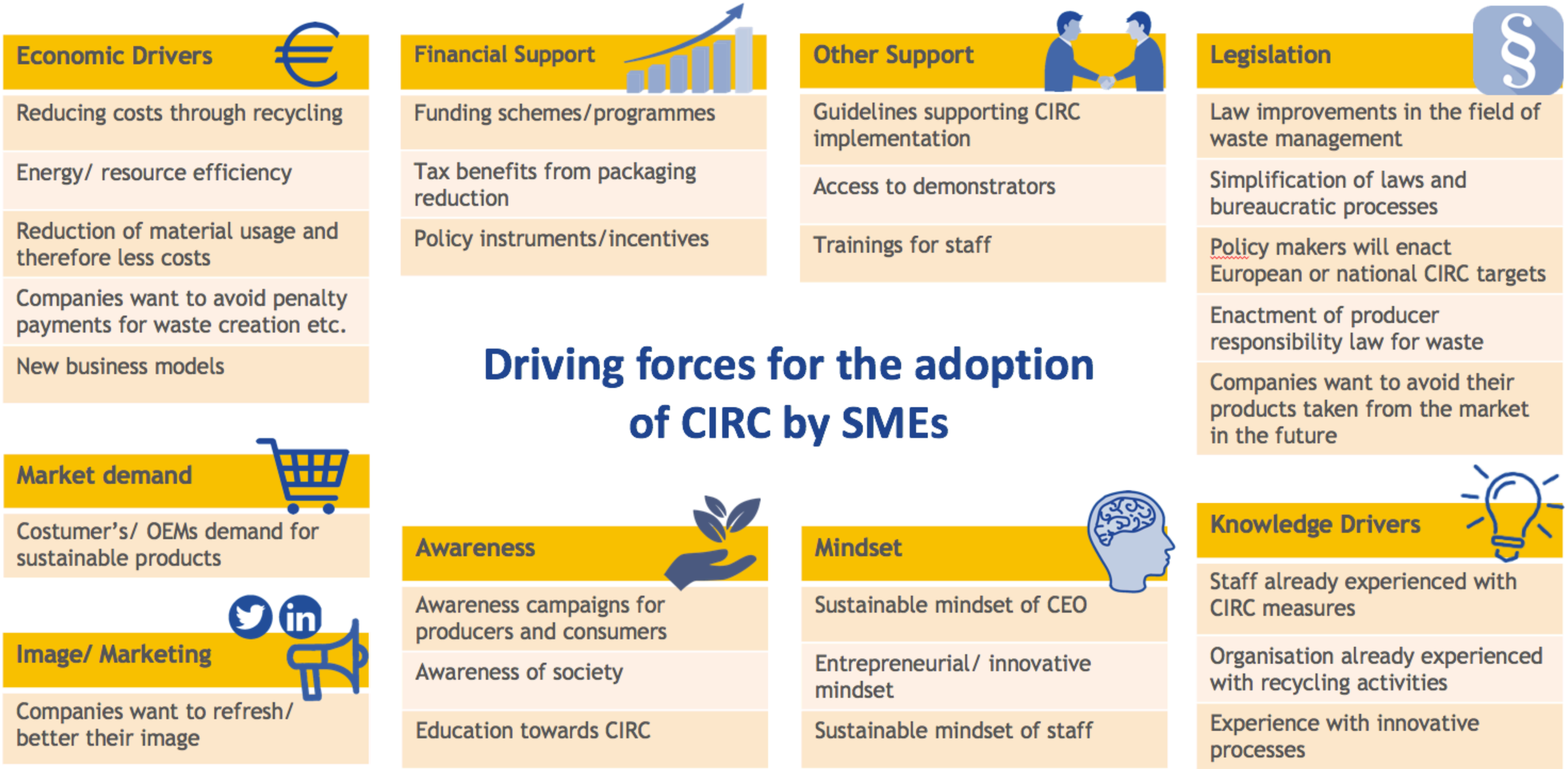

Figure 7 Driving forces for the adoption of CIRC by SMEs in Central Europe

3.1.1. Saxony

Due to the combined expertise the Saxon tandem was able to identify the most critical and uncertain driving forces (*company mindset* and *market drivers*). The following 4 scenarios has been developed as a result of this careful evaluation and final choice:

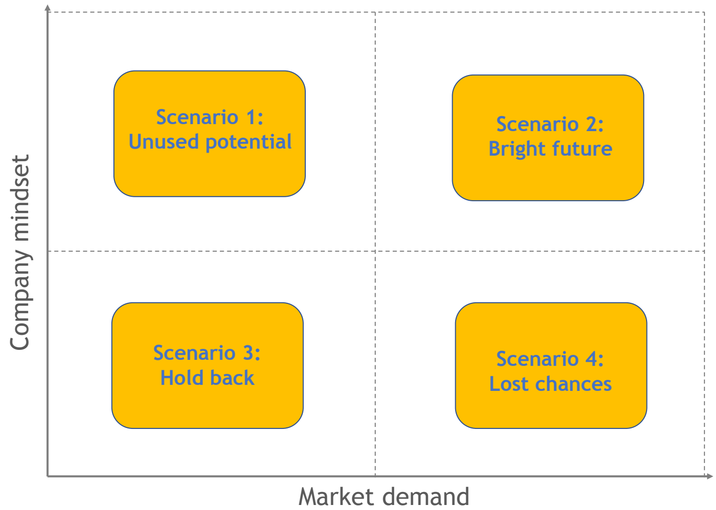

Figure 8 CIRC-scenario-matrix for Saxony

- **Scenario 1: Unused potential**

Adoption takes place only to the extent what is required and accepted by the market since the market demand is very low. But since the framework of legislation/support schemes which is favouring an adoption and due to the company's culture, SMEs that can afford to invest above what is required will do so.

- **Scenario 2: Bright future**

In this scenario the adoption of CIRC takes place to a very high extent (close to 100 percent). No side effects are expected since company mindset and market drivers are high, and the legislation is a further push.

- **Scenario 3: Hold back**

The adoption takes place at minimum level. SMEs will have to be active in the field due to legislation, but their efforts will only comply with legislation and not go further beyond. Their lacking innovative and sustainable mindset is a strong hold back.

- **Scenario 4: Lost chances**

Due to a high market demand SMEs will have to adopt to CIRC even though it is not on the organisations agenda otherwise they'd go out of business.

3.1.2. Liberec & Usti

In a collaborative effort the Czech tandem identified *cost reduction* and *technical support* as the most critical uncertainties which lead in a further development to the following 4 scenarios:

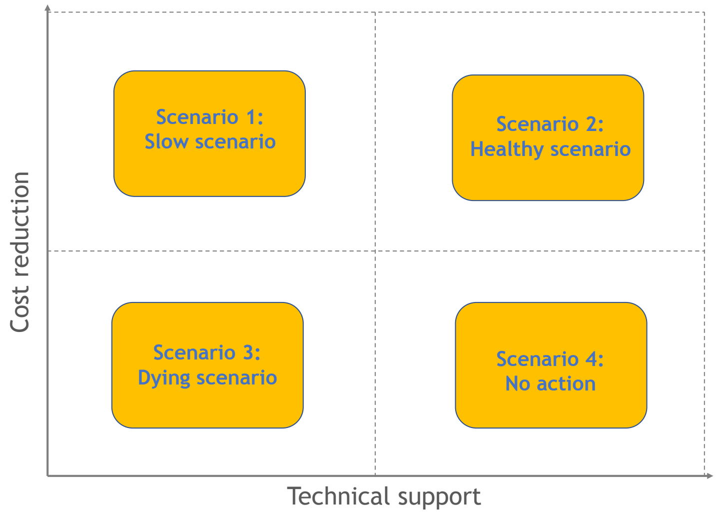

Figure 9 CIRC-scenario-matrix for Liberec and Usti

- **Scenario 1: Slow scenario**

Due to the advantages of the measures in terms of cost reduction many SMEs are likely to adopt circular economy principles within their business activity. But the implementation of the measures and techniques is difficult, resource intensive and risky without technical support. Due to a lack of demonstrators some companies will not be able to take this step and invest without proof-of-concept. This will create the need for research and support organisations. The adoption will be much lower in comparison to scenario 2.

- **Scenario 2: Healthy scenario**

Due to a high cost reduction in the everyday business and the technical support that is offered, the Czech Republic will see a big progress in this field, attracting more SMEs to implement CIRC measures, including also very small companies. Competition in industry will happen due to certain implementation derived from related legislation (regional, national or on EU level). Even if there is no financial support in form of funding schemes SMEs will adopt CIRC to a large extent.

- **Scenario 3: Dying scenario**

Even with the implementation of related legislation the low technical support and especially the lacking of economic incentives are counterforces that will disable a development towards circular models.

- **Scenario 4: No action**

This scenario has been described as politically horrible: SMEs will be forced to adopt only through legislation. For marketing purposes, the topic could have an added value. Only specialised companies that address a sustainable end-user clients might adopt.

3.1.3. Bratislava & Žilina

The regional tandem of Slovakia identified the following two driving forces as the most critical and uncertain: *knowledge and awareness* and the *efficiency of the production.*

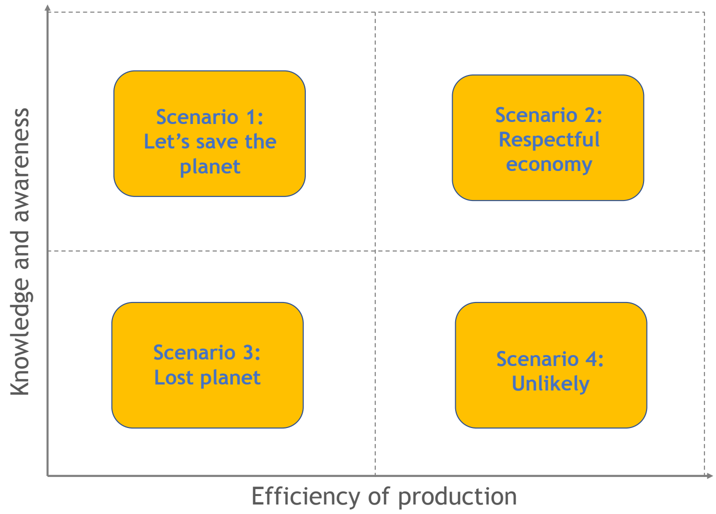

Figure 10 CIRC-scenario-matrix for Bratisalva and Žilina

- **Scenario 1: Let’s save the planet**

Teaching has a high importance concerning low knowledge & awareness, which is the starting point. In 10 years, a lot of innovation will be seen and the public as well as organisations will be aware of the benefits that circular material flow models can have for human health and the environment. The lacking benefits through increased efficiency may be a hold-back for some SMEs though.

- **Scenario 2: Respectful economy**

SMEs understand the benefits and possibilities of innovating their processes and products to support circular economy not only out of sustainable beliefs (awareness) but also because they experience an economic benefit due to higher production efficiency. This scenario can be seen as the perfect situation: almost all SMEs will adopt certain measures to become circular, which will foster the creation of smart and innovative ideas.

- **Scenario 3: Lost planet**

The public awareness about the topic stays low and people will behave the same way, entailing low recycling rates even at household level. Since CIRC measures are not perceived as beneficial to production efficiency, industry will not be willing to adopt.

- **Scenario 4: Unlikely**

In this scenario, it is unlikely that the industry will realize the benefits of circular economy in production efficiency if there is no awareness on the topic, since both situations almost fall in contradiction. However, it might be the case that some companies have an economic activity relying in other regions in Europe, such as having automotive OEMs or large textile end-users outside of Slovakia. For some of this big players, certain requirements in terms of sustainability should be met by suppliers. This leads to a lot of space of innovation, since local and regional companies will be fostered to adopt circular economy principles for the sake of efficiency and external compliances, although at a slow pace.

3.1.4. Lower Silesia

The Polish tandem identified from all driving forces the *market demand* and the *funding and investment* as the most critical uncertainties which lead in a further development to the following 4 scenarios:
Currently support schemes are important for universities but not so much for companies since it is too much effort and the uncertainty of receiving the funding is quite high. In the area of CIRC no regional or national funding schemes are offered explicitly for this topic. And in general, the topic is quite new and covers

mostly recycling. Both the funding schemes and the market demand are very dependent on external factors especially the implementation of EU or national legislation and to what extent this will affect SMEs.

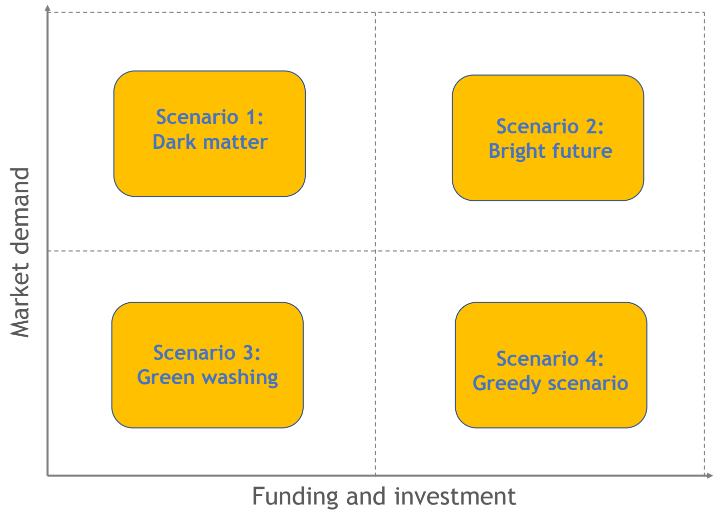

Figure 11 CIRC-scenario-matrix for Lower Silesia

- **Scenario 1: Dark matter**

The scenario foresees a high market demand but no framework that offers funding schemes and investment support. Therefore, SMEs unlikely are able to invest in these measures This will lead to the disruption of several businesses.

- **Scenario 2: Bright future**

SMEs will adopt CIRC measures; they will serve the market and are incentivised to adopt not only financially but also because of the legislation would force them to do so.

- **Scenario 3: Green washing**

SMEs would not adopt since the financial incentive is missing but would need to do so anyway since it is very certain that the legislation will change drastically in the next ten years. This scenario is very unlikely to happen because of the regional and EU wide legislation that will be implemented which will also substantially influence the market demand. The risk of green washing through SMEs that cannot effort to or are unwilling to restructure their processes accordingly is very high. Legislation would need to set-up monitoring programs.

- **Scenario 4: Greedy scenario**

The fourth scenario is very related to the third one. Here again companies will implement green marketing strategies with the addition that they will apply for the funding with no real innovative results.

3.1.5. Liguria

The Ligurian tandem identified as most critical uncertainties for the adoption of CIRC *legislation* and *incentives*: The two measures are strongly connected. Legislation generally obliges to do something while incentives encourages adoption of specific measures. They are considered the main drivers, above all because legislation defines what could be classified and managed as waste and as a resource (i.e. definition of end of waste is very critical in Italy actually). But those two are also highly uncertain since EU legislation for example takes time to be implemented in national law and incentivisation is highly connected to the economic situation in 10 years.

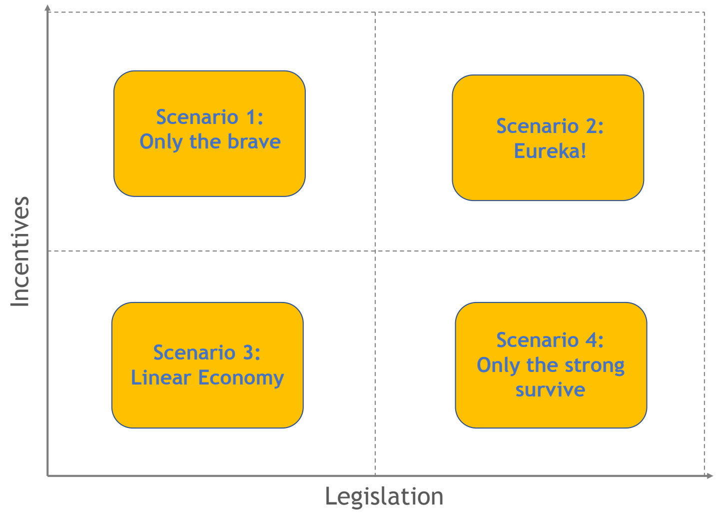

Figure 12 CIRC-scenario-matrix for Liguria

- **Scenario 1: Only the brave**

Incentives are offered and lead to the launch of new scenarios but generating uncoordinated initiatives on the territory since the legislation does not support a unified circular economy strategy.

- **Scenario 2: Eureka!**

The action is coordinated by national laws. Organisations (i.e. SMEs) not able to comply immediately could be supported by incentives, allowing their survival in the market. Adoption to CIRC measures is inevitable since the products or the process will not comply with national law and therefore lead to penalty payments or to the take-out of products from the market which will be a disruptive development for the whole organisation.

- **Scenario 3: Linear Economy**

The system remains resilient to the introduction of circular economy logics due to lacking legislation and incentives, reiterating the same consolidated production methods.

- **Scenario 4: Only the strong survive**

Organisations, SMEs in particular, will be competitive if they will be able to change and innovate their processes out of own strength.

4. Foresight scenarios for Central Europe

In this chapter we present the four scenarios for Central Europe, resulting from analysing all regional scenarios. It might be necessary to come up with new clustering categories, in order to include as many factors as possible.

4.1.1. Foresight scenarios for AM in Central Europe

Among the partners the vision for AM adoption and the driving forces that are most critical and uncertain are quite aligned. Market demand and funding/ financial support have been named several times. Others include:

- Innovative mindset
- Synergies
- Standardisation of products

Those uncertainties were used to create four scenarios that showcase the possible developments in Central Europe in 10 years.

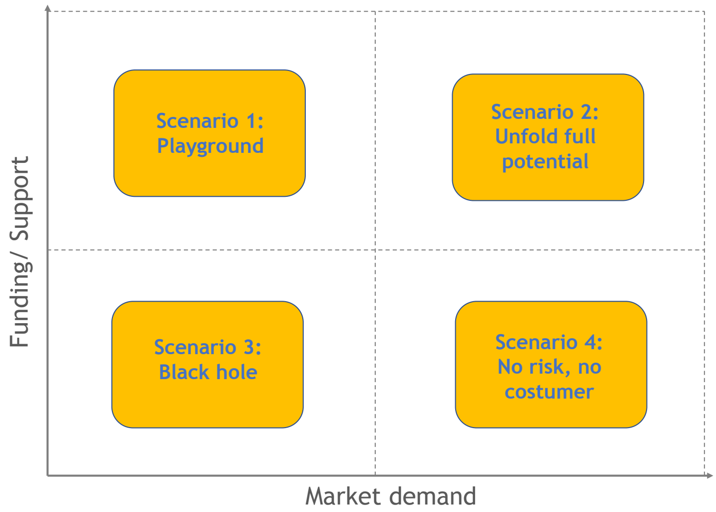

Figure 13 AM-scenario-matrix for Central Europe

- **Scenario 1: Playground**

In this scenario with a low market demand and high funding support it is expected that the adoption of AM technologies is quite low since the market doesn't demand the products and this is assumed to be the strongest driver. Since the access to funding support is quite high SMEs with highly innovative background will adopt the technologies for prototyping or in the R&D phase. In the creative industry the adoption to AM technologies is expected to be among the highest since the funding promotes the realisation of innovative and creative ideas with new manufacturing technologies (e.g. health sector).
The creation of industrial standards is usually driven by industry. Since big players (mainly OEMs) are not interested in the promotion of 3d printed products it is unlikely that standards will be available. Following the evaluation and considerations of D.T1.1.2 and D.T1.1.3 this scenario is in general very unlikely to happen. It was assessed that the regional markets are very much connected to the German market where the adoption of AM technologies started and is already quite advanced. This will act as a pull for the rest of Central Europe to join the movement.

- **Scenario 2: Unfold full potential**

Adoption of AM will take place to a high extent beyond prototyping starting with the strongest or most innovative sectors. This development will be especially relevant for well-established SMEs as much as for new companies and start-ups. Part of the development will be the build-up of a new value chain with many actors connecting on local, regional and international level. Here the role of incubators is essential.
The development of standards will be fast and extensive since OEMs demand products that comply with own and their costumer's quality requirements. This will be especially relevant in strategic sectors such as automotive, aeronautics, and aerospace.
The creation of synergies will come naturally in order to be able to fulfil the markets demand. Those will also solve challenges like a lack of human resources which might otherwise slow down the adoption in certain regions. One of the straight forward synergies will come with academia, as the key partner having the expertise. However, different measures for transfer of knowledge will have to be applied and monitored in order to be effective. Furthermore, funding for consortiums (e.g. synergies) with innovative projects will be available and will not only accelerate the adoption but also the development of the entire AM landscape.

- **Scenario 3: Black hole**

Low market demand and funding will stop the adoption of AM in most sectors. Sectors like the creative industry might still use the technologies and research organisations and universities might still work with it but in general the interest in the technology will be lost and industrial scale. Especially research

organisations are dependent on public funding which will be a further obstacle to keep exploring the opportunities. Even in niche markets the adoption will stay low since the supplying and supporting companies (like material or technology providers) will also disappear from the market or at least minimise their product portfolio. Many companies will have to rely in conventional production methods. Medical products such as organs or transplants are in many cases decoupled from the market demand and are driven more from the research and the health sector. Opportunities in the field of AM will present themselves.
Companies that already started investing will have to orientate their business to new markets that actually demand 3d printed products or return to traditional manufacturing techniques. Generally, the orientation towards other markets outside CE might be seen as an opportunity. But due to globalisation it will be very unlikely that only few markets will promote AM while others stay with traditional or other manufacturing technologies.

- **Scenario 4: No risk, no costumer**

Stronger SMEs and large companies will adopt the technology in order to meet the market demand. But in general, the adoption will be slower than in scenario 2. For those SMEs that don't have own resources to invest in these technologies this scenario will be a disruptive development for their business.
The creation of synergies will be necessary for SMEs if they want to remain competitive in the market since funding is not available. The development of standards will be driven by the market demand, especially OEMs will be involved in this process.

4.1.2. Foresight scenarios for CIRC in Central Europe

The particularities of each region and the different stage of implementation of national legislation and awareness concerning circular economy lead to a very unaligned view among the partners which driving forces are the most critical and uncertain. Between the regional partners the following have been identified:

- Market demand
- Mindset
- Funding/ Financial support
- Cost reduction
- Efficiency
- Technical support
- Knowledge/awareness
- Legislation
- Incentives

These have been further clustered into knowledge and economics related drivers and in drivers surrounding public and legal support. Since the identification of economic drivers is highly related to the knowledge and awareness by companies the exercise doesn't include them as separately. In Central Europe, therefore, *knowledge* and *public and legal support* are assumed to be the most critical uncertainties.
Those were used to create four scenarios that showcase the possible developments in Central Europe in 10 years.

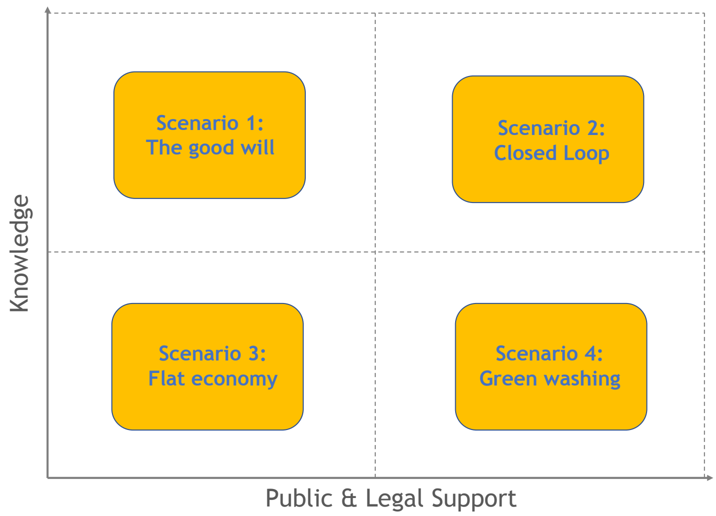

Figure 14 CIRC-scenario-matrix for Central Europe

- **Scenario 1: The good will**

A scenario which stems from high awareness and knowledge paired with low public or legal support is in general very unlikely to happen. Since broader public awareness on a certain topic usually is related to discussion of policy makers - still it will be evaluated.

Those SMEs that can afford to invest own capital in the innovation of processes and products will adopt to certain measures and those in most cases will be very effective since technical support is available. The knowledge on economic benefits will be a huge driver but is limited by the own capabilities. Micro and small SMEs will probably not be able to invest high sums with return to be expected much later.

- **Scenario 2: Closed loop**

Adoption takes pace to a very high extent in a high knowledge – high support scenario. Especially those SMEs that already invested in certain measures and are convinced about the economic benefits will be eager to invest further. SMEs will understand that circular economy is more than just recycling of waste water, materials and energy reduction. Eco-design concepts will be implemented, and new products will enter the market that fulfils not only the legal requirements but also the high standards of end-consumers. The high awareness through the public is, therefore, critical to the success of this scenario. Following this development, the change of the entire value chain will be seen with the build-up of reverse logistics and secondary raw material markets.

- **Scenario 3: Flat economy**

The lacking legal framework and incentives will lead to SMEs not adopting. This is also due to their low awareness for environmental concerns and economic benefits. The implementation of such measures or techniques will be seen only in companies that export outside of Central Europe/ Europe where a legal framework requires SMEs to comply.

- **Scenario 4: Green washing**

The legal support is favourable in this scenario and also funding and other incentives are available but lacking awareness and knowledge about the economic benefits will prevent SMEs to fully commit to circular solutions. The goal is only to reach legal compliance. In many cases SMEs will try to look green since the legal regulations in the past and present in many countries are possible to bend. Furthermore, this scenario will lead to a waste of investment due to the failure of many concepts that aim at implementing circular measures. This is related to lacking technical support and access to demonstrators.

5. Conclusions

Different scenarios were developed for the regions that are parts of the AMICE project and focusing on the adoption of AM and CIRC under different circumstances. For this exercise, each tandem of partners took part of interactive sessions in which the driving forces for adoption were analysed with respect their importance and level of certainty. In this stage is were different similarities and differences between regions appeared, given their current situation and sectors of interests.

The adoption of AM found more similarities in the driving forces between regions than in the case of CIRC. An important reason for this is the level of awareness and the current legislation framework, which is different among the regions that were analysed. In fact, legislation was identified as an important uncertainty in some regions. In these cases, the expected scenarios in ten years from now should be taken with caution since the effect of external factors might be relevant. Regardless this situation, the scenarios developed gave enough information for developing a strategy for the upcoming years, as it is presented in the next deliverable.