SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

Global and Societal Milestones

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1. Executive summary

The SAM (Sector Skills Strategy in Additive Manufacturing) project, aims to deliver together with all partners and stakeholders a shared vision and collaborative skill solutions capable to foster and support the growth, innovation and competitiveness in the Additive Manufacturing (AM) sector.

Within work package 1 there is one generic deliverable (D1.1 Glossary) and four deliverables (see Figure 1) that look individually to specific fields, thus supporting the definition of the European AM Skills Strategy. The European AM skills strategy is based on three pillars: firstly, global and societal challenges, secondly technology development and thirdly professional profiles (skills).

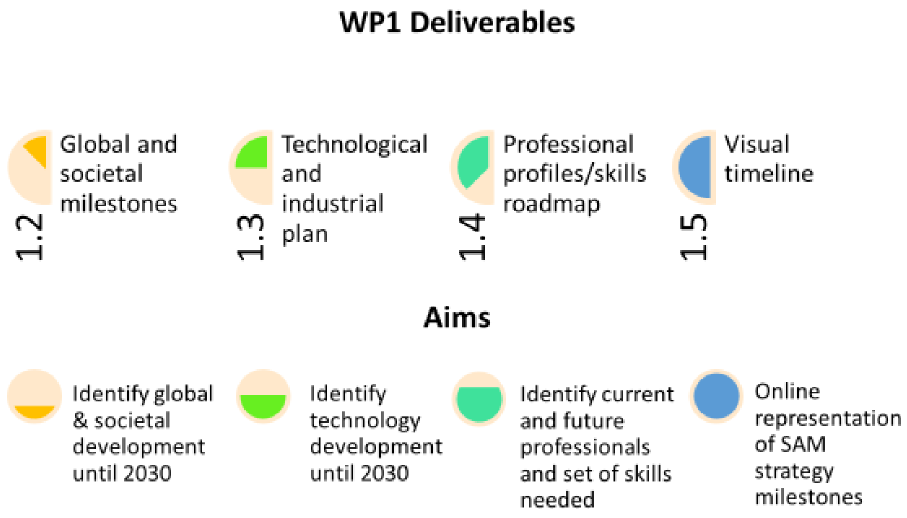


Figure 1 - Overview of WP1 results and their objectives

The deliverable D1.2 corresponds to the characterization of **Global and Societal Milestones**, which aims to identify global and societal developments until 2030, including all the transformations that can direct and indirectly impact on the Additive Manufacturing Sector and Skills and also the necessary European AM Skill Strategy to address these transformations. These transformations are usually taking place as gradual evolutions rather than sudden changes. Nevertheless, they are characterised within this report by the milestones that mark a point in time where the transformation reaches a level that impacts the demand on skills. This includes the needs of today as well.

These global and societal challenges together with technological developments (D1.3) and current professional profiles/skills roadmap (D1.4) are critical to ensure that future skills needed in AM are identified in due time, thus guaranteeing that a skillful workforce is ready when industry requires it. The results from the three WP1 deliverables will be represented graphically as a visual timeline in the AM Observatory (WP4) as relevant Technological Trends to consider until 2030.

The challenges analysed in the current document are aligned with those identified as priorities in the Europe 2020 strategy and thus reflected in the H2020 Programme, namely:

- Health, demographic change and wellbeing;
- Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the bioeconomy.
- Secure, clean and efficient energy;
- Smart, green and integrated transport;
- Climate action, environment, resource efficiency and raw materials;
- Secure societies - protecting freedom and security of Europe and its citizens.

From the list of fields listed above, the report is addressing the ones that are commonly expected to be impacted by AM Technology developments and to be used within industry, as reflected by ASTM Committee on AM technologies Standards (42) composition [1], where the subcommittees are organised to address specific segments within the general subject areas (e.g. Environment, Health, and Safety, Transportation/Heavy Machinery, Consumer, among others).

Food security is not analysed in this context, although some references are made to AM use in food industry in section 5 "Innovative and Inclusive Society".

Within the report, Global and Societal challenges, and their impact on AM in specific fields, are analysed in detail, thus making sure to align findings with European priorities, objectives and work areas. The outcome of this process led to the establishment of milestones defined in terms of technological requirements and its relationship with AM skills and other needs priorities within the next 6 months (Real case scenarios), 2 years (Short-term scenarios) and 10 years (Foresight scenarios) for the selected challenges. These findings are the baseline to define the key driving actions that shall be considered within the European AM skills strategy. Those actions refer to the linkage of AM Skills with quality, standardisation, involvement with sectoral and non-sectoral players, implementation of training according with the skills priorities, as well as the promotion of raise awareness among general public towards AM contributions to deal with the global and societal challenges.

Conclusions revealed that the use of AM within the analysed fields is strongly influenced by common challenges, that will imply the continuous need, from now on until 2030, for technological skills such as the optimization of AM processes, AM design, AM materials science, quality and post-processing. While skills on circular economy, recycling, resource efficiency management, business models and economics in AM are appearing as priorities from 2022 to 2030.

Moreover, common milestones and related technological skills throughout the different scenarios are analysed, with different levels of knowledge and depth as time progresses, linked to the enlargement of the spectrum of materials and processes in AM and the production of final parts.

Finally, the conclusions point that the identified challenges for each field, may be addressed by specific skills. For instance, in the case of health and demographic changes, aging population and personalisation are the main challenges that may be related with biomaterials and green skills for printing human body parts in bio-tissues. For citizens security, the development of AM skills is foreseen to influence the global implementation of process security for the prevention of malicious actions.

2. Introduction

SAM addresses the common vision and actions to support the growth, innovation and competitiveness of the AM sector.

The Global and Societal Milestones report, is the first deliverable of WP1, which together with the Technological and Industrial Plan (D1.3) will feed the remaining work package deliverables, namely the professional profiles/skills roadmap (D1.4) and the visual timeline (D1.5).

The present deliverable D1.2 is a critical input for the definition of the European AM skills strategy. In fact, the identification of AM Skills needs, based on global and societal developments is essential to discover gap drivers and to set objectives and supporting actions in due time to avoid shortage or lack of skilled professionals required to support innovation and industrial implementation of AM.

Moreover, D1.2 contributes to feed the AM skills "Forecast Methodology "(WP2), the "Methodology for Design and Review Professional Profiles and Skills" (WP3) and the "AM Observatory" (WP4). The estimated Milestones defined will be kept updated, as they will be integrated in the AM Observatory in the initial AM strategy – Global and Societal Pillar (see Figure 2).

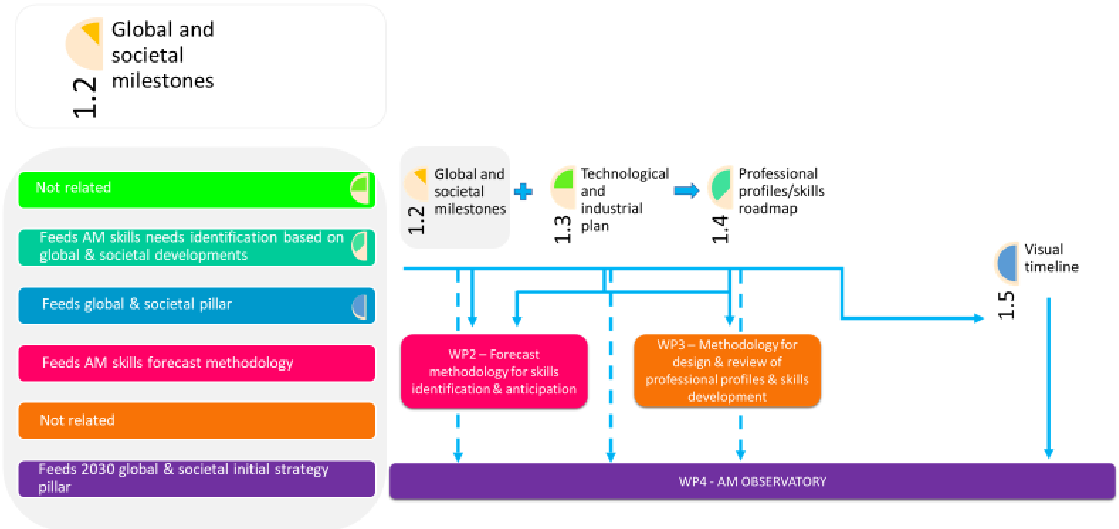


Figure 2 - Interaction flow between D1.2 and remaining project outcomes and work packages

The approach starts from the global, societal and technical trends and proceeds by the skills needs anticipation matching with professional profiles. Further on, the European AM skills strategy from 2019 to 2030, as represented by the 3 pillars/streams of the strategy and the timeline is defined. The following objectives are defined in SAM:

- Global and societal change analysis with milestones and related skills definition. (D1.2)
- Major technical developments analysis (D1.3)
- Current and Future Professional Profiles (skills) identification (D1.4),
- Continuous improvement and development process that will allow maintaining the skills strategy updated

The current report deals with the first stream of the strategy **Global and Societal Milestones** from 2019 to 2030, thus addressing all the transformations that can direct and indirectly impact on the Additive Manufacturing Sector and Skills. The objective of this document is to analyse the global and societal challenges per field, aligned with European and worldwide policies, in order to understand how external elements are related to the AM technology and can influence the skills development. This information will be used to define the baseline actions that shall be considered within the European AM skills strategy. Another point to achieve within this report, is to clarify if the identified challenges determine the need for specific AM skills in a certain period of time and for a certain sector, or if it rather determines the need to address cross- sectorial skills covered in limited scenarios, i.e. Real case (2019); Short -term (2020-2021) and/or Foresight (2022 – 2030).

3. Methodology

The methodology applied to the development of the Global and Societal Milestones Report is the result of an extensive desk research on the challenges and priorities addressed by the Europe 2020 strategy and thus reflected at European Research programmes such as Horizon 2020, the coming Horizon Europe and other key worldwide policies.

The rationale used for structuring the report consists in describing:

- **Overall European Strategy** summarizing key data on H2020 programme and considering new insights from the Horizon Europe programme (2021 to 2027);
- **International policies and agreements** like Sustainable Development Goals (2015-2030), 2015 Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC);
- **AM Specific trends/challenges/opportunities** using the AM-motion roadmap [2] as starting point to understand the relationship between AM and the actions related to Health, Aerospace, Automotive, Consumer Goods and Energy, and other visionary reports available for the remaining sectors.
- **Estimation of milestones** in terms of technological trends and required AM skills linked to identified global and societal challenges. The proposed milestones estimation is segmented into the following timeframe: Real case (2019); Short -term (2020-2021) and Foresight (2022 – 2030). In each section, the milestones are defined as important achievements to what has to be done in the future to assure AM potential deployment in different areas and sectors. Although the focus of the SAM project is therefore not so much on the milestones, but rather on the impact on the common required skills. For this reason, the requirements concerning the evolution of required technological skills, linked to the milestones, are defined for the different timeframes.
  The milestones classification is represented in a table in each section, having the following correspondence: The first column gives a descriptive name to the milestone (for later reference). The second column provides a concise description of what is the present, what is to be expected in the short term and in the long term. The third column gives an overview of the related required technological skills. The fourth column has room for other skills for the milestone, including transversal, green and digital skills.
- **Drivers of action that will be used to define the European AM skills strategy,** based on the analysis of challenges per field, milestones and required set of AM skills.

In order to have a clearer correspondence with the classical sectorial division employed in governmental strategic documents, the same classification is used in the different sections of the report, namely:

- Health demographic change and well-being
- Efficient Energy
- Smart, green and integrated transport
- Environment and efficient resources
- Innovative and inclusive societies
- Citizens Security

These Societal Challenges are also fully aligned with the new cross-sectorial Clusters approach, which is proposed for "Pillar 2 Global Challenges and European Industrial Competitiveness" within new Horizon Europe Programme (2021-2027) [3]. Proposed Clusters comprises:

- Health
- Culture creativity and inclusive society
- Civil security for society
- Digital, Industry and space
- Climate, Energy and Mobility
- Food, bio economy, natural resources, agriculture and environment

Beyond investment, another advantage of the Horizon programme and this sectorial approach is the amount of research that has been done, namely in the framework of the AM-motion H2020 project. The related AM-roadmap, developed and validated with more than 200 experts, summarises all findings and the results are reused and updated here.

The sectorial approach is indeed the most relevant for identifying the needs for the AM workforce and will have the largest impact on the AM-industry as a whole. However, a separate, short section dedicated to AM and the general public is added. While the effect on the evolution of the AM-sector is indirect and probably small, the required effort is very high.

The conclusion at the end contains the overall projected milestones relating the identified challenges in each field to the related skills development segmented into the different scenarios, which will be integrated in the timeline (D1.5) in the AM Observatory.

2. Health, demographic change and wellbeing

2.1 The overall European strategy

Health, demographic change and well-being is high on the political agenda of every government, simply because any citizen will be affected by it at some point of their life. It aims to keep people healthy, older people active and independent for longer and supports the development of new, safer and more effective interventions. R&I under Horizon 2020 contributes to the sustainability of health and care systems and to get a better health for all.

The programme vision is ambitious. In this case, sustainable means essentially affordable. The strategy is clear for that: more effective, better and cheaper treatments (less expenses), more prevention (less expenses) and keeping older people longer active more income. [4]
The following table represents some of the challenges as defined in H2020 programme.

Work area	Challenge
Market	- The rising and potentially unsustainable health and care costs, mainly due to the increasing prevalence of chronic diseases, to an ageing population requiring more diversified care and to increasing societal demands
Environment	- The influence on health of external environmental factors including climate change
Policies	- Overcome the risk to lose our ability to protect the populations against the threats of infectious diseases - Reduce health inequalities and access to health and care

[5]

Within the next framework programme, Horizon Europe (2021-2027), the strategy is defined in 3 pillars:

- Pillar 1: Open Science
- Pillar 2: Global Challenges and Industrial Competitiveness
- Pillar 3: Open Innovation

Through pillar 2 “Global and Societal Challenges of Industrial Competitiveness” the **Cluster 1 “Health**” is included.

In a nutshell, the main priorities regarding the Health sector challenges are identified by Horizon 2020 [4] [5] and Horizon Europe programmes [6] [7]. The following table shows the main priorities and important areas to be covered.

Programme	Main priorities	Objectives
Horizon 2020	Personalising health and care	– Improve our understanding of the causes and mechanisms underlying health, healthy ageing and disease; – Improve our ability to monitor health and to prevent, detect, treat and manage disease; – Support older persons to remain active and healthy; – Test and demonstrate new models and tools for health and care delivery.
	Building on the principle of openness	– Effective integration of personalised medicine approaches into healthcare services and systems to the benefit of patients and citizens; – Fighting infectious diseases and the growing threat of antimicrobial resistance; – Addressing the needs of the most vulnerable groups and the global increase of chronic diseases; – Decoding the role of environment – including climate change and air quality – on health and developing mitigating measures; – Exploring the digital potential for health innovation and healthcare, including the building of a 'European health research and innovation cloud'; – Stimulating innovation in the European healthcare domain and industry by exploring the application of advanced technologies, improve the health of the workforce and promote regulatory science.
Horizon Europe research and innovation funding	Health throughout the life course	– Better understanding of human health, specific health and care needs, and individual aspects of health promotion and disease prevention; – Innovative tools and digital solutions fostering health literacy and citizen/patient health empowerment; – Better understanding, identification, assessment and management of environmental, occupational, social and economic factors on human health and wellbeing; – Better collection, sharing, combination and analysis of environmental, occupational and human health-related data.
	Non-communicable and rare diseases	– Better prediction, monitoring, and surveillance of risk factors, early warning of health emergencies, and evidence for informed policy making; – Better understanding of diseases and their drivers as well as better methodologies for diagnosis, treatment, monitoring and outcome assessment;

		– Improved and safe health technologies and medical interventions validated and tested in clinical practice, including personalised medicine approaches; – Innovative solutions to inform reforms and transformation of health care systems, including simulation models supporting policymaking; – Methods, tools and pilots for take-up and scale-up of innovation in health care systems as well as for assessment of health system performance.
	Tools, technologies and digital solutions for health and care, including personalised medicine	-Strengthened framework with interoperable data sources and infrastructures for [Secure] sharing, access, use and analysis of real-world health data Improved and safe health technologies and medical interventions validated and tested in clinical practice, including personalised medicine approaches SDG 3 - Ensure healthy lives and promote well-being for all at all ages European Social Pillar - Everyone has the right to timely access to affordable, preventive and curative health care of good quality New health services, methodologies, technologies
	Environmental and social health determinants	-Better methodologies for assessing health outcomes, and better estimation of economic, societal and health costs
	Infectious diseases, including poverty-related and neglected disease	– Better prediction, monitoring, and surveillance of risk factors, early warning of health emergencies, and evidence for informed policy making; – Better understanding of diseases and their drivers as well as better methodologies for diagnosis, treatment, monitoring and outcome assessment; – Improved and safe health technologies and medical interventions validated and tested in clinical practice, including personalised medicine approaches; – Innovative solutions to inform reforms and transformation of health care systems, including simulation models supporting policy-making; – Methods, tools and pilots for take-up and scale-up of innovation in health care systems as well as for assessment of health system performance
	Health care systems	Data-driven tools and digital solutions for biomedical research, prevention, diagnosis, therapy, health monitoring and disease surveillance designed, developed, validated, tested and deployed in health

These priorities are fully aligned with the European Commission strategy for Health with a target impact until 2030. They present briefly the EC comprehensive strategy for Horizon Europe programme Pillar 2. Context Health care systems in the EU need to be adapted and reformed to cope with societal changes (e.g. demographic, epidemiological, technological and environmental transitions). Ageing population, increasing number of people with multiple chronic conditions, higher demand for healthcare by citizens, expensive innovative products and solutions, etc. are some of the major issues that are to be tackled under Horizon Europe scope.

The programme aims to reach specific objectives either by developing Health and Care Systems R&I Partnerships or by boosting Innovative Health Initiatives. With these two foundations the European Commission aims to reach a goal of boosting research in policy, uptake and scale-up of innovations to accelerate transformation of national/regional health care systems and accelerate the development of safer and more effective innovative healthcare interventions that respond to unmet public health needs, and that can be taken up by healthcare systems. [7]

2.2 AM specific trends/challenges/opportunities until 2030

One of the key strategies in healthcare is personalisation. This requires, so-called mass-customisation, where slight variations of products (e.g. medicine, medical devices, or prostheses) are tailored to each individual patient. At this moment, AM is the most cost-effective way to produce the mechanical components of individualised products.AM presents transformative potential manufacturing methods in the health sector being able to provide patient-specific solutions (e.g. from smart wheelchairs to orthopaedic implants), thus enabling Personalised Medicine approaches, which in the medium term can be affordable for the majority of the population.

The earliest example is probably the in-the-ear hearing aid (see Figure 3). Since 2000, Phonak and Siemens, together with Materialise started with the development of the technology and the related tools to realise this and in a later phase, roll it out to the market. Even before the introduction of AM, the hearing aids were patient-specific, the manufacturing was purely based on manual craftsmanship. So, the traditional method was already an example of mass-customisation. With the introduction of AM, the craftsmanship was replaced by engineering.

Figure 3 - Patient-specific hearing aids by AM

Other early examples of mass customisation and AM in healthcare are the dental applications: the dental drilling guides for implant placement [8] and Invisalign [9]; a printed (transparent) orthodontic device. This required a completely different market approach since mass-customisation is not yet well established and the required supply chains are not yet in place, unlike in the hearing aid market. Since then a number of specific health-related applications have appeared and some of them have become even standard practice.

Besides those initial examples showed before, there is a huge amount of effort invested in AM with respect to the healthcare sector. However, the application of AM to this sector is happening slowly. There are several reasons for this:

- For a long time, there was no *technology pull* in the healthcare sector with respect to AM. It was unknown and the applications are not obvious for the experts in the field. Therefore, the applications came mainly from using existing AM technologies in the medical sector. Nowadays this has changed. Medical requirements are now part of the research agenda in AM, leading to significantly more potential applications of AM in the healthcare sector.
- The medical industry has only limited experience with mass customisation. The industry has focused on mass production. The logistics involved are much simpler. They do not require the capturing of patient specific data (e.g. scanning), processing it manufacturing the individualised product and getting it to the right person. Developing (semi)automated systems for that takes time and is expensive. Thanks to the AM hype a few years ago, there is already much more awareness, linked to an educational work, about the possibilities of AM in the medical world.
- The certification of new medical products is tailored more towards mass production of large series of products, although it is difficult to have individualised products approved. This has a serious effect on the time-to-market of individualised products. Also, this is changing albeit slowly. The fast evolution in IT is speeding this up as well. Generic platforms are emerging to enable individualised products (Manufacturing but also the complete logistics around it).
- The medical market is scattered and complex, especially in Europe. Medical insurance is organised regionally and negotiations for coverage of treatments need to be done within each region separately. Even within certain countries, there are different insurance systems in place. It remains an extra barrier, especially in Europe, to bring new medical technology to the market.

The AM environment in the healthcare sector has changed and is still changing. There is a wide variety of research areas today and new applications are being developed. Apart from the personalisation of healthcare, there is not really a global strategy set out or centrally organised for AM in healthcare. The choice for AM in personalisation is however obvious, since there is no cost-effective alternative.
Apart from being a conservative (mainly because of patient safety) industry, the medical sector is also very competitive. Managing IP (Intellectual Property) and the related rights (IPR) is essential in this market to protect long term investments and ensuring competitiveness. Consequently, the individual strategic agendas of the industrial players are not made public.
Academic research is more open but typically still at lower TRL-levels (Technology Readiness Levels form a classification not commonly used in healthcare), although basic research is also done on an industrial level, much more than in other sectors. It is mainly on this area that this section is focusing on. The basic research probably has the most predictive value for the new applications on the long term.
There are several ways to make a classification of AM in healthcare. The list below has become a standard for AM (Wohlers report, AM-motion roadmap, America Makes):

- Pharmaceutical products: Drugs, Drug delivery systems; **(AM medical products and tools)**
- Medical instruments: surgical guides and tools, case specific surgical models' prostheses and orthoses, etc.; **(AM medical products and tools)**
- Medical implants: dental implants, biodegradable implants, orthopaedic and cardiovascular implants, 4D Biocompatible Implants, etc.; **(AM implants and prothesis)**
- Assistive and Prosthetic devices: Orthoses, Prosthetic limbs, advanced hearing aids, Exoskeletons, bespoke assistive devices, insoles, dental aligners, tweezers, etc.; **(AM medical products and tools)**
- Living tissue and organs: Bioprinting, can offer innovative solutions in the field of tissue engineering (i.e. printing biological tissues and potentially even organs) for patient-specific regenerative medicine and drug testing. **(Living tissues and organs)**

This is indeed a very rough and somewhat unconventional classification in healthcare, where usually the split up is done according to medical discipline: Cardiology, orthopaedics, stomatology… With the new classification, it is easier to map the expected technological advances.

The topics in the different sub-sectors are not all at the same M*arket Readiness Level*, which makes difficult to predict when they will all be fully in place. There is a good overview of what to expect in the coming years developed during the AM-Motion project. It is depicted in Figure . It shows the current initiatives together with a rough planning: short (2019-2021), mid (2022-2024) and long term (beyond 2024) research.

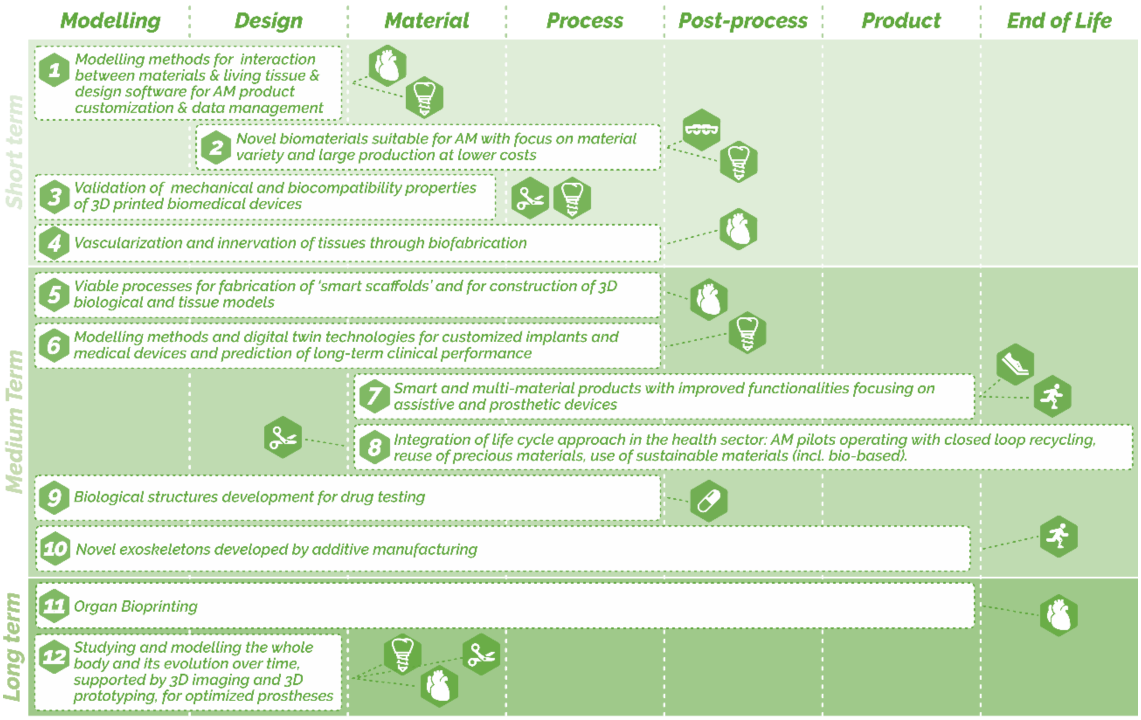


Figure : Gap analysis in the health sector in the short, medium and Long terms (Source: AM-motion roadmap)

The gaps identified (see Figure 4) were also connected with the health care target products (see Figure 5).

N	Action Name	Type of Activity	TRL		Target Products						
			Initial TRL	Target TRL	Assistive and Prosthetic Devices	Surgical Guides, Tools & Models	Medical Implants	Other Dental Products	Other Customised Products	Living Tissues & Organs	Pharmaceuticals Products
1	Modelling methods for interaction between materials & living tissue and Design Software for AM product customization and data management	RIA	3-4	5-6	⬢	⬢	⬢			⬢	
2	Novel biomaterials suitable for AM with focus on material variety and large production at lower costs	IA	4-5	6-7		⬢	⬢	⬢	⬢	⬢	
3	Validation of mechanical and biocompatibility properties of 3D printed biomedical devices	IA	5-6	7-8	⬢	⬢	⬢	⬢		⬢	
4	Viable processes for fabrication of 'smart scaffolds' & for construction of 3D biological & tissue models	RIA	1-2	3-4						⬢	⬢
5	Vascularization and innervation of tissues through biofabrication	RIA	3-4	5-6						⬢	⬢
6	Modelling methods and digital twin technologies for customised implants and medical devices and prediction of long-term clinical performance	RIA	2-3	4-5		⬢	⬢			⬢	⬢
7	Smart products with improved functionalities	RIA	2-3	4-5	⬢	⬢	⬢	⬢		⬢	
8	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)	RIA	2-3	4-5	⬢	⬢	⬢	⬢			
9	Biological structures development for drug testing	RIA	2-3	4-5						⬢	⬢
10	Novel exoskeletons developed by additive manufacturing	RIA	2-3	4-5	⬢						
11	Organ Bioprinting	RIA	2-3	4-5						⬢	
12	Studying and modelling the whole body and its evolution over time, supported by 3D imaging and 3D prototyping, for optimized prostheses	RIA	1-2	3-4	⬢	⬢	⬢			⬢	⬢

Figure 2

Relation of the gaps with the AM products for the Health Sector (Source: AM-motion roadmap)

2.3 Resulting milestones estimation

The method applied in this section to come to the list of milestones for the Health Sector was based on several sources, starting from the gaps and actions identified in the roadmap of AM-motion, the Wohler's report to visionary articles to identify current (academic) research fields and the maturity level within each area.

The "AM-motion" AM roadmap is the only report, based on a systematic, scientific and objective approach that focus the gaps and actions per sector and value chain segment to foster AM development and market uptake. Those gaps and actions identified are based on a consensus among a large group of experts (more than 200).

An article published in January 2020 [10]. that gathers the opinion of 100 additive manufacturing leaders on how 3D printing will develop during the next ten years, which reveal as general trends simply process maturity, integration into standard manufacturing and emerging new applications.

The Wohler's report [11] , which provides an annually update on the global state of the industry, for 25 years. While the report (and similar ones) also report on what is happening at academia in research.

Moreover, new visionary documents are being published constantly, albeit more moderate and less detailed than in the past. A nice example is "Future of 3D printing, a glimpse at next generation making" [12], which mentions in the section on medicine, bio-printing, prosthetics and drugs as examples.

The following Milestones were identified under 3 distinct areas: Design and Modelling, Materials and Production Process.

1) Design and Modelling

Milestone: **Modelling methods for interaction with Human body**

As mentioned above, AM is being successfully implemented in the healthcare sector, however there is a wide variety of research areas to be developed. Design and Modelling is one of the most relevant areas for being able to provide patient-specific solutions. Customization on medical applications requires design for unique shapes of individual patients. With the design freedom provided by AM, medical devices or components can be designed, modified and printed in order to perfectly interface with the patient.

2) Materials

Milestone: **Materials for AM applicable to health**

As in any other sector, materials represent a significant part of AM production. In health the most used materials are metallic, plastic, ceramic, electronic, biological, and composite [13]. Although there is a wide range of materials used in additive manufacturing for the health sector, the finding of new materials has been identified of most relevance in this sector, since it wides up the range of AM applications in this field. A concrete example is the application of AM to the regeneration of complex tissues and organs, which is not yet feasible since there is an unavailability of appropriate biocompatible materials to enable this progress. [14]

3) Production Process

Milestone: **Bio-Printing**

The improvements on the AM processes used, is one of the key challenges of bioprinting. One of the greatest advances leading to 3D bioprinting was the development of biomaterials, cells and supporting components for the fabrication of functional living tissues. Various bioprinting technologies have been developed and utilized for applications in life sciences, ranging from studying cellular mechanisms to constructing tissues and organs for implantation, including heart valve, myocardial tissue, and blood vessels. However, bioprinter technologies need to increase resolution and speed and should be compatible with a wide spectrum of biocompatible materials. Higher resolution will enable better control in the 3D microenvironment.

Milestone: **Integration of life-cycle analyses approach in health**

The health sector is challenged to decrease its environmental impact, but at the same time ensuring affordable and qualitative medical care [15]. This is also true in the case of additive manufactured components/elements used in the health sector. Analyzing the AM sustainability assessment, the three dimensions of sustainability (environment, economics and society) of AM need to be taken into consideration, especially for the health [16]. For example, when looking at implants manufactured by AM all these dimensions need to be considered and, in order to see a higher uptake of AM in the health sector, this integration is critical.

Milestone: **Smart innovative products**

The use of AM in the health opens up all sort of new possibilities when it comes to health care, being by manufacturing new innovative tools for surgeries allowing surgeries that were impossible to do in the past to be possible with the support of AM [17] or by allowing developing new products that can support the treatment of specific diseases/conditions [18, 19] or just, like we saw during the COVID-19 situation, allowing access to new products that can be used in fighting new diseases [20].

As a result, the defined milestones are defined as important achievements to what has to be done in the future to assure AM potential deployment on the health sector. Global and Societal milestones (see Table 1) have been identified until 2030 to overcome the identified challenges related to the Health Sector.

List of challenges in Health field: digital solutions for health care, personalised medicine (personalized prosthesis, devices and instruments), tissue and organ bioprinting.

Table 1 - Milestones and related skills in the Health Sector**Milestones (technology related)**	**Timeline (3 scenarios)**	**Related technological skills**	**Other skills (e.g. transversal digital, green)**
Modelling methods for interaction with Human body	[2019] Real and [2020-2021] Short term (Methods of interaction between materials and living tissue) [2022-2030] Foresight (Studying and modelling of the whole human body and its evolution over time)	Modelling for AM Design for AM Simulation Software Biomaterials Materials Science Metallurgy Structural integrity	Spotting opportunities to create value Creativity Vision Problem Solving
Materials for AM applicable to health	[2019] Real and [2020-2021] Short term (Novel bio-materials suitable for AM) [2019] Real and [2020-2021] Short term (Large production at lower costs) [2019] Real and [2020-2021] Short term (Validation of mechanical and thermal properties of existing materials)	Biomaterials Materials Science Metallurgy Structural integrity Value chain Production industry techniques and methods	Spotting opportunities to create value Creativity Vision Working with others Problem Solving Planning and Organisational skills Communication Circular economy
Bio-Printing	[2022-2030] Foresight (AM applied tom printing human body parts in bio-tissues)	Standards for Parts and Processes Modelling for AM Design for AM Simulation for AM Biomaterials Materials Science Metallurgy Structural integrity	Spotting opportunities to create value Creativity Vision Working with others Problem Solving Planning and Organisational skills Communication Learning through experience

		Production industry techniques and methods AM processes Quality control in AM Inspection of AM parts	Resource efficiency management Circular economy
Integration of life-cycle analyses approach in health	[2022-2030] Foresight (Operation with close loop recycling, reuse of precious materials and use of sustainable ones)	Integrated production Value chain Production industry techniques and methods AM processes Interaction between several production processes Design Modelling Data analytics related to AM	Working with others Problem Solving Planning and Organisational skills Communication Eco-Design Resource efficiency management Business for AM Green awareness Circular economy Recyclability of AM parts Simulation Software
Smart innovative products	[2022-2030] Foresight (Novel multi-material products with improved functionalities focusing on assistive and prosthetic devices) [2022-2030] Foresight (Novel skeletons developed by AM)	AM processes Quality control in AM Modelling for AM Design for AM Materials Science Materials for AM	Spotting opportunities to create value Creativity Vision Simulation Software

Looking at the challenges, milestones and set of skills identified and justified along this section, it is possible to infer that the AM skills strategy to be adopted shall address key driving actions linked to: quality, standardisation, implementation of AM training and involvement of relevant sectoral players as explained in the textbox below.

The required EUROPEAN AM SKILLS STRATEGY shall consider…

- linking training development and standardization activities to guarantee the quality and alignment of standards of Health parts/products produced.
- linking stakeholders of the AM value chain, in order to tackle the range of skills needed.
- implementation of different training methodologies and tools for the different qualifications levels in AM, in order to tackle the diversity of skills required, including technological, green and digital.
- involving sectoral stakeholders, including from the Health Sector in the identification and validation of necessary skills/qualifications.
- ensuring that Health sector and/or AM process specific skills/qualifications are identified and addressed.
- continuous monitoring of AM technology developments and it is impact on the Health sector and for the overall people wellbeing.
- raising awareness of the general public, including children, non-manufacturing professionals and students towards the AM advantages /contributions for Health and wellbeing.

3. Efficient Energy

3.1 The overall European strategy

The EU aims to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions. This objective is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement. The 2030 climate and energy framework includes EU-wide targets and policy objectives for the period from 2021 to 2030. Key targets for 2030 are [21]:

- At least 40% cuts in greenhouse gas emissions (from 1990 levels)
- At least 32% share for renewable energy
- At least 32.5% improvement in energy efficiency

In this sense, one of the prior challenges in Europe is reacted to energy as it is needed to obtain and to ensure a "secure, clean and efficient energy".

This global challenge is also included in the draft Horizon Europe programme proposed by European Commission for the 2021-2027 period under Pillar 2 (Global Challenges and Industrial Competitiveness) and so-called "Climate, Energy and Mobility" cluster.

The Energy Challenge is needed to move from the current resources and to promote a more reliable, sustainable and competitive type of energy, including renewable. However, there are some problems such as limited amount of resources. In addition, there is a growing demand of energy and climate change. In fact, reducing overall energy consumption and its carbon footprint is a great societal challenge of contemporary society.

Aimed energy transition is underpinned by the EU2020 and 2030 energy and climate objectives and is part of the longer-term EU strategy for the emissions reduction by 2050 (80-95% compared to 1990 levels). Energy is a top priority for the European Commission and the ambitious is to become 'the world number one in renewable energies' [22].

According to the Horizon 2020 [23], there are several challenges to be faced to achieve a secure, clean and efficient energy in Europe (see Table 2).

Table 2 - H2020 working areas and challenges (adaptation for Efficient Energy)

Work area	Challenge
Energy consumption	- Reduce energy consumption - Reduce carbon footprint
Sources and environment	- Reduce carbon footprint - Employ alternative fuels and mobile energy sources - Achieve a low-cost and low-carbon electricity supply
Knowledge and technology	- Obtain new knowledge regarding the exploitation sources and the sustainable use of the energy - Employ new technologies to achieve a safe, clean and efficient energy - Promote no-nuclear energy research - Promote ICT innovation related activities applicable to energy
Management	- Achieve a European electricity grid cohesive and smart - Apply a robust decision making and achieve a public engagement
Market	- Acceptance of the energy and ICT innovation by the market

On the other hand, the main priorities regarding the Energy challenges are identified by Horizon 2020 programs [23]. The following table shows the main priorities and the most important areas to be covered.

Table 3 - Horizon Europe priorities and objectives (adaptation for Efficient Energy)

Main priorities	Objective	Key areas to be focused on
Energy efficiency	-Reduce the primary energy consumption by 2020 and 2030	Research and demonstration activities focused on buildings, industry, heating and cooling, energy related product and services, ICT integration and telecom sector
Low Carbon Technologies	- Develop cost-effective and resource-efficient technologies to decarbonise the energy system - Develop secure energy supply - Complete the internal market of energy	Research activities in Photovoltaics, Concentrated Solar Power, Wind energy, Ocean Energy, Hydro Power, Geothermal Energy, Renewable Heating and Cooling, Energy Storage, Biofuels and Alternative Fuels, Carbon Capture and Storage.
Smart Cities & Communities	- Develop urban areas in a sustainable way by the use of new, efficient and user-friendly technologies and services - Achieve commercial-scale solutions with a high market potential	Research and Development and Implementation in Energy, Transport and ICT areas.

These priorities are fully in line with the "areas of intervention" foreseen for "Climate, Energy and Mobility" Cluster in Horizon Europe.

Climate, Energy and Mobility	• Climate science and solutions • Energy systems and grids • Communities and cities • Industrial competitiveness in transport • Smart mobility	• Energy supply • Buildings and industrial facilities in energy transition • Clean, safe and accessible transport and mobility • Energy storage

Figure 3 – Areas of Intervention in Cluster Climate, Energy and Mobility

Moreover, the 2015 Paris Agreement, which is an agreement within the United Nations Framework Convention on Climate Change (UNFCCC), set the priority to invest in a low-carbon innovation. In addition, the European Commission, in the "Clean Energy for All Europeans" package related to energy legislative framework [24], aims to achieve three global goals [25]: *(i) energy efficiency first, (ii) Europe as a leader in renewables, and (iii) a fair deal to consumers.* It will encourage the creation of the *Energy Union,* which its strategy has a renewable energy; smart energy systems; energy efficiency and Carbon Capture Utilization and Storage (CCUS) as the core priorities regarding low-carbon energy sectors.

The new energy legislative framework enables to fix new targets (see Figure 7) for the European Union for 2030 in order to improve Europe´s industrial competitiveness, boost growth and jobs, tackle energy poverty and improve air quality. .

Figure 4 - Agreed headline targets for 2030 framework for Energy and Climate

The Strategic Energy Technology (SET) Plan has been the research and innovation pillar of the EU's energy and climate policy since 2007. This Plan was revised in 2015. Figure 8 below shows the ten key actions of the integrated SET-Plan *[26]*.

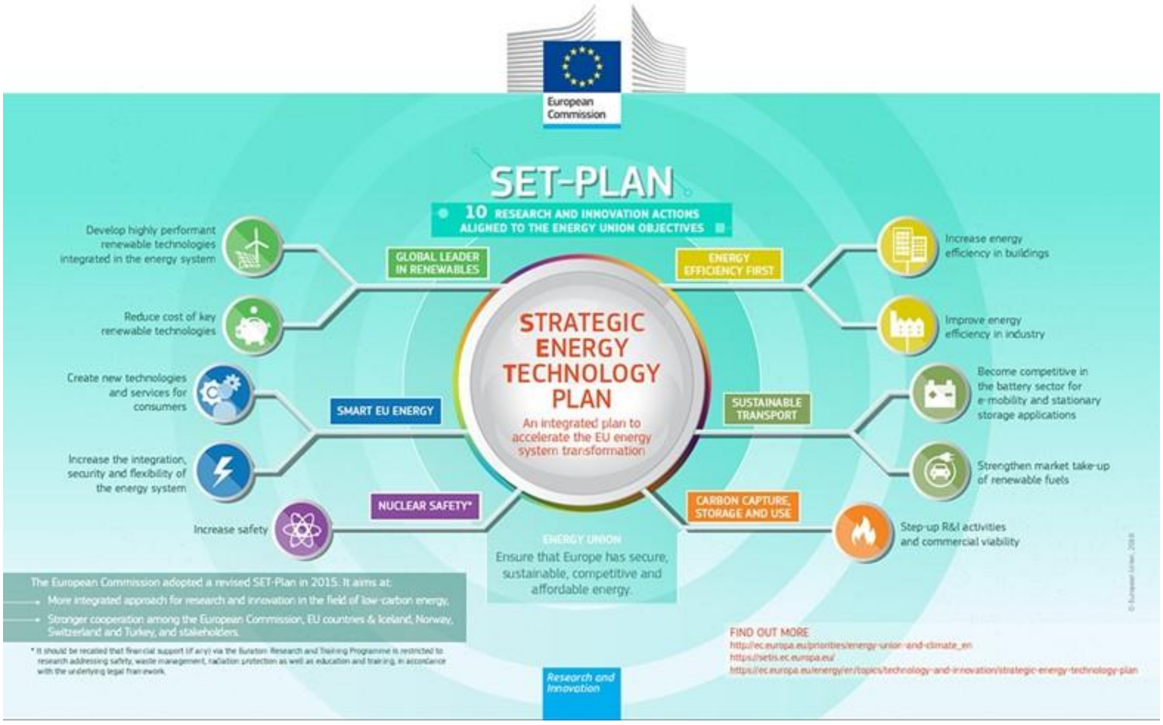


Figure 5 - Scheme of the ten key actions of the integrated SET-Plan5

3.2 AM specific trends/challenges/opportunities until 2030

A recent research analysed the potential effect of AM on the global energy demand up to 2050. Four scenarios were drafted including extended versus limited globalisation and limited versus extensive adoption of AM technologies [Verhoef et al, 2018]. Authors concluded that AM can potentially decrease energy demand by at least 5% and as much as 27%, depending mainly on its the widespread implementation and can contribute decisively to achieve the aimed energy targets. Even with a lower degree of implementation, the energy saving impact of AM is remarkable and demands more attention and activation in energy and innovation policies. [27]

Like other sectors, the energy sector has the challenges of reducing capital expenditure and to simplify and speed up the supply chain. AM addresses these issues in both conventional and new energy fields. Research and Markets reported in August 2018 revealed that research activities developed AM products for energy applications and future products, and conclude that AM can significantly boost efficiency, lower capital and operation costs and reduce time-to-market for energy companies. The report states this clearly:

"*The redesign of energy product supply chains allows for local manufacturing at (or near) the client location to become a reality. This entails not only the faster replacement of components, but also the introduction of newer and lighter materials). With an increasing push from product manufacturers and the increasing adoption by energy companies, several new standards and regulations are expected to come into place in order to integrate Additive Manufacturing into the energy industry. With Additive Manufacturing reducing product costs by 40% and the time to market by one-third, it is expected to make a significant contribution toward the energy industry in the future*." [28]

In this line, SIEMENS Energy, a pioneer and leader in the industrialization of AM, thinks that this technology brings huge opportunities to the energy industry by enabling new manufacturing and repairing possibilities. This company is already implementing AM to develop new aero-derivative, gas and steam turbines and compressors. They claim that these components can be designed faster, with more flexibility, improved materials and optimized efficiency). Therefore, besides reduced time-to-market of new and more efficient parts, AM enables quick upgrading of existing assets (**repair of components by AM**). [29]

Additional key drivers for the energy sector for the adoption and development of AM technologies include:

- Improve fuel efficiency and overall energy usage.
- Reduction of emissions
- Complex parts
- Life cycle costs
- High performance materials **(new and improved materials)**
- New opportunities for product development process
- Improve maintenance, repair and overhaul processes
- Reduction of production costs

In this context, the following applications areas of AM technologies in energy sector have been identified:

- Production of complex parts with high accuracy and improved material properties for the use in power turbines (**more efficient components**).
- Repair and production of more efficient parts for industrial gas turbines (**repair of components by AM**).
- Manufacturing of components enabling quick upgrading of part design.
- Rapid prototyping and on-site production of Oil and Gas industry metal and large parts (**on-site production of spare parts)**.

- Manufacturing of more efficient and innovative valves (intricate shapes, hollow structures, woven meshes,…) (**more efficient components**).
- Manufacturing of wind turbine components (**more efficient components**).
- Manufacturing of components for new ocean energy systems (**more efficient components**).
- Chemical injection stick tools and nozzle tools.

Moreover, AM can affect to the energy demand in industry in two ways [30]:

- Simplification of the supply chain, eliminating the production of components at different sites, since the final product can be manufactured near the end. On-demand production will be established. Thus, energy consumption during transportation will be reduced. In addition, energy consumption needed for the extraction of materials will be reduced as the needed amount of raw material as well as waste material decrease.New product will be developed with require less energy during their lifetime. As example, products with new designs can have improved energy efficiency. Parts which are light weight for aerospace industry will reduce fuel consumption, etc. It is estimated that between 5% and 25% energy will be saved by 2050 in comparison with current baseline in the aerospace sector due to the weight reduction achieved by new AM designed parts. In the construction sector energy savings between 4 and 21% will be achieved due to feedstock reduction and saving during use phase.

The following figures from AM-Motion shows AM gaps for short (2019-2021) , mid (2022-2024) and long terms.

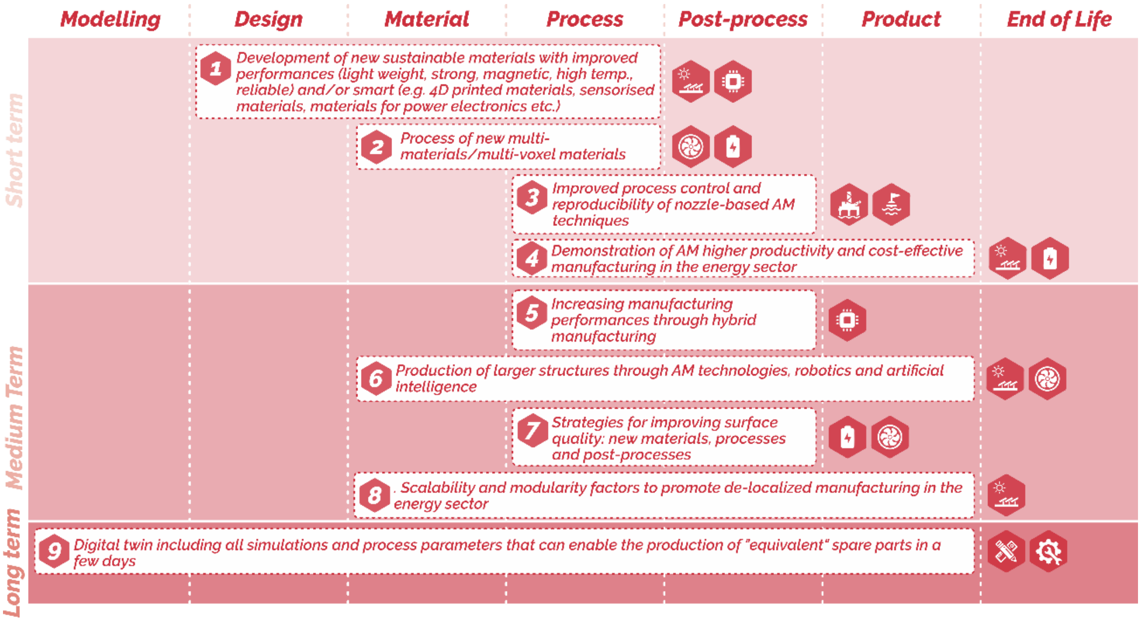


Figure 9: Gap analysis in the energy sector in the short, medium and Long terms (Source: AM-motion roadmap)

N	Action Name	Type of Activity	TRL: Initial TRL	TRL: Target TRL	Turbine Parts	Oil and gas industry products	Renewable Energy industry components	Energy storage	Electromechanical and 3D electronic components	Floating Platforms components	Concept modelling, prototyping and design	Spare parts & repair
1	Development of new sustainable materials with improved performances (light weight, strong, high temperature, reliable) and/or smart (e.g. 4D printed materials, sensorised materials etc.)	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
2	Process of new multi-materials/multi-voxel materials	RIA	2-3	4-5	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
3	Improved process control and reproducibility of nozzle-based AM techniques	IA	4-6	7	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
4	Demonstration of AM higher productivity and cost-effective manufacturing in the energy sector	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
5	Increasing manufacturing performances through hybrid manufacturing	IA	5	6-7	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
6	Production of larger structures through AM technologies, robotics and artificial intelligence	RIA	4-5	6	⬢	⬢	⬢	⬢		⬢	⬢	⬢
7	Strategies for improving surface quality : new materials, processes and post-processes	IA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
8	Scalability and modularity factors to promote de-localised manufacturing in the energy sector	RIA	1-3	4-5		⬢	⬢	⬢		⬢		⬢
9	Digital twin including all simulations and process parameters that can enable the production of "equivalent" spare parts in a few days	IA CS	5	6-7							⬢	⬢

Figure 60- Relation of the gaps with the AM products for the Energy Sector (Source: AM-motion roadmap)

3.3 Resulting milestones estimation

Having in mind, on one hand the energy related challenges, demanding targets and environmental policies and on the other hand the huge potential of AM to reduce energy consumption, it is very likely that in the following years many industrial companies from the oil and gas, land based energy turbines, wind turbines, energy storage and off-shore sectors will successfully develop and implement new AM based solutions. This is already being done by different key players and certification entities like DNV, Lloyd's Register, among others. A good example is a recent Joint Industry Project (JIP) where different energy operators, contractors and fabricators have determined requirements to introduce AM components in Oil and Gas related applications. They have explored technical and economic feasibility of manufacturing and repairing several components, benefits of using AM, certification paths and skill needs. In June 2019 they come up with a "Guideline for production-ready parts".

After the overall analysis of the energy related societal and global challenges and industrial initiatives, the following milestones (see Table 5) and related skills have been identified until 2030 in the field of Energy.

The Milestones were identified for the areas of Production Process and Materials, as follows:

1) Production process
Milestone: Development and industrialization of more efficient components (power turbines, wind turbines, valves, tools)

It has been reported that AM will significantly contribute to the development and industrialization of more efficient components. Regarding the improvements in terms of production process, this can be achieved by enabling new and optimised manufacturing possibilities as well as repairing capabilities. Here, the freedom of design provided by AM processes can play a role by improving countless heavy or less-than-aerodynamic components for the energy sector. These components can be designed faster, with more flexibility, improved materials and optimized efficiency. Moreover, AM enables quick upgrading of existing assets (by reparability, reusability and recyclability), contributing to a more efficient production.

Milestone: Repair of components by AM

AM is used with a wide range of benefits when compared to traditional manufacturing. One major benefit is the reduction of production lead time due to the application of AM to repair of manufacturing components. [31] In the Efficient Energy field, AM is mainly applied to repair of components of gas turbine [32] parts and is foreseen as a relevant milestone in this field, since the technological increase in this field will certainly allow AM application to more parts of the Energy system.

Milestone: On-site production of spare parts

AM has potential to transform the supply chain of different sectors, by enabling on-demand, on site, spare part manufacturing, which removes the need to storage of spare parts in warehouses and reducing wait time of parts. This technology has already proven its impact on the maritime industry, architectural and aerospace, in which can enable lead-time reduction to deal with supply issues around titanium forgings (typically 12+ month lead times) and also the introduction of newer and lighter materials. With this increasing push from product manufacturers and the increasing adoption of AM techniques, it is expected a significant contribution toward the energy industry in the future.

2) Materials

Milestone: New and improved materials

Materials take an important role in AM, since there are many different that use different kinds of feedstock, and like other fields Efficient Energy also benefits from the developments made in terms of materials. The trend of development in terms of new materials is forecasted to have the following impact: Quality of parts produced; Innovative structures production; Cost reduction of parts produced; Reduction of manufacturing energy; New parts with innovative characteristics; Wide applications in reconditioning of damaged components; Reduction of feedstock; amongst others. [33]

Although the idea of “Develop Materials” or “Create Materials” by AM is highlighted in some studies [34], a series of scientific, technological and engineering problems remain to be solved in future. Being so this milestone was identified to have a significant impact on Efficient Energy field.

List of challenges in the Energy field: reduce energy consumption, reduce greenhouse gas emissions, increase the use of renewables and sustainable resources, increase energy efficiency, reduce manufacturing costs and simplify and speed up the supply chain, extend the life of products and materials (circular economy).

Milestones (technology related)	Timeline (3 scenarios)	Related technological skills	Other skills (e.g. transversal, digital, green)
Development and industrialization of **more efficient components** (power turbines, wind turbines, valves, tools)	[2019] Real case and [2020-2021] Short term (small size and complex components of valves, turbines …) [2022-2030] Foresight (large size components – anchors, wind turbine blades …)	AM processes Simulation Design for AM Structural integrity Post-processing Non-destructive testing Certification and validation Ability to think in 3D Standards for parts	Spotting opportunities to create value Creativity Vision Problem Solving Eco-design part
Repair of components by AM	[2019] Real case and [2020-2021] Short term	AM processes Post-processing Non-destructive testing Certification and validation AM part inspection Tolerances/testing/quality control/methodology Robotics/automation AM equipment acquisition	Spotting opportunities to create value Creativity Working with others Resource efficiency management Green awareness Eco-Design Circular economy System development for automated repairing Problem Solving
New and improved materials	[2019] Real case and [2020-2021] (new sustainable materials with improved performance: lightweight, strong, magnetic, high temperature) [2022-2030] Foresight (smart materials: 4D printed, sensorized, for power electroncis).	AM processes Structural integrity Materials analysis and characterisation Certification and validation Materials development (harsh environments, high temperature,) Metallurgy Materials for AM	Vision Creativity Problem Solving
On-site production of spare parts	[2020-2021] Short term (small size polymeric and metallic parts) [2022-2030] Foresight (large size metal parts	AM processes Post-processing Non-destructive testing Certification and validation Tolerances/testing/quality control/methodology AM equipment acquisition	Spotting opportunities to create value Planning and Organisational skills Learning through experience Working with others New business and service models: distributed manufacturing, connected value chain

The identified and justified milestones throughout this section reflect the important achievements to be done in the future in terms of skills development to assure AM potential deployment for the Energy Sector. Looking at the challenges and set of skills required it is possible to infer that the AM skills strategy to be adopted shall address key driving actions linked to: quality, standardization, implementation of AM and involvement of relevant sectoral players as explained in the text box below.

The required EUROPEAN AM SKILLS STRATEGY shall consider…

- linking training development and standardization activities to guarantee the quality and validation of the parts produced, thus aligned with the defined standards.
- linking stakeholders of the AM value chain, in order to tackle the range of skills needed.
- implementation of different training methodologies and tools for the different qualifications levels in AM, in order to tackle the diversity of skills required, including technological, green and digital.
- involving sectoral stakeholders, including from the Energy Sector in the identification and validation of necessary skills/qualifications
- ensuring that Energy sector and/or AM process specific skills/qualifications are identified and addressed
- continuous monitoring of AM technology developments and it is impact on the Energy sector
- raising awareness of the general public, including children, non-manufacturing professionals and students towards the AM advantages /contributions for Energy Efficiency.

4. Smart, green and integrated transport

4.1 The overall European strategy

One of the priorities identified for the Horizon 2020 programme is to support Europe in achieving a transport system that is resilient, resource efficient, climate and environmentally friendly, safe and seamless for the benefit of all citizen, the economy and society. This priority is related to the objectives of the Societal Challenge "**Smart, green and integrated transport**" [35].

The following list shows the activities identified in Horizon 2020 for this Societal challenge:

a) Resource efficient transport that respects the environment. The aim is to minimize transport's systems' impact on climate and the environment (including noise, air and water pollution) by improving its efficiency in the use of natural resources, and by reducing its dependence on fossil fuels and energy imports.
b) Better mobility, less congestion, more safety and security. The aim is to reconcile the growing mobility needs with improved transport fluidity, through innovative solutions for seamless, inclusive, affordable, safe, secure and robust transport systems that make full use of modern information and communication technologies (ICT) capabilities.
c) Global leadership for the European transport industry. The aim is to reinforce the competitiveness and performance of European transport manufacturing industries and related services on global markets including logistic processes and retain areas of European leadership (e.g. such as aeronautics).
d) Socio-economic and behavioural research and forward-looking activities for policy making. The aim is to support improved policy making which is necessary to promote innovation and meet the challenges raised by transport, including the internalization of external costs, and the societal needs related to it.

Looking at these activities and the priorities of the AM sector it is possible to relate/connect these activities and a possible impact, being it direct or indirect, to the AM sector. This relation will be shown and discussed in the following sections. However, in order to relate these activities with AM it is important to, first, establish a relation between the presented Societal Challenge and the Transport Sector, since this is the industrial sector that will have a higher impact/involvement in this Societal Challenge. The Transport sector is fundamental to EU's economy and society, employing around 10 million people and accounts for about 5% of gross domestic product (GDP). Effective transport systems are key to European companies' ability to compete in the world economy. Logistics, such as transport and storage, account for 10–15% of the cost of a finished product for European companies. The quality of transport services has a major impact on people's quality of life.

Within Horizon 2020, Research and innovation (R&I) programme, the EU is promoting research aiming to strengthen competitiveness in transport industries and to develop a better European transportation system that is resource efficient, climate and environmentally friendly, safe and seamless for the benefit of all.

According to the Horizon 2020, [36] there are several challenges to be faced to achieve a smart, green and integrated transport system in Europe:

Table 5 - Horizon 2020 work areas and challenges

Work area	Challenge
Policies	- Promote innovation and meet the challenges raised by transport - Internalization of transport industry - Standardization of services
Sources and environment	- Reduce carbon footprint - Reducing CO2 emissions - Decrease oil dependency
Market	- Change towards service-orientation

Knowledge and technology	- Increase transport safety - Decrease noise pollution - Safer and greener transports - Road transport automation - Integrated, multimodal, low-emission freight transport systems and logistics
Cooperation	- Multilateral cooperation in aviation for a safer and greener aviation - Cooperation with China, India CELAC and/or other third countries on reduced emissions and green vehicles

Also the Horizon Europe research and innovation funding programme (2021 to 2027) through the pillar 2" Global and Societal Challenges of Industrial Competitiveness, Cluster 4 " Climate, Energy and Mobility" proposed to address in an integrated way issues of the transport and energy sectors.

In a nutshell, main priorities regarding the Transport challenges are identified by Horizon 2020 and Horizon Europe programmes [37]. The following table should the main priorities and the most important areas to be covered.

Table 6 - Summary of priorities and objectives in Transport Sector

Programme	Main Priorities	Objectives	Key areas to be focused on
Horizon 2020	**Resource efficient transports**	Minimize impact on climate and the environments	Investment in the production of clean and silent aircrafts/vehicles and vessels
	Mobility improvement allied with safety and security	Reduce traffic congestion; Reduce accident rates, fatalities and causalities	Investment in the development of new concepts of freight transport and logistics
	Global leadership for the European transport industry	Reinforce the competitiveness and performance of European transport manufacturing industries and related services including logistic processes and retain areas of European leadership Improve the policy making to promote innovation and meet the challenges	Research in hybrid/electric aircraft, supersonic aviation, safety in road mobility, multidisciplinary and collaborative aircraft design tools and processes, new multifunctional and intelligent parts, improved production and maintenance for the transport sector
Horizon Europe research and innovation funding	**Industrial Competitiveness in Transport**	Shift towards clean technologies, connectivity and automation, linked to design and manufacture of aircraft, vehicles and vessels	– Merging of physical and digital vehicle/vessel/aircraft design, manufacturing, operations, standardization, certification and regulations and integration (including integration between digital design and digital manufacturing); – Vehicle/vessel/aircraft concepts and designs,

			including their spare parts, using improved materials and structures, efficiency, energy storage and recovery, safety and security features with less environment and health impact. – On-board technologies and sub-systems, including automated functions, for all modes of transport taking account of relevant infrastructure interface needs and exploring; technological synergies between modes; safety/accidence avoidance systems and enhancing cybersecurity; developing the human-machine interface; – New materials, techniques and methods of construction, operations and maintenance of infrastructures, ensuring reliable network availability and full life-cycle approach; – Infrastructure maintenance, regeneration and upgrading transport integration, interoperability and intramodality.
	Clean Transport and Mobility	Rethinking the whole mobility system including users, vehicles, fuels and infrastructures. Deployment of low-emission alternative energies and market uptake of zero-emission vehicles/vessels/aircrafts. Electrification and the use of fuel cells for cars, buses and light duty vehicles it is essential to accelerate research and innovation solutions for other sectors such as aviation, maritime and inland navigation.	– Electrification of all transport modes (e.g. batteries, fuel cells, hybridisation, etc.) including new technologies for vehicle/vessel/aircraft powertrains, fast charging/refuelling, energy harvesting and user-friendly and accessible interfaces with the charging infrastructure, ensuring interoperability and seamless services provision; development and deployment of competitive, safe,

			– high-performing and sustainable batteries for low and zero-emission vehicles; – Sustainable new fuels and new smart vehicles/vessels/aircraft for existing and future mobility patterns and supporting infrastructure; technologies and user based solutions for interoperability and seamless services provision; – Reducing the impact of mobility on the environment and human health.
	Smart mobility	Smart mobility supported by the use of digital technologies, advanced satellite navigation (EGNOS/Galileo), and artificial intelligence.	Digital network-and traffic management: advanced decision support systems; next generation traffic management (including multi-modal network and traffic management); contributing to seamless, multimodal and interconnected Mobility for passengers and freight; use and limitations of big data; use of innovative satellite positioning/navigation (EGNOS/Galileo); – Single European Sky: solutions for higher degrees of automation, connectivity, safety, interoperability, performance, emission reduction and service; – Rail technologies and operations for a high-capacity, silent, interoperable, and automated railway system; – Connected, cooperative and automated mobility systems and services, including technological solutions and non-technological issues
	Energy Storage	Low-emission, decarbonized transport will require a growing share of electrical and/or other alternatively fuelled vehicles, with better-performing and cheaper, recyclable and	Technologies including liquid and gaseous renewable fuels and their associated value chains, for daily to seasonal energy storage needs;

		reusable batteries, as well as local provision of synthetic/renewable fuels such as hydrogen and innovative solutions for on-site storage.	– Batteries and the EU value chain, including design, large-scale battery cell production technologies, reuse and recycling methods; – Low zero-carbon hydrogen including fuel cells, and the EU value chain from design to end use across various applications.

These priorities are fully in line with the European Commission strategy called Transport 2050 [38] [39], that presents the EC comprehensive strategy that relies on a sustainable mobility and innovative solutions for the development of new technologies for greener, smarter and efficient transports.

The above measures should be taken in consideration so that citizens, the economy and society as a whole, could benefit from an environment friendly and resource efficient European Transport System, for terrestrial, air and sea transportation.

Although each transport mode AIR, ROAD, RAIL, MARITIME AND INLAND WATERWAYS has their own specific strategy “Sustainable strategy” [40] there is a common approach of investment on Technical innovations and a shift towards the least polluting and most energy efficient modes and this is where AM will play an important role in allowing manufacturing of new components with new designs and making components with reduced weight energy efficient modes.

4.2 AM specific trends/challenges/opportunities until 2030

The transport sector can be divided into several transport modes, as previously explained. Although there is a division in groups, when considering AM, Transport sector can be divided by type of product that is provided or a more segmented sector. On one hand, a reason to do such division is due to being easier to get more information when looking to a segmented sector separately, and on the other hand because AM development and implementation have different objectives for each Transport sub-sector. Therefore, the segmented sectors we aim to flourish our knowledge are:

- Aerospace;
- Automotive;
- Railways;
- Maritime;
- Urban Transportation

While considering the state-of-art of the segmented sectors previously defined, it was observed that the two more developed and with a higher impact in the short term, in terms of AM, are Aerospace and Automotive. In this sense, those sectors are deeper analysed in this report. Two different AM applications can be distinguished: MRO (maintenance repair and overhaul) and part production. Part production is already under a wide utilization in these two fields, and MRO is increasing each day.

With regards Aerospace, part production is already under use one example is the fact that Airbus is producing aircraft parts with AM technology since 20 June 2014 [41] [42]. The part production can be segmented in different section as it can be observed on AM Motion figures above.
On the other hand, Aerospace MRO is seen as a very significant part of the market. Some studies predict that there will be a significant increase in maintenance and repair on the next couple of years (see Figure 12).

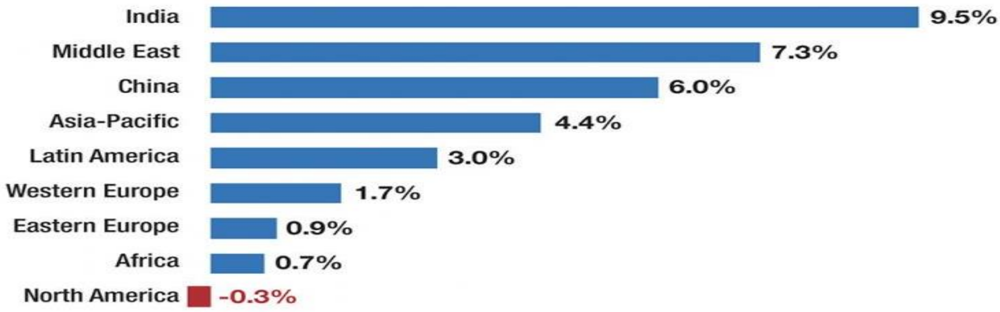


Figure 7 MRO Growth Rates by Region, 2019-28 [5]

Considering EU we can observe that there will be an increase on MRO, although not as big as on other continents, but considering MRO market has already very a high invoice, 1% growth represents a positive trend in MRO, so when relating to AM we can maintain that this will be an enormous focus to look into in the future.

Recently there were some developments on certifying personnel for utilizing AM technology in MRO. Furthermore, Lufthansa Technik launched an Additive Manufacturing Centre for aircraft MRO [43]. Since 2016 there has been an effort to develop certification for the use of AM when repairing aircraft parts [44], and some studies predict that during 2019 additive manufacturing metal repairs will be putted to practice [45].

The following picture makes a decent overview of gaps of the AM value chain to market for the Aerospace sector.

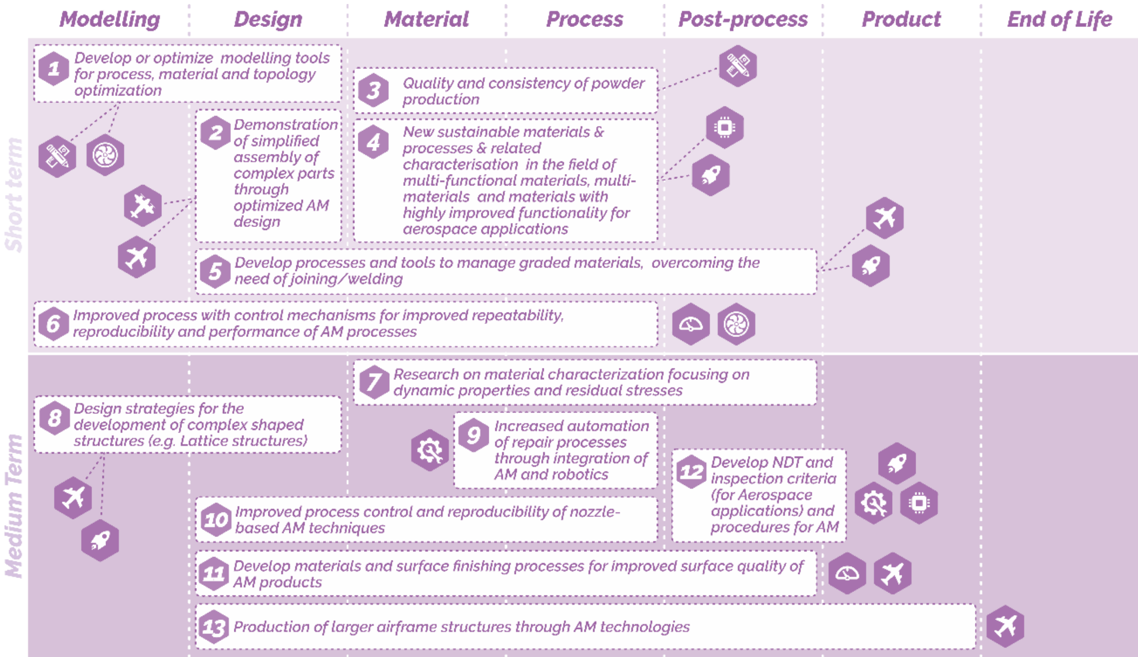


Figure 8 - *Gap analysis in the Aerospace sector (in the short, medium and Long terms (Source: AM-motion roadmap)*

Accordingly, to the data collected on AM Motion project, it can be seen that for short term the Aerospace sector wishes to achieve developments on several aspects of part production, while for mid-term aims achieving more challenging aspects on part production and automation of part repairs.

Furthermore, to complement this graphic there is a table with where those e gaps are relate do the AM potential products in the aerospace sector and respective actual Technological Readiness Level (TRL) and TRL to achieve on the next years. The present TRL is medium and Industry wishes to target a higher TRL in the next couple of years.

N	Action Name	Type of Activity	TRL		Target Products								
			Initial TRL	Target TRL	Turbine Parts, Engine	Small aircraft wings & fuselage and their components	Cabin & Cockpit parts	Other omplex parts	Components of large aircraft wings and fuselage	Spare parts & repair	Concept modelling, prototyping and advanced moulds	Niche, low volume parts	Embedded electronics
1	Develop or optimize modelling tools for process, material and topology optimization	RIA CSA	5-6	7	⬢	⬢		⬢	⬢	⬢	⬢	⬢	⬢
2	Demonstration of simplified assembly of complex parts through optimzed AM design	IA	6	7	⬢			⬢	⬢	⬢	⬢	⬢	⬢
3	Quality and consistency of powder production	IA	6	7	⬢	⬢		⬢	⬢	⬢	⬢	⬢	⬢
4	New sustainable materials and processes and related characterisation in the field of multi-functional materials, multi-materials and materials with highly improved functionality for aerospace applications	IA	4-6	7	⬢	⬢	⬢	⬢	⬢	⬢		⬢	⬢
5	Develop processes and tools to manage graded materials, overcoming the need of joining/welding	RIA	2-3	5	⬢	⬢		⬢	⬢	⬢		⬢	
6	Improved process with control mechanisms for improved repeatability, reproducibility and performance of AM processes	IA	4-6	7	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
7	Research on material characterization focusing on dynamic properties and residual stresses	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢		⬢		
8	Design strategies for the development of complex shaped structures (e.g. Lattice structures)	IA	5-6	7	⬢	⬢		⬢	⬢		⬢		
9	Increased automation of repair processes through integration of AM and robotics	IA	5-6	7	⬢			⬢		⬢		⬢	⬢
10	Improved process control and reproducibility of nozzle-based AM techniques	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
11	Develop materials and surface finishing processes for improved surface quality of AM products	IA	6	7	⬢	⬢	⬢	⬢	⬢	⬢		⬢	
12	Develop NDT and inspection criteria (for Aerospace applications) and procedures for AM	CSA IA	6	7	⬢	⬢	⬢	⬢	⬢	⬢			⬢
13	Production of larger airframe structures through AM technologies	RIA	3-4	6					⬢		⬢		

Figure 14 Relation of the gaps with the AM products for the Energy Sector (Source: AM-motion roadmap)

The relevance of the Aerospace sector is clear even when analysing the current developments done in Standards for AM. Analysing ISO [46], CEN [47], ASTM [48] and AWS [49] Standardization Bodies it is possible to see that the Aerospace sector is one of the few sectors that already has sector-specific standards for AM. Adding to this, there is already a great focus at FAA and EASA to develop standards and requirements for MRO and Part Manufacturing. A good example of this was the NorskTitanium that was the first flying part certified by FAA.
Regarding Automotive sector, maintenance and repair is not much representative as it was for Aerospace. This is due to the fact that most of the time parts are replaced instead of repaired. Part production is the most significant in terms of use of AM technology, as some studies [50] reveal that AM parts can be 20% stronger and 40% stiffer. There is a large number of companies already producing plastic and metal parts with AM technology, and there are already few cars totally produced with AM technology. [51]
Currently one of the main barriers identified for automotive sector is to understand AM technology and how to design for it. Some studies state that when achieving standardization and harmonization of the processes the industry as whole will certainly adopt the technology and use of AM will increase significantly. [11] [52] Other studies state that in a foresight scenario AM will be used in a way that customers can buy a customized car [53].

This data is aligned with DRIVES (Development and Research on Innovative Vocational Educational Skills) project findings, which have identified new technologies and business models on the production and capability of cars. The project has recognised 3D printing as a technology that can lead to a reduction in the costs of production as well as a reduction in defects and will also have an impact on jobs and skill requirements. Moreover, AM/ 3D printing is useful for rapid prototyping and advanced manufacturing and enables prototypes to be 'moved' within the supply chain very quickly and efficiently.
Although the forecast report [54] has placed 3D PRINTING is the bottom of the list of drivers of change for the overall sector, for SME's 3D printing is among the most important and urgent (2020) drivers of change, linked to how this technology is able to increase flexibility and reduce the time to market of products in the context of disruptions to complex supply chains.

The following figures from AM Motion, serve as a RoadMap of the AM trends for Short (2019-2021) and mid (2022-2024) and long-term actions (2025-2028)

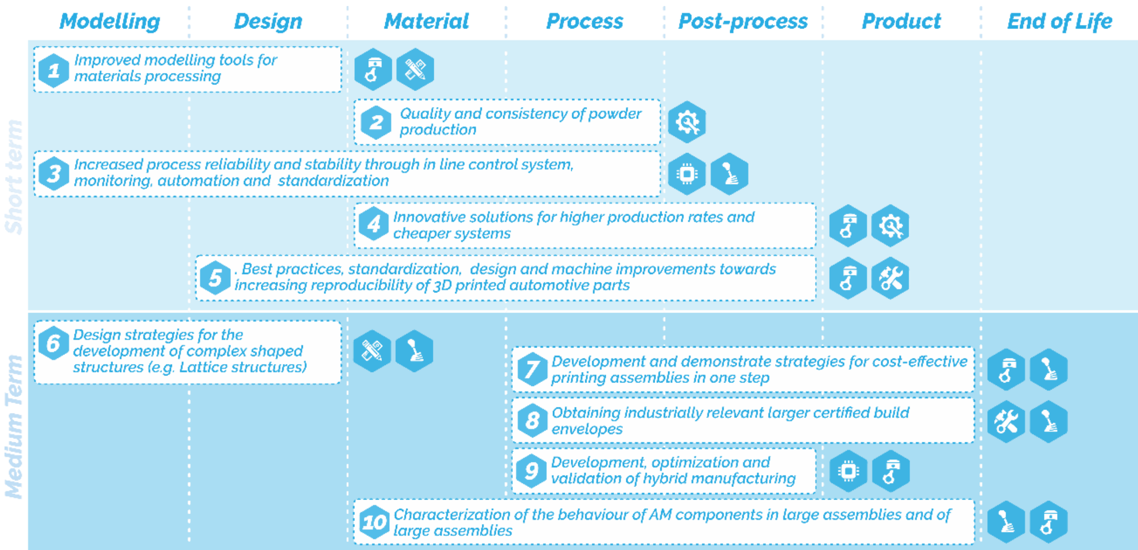


Figure 15 - Gap analysis in the automotive sector (in the short, medium and Long terms (Source: AM-motion roadmap)

N	Action Name	Type of Activity	TRL: Initial TRL	TRL: Target TRL	Target Products: Engine Components	Target Products: Embedded Electronics	Target Products: Auxiliary means of production & supports	Target Products: Concept modelling, prototyping & design	Target Products: Spare parts & Repair	Target Products: Niche, low volume parts
1	Improved modelling tools for materials processing	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢
2	Quality and consistency of powder production	IA	5-6	7	⬢	⬢	⬢	⬢	⬢	⬢
3	Increased process reliability and stability through in line control system, monitoring, automation and standardization	IA	6	7	⬢	⬢	⬢	⬢	⬢	⬢
4	Innovative solutions for higher production rates and cheaper systems	IA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢
5	Best practices, standardization, design and machine improvements towards increasing reproducibility of 3D printed automotive parts	IA CSA	6	7	⬢	⬢	⬢	⬢	⬢	⬢
6	Design strategies for the development of complex shaped structures (e.g. Lattice structures)	IA	5-6	7				⬢		⬢
7	Development and demonstrate strategies for cost-effective printing assemblies in one step	IA	6	7	⬢	⬢	⬢	⬢	⬢	⬢
8	Obtaining industrially relevant larger certified build envelopes	CSA IA	5-6		⬢	⬢	⬢		⬢	⬢
9	Development, optimization and validation of hybrid manufacturing	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢
10	Characterization of the behavior of AM components in large assemblies and of large assemblies	IA	5-6	7	⬢			⬢		⬢

Figure 16 Relation of the gaps with the AM products for the Automotive Sector (Source: AM-motion roadmap)

As for short-term action to be undertaken, the report identifies as more relevant, to develop the know-how of the technology and to find out how the industry can benefit from AM. It has already been identified that the industry can benefit but not all the benefits were yet identified, and naturally (from being an emergent technology) not all companies' individual knowledge is being shared. Moreover, Industry sees as relevant to develop the standardization of the processes so that AM can be spread on the overall market. Finally, the a current TRL considerably high for short term scenario.

On the other hand, for midterm scenario, actions, also present a significantly high TRL. For a midterm horizon, the Industry considers as relevant more challenging aspects of parts production, as well as more cost-effective practices.

Another very relevant sector is the Railways sector that is now starting to get into the AM technology. Similarly, to Aerospace and Automotive sectors, the use of AM in railways can be divided into maintenance and parts production. Railways behave most like the automotive sector in the sense that part production has more significance when compared to maintenance and repair. The use of AM in this sector is not widespread across EU compared to the two previous sectors, being some countries more developed than others. Germany for instance is investing a lot of efforts on using AM specifically for this sector. Although it is not so developed in terms of AM, it is considered while considering foresight predictions (next 10 to 30 years), because the European Union also considers this sector of most relevance under the scope of the described CLUSTER 4 “Climate, Energy and Mobility” of the “Global and Societal Challenges of Industrial Competitiveness” strategy.

While considering Maritime sector, it was possible to identify that the European strategy for the “Climate, Energy and Mobility” area aims to develop this sector. For a short-term scenario there is not a high utilization of AM technology expected. When considering small vessels, the sector behaves similarly to the automotive, few boats that are totally produced with AM exist [55]. While considering big vessels the sector behaves more closely to the Aerospace sector, due to the manufacturing of large parts being more difficult with AM, although spare parts and repairs are being manufactured with AM for the maritime sector [56] [57]. It should be noticed that big vessels are more aligned with the European strategy for a foresight prediction, as these vessels are the ones destined to a climate awareness and energy efficient transportation of goods and people. This data is aligned with MATES (Maritime Alliance for fostering the European Blue Economy through a Marine Technology Skilling Strategy) project findings which identify 3D printing as one of the paradigm shifters and future trends within shipbuilding (from 2025 onwards) and offshore renewable energy sectors (from 2025 onwards). [58]

Through the analysis of the data previously presented it is possible to conclude that the AM sector will tackle EU strategy for mobility and transports (presented on the previous chapter) in the following 3 key aspects:

- Reduction of production materials
- Innovation
- Competitiveness

AM is a technology that allows production of parts to be conducted with less material than production with other methods. AM parts can be manufactured in a more complete state thus reducing the amount of ‘connective tissue’ required to put them together and decreasing part count. In this way it is ensured that the materials used in AM are less than with other production technologies. [59] [60] Due to this Materials Reduction AM tackles the European objectives related to Resource Efficiency and Greener Transports. Furthermore, in general AM production reduces the weight of the parts produced due to the application of topology optimisation [61] [62] and therefore the manufactured parts of vehicles weight less and the CO2 emissions and carbon footprint are reduced.
The second AM key aspect that tackles EU objectives is the fact that this new technology brings innovation to the transport sectors. AM allows parts production lead time reduction, modular production alternatives, onsite manufacturing, and the ability to create parts, tools and even complete vehicles parts on-demand, restructure supply chain management and repair of manufactured parts. [63] [64] Through these advantages brought to the Mobility and Transports areas it is concluded that AM tackles EU objective of promoting innovation on the transports’ sectors. Finally, the last AM key aspect is bringing to the Mobility and Transports area is to raise Competitiveness of the sectors. Due to the innovations that this technology brings to the market it is foreseen that the market overall competitiveness increases significantly. [65] Being so, the EU objective of Global Leadership for the EU transport Industry is tackled.

4.3 Resulting milestones estimation

On this chapter, the Milestones classification is conducted for transports and mobility areas, through the analysis of AM Motion results and a comparison with the behaviour of the AM current market (supported by the relevant literature).

The milestones identification was categorized in 4 distinct groups, namely Design and Modelling, Materials used in production, production Process and building of Large Parts. In each group the challenges to overcome in AM are related and therefore were separated so that the milestones identification and further estimation of skills needs is coherent, as detailed below:

1) Design and Modelling

Milestone: **Developing and optimising modelling tools for the process, material and topology optimisation**

Design and Modelling is a key area of focus in AM technology, due to the relevance of advanced design, modelling and simulation techniques in production, since it is strictly important in early decision making on part orientation for a component manufactured using AM. [66].

Studies indicate that one of the key short-term developments in AM are related to the improvements made regarding modelling. Currently on the market there is a lack of knowledge between the results found in practical work and the KPIs that resulted from modelling and simulation processes. [67] Also, modelling is considered to be one of the current gaps in the AM sector, and it is necessary to define the specific gaps in modelling in order to move forward [68].

For instance, modelling tools are of most relevance in aerospace sector since in this way it is possible to conduct a serious weight reduction of the parts produced and reduce the overall weight of the aircraft. [69]

Milestone: **Demonstration of simplified assembly of complex parts through optimized AM design**

One major advantage of AM compared to traditional Manufacturing is the assembly of complex parts. This has been identified as a gap that has a strong impact in AM sector. Assembly of complex parts is one of the focus of AM since this technology can overcome the limitations of traditional manufacturing methods to create highly complex parts with improved functionality. Assembly of complex parts needs a clear involvement of up to date design techniques, since it is required advanced design in order to produce parts with a high level of complexity. [70] [71] Being so, another Milestone is encountered and with a TRL level increase in the field of optimized Design the AM sector will clearly benefit from it.

Milestone: **Design strategies for the development of complex shaped structures**.

Another key aspect of AM is the possibility of producing complex structures. [72] The reason for the development of design strategies is to achieve structural optimisation of the parts produced. Since two significant advantages of this technology are the reduction of lead time production and production material used (as explained before) the development of design strategies takes a significant towards these goals [73]. Moreover, the resulting design often contains complex internal structures or integrated joints which are impossible to manufacture conventionally [74], in a way that this Milestone was defined as a fundamental technology development that when improved will significantly boost transports sectors. [75]

Milestone: **Development and demonstrate strategies for cost effective printing assemblies in one step**

The final aspect to consider in Design and Modelling field is the aim of achieving reduction of cost of parts produced and assembled in AM. Since AM is a quite recent technology, parts produced are still manufactured with high costs. Only some parts are produced in AM with cost efficiency and with the development of the technology naturally more parts can be produced with lower costs. Assembly of parts in one step in AM is still a challenge to be achieved on the upcoming years and with effective developed

Design Techniques the industry can be catapulted to cheaper parts production. In this way the last Milestone defined is**.** [76]

2) Materials in AM Production

Milestone: Quality and consistency of powder production

The second area/segment of focus of this analysis is the relevance of Materials in AM production. Materials take an important role in AM, since there are many different processes (e.g. DED, PBF, VAT photopolymerization, Material Jetting, Binder Jetting, etc.) that use different kinds of feedstock [77].
One fundamental aspect that was identified as a development gap in AM Motion in the transports field (Aerospace and Automotive sectors) is the powder production (used in several AM processes). Due to the fundamental role of Powder production in AM linked to the way specific characteristics of the grains influence directly the overall quality of the parts produced. [78], which has been confirmed within AM Motion results, Quality and consistency of powder production is considered a Milestone for Transports field.

Milestone: New sustainable materials and processes and related characterization in the field of multifunctional materials, multi-materials with highly improved functionality for aerospace applications

Moreover, there has been identified the need of having materials with different behaviours for production of parts in the Aerospace sector. Aerospace sector benefits from the use of a wide range of materials in parts production such as composites, metal alloys, including titanium, graphite, and fiberglass for instance. Aerospace sector is also aiming at finding new materials to be used on production of parts, mainly with the aim to reduce production costs and produce lightweight parts [79] [80]. Currently there is research undertaken on the use of new materials, namely composites, multi-materials and multi-functional materials. [81]. Besides that, it was explained before the relevance of Materials in AM and the research on this field is a fundamental Milestone of the sector. Specifically, for Transports sector materials characterization is divided into three distinct groups: Metals Ceramics and Polymers [82] [83]. Being AM a quite recent technology it is moving towards innovation in terms of materials used. In the transports fields the use of new sustainable materials is causing serious improvements in AM technology, being the use of composites a development with significant impact in the AM field. [84]

Milestone: Research on material characterization focusing on dynamic properties and residual stresses

The last Milestone identified on the materials area is "Research on material characterization focusing on dynamic properties and residual stresses". The microstructure and mechanical properties of the as-built parts are mainly influenced by the thermal cycles involved in the additive manufacturing process. Residual stress caused by this thermal cycle in AM is the critical issue for the produced metal parts since the steep residual stress gradients generate part distortion which might deteriorate the performance of the end-use parts. The characterisation of the deposited material might mitigate the effects of residual stresses and allows to correlate its behaviour with the dynamic properties. [85] Being so, research on material's characterization will significantly boost AM sector, promoting a change of paradigm in its associated fields, namely transport and mobility.

3) Production Processes

Milestone: Development, optimization and validation of hybrid manufacturing

The third area of research for this Milestone characterization analysis is related to the improvements on the AM processes used in parts production. A key focus of these processes improvements is not the finding of new processes but combining existing production processes into one hybrid process that combines the best of both techniques. Due to the impact that these hybrid processes have on AM sector a new Milestone is defined "Development, optimization and validation of hybrid manufacturing." On a short term it was identified that the technological improvements related to this Milestone will be focused on hybrid techniques combining Additive and Subtractive Manufacturing. Currently short-term research is focused on combining both Additive and Subtractive Manufacturing techniques. [86] Several studies were conducted on this field [87], which successfully combine AM and SM technologies in order to build large manufacturing parts, LASIMM project was able to increase overall TRL level of Large Additive Subtractive Integrated Modular Machine (Hardware) from 2 to 7 [88].

Milestone: **Development of processes and tools to manage graded materials, overcoming the needs of joining/welding.**

Another relevant aspect to consider regarding processes is the behaviour of the process when working with graded materials. AM Motion classifies this gap as having a TRL of 2-3, which means the developments on this field are still in a quite initial stage. Studies indicate that the impact of successful application of processes directed to joining graded materials will boost the technology, although it is not an area of focus since the technology is not fully developed. [89]

Milestone: **Improved process with control mechanisms for improved repeatability, reproductivity and performance of AM processes.**

Besides that, a gap identified in AM is the need of having process control mechanisms. AM Motion identifies this gap both for Aerospace and Automotive sector, and since the relevance it has on AM processes in general it is possible to extend its scope of impact also to the remaining sectors from transports field. Studies indicate [90] [91] that there are still many technical challenges in AM that continue to hamper the widespread adoption of AM and achieving its full potential. One major barrier is the quality of produced parts, which is still not sufficient to meet the strict requirements of the industrial sectors. To date, quality and repeatability are still regarded as the Achilles Heel of AM. Recent studies [92] indicate that this is still a gap that needs improvement due to its relevance for the technology and the impact it has on the sectors affected by AM.

Milestone: **Increased automation of repair processes through integration of AM robotics**

Automation is a topic of interest on todays' technology and like in other areas AM benefits a lot from the integration of this field in the technology. Due to the complexity of AM parts production, automation of AM robotics is implemented mainly on repair processes and is in this area that it has higher impact due to the irregularity of the process itself. This is considered to be an important gap in AM market and several studies indicate the relevance of having automation since with this it increases effectiveness and reduces lead time production [93]. Parts repairs through AM highly benefit from automation because it increases the overall part quality, which is one of the main challenges in this field. [94] In previous chapters it was mentioned that AM takes a significant role in Aerospace in MRO (Maintenance Repair and Overall) due to reducing lead times to half of the normal production values, being so the achievement of this milestone will certainly increase competitiveness in the Aerospace sector.

Milestone: **Improved process control and reproducibility of nozzle-based AM techniques**

One of AM main challenges is to ensure reproducibility of the process applied, part quality between machines or for the same machine at different times should be the same, which not always occurs. [95]

Other specific challenges of the AM sector are to reduce production rates and implement cheaper production systems. [96] Therefore, developments on these areas will certainly impact AM market and consequently the transports sectors.

Milestone: **Innovative solutions for higher production rates and cheaper systems.**

AM Motion has identified this gap in the AM market and since it has been validated amongst industry as still valid on current days it is considered an AM Milestone. With the achievement of this Milestone more production processes will be able to implement AM and more parts will be built. In transports sector where two of the drivers of AM implementation are the reduction of production costs and lead time production this Milestone represents a significant impact in the fields. [97]

4) Large-Scale Parts Production

Milestones: **Production of larger structures through AM technologies;**
Obtaining industrially relevant larger certified build envelopes and Characterization of the behaviour of AM components in large assemblies and of large assemblies

Obtaining industrially relevant larger certified build envelopes and Characterization of the behaviour of AM components in large assemblies. The final field of developments considered in this Milestones estimation is the building of large parts. AM has a challenge of producing parts only until a determined size. This is still a grey area in the AM sector since technology is not yet developed, although it is predictable that on the upcoming years revolutionary developments will be made on this field. AM Motion identified in its gap analysis two major deal breakers considering building of large parts. The following Milestones were than identified: "Production of larger airframe structures through AM technologies", which will have a considerable impact in the Aerospace sector since more parts can be produced using AM in this sector; "Obtaining industrially relevant larger certified build envelopes and Characterization of the behaviour of AM components in large assemblies and of large assemblies", which will impact all sectors in the transports and mobility field.

Table 8 encompass the Global and Societal milestones and necessary AM Skills that have been identified until 2030 to overcome the challenges related to the Transport sector.

List of challenges in the Transport field: Resources efficient transport, industrial competitiveness, clean transport and mobility, innovation, standardisation, safer and greener transports

Table 7 - Milestones and related skills in the Transport Sector

Milestones (technology related)	**Timeline (3 scenarios)**	**Related technological skills**	**Other skills (e.g transversal, digital green)**
Develop or optimize modelling tools for the process, material and topology (Aerospace and automotive)	[2019] Real case and [2020-2021] Short term (optimization modelling for the most used materials and processes) [2022-2030] Foresight (development and optimization for other materials and processes	AM processes Design for AM Materials science Materials for AM Metallurgy Structural integrity	Spotting opportunities to create value Creativity Vision Working with others Problem Solving

	that are now reaching the market and industry)	Modelling for AM Evaluation of correlation between process parameters and part properties Evaluation of Defects	Software systems for efficient and optimized modelling for AM Planning and Organisational skills
Demonstration of simplified assembly of complex parts through optimized AM design (All sectors)	[2019] Real case and [2020-2021] Short term (software capable of design optimization for AM, focused on the main used processes) [2022-2030] Foresight (software capable of design optimization for all AM processes)	AM processes Design for AM Structural integrity Standards for AM Design	Creativity Vision Problem Solving Design Software
Quality and consistency of powder production (Aerospace and automotive)	[2019] Real case and [2020-2021] Short term (identification of feedstock properties and quality) [2022-2030] Foresight (definition of feedstock testing and validation criteria to ensure part quality)	Quality Systems for AM Quality Control for AM Feedstock control and characterization Materials Science Metallurgy Relation between feedstock and part quality Standards for AM inspection	Creativity Resource efficiency management Green awareness Circular economy
New sustainable materials and processes and related characterization in the field of multifunctional materials, multi-materials with highly improved functionality for aerospace applications (Aerospace)	[2019] Real case and [2020-2021] short term (reliability of AM produced parts) [2022-2030] Foresight (reliability of AM produced parts during their lifetime and in accordance to different sectors requirements) [2022-2030] Foresight (sustainability and recyclability of AM parts)	AM processes Quality control in AM Inspection of AM parts Simulation and modelling of AM parts Materials for AM Materials Science Metallurgy Business models and economics for AM	Spotting opportunities to create value Creativity Working with others Problem Solving Circular economy Green awareness Resource efficiency management Environmental and economic sustainability Recyclability of AM parts
Development of processes and tools to manage graded materials, overcoming the needs of joining/welding	[2022-2030] Foresight (development of processes to manage graded materials and to overcome the need of joining/Welding parts)	AM processes Post processing Joining/welding of AM parts Materials for AM Metallurgy AM modelling with multi-materials	Creativity Problem Solving Planning and Organisational Skills Resource efficiency management Green awareness

Improved process with control mechanisms for improved repeatability, reproductivity and performance of AM processes	[2019] Real case and [2020-2021] Short term (development of control mechanisms for optimized AM process) [2022-2030] Foresight (development of real time control systems and data)	AM processes Quality control in AM Inspection of AM parts AM material testing Modelling for AM Structural Integrity of AM parts	Problem Solving Spotting opportunities to create value Creativity Vision Communication Planning and Organisational skills Working with others Data analytics related to AM
Research on material characterization focusing on dynamic properties and residual stresses	[2019] Real case and [2020-2021] Short term (material characterization on dynamic properties and residual stresses)	AM Processes Post processing AM material testing Material Science Materials for AM Metallurgy Material behaviour Residual stresses control	Creativity Vision Resource efficiency management Green awareness
Design strategies for the development of complex shaped structures (Aerospace and automotive)	[2019] Real case and [2020-2021] Short term (design capability of complex structures using the most "common" AM processes) [2022-2030] Foresight (design capability of complex structures using all the AM processes)	AM processes Design for AM Simulation and modelling of AM parts Topology Optimization Structural Integrity of AM parts Evaluation of parts durability Standards for AM Design Design Modelling	Creativity Vision Problem Solving Simulation Software Eco-Design Resource efficiency management
Increased automation of repair processes through integration of AM robotics	[2019] Real case [2020-2021] Short term (robotics in AM and repair using AM) [2022-2030] Foresight (repair of complex parts/structures using AM)	AM processes Repair using AM Robotics System development for automated repairing /Automation repair strategies Certification and validation	Planning and Organisational skills Problem Solving Spotting opportunities to create value Creativity Working with others Resource efficiency management Circular economy
Improved process control and reproducibility of nozzle-based AM	[2019] Real case [2020-2021] Short term (Post-processing of AM parts)	AM processes Post-processing	Spotting opportunities to create value Creativity

techniques (Aerospace and automotive)	[2022-2030] Foresight (combining post-processing, including subtractive manufacturing, with AM)	Combined AM and Subtracting Manufacturing Joining/Welding of AM parts Assembly of parts to create complex geometries Quality Control for Hybrid processes Hybrid solutions	Vision Communication Planning and Organisational skills Problem Solving Working with others
Production of larger structures through AM technologies	[2022-2030] Foresight (larger AM parts production)	AM processes Design for AM Post-processing Quality control Parts production AM Machinery Materials Science Metallurgy	Spotting opportunities to create value Creativity Vision Problem Solving Learning through experience
Innovative solutions for higher production rates and cheaper systems (automotive)	[2022-2030] Foresight (larger AM parts production)	AM processes Post-processing Parts production AM Machinery Laser Processes Parallel AM Metallurgy	Spotting opportunities to create value Creativity Vision Communication Planning and Organisational skills Problem Solving Working with others Business for AM Resource efficiency management Circular economy
Development and demonstrate strategies for cost effective printing assemblies in one step	[2019] Real case and [2020-2021] Short term (design of AM parts) [2022-2030] Foresight (new design methodologies that align materials with functionality)	AM processes Design for AM Materials for AM	Spotting opportunities to create value Creativity Vision Problem Solving Resource efficiency management Business for AM
Obtaining industrially relevant larger certified build envelopes and Characterization of the	[2022-2030] Foresight (larger AM parts production)	AM processes Post-processing	Spotting opportunities to create value Creativity

behaviour of AM components in large assemblies		Materials for AM AM Machinery Parallel AM	Vision Problem Solving
Development, optimization and validation of hybrid manufacturing	[2019] Real case [2020-2021] and Short term (design of AM/SM parts and usage of small and simple hybrid systems) [2022-2030] Foresight (larger and more advanced hybrid systems)	AM processes SM processes AM Complementary processes Post-processing Design for AM and SM Quality Control Hybrid solutions	Spotting opportunities to create value Creativity Vision Communication Planning and Organisational skills Problem Solving Working with others Circular economy

The identified and justified milestones highlight the impact that AM will have in the transport sector and the importance of AM to ensure the sector reaches its intended objectives. Despite the fact that the presented results are related to just two section of the transport sector, aerospace and automotive, it is clear that some of the identified objectives and required skills are transversal to other sections of the transport sector, e.g. the Maritime and the Railway sectors.

Looking at the challenges and set of skills required by the Transport sector, it is possible to infer that the AM skills strategy to be adopted shall address key driven actions linked to: quality, standardisation, implementation of training and involvement of relevant sectoral players, as explained in the box below.

The required EUROPEAN AM SKILLS STRATEGY shall consider…

- linking training development and standardization activities to guarantee the quality and alignment of standards of the transport's parts produced.
- linking stakeholders of the AM value chain, in order to tackle the range of skills needed.
- implementation of different training methodologies and tools for the different levels of qualifications in AM, in order to tackle the diversity of skills required, including technological, green and digital.
- involving sectoral stakeholders, including from the Aerospace, Maritime, Automotive and Railways sectors in the identification and validation of necessary skills/qualifications
- Ensuring that transport sector and/or AM process specific skills/qualifications are identified and addressed
- Continuous monitoring of AM technology developments and it is impact on the Transport sector
- raising awareness of the general public, including children, non-manufacturing professionals and students towards the AM advantages / contributions for more green and smart transports.

5. Innovative and inclusive society

5.1 The overall European strategy

Growing socio-economic inequalities within Europe are widely considered a major challenge for cities (Eurostat, 2016). Additionally, rural depopulation and marginalisation is an increasing phenomenon (ESPON, 2017). Europe's level of urbanization is, in fact, expected to increase to about 83.7% in 2050 (European Commission).

Factors like race, gender, birthplace, family background explain a large percentage of income inequality (Bubbico and Freytag, 2018). Moreover, according to Bubbico and Freytag (2018), the inequality of opportunities - i.e., the lack of access to services and employment - prevents people from fully expressing their economic potential, generating negative effects on countries' growth.

Supporting inclusive, innovative and reflective societies is a key priority in the Europe 2020 strategy, setting a common target to lift 20 million people out of risk of poverty by 2020. This ambitious goal is backed by the flagship initiative "European Platform against Poverty and Social Exclusion". The EU financially supports such actions through its Social Investment Package, the new umbrella Programme for Employment and Social Innovation and the European Social Fund. The Youth Employment Initiative supports young people who are not in education, employment or training (NEETs). Moreover, the EU Pillar of Social Rights was launched in 2017. It builds upon 20 key principles, structured around three categories: 1) Equal opportunities and access to the labour market; 2) Fair working conditions; 3) Social protection and inclusion.

Supporting inclusive, innovative and reflective societies is also a key objective of the Horizon 2020 programme, since there is considerable potential for Europe to become more inclusive through opportunities provided by new innovation models and citizens engagement, including engagement of vulnerable groups (H2020 SC6 Expert Advisory Group, 2017).

Table 9. H2020 Inclusive, innovative and reflective societies 2018-2020

Challenges	Research and Innovation Priorities
Migration	• Management of human mobility Innovative (including digital) solutions for the successful integration of migrants into local communities
Socio-economic and cultural transformations in the context of the fourth industrial revolution	• Innovative solutions for inclusive and sustainable cities, rural environments and regional development • Collaborative, co-creative, sharing economies and societies • Development of cultural and creative industries and the arts • Inclusive and digital education
Governance	• Solutions to reverse inequalities, radicalization, extremism • Participatory, citizen-centric digital forms of delivering public goods and services • Cultural creativity, IPR and copyright

Also, in Horizon Europe research and innovation programme, within pillar 2 'Global Challenges and Industrial Competitiveness', cluster 2 will be focused on Culture, Creativity and Inclusive Society. Specifically, the cluster will pertain to "democratic governance, cultural heritage and the creative economy, social and economic transformations". However, citizen's empowerment as consumers, as producers, as entrepreneurs and as innovators; socially acceptable and inclusive digital transformations, and socio-economic innovations will be transversal topics that crosscut other clusters of Pillar 2.

Table 10 Horizone Europe Objectives, Impacts, R&I orientations

Horizon Europe cluster	Policy objectives	Impacts	Research and Innovation Priorities

Cluster 2: culture, creativity and inclusive society	Strengthen European democracy; Support an economy that works for people; Make Europe fit for the digital age; Protect cultural heritage and the European way of life; Make Europe Stronger in the World; Manage migration and mobility;	Better representation, participation, openness, pluralism, non-discrimination; Promotion of the culture and creative sectors; Lower inequalities; Inclusive growth; High quality new knowledge. Support for EU migration and integration;	1) Research and innovation to strengthen core democratic values; the role of digital technology in **participatory, active and inclusive citizenship**; 2) **innovative approaches, new and emerging technologies to foster cultural and creative sectors**; new forms of cultural and artistic expression; 3) activities to help **reverse inequalities, develop human capital, increase equal opportunities and tackle social exclusion**; to assess the multidimensional impacts of globalisation, demographic changes and technology; **digital transformation of education and training**; digital transformation and modernisation of public administrations; support **EU migration and mobility**
Cluster 4: digital, industry and space **(focus on inclusiveness)**	Involvement and empowerment of workers, consumers and firms to make sure that they co-design, have access to, and take up, technologies. Development of skills, the involvement of the young, and the development of regions, cities and rural areas – ensuring a socially fair transition not leaving anyone behind.	Higher inclusiveness, by helping industry provide attractive and creative jobs in Europe; Making a two-way engagement in the development of technologies; Developing human-centred approaches and promoting social innovation; Helping foster skills and empower the young in the digital and advanced manufacturing areas.	1) Expanding the creation of new, **value-added job creation through technology-driven innovations**; **innovative business approaches, such as customisation and product-service systems**; and applications of emerging technologies such as AI and human-robot collaboration that provide the basis for **improving the quality of jobs**. 2) Capitalising on the **digital transformation to raise productivity and realise shorter innovation cycles, new business models, urban and distributed manufacturing, higher quality products and enhanced workplace skill-sets**. 3) Involvement of creative professionals who support an **"innovative materials by design" approach, to answer the consumer demand for innovative products combining functionality with aesthetics**, as well as the need to protecting artefacts of cultural heritage.

5.2 AM specific trends/challenges/opportunities until 2030

According to [98], AM enables the shift from global, centralized, large-scale production to more local production models. This can help communities to produce their own goods (e.g., less critical spare parts) and companies to produce near to customers and adapt their products to local market needs [98] both in urban and rural locations. AM can also be an enabler of new collaborative innovations, such as fab labs as places of shared production [99], and frugal innovations [100] that aim at creating ad-hoc solutions to meet the needs of resource-constrained customers at low-cost (e.g., 3D Printer from e-waste or 3D-printed prosthetics developed in Africa).

AM can also be an asset for the creative economy and entrepreneurship. Prosumers are already using design databases to buy or download free product designs for AM. According to [101], in 2030 customers will be able not only to customize existing products by modifying their design files with a user-friendly toolkit, but also to co-create and co-design their solutions. They may also become “designers” who sell their digital files to AM platforms and marketplaces to increase their income. Future customers will even have their own printers at home [101].

Moreover, according to the AM Motion Roadmap, in the consumer goods industry AM “allows to create intricate design or geometric free structures, enabling artists, designers, jewellers and fashion designers to make one off bespoke pieces” (AM Motion, 2016). Today AM jewellery has gained a higher adoption than fashion products. This is mainly attributed to currently available materials that are suitable for the application [102]. In contrast, in the fashion industry, AM is mostly used to produce rigid, non-flexible parts of garments and apparels, while companies like Adidas and New Balance are starting to 3D print midsoles for shoes. In future those products could be also enhanced by incorporating printed sensors and electronics components [103]. Additionally, other than for industrial applications, fusing creativity, with digital innovation and traditional artisanship may provide novel employment opportunities for new generations of “digital craftsmen” producing a variety of personalized “digitally handmade” artefacts, such as furniture, accessories, ceramics, lighting and so on.

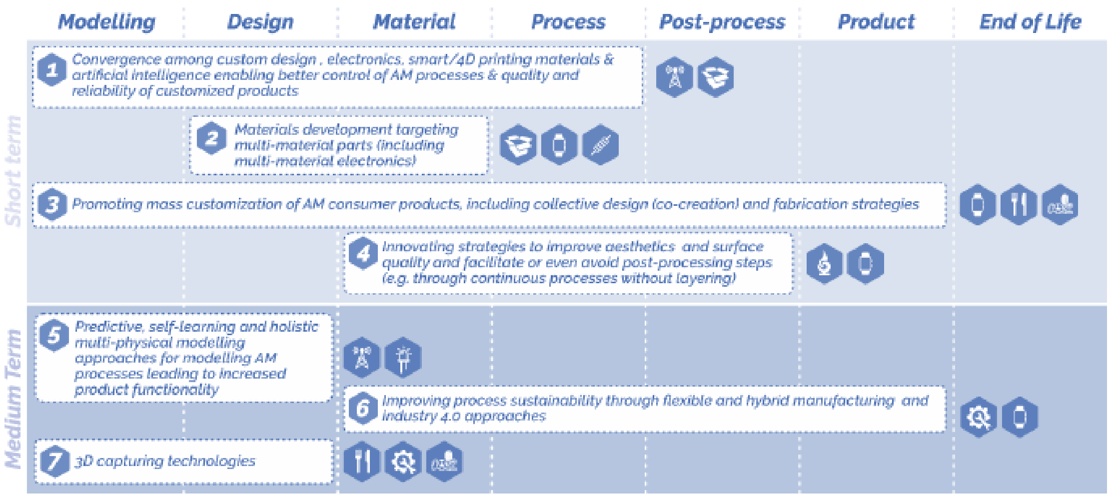


Figure 9 - *Gap analysis in the Consumer Goods sector (in the short, medium and Long terms (Source: AM-motion roadmap)*

N	Action Name	Type of Activity	TRL		Target Products								
			Initial TRL	Target TRL	Wearables	Sensors and Antennas	Basig electronic components	Other electronic parts	Household utensils	Entertainment	Spare parts and repair	Packaging	Art
1	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	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
2	Materials development targeting multi-material parts (including multi-material electronics)	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
3	Promoting mass customization of AM consumer products, including collective design (co-creation) and fabrication strategies	IA CSA	5-6	7	⬢		⬢		⬢	⬢	⬢	⬢	⬢
4	Innovating strategies to improve aesthetics and surface quality and facilitate or even avoid post-processing steps (e.g. through continuous processes without layering)	IA	6	7	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
5	Predictive, self-learning and holistic multi-physical modelling approaches for modelling AM processes leading to increased product functionality	IA	5-6	7	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
6	Improving process sustainability through flexible and hybrid manufacturing and industry 4.0 approaches	RIA	4-5	6	⬢	⬢			⬢	⬢	⬢	⬢	
7	3D capturing technologies	IA	5-6	7	⬢	⬢			⬢	⬢	⬢	⬢	⬢

Figure 10 - *Relation of the gaps with the AM products for the Consumer Goods Sector (Source: AM-motion roadmap)*

Finally, another emerging sector of application is the food industry. Some 3D food printers are already on the market, such as Choc Edge Choc Creator V2.0 Plus, Natural Machines Foodini, byFlow Focus etc. In future, two key drivers for the use of AM in food and nutrition are likely to be the use of the technology to answer specific dietary- and nutrition-related demands, and the use of the technology to create new opportunities both in the industrial food production sector, for new start-ups (e.g., BluRhapsody is the pasta printing spinout of Barilla), professional services (e.g., restaurants) or even domestic use (Pinna et al., 2016).

5.3 Resulting milestones estimation

The following Global and Societal milestones have been identified until 2030 to overcome the identified challenges related to Consumer Goods. Specifically, after the previous explanation of the relationship between AM and EU objectives for an innovative and inclusive society, the analysis of AM-Motion led to the prioritization of the consumer goods sector and the related milestones. Other ones (e.g. 3D food printing) still represent very niche application areas [104] and will be investigated by the SAM Observatory as they become more mature in future. For the identification of the milestones for consumer goods, the AM Motion roadmap was used with further information retrieved from new and complementary documents. Finally, the milestones were organized into 3 distinct categories focused on: 1) Materials, 2) Design and Modelling, 3) AM processes and post-processes due the common challenges linked to the estimations.

1) Materials

Milestone: Multi-material parts

Improvements in the combination of different materials and the development of composite materials with the same or enhanced properties than materials used in traditional manufacturing will be crucial to additively manufacture a wider variety of complex objects and to do so more efficiently. For instance, it will be possible to print electronics, insulators, conductors, and plastic substrates all together [105] and such mixed-material products will have everyday benefits in various applications such as wearables [105]. Moreover, the emergence of 4D printing will enable the use of 'smart materials' that can transform their form or function in a pre-programmed way in response to an external stimuli such as heat, water, chemical, pressure, etc. [106]. In this respect, programmable wood and programmable textiles are both anticipated to grow at a CAGR exceeding 20% from 2019 to 2025 [107].

2) Design and Modelling

Milestone: **Mass customization of AM consumer products, including collective design**

In the consumer goods industry, manufacturers are always on the lookout for ways to provide more customer-centric products cost-effectively. AM can allow the industry to move from mass production to mass customization and personalized production [98] . Current examples of this shift include running shoes tailored to an individual's feet, as well as jewelry and other items that are valued for their personalized designs. It is expected that in the future, users will play an increasingly important role, not only in product customization through online platforms to share, sell and/or collaboratively create new AM designs but eventually becoming micro-manufacturers thanks to the development of affordable home-printing solutions (with small machines) or in local AM shops [101]. In this respect, an appropriate IP framework will be needed.

Milestone: 3D capturing technologies

3D capturing and 3D scanning technologies allows users to create a digital replica instead of designing it from scratch. The creation of software and algorithms combined with the usage of low-cost commercially available equipment in order to capture 3D geometry - e.g. app to capture pictures from mobile devices and augmented reality to show customers personalized products before producing them [108]– can significantly benefit the costumer experience and improve industry processes. 3D scan can also play an important role in quality control, reverse engineering and spare part management. For instance, when a product is discontinued, it can be difficult or impossible to find replacements parts. With 3D scanning and AM, individual parts can be made to maintain products even in the absence of the original manufacturer [105]. In this respect, an appropriate IP framework will be needed.

Milestone: Predictive, self-learning and holistic multi-physical modelling approaches

Establishing linkages between materials, electronics design and AM geometry design in one design system will enable first time right production of intelligent (IoT) AM products [103]. Moreover, according to the AM-Motion roadmap, the adoption of holistic, predictive modelling approaches using multi-physics simulation and going from process parameters and simulation to product mechanical properties will be crucial in future. The exploitation of self-learning models with iterative corrections will yield first time right products.

3) AM processes and post-processes

Milestone: **Hybrid manufacturing and adoption of the Industry 4.0 approach**

Although AM is being used in industries, its full capacity is not well exploited yet. The effort in developing Hybrid-AM processes, which include both AM and conventional manufacturing processes will increase considerably in the next years. Moreover, due to the digital transformation trend, both consumer goods companies and AM machine manufacturers will integrate AM into the new overall Industry 4.0 visions [109] that aim at creating automated, connected and integrated systems in the factory and across the value chain, as well as end-to-end intelligent/IoT AM parts' lifecycles. To this end, AM will be more and more combined with other Industry 4.0 enabling technologies such as the Industrial Internet of Things, Digital Twins, Big data and Artificial Intelligence, and Robotics.

Milestone: Low/no need of post-processing

According to the AM-Motion roadmap, as AM is transitioning to an end-part manufacturing process, scaling and automating post-processing have become one of the key bottlenecks to establish AM production. Therefore, improvements in design for AM, development of AM processes and advanced (automated) solutions to reduce and/or eliminate the need of post-processing will be increasing in future.

After the overall analysis of the societal and global challenges, the following milestones and related skills have been identified until 2030 in the field of Innovative and Inclusive Society (see Table 11):

List of challenges in the Innovative and Inclusive Society field: migration and human mobility; co-creative, sharing economies and societies; inclusive and digital education; equality, radicalization, extremism; Participatory, citizen-centric digital forms; IPR and copyrights.

Table 11 - Milestones and related skills in the Innovation and Inclusive Society

Milestones (technology related)/AM motion when applicable)	**Timeline (3 scenarios)**	**Related technological skills**	**Other skills (e.g transversal, digital green)**
Multi-material parts	[2019] Real case and [2020-2021] Short term (multi-material parts) [2022-2030] Foresight (Smart/4D multi-material parts)	Materials for AM properties and performance Material Science Design for AM Modelling Design and testing of new materials Multi-material product design for AM AM process 4D printing methods	Simulation Software and tools Creativity Vision Working with others Problem Solving
Mass customization of AM consumer products, including collective design (co-creation) and fabrication strategies	[2019] Real case and [2020-2021] Short term (Mass-customization of existing products) [2022-2030] Foresight (Co-creation and fabrication platforms for new product-services)	Design for AM Product design Materials for AM AM processes Production models Privacy, IP management and legal issues	Database software AM software Customer handling Sharing/purchasing/selling platforms Business for AM Creativity Co-creation and collaborative innovation Vision Working with others Planning and Organisational skills Communication
3D capturing technologies	[2022-2030] Foresight (Low-cost commercially available equipment in order to capture 3D geometry)	Modelling for AM Design for AM Standards for AM parts Standards for 3D scanning processes	Geometry algorithms and computer vision 3D capturing tools and scanning AM files software Creativity Vision

			Problem Solving Spotting opportunities to create value Privacy, IP management and legal issues
Predictive, self-learning and holistic multi-physical modelling approaches, for modelling AM processes leading to increased product functionalities	[2022-2030] Foresight (Predictive, self-learning and holistic multi-physical modelling approaches)	Materials for AM AM processes Multi-physical modelling and simulation Modelling for AM AI for AM	Software platforms Predictive self-learning algorithms Data analytics related to AM Problem Solving Planning and Organisational skills
Process sustainability through flexible and hybrid manufacturing and Industry 4.0 approach	[2022-2030] Foresight (AM integrated or combined with other processes in Industry 4.0)	Design and management of smart & hybrid systems and processes Value chain Digital manufacturing Industry 4.0 Design for AM Management of smart product lifecycle Production models Hybrid Solutions Standards	Resource efficiency management Green awareness Circular economy Environmental and economic sustainability Recyclability of AM parts IT/OT system integration Data analytics related to AM Business for AM Working with others Communication Problem Solving Planning and Organisational skills Communication
Improved aesthetics and surface quality, low/no need of post-processing (e.g. continuous processes without layering)	[2019] Real case and [2020-2021] Short term (Reduced need of post-processing) [2022-2030] Foresight (No post-processing)	Design for AM Materials for AM AM process Quality for AM Post processing	Spotting opportunities Creativity Problem Solving Learning through experience

The milestones that were identified and justified throughout this section reflect the important achievements to be done in the future in terms of skills development to assure AM potential deployment for Innovative and Inclusive Societies. Looking at the challenges and set of skills required by professionals of this sector, it is possible to infer that the AM skills strategy to be adopted shall address key driving actions linked to: involvement of non-sectoral players (e.g. recruitment agencies), continuous monitoring of updates on technological development, implementation of training and raise awareness.

The required EUROPEAN AM SKILLS STRATEGY shall consider:

- linking stakeholders of the AM value chain, in order to tackle the range of skills needed.
- implementation of different training methodologies and tools applied to different levels of AM qualifications, in order to tackle the diversity of skills required, including entrepreneurship, green, and digital.
- involving diversity of stakeholders, including non-sector specific organisations (e.g. Recruitment Agencies) in the identification and validation of necessary skills/qualifications
- Continuous monitoring of AM technology developments and it is impact on the Transport sector
- raising awareness of the general public, including children, non-manufacturing professionals and students towards AM advantages / contributions for more innovative and inclusive societies

6. Environment and Efficient Resources

6.1 The overall European strategy

Currently, the efficient use of resources and the reduction of environmental impact are fundamental variables for any human activity that involves the manufacture and distribution of goods and services.

This has been recognized in the H2020 framework programme [110] through the identification of the societal challenge "Climate Action, Environment, Resource Efficiency and Raw Materials" [111], which in recent years has supported and encouraged R&D activities that take into account two fundamental elements, which are understood as basic for sustainable development:

- Efficient and rational use of resources, recovery of waste. Fortunately, the classic "use and throw" is being replaced by more rational approaches, in which it is promoted an optimization of the use of resources in the productive processes, as well as the conceptual extension of the life cycle of the products towards their stages of waste disposal and revaluation.

- Reduction of the impact of human activity on climate change. The progressive knowledge of how human activity exerts a real impact on the planet's global warming process imposes the need to progress towards a low-carbon economy, in which energy consumption and emissions associated with human activity are required to be maintained at a level that minimize the overall impact on the climate in the coming decades.

As a result of the previous approach, this H2020 societal challenge mainly covers the following objectives and lines of activity (table 12):

Table 12: "Climate Action, Environment, Resource Efficiency and Raw Materials" Objectives and Lines of Activity (as textually defined by ref 13)

Objectives	Lines of Activity
➢ To achieve a resource – and water - efficient and climate change resilient economy and society. ➢ Protection and sustainable management of natural resources and ecosystems. ➢ Sustainable supply and use of raw materials, in order to meet the needs of a growing global population within the sustainable limits of the planet's natural resources and eco-systems.	➢ Climate Action - Informed decisions for a climate-resilient low-carbon society ➢ Cultural Heritage - Engaging a new cultural heritage agenda for economic growth ➢ Earth Observations - Crucial info on climate, energy, natural hazards and other societal challenge ➢ Nature-Based Solutions - Providing viable solutions of natural ecosystems ➢ Systemic Eco-Innovation - Generating and sharing economic and environmental benefits

H2020 has supported and will continue to support until its completion activities and projects focused on achieving the best possible compromise between progress and environmental sustainability. It is noteworthy that this empowerment work developed by the European Union through the present and previous Framework Programs does not end in 2020, since the heir scheme "Horizon Europe" [112] is in under preparation, and includes [113] a Pillar (2) called "Global Challenges and European Industrial Competitiveness" where the clusters "Health", "Digital, Industry and space", "Climate, Energy and Mobility" and "Food, bioeconomy, natural resources, agriculture and environment" will include elements aligned with different issues related with sustainability Table 13):

Table 13 - Horizon Europe Clusters and areas of intervention

Clusters	Areas of Intervention	
Health	• Health throughout the life course Non-communicable and rare diseases • Tools, technologies and digital solutions for health and care, including personalized medicine	• Environmental and social health determinants • Infectious diseases, including poverty-related and neglected disease • Health care systems
Digital, Industry and space	• Manufacturing technologies • Advanced materials • Next generation internet • Circular industries • Space, including Earth Observation • Emerging enabling technologies	• Key digital technologies, including quantum technologies • Artificial Intelligence and robotics • Advanced computing and Big Data • Low-carbon and clean industry • Emerging enabling technologies
Climate, Energy and Mobility	• Climate science and solutions • Energy systems and grids • Communities and cities • Industrial competitiveness in transport • Smart mobility	• Energy supply • Buildings and industrial facilities in energy transition • Clean, safe and accessible transport and mobility • Energy storage

All these aspects are part of a question of great complexity, whose response is critical to lead to an industrial activity that can truly be defined as sustainable, which is: "How should industrial processes evolve to increase the welfare of current society, without compromising the welfare of future societies?" As already anticipated, the answer to this question is far from being answered from a single perspective, but it is possible to analyse what can be the implications of the technology on which SAM project develops its work, AM.

6.2 AM specific trends/challenges/ opportunities until 2030.

In this sub-section of the document, the differentiating aspects of AM technologies in terms of environmental impacts are presented, after carrying out a desktop study in this matter. The aim is to identify key aspects where AM technologies could differ from traditional ones, as a required basis for the identification of future points of action for taking full advantage of AM Technologies, environmentally speaking: how they can lead to a modification of environmental impacts in the overall manufacturing process, following a "cradle to grave" approach (from the production of raw materials to the product end of life).

During the last years, the existing literature [114] has addressed several of the differentiating aspects of AM , when it comes to environmental impact assessment:

- By their nature, AM technologies tend to make a more rational use of raw materials, since their basic "layer by layer" concept consists on adding the material exclusively required for the formation of a part. Even taking into account the nuances associated with each specific technology (such as the greater or lesser recyclability of the material necessary for the process but not directly used in the printed parts, or the need for additional support structures) these technologies are potentially more efficient regarding this aspect compared to other technologies, especially those based in the machining of materials.

- Making direct manufacturing from a digital file possible, the savings associated with not needing to generate/use additional resources to produce prototypes (tools, moulds, etc.) would lead again to a more rational use of resources. In return, to be processable, the raw materials demand additional processes, perhaps the clearest case being the atomization of plastics and metals used in laser sintering/melting based technologies.

- As an extension of the previous characteristic, additive manufacturing is also a key technology for the customization and adaptation of short series products in a sustainable way, based on the possibility of introducing modifications that do not involve significant changes in production structures. On the contrary, and although additive manufacturing technologies are continuously progressing the tend to be currently limited for the manufacture of large volumes, taking into account that technologies such as hot and cold forming of plastics and metals are practically unbeatable in terms of speed and cost.

- Beyond the technology itself, perhaps one of the (possible) greatest consequences can be the potential role of additive manufacturing as a driver for the decentralization of manufacturing activities for certain cases, allowing to evolve from a paradigm where a products must be manufactured in a centralized manner (and transported long distances), to a situation in which products manufacturing could "approach" and even be transferred directly to the final customers.

In light of the above, **AM has the potential to modify a good part of the stages of development, manufacturing, disposal and recycling of a product**, so it is obvious that when it comes to focusing on the environmental variable, it must be done from a global perspective, which includes the entire life cycle of a product, and not just its isolated stages.

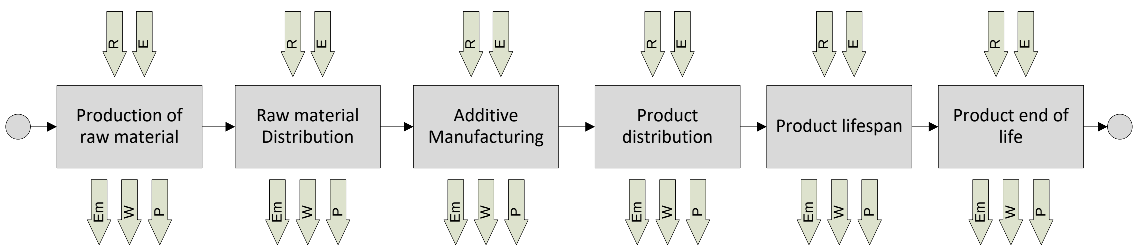


Figure 11: inlets (resources, energy) and outlets (emissions, wastes, products) across a manufacturing process based on additive technologies (diagram extracted from AM-motion project Deliverable 3.3: "Regulatory, EHS and IPR framework and actions report")

Additionally, it is necessary to take into account that the **environmental variable has to be considered for any industrial activity**. In this sense, the valuable work developed in the AM-Motion project was able to carry out this same assessment, introducing actions directly related to consideration of the environmental sustainability as a high relevance variable in its roadmaps. This is specifically contemplated in practically all the sectors addressed by AM-Motion project, having defined related actions in the **Health** (Action 8: Integration of life cycle approach in the health sector), **Aerospace** (Action 4: New sustainable materials and processes and related characterization in the field of multifunctional materials, multi-materials and materials with highly improved functionality for aerospace applications), **Consumer and electronics** (Action 2: Materials development targeting multi-material parts), **Industrial equipment and tooling** (Action 6 : Novel manufacturing processes increasing quality, sustainability and consistency of powder production), **Construction** (Action 8: Environmentally sustainable multimaterial printing and integrating components in to the build) and **Energy** (Action1: Development of new sustainable materials with improved performances and / or smart) sectors.

This cross-sectoral approach led AM-Motion to additionally integrate this subject into its roadmap on cross-cutting technical actions, including action number 8 (Role of AM in circular economy/circularity for material resources: need for recycling parts made with AM and for using recycled materials to produce AM components/products) directly aligned with the incorporation of the environmental variable.

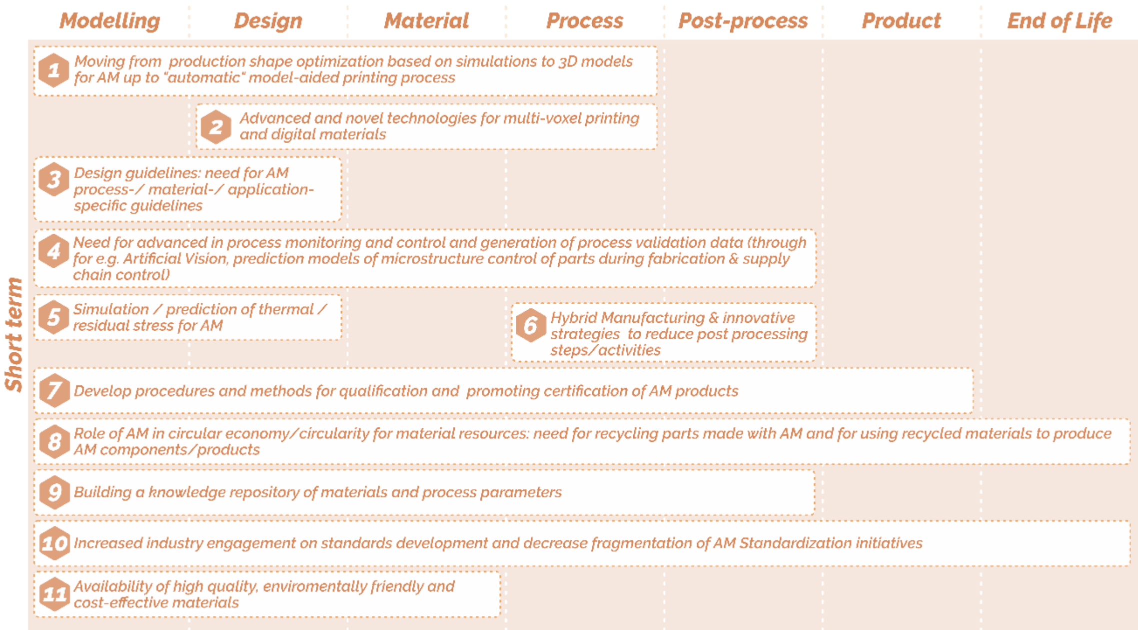


Figure 12 Cross Cutting Gap analysis (in the short, medium and Long terms (Source: AM-motion roadmap)

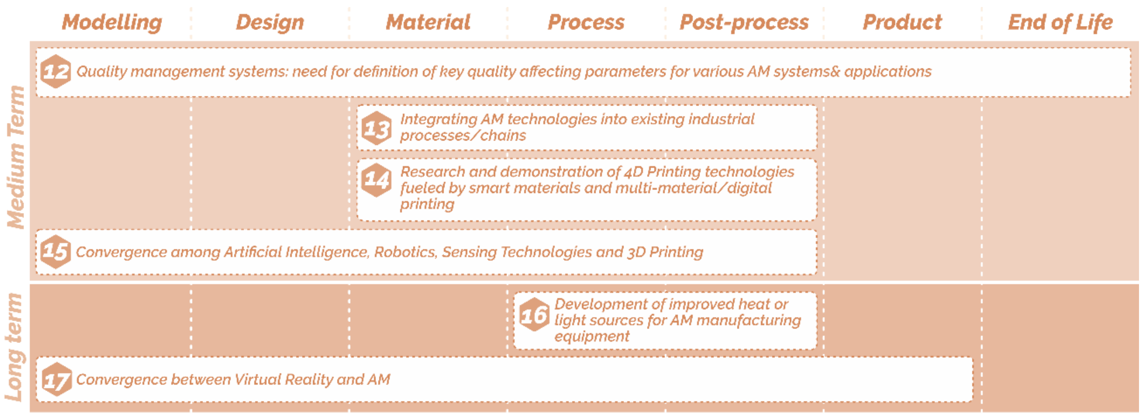


Figure 13 - Relation of the gaps with the AM products for the Energy Sector (Source: AM-motion roadmap)

As a result of the previous work, there are two main blocks of action to focus when exploring how additive manufacturing can help in achieving higher levels of industrial sustainability:

- Implementation of Life Cycle Analysis (LCA) tools as means to incorporate the environmental variable into the decision-making processes, developing in turn the impact evaluation models and indicators that allow a complete and correct impact characterization of the applications that make use of additive manufacturing technologies.

- Development of adapted recycling processes and systems, regulations and standards, capable of increasing the overall efficiency in the use of raw materials, while ensuring compliance with quality and safety standards.

Without miscarrying the relevance of developing adapted processes, systems, regulations and standards for additive manufacturing recycled materials (this labour is of eminent importance, although a non-exclusive issue of AM), works aimed at the implementation and **extensive use of the LCA as a tool for environmental impact assessment** of activities based on AM technologies are of capital importance. LCA provides an objective assessment when comparing the potential environmental impact of various alternative processes, which is especially valuable if it is considered that the additive manufacturing spectrum is composed nowadays by seven different groups of technologies [115], each of which develops the “layer by layer” manufacturing concept in a differentiated way (greatly varying the technical capabilities and material and energy requirements necessary to reproduce a given geometry).

Regarding AM environmental impact through **the implementation of LCA tools, the existing literature has increased considerably over recent years,** so it is possible for this document to provide a brief analysis of the current state of art. This document is using the different process stages (see Figure 11) as a basis for analysing how additive manufacturing has the potential to impact the entire life cycle of a product:

- Extraction, production and acquisition of raw materials. Articles as “Environmental Impact of Additive Manufacturing Processes: Does AM contribute to a more sustainable way of part manufacturing?” [116] provides relevant information when evaluating how the production processes of raw materials can be modified to make these materials suitable for its use in additive manufacturing, as it provides information about aspects as the energy requirements associated with the atomization of certain metallic materials. The sources of this article estimate in 8.1 MJ/kg the energy needed to atomize the alloy AlSi10Mg (a 3.6% increase over the estimated energy cost to obtain this alloy in a state prior to atomization), while declaring at the same time a certain lack of available data for evaluating the requirements and impacts for other AM processes and materials.

  The above are an indication that some processes of transformation of raw materials for additive manufacturing may involve theoretical variations in the environmental impact of this stage.

- Manufacturing process. As a general note, most of the existing literature uses subtractive technologies as a reference for comparison, possibly nowadays the clearest "competitors" of AM technologies in terms of capacity and cost. In either case, there are important differences between the most widespread additive manufacturing technologies:

  - *Powder Bed Fusion Technologies*. The technologies within this category [117] tend to require estimable amounts of energy for manufacturing operations, although their power consumption will depend on the specific material and technology. As an example of the search for the point of balance of these technologies from this perspective, the article "Comparative environmental of additive and subtractive manufacturing technologies" [118] presents a comparative study of the impact of EBM and subtractive technologies, based on the manufacture of a small turbine (130 mm diameter). One of its main conclusions is that the minor impact of the EBM technology with respect to the subtractive technology was produced when the ratio between the volume of starting block of material and the volume of the part was greater or equal to 7. Articles as the refereed one are pointing out that size, geometry and complexity of each part are critical variables for any kind of comparison [119].

  - *Directed Energy Deposition*. Certain articles (such as “Toward a Sustainable Impeller Production Environmental Impact Comparison of Different Impeller Manufacturing Methods” [120]) show that, in general, the use of these technologies reaches its maximum efficiency when they are used in re-manufacturing works of existing elements, followed by their use as hybrid solutions for manufacturing parts in conjunction with subtractive technologies.

  - *Material Extrusion and Material Jetting Technologies*. With regard to extrusion technologies, articles as "Comparing environmental of additive manufacturing vs traditional machining via life-cycle assessment" [121], conclude that an extrusion based AM process can be more advantageous from an environmental point of view than a traditional machining process. This same article also introduces in the comparison a machine under the material jetting technologies group (Object Connex 350), which unlike the Material Extrusion technology seems to present an environmental profile of greater impact than the subtractive technology. In both cases the article declares that it is considered that the products obtained from these differentiated processes are both suitable from a quality point of view. The foregoing is indicative that for the assessment of the impact of this technology (but really, for all AM technologies) it is highly relevant to consider whether alone they can provide the level of finishing and quality necessary for the application sought.

  - *Other AM technologies.* The existing literature on this subject for the rest of available AM technologies (binder jetting, VAT photopolymerization, Laminated Object Manufacturing) it is noticeably scarcer [122], probability due to these technologies having achieved a lesser approximation to a stage of industrial production.

- Product distribution. From a theoretical point of view, it is clear that AM technologies pose the serious possibility that the manufacturing of some products can be decentralized, something that could be transformative in many ways. Some articles in the literature have evaluated this, as is the case of "Life Cycle Assessment of 3D Printed Products in a Distributed Manufacturing System" [123]. The aforementioned article establishes a comparison between a centralized production system and a fully distributed system for the production and transfer to consumers of a model of eyeglasses (AM manufactured thanks to an extrusion process). The article concludes that the impacts associated with transportation are not excessively significant with respect to those caused by the demand for electricity for the production of the plastic filament and the printing of the glasses. This seems to be a conclusion with which other articles of the literature agree

[124], which highlights that the potential logistic change does not necessarily have to act as a driver for a reduction of environmental impacts, in which additionally, advances in bio-fuels [125] [126] and electric mobility [127] [128], can lead to a progressive reduction of impacts of existing transport means.

- Product life. The applications in which the reduction of weight can be a fundamental element for the functionality and performance through the lifespan of the product are one of the main drivers for additive manufacturing adoption. In this sense, there are particularly notable examples in the aeronautical industry in recent years, being one of the most important ones the collaboration between EADS and EOS around the redesign of a bracket [129] (originally made of steel by casting). This case study made use of topological design methods and laser sintering technologies, resulting in a new lightened bracket built in titanium, which was estimated to reduce the environmental impact on the design, manufacturing process and initial useful life by 40%.

- End of life and recycling of the product. The prevailing concept today is “circular economy”, through which it is intended to reduce net consumption and production of resources and waste. In this sense, it is likely that the main benefit of additive manufacturing could be associated with its potential role in helping to "simplify" the design of certain products. Thus, the possibility that thanks to AM certain complex products (large number of components, several material diversity) can be manufactured in a smaller number of materials and with a smaller number of components, is a basic element when it comes to reducing waste and facilitate subsequent recycling, reducing the net impact of the entire life cycle. Articles as "Unlocking value for a circular economy through 3D printing: A research agenda" [130] help in achieving a wider understanding of this matter.

Given the above, it is obvious that:

- The adoption of AM can lead to the modification of the environmental impacts associated to industrial manufacturing activities, with a **great potential for achieving higher levels of sustainability if correct balances between the use of the adequate combination between technology and applications are found.**

- The search for this balance for every technology and application is of capital importance for exploiting the full potential of this technologies from and environmental point of view. This leads to the need for a **further generation of information on how these technologies contribute to the impact on different stages of manufacturing, and how the new production models possible thanks to them behave from an environmental perspective**.

6.3 Resulting milestones estimation

Based on the previous review and the final highlights on Environment and Efficiency challenges, it is possible to determine what are the aspects that would need to be further addressed in order to increase the vision over the capacity of AM technologies to promote sustainability of industrial activities and more importantly to identify the related technological skills in order to have professionals able to deal with these aspects and take maximum advantages of AM technologies. Some of them are AM specifically related and others such as sustainability knowledge or resource efficient management are more traversal and can be categories as green skills (see Table 14).

The Milestones were identified on the 3 distinct areas of focus: Design and Modelling, Production process and Products, as follows:

1) Design and Modelling

Milestone: Development of design rules for sustainability, regarding AM technologies

As explained previously, Design and Modelling assume a significant role in Additive Manufacturing. Being so, there have been identified some relevant impacts of application of design rules in sustainability of the manufactured parts. One key step in sustainable manufacturing is part selection. While changing from conventional manufacturing to Additive Manufacturing it is important to take in consideration the sustainability of the parts produced and manufacturers are looking to design as having a key role in this parts. [131] Moreover, design rules take a significant impact in the manufactured parts through AM processes, due to the variety and complexity of the processes. [132] Since design rules have a significant impact and industry is moving towards sustainable production it is being considered the development and implementation of specific design rules towards sustainability. In order to maximize the potential to increase sustainability, any of the improvements that are achievable thanks to the introduction of AM must be translated into indications and recommendations for designers, whose work determines the environmental performance of products and production processes.

2) Production process

Milestone: Impact of different AM technologies in the sustainability ratios

It is clear that AM, regardless of the process, will have a great impact in creating opportunities that can result in a more sustainable production and consumption [133]. The transition to direct digital manufacturing will also support the use of AM in spare parts for repair and remanufacturing will enable product life extension. This type of innovation will lead to changes in the distribution of manufacturing, on the reconfiguration of value chains but also in the overall consumption of materials. Benefits are also found to exist across the product and material life cycles through product and process redesign, improvements to material input processing, make-to-order component and product manufacturing, and closing the loop [134]. On the other side, topics like energy and resource consumption of the AM unit processes itself as well as the material production can also have negative aspects in the sustainability of the process. However, by combining the benefits of AM in combination with functional improvements during the use phase of AM manufactured parts (as example, the case of lightweight components) it becomes even more clear that AM, as a full manufacturing process, will have a positive impact in the sustainability ratios [135] [136].

Milestone: Expansion of the base of case studies and literature on LCA regarding redesign processes for AM technologies.

AM has the potential to impact the entire life cycle of a product at different levels, being at the Extraction, production and acquisition of raw materials level, at Manufacturing process level, Product distribution level, Product life level and End of life and recycling of the product level. However, due to its nature and the fact that it is still considered as a "new" process more knowledge on how to adapt design/AM process/application is still required to ensure a good balance and high levels of sustainability. However, more work is still required in this area and this is one of the reasons why training/qualification in AM is required to ensure that, based on the current knowledge, companies are capable to select, based on sustainability and life-time of the product, when to choose AM and when not.

Milestone: Analysis of the impact of distributed production business models

Additive Manufacturing is moving towards a distributed production. Although it is very complex to evaluate the environmental impact of decentralizing production, especially when the technologies that are basic for a centralized scheme and a distributed one based on additive manufacturing technologies are so different. Some key factors may be evident, since having additive manufacturing technologies not yet reached their maximum development and efficiency [137] the translation of a centralized system for production towards a distributed production system based exclusively on AM technologies would be possibly penalized in terms of environmental impact.

Although, there is not a clear evidence of the environmental impact of AM decentralized production, a path towards a sustainable production must be set. AM technologies can lead to new business models, in which for certain products it may be feasible and profitable to bring the production closer to the end user, based on a dissemination of the productive means. Furthermore, there must be an integration with the circular economy concept, it is necessary to study how these "production networks" can be efficient at productive levels, but it is also necessary to study their capacity to create complementary networks capable of ensuring optimal discarding and recycling of products that have reached their end of life.

3) Product

Milestone: Improved quality and durability of manufactured products

It is known that the demand for of higher levels of industrial sustainability has been reported as one of the topics in which additive manufacturing can help. The third segment of focus of this analysis is the need for the production of components in an efficient and responsiveness way. Beyond the optimisation of the AM processes for efficient use of material and energy already mentioned, the quality and durability of the components produced also need to be addressed. Improved quality and durability of the parts will enable their reparability, reusability and recyclability, which will have a positive impact on the environment.

List of challenges in the Environment and Efficiency fields: rational use of resources, recovery of waste; reduction of the impact of human activity on climate change; maintenance of a sustainable industry.

Table 14: Milestones and related skills for environmental and efficient resources

Milestones (technology related)	**Timeline** (3 scenarios)	**Related technological skills**	**Other skills (e.g transversal, digital green)**
Improved advantages in terms of quality and durability of manufactured products.	[2019] Real case and [2020-2021] Short term (industry established AM technologies) [2022-2030] Foresight (industry emergent AM technologies)	AM processes Materials Science Quality for AM LCA methods and software Standards for AM Design and Operators	Spotting opportunities to create value Problem Solving Planning and Organisational skills Communication Learning through experience Business for AM
Impact of different AM technologies in the sustainability ratios	[2019] Real case and [2020-2021] Short term (industry established additive manufacturing technologies) [2022-2030] Foresight (industry emergent additive manufacturing technologies)		Creativity

<table>
<tr><th>Milestones (technology related)</th><th>Timeline (3 scenarios)</th><th>Related technological skills</th><th>Other skills (e.g transversal, digital green)</th></tr>
<tr><td>Expansion of the base of case studies and literature on LCA regarding redesign processes for AM technologies.</td><td>[2019] Real case and [2020-2021] Short term (industry established AM technologies)

[2022-2030] Foresight (industry emergent AM technologies)</td><td></td><td>Eco-Design

Resource efficiency management

Green awareness

Circular economy

Environmental and economic sustainability</td></tr>
<tr><td>Analysis of the impact of distributed production business models</td><td>[2019] Real case and [2020-2021] Short term (industry established additive manufacturing technologies)

[2022-2030] Foresight (industry emergent AM technologies)</td><td rowspan="2">AM processes

Required sectorial Know-how

LCA methods and software

Design for AM

AM related technologies

Methods and tools for different combinations between technologies and distribution models comparison

Standards for AM Design</td><td>Spotting opportunities to create value

Creativity

Problem Solving

Communication</td></tr>
<tr><td>Development of design rules for sustainability, regarding AM technologies</td><td>[2019] Real case and [2020-2021] Short term (industry established AM technologies)

[2022-2030] Foresight (industry emergent AM technologies)</td><td>Spotting opportunities to create value

Problem Solving

Business for AM</td></tr>
</table>

Looking at challenges and set of skills required by professionals of this sector, it is possible to infer that the AM skills strategy to be adopted shall address key driving actions linked to: quality, standardization, implementation of AM and involvement of relevant sectoral players as explained in the text box below.

The required EUROPEAN AM SKILLS STRATEGY shall consider…

- linking training development and standardization activities to guarantee the quality, sustainability and efficiency of the parts produced, thus aligned with the defined standards.
- linking stakeholders of the AM value chain, in order to tackle the range of skills needed.
- implementation of different training methodologies and tools for different levels of AM qualifications, in order to tackle the diversity of skills required, including technological, green and digital.
- involving sectoral stakeholders, including from the Energy Sector in the identification and validation of necessary skills/qualifications
- ensuring that Energy sector and/or AM process specific skills/qualifications are identified and addressed
- continuous monitoring of AM technology developments and it is impact on the Environment, Efficiency and Sustainability sector
- raising awareness of the general public, including children, non-manufacturing professionals and students towards the AM advantages /contributions for the Environment.

7. Citizens Security

7.1 The overall European strategy

Security is a concept that cuts across several dimensions of the EU's domain: resilience against natural and human-made disasters fight against crime and terrorism, creation of new forensic tools, development of capabilities for peacebuilding and conflict-preventions, as well as cyber-security.

These are all different facets of the understanding of security, all featuring prominently in the EU's Research and Innovation strategy. The Horizon 2020 programme highlighted the importance of research for supporting the fight and prevention of security threats in the European Union. Several calls for proposal seek a more ambitious and coordinated approach looking for solutions that could include a diverse and innovative set of security instruments.

Furthermore, in line with the EU security strategy, the programme looked at the citizens perspective as they are often the victim of many forms of insecurity for more ambitious, coordinated and holistic approaches.

The latest Horizon 2020 the work programme 2018-2020 entitled "Secure societies - Protecting freedom and security of Europe and its citizens" aims to support the implementation of the Security Union priorities. Focus areas and expected impact, are detailed in the table below.

Focus areas	• Reacting to and recovering from natural and man-made disasters; • Preventing, investigating and prosecuting crime including organised crime and terrorism; • Improving border entry security; protecting infrastructure against natural and man-made threats, including cyber-attacks; • Digital security, privacy and data protection; • Space related research
Expected impacts	• Enhance the resilience of our society against natural and man-made disasters, • Fight crime and terrorism ranging from new forensic tools to protection against explosives; • Improve border security • Provide enhanced cyber-security

In Horizon Europe the topic of security will be included in the cluster "Civil Security for Society". Security research will serve as a tool develop reactive and proactive approaches to security based on foresight and anticipation. The European Commission have identified specific policy objectives and targeted impacts which should be taken into consideration and achieved within the timeframe of Horizon Europe.

Policy Objectives	• Disaster risk management Activities to support implementation of: • Union Civil Protection Mechanism, • EU Adaptation Strategy • Sendai Framework for Disaster Risk Reduction (2015-2030) • Paris Agreement • EU CBRN and Explosives Action Plans. • Protection and security Activities will support implementation of: • European Agenda on Security and the development of a Security Union. • EU Maritime Security Strategy • Cybersecurity,

	Activities will support implementation of: • NIS Directive • GDPR • Cybersecurity Act • Future e-Privacy Regulation
Targeted impacts	• Improved disaster risk management and societal resilience; • Improved management of air, land and sea EU external borders; • Better protection of citizens from violent attacks in public spaces; • Improved security and resilience of infrastructure and vital societal functions, • Improved maritime security, • Fighting crime and terrorism more effectively

While AM relates to some extent to many aspects of the security union priorities, the latter on cybersecurity is arguably more of a talking point in the technology than the others. As the Work Programme for 2018-2020 of Horizon 2020 states, the cybersecurity challenge refers in particular to:

increasing the security of current applications, services and infrastructures by integrating state-of-the-art security solutions or processes, supporting the creation of lead markets & market incentives in Europe, following an end-user driven approach, including for instance law enforcement agencies, first responders, operators of critical infrastructures, ICT service providers, ICT manufacturers, market operators and citizens.

As highlighted earlier in Section 2, the new multi-annual EU's research programme entitled Horizon Europe programme reshuffles to some extent the challenges identified.

Several funding activities have been envisaged by the European Commission to this respect, including the earmarking of investments for the creation of pan-European network bringing together national cybersecurity centres across Europe. [138] In parallel to that, the current European strategy is substantiated by critical policy actions. As an example, the Cybersecurity Act put proposed by the European Commission will pave the way for the creation of an EU-wide Cybersecurity Certification scheme where products, including machinery, services and/or systems will be ranked according to the cyber-risk associated with their application area or use. Products, services and systems meeting requirements successfully in place for that specific domain and dimension would obtain a certificate of conformity by authorities. [139] The scheme will mostly be voluntary on manufacturers and service providers placing their solutions on the EU market.

Disaster-Resilient Societies is another important security priority in which AM could play a role. Such topic was included first in Horizon 2020 and now the Horizon Europe programme.

As Climate change, population growth and urbanisation can amplify the impacts of natural and human-made disasters the EU is promoting cooperation among the Member States and supporting different actions.

On this topic, Horizon 2020 focused on solutions which could advance innovation to reduce the loss of human life and to reduce environmental, economic, material and immaterial damage from natural and human-made disasters (including climate-related weather events, earthquakes and volcanic events, space weather events, industrial disasters, crime and terrorism threats).

In the upcoming Horizon Europe, this topic is included in the "civil security for society cluster" and will look again on the same areas of Horizon 2020 trying to develop solutions to:

- reduce the impact of the disaster on citizens, environment and economy;
- prevent and/or manage material and immaterial damage, in particular in vulnerable groups and areas, including heritage sites.

Another sector related to security topic is defence. AM is set to have a significant role in this sector, which has been already a topic of research during Horizon 2020.

The newly created European Defence Fund builds on the 2014-2020 preparatory action on defence research, which looked at ways to boost investment on targeted collaborative research and the development of a European Defence Industrial Development Programme. Under the 2021-2027 MFF, their collective budget increases almost twenty-fold (from €575.3 million to €11.5 billion). The Fund is being set up to support European industries in being more innovative and competitive, boost cross-border integration within the EU and specifically support SMEs and MidCaps in the defence sector [140].

The European Defence Fund's objective is to foster the competitiveness, efficiency, and innovation capacity of the European defence industry, by supporting:

Collaborative research project with the aim to maximise innovation and invest in new defence products and technologies (including disruptive ones).

Collaborative development projects of defence products and technologies based on the priorities commonly agreed by the Member States within the framework of the Common Foreign and Security Policy. [141]

7.2 AM specific trends/challenges/opportunities until 2030

Within this sub-section, a more detailed analysis is made to understand the relationship between AM technology and the global and societal challenges identified for Citizens Security, namely for: Cybersecurity, Disasters and Defence.

Cybersecurity

Discussions on cybersecurity in AM have intensified over the last years as a result of the heightened relevance of this topic.

The technology relies on digital files and network connectivity to produce components. The CAD file containing the digital design of the product can be stolen or corrupted, potentially leading to the premature failure of the process, with implications for the whole value chain. Attacks of a similar kind may also be conducted in the STL stage when the file is converted from CAD into STL format, readable by the machine.

Developing an AM cybersecurity strategy can be challenging, as cyber risk implications of AM could affect multiple parties throughout the supply chain, from suppliers to owners, managers, and purchasers of AM systems, to distributors and purchasers of AM products. Cyber risk can impact each stage of the digital thread, from design and scan to quality assurance and printing, to use in the field and even disposal of the AM objects or printers.

In the stage of production, risks are linked to the alteration of defined process parameters, leading to situations such as a misaligned printer head or altered laser intensity. As a practical example, researchers at Virginia Polytechnic Institute and State University presented in a 2017 paper the impact of a cyber-physical attack case study on a polymer additive machine. The attack concerned the STL file structure. Researchers estimated the attack led reduced the mechanical strength of the part. The average reduction in yield load was of 14%, that of strain at failure of about 5%. The voids, generated in that part, also proved difficult to identify with conventional techniques [142].

In this sense, additive processes, which rely on building parts layer-by-layer, are more exposed to the negative effects of cyber-attacks in comparison to subtractive processes. Any intentional defect can be hidden in the interior of a part produced and became more difficult to identify by the inspector. [143]

Reliance on digital data files—and connectivity to transmit them—has at the same time numerous benefits and threats. If a file gets stolen, hackers can have access to the full design corrupting the original in such way, for instance, to create failure points in critical components without the designers' knowledge.

There is different level of cyber-attacks that can affect the AM supply chain:

- Printer level attack: Printers are directly (change of manufacturing condition to embed a defect in the part) or indirectly (via malware or sabotaging the power supply) subject to hacking attack provoking disruption in the supply chain.

- Raw material attack: Attacks can be directed to delay the shipment of the material (which would impact the on-demand characteristic of AM) or directly compromise the quality of raw materials (e.g. increasing the oxygen content by hacking into the electrical system to change the oxygen valve settings, leading to surface oxidation of feed metal powder particles.

- Design level attacks: Hackers can mutate the designs or steal the files for unauthorised production [144].

The industry has developed a variety of solutions to cope with these challenges:

Identify3D, for instance, is a platform assigning contractual rights and manufacturing licensing rights for carefully selected people in the supply network. Through Identify3D, design engineers can store all relevant design data into an encrypted folder and entrust specific users, such as determined qualified operators, access to it in order to produce a given number of components within a given period. The platform also allows determining with which specific equipment the user is entitled to generate the part, based on the design data storage in the encrypted container [145] [146]

Companies continue to develop and adopt new solutions (e.g. blockchain) to mitigate cyber risks and minimise any possible malicious actions by third parties. In a cyber-physical system such as AM, the threats can lead to hardware problems. Hence, it is essential to develop a collaborative defence approach where security and AM professionals work together covering all potential flows in the supply chain. [147]

Disaster-Resilient Societies

The World Health Organisation (WHO) estimates such disasters kill over 90,000 and affect over 160 million people each year. Sadly, the majority of those affected live in impoverished areas, where infrastructure is already poor and vulnerable, and delivering aid can prove problematic. An increase in urbanisation, plus a growing population, has also contributed to a surge in the financial costs of natural disasters in recent years.

AM can impact the way organisations provide aid by addressing a significant challenge in humanitarian relief: getting assistance directly on site as well as produce customised parts and products, allowing local communities a faster recovery.

The AM production can help to create standardised goods—such as medical tools— on an as-needed basis improving the time-efficiency in product delivery.

By integrating AM/3D printing into humanitarian aid efforts, the overall cost and impact of natural disasters can decrease, due to the relatively low costs associated with the technology compared to current aid efforts.

AM/3D printing can reduce time and money used in the procurement of goods by reducing the amount of capital required for manufacturing at a given location, allowing distributed

Manufacturing or more localized manufacturing to occur. By manufacturing goods locally at the site of a disaster response, the only materials that need to be shipped to the site of a disaster are the raw materials needed for manufacturing. These raw materials typically take up far less storage and transport space, are far more durable and require far less packaging than the actual goods needed in a disaster response.

The on-demand fabrication of parts allowed by 3D printing can also help to reduce the mismatch of what is needed in a crisis and what is supplied, allowing a degree of local customisation previously impossible. Many relief organisations ship thousands of items that are not required and find they need many that were not sent. The International Committee of the Red Cross and Red Crescent (ICRC), for example, has a set catalogue of nearly 10,000 different items that it ships to any given disaster. In recent years, Red Cross has for used 3D printing to print their WASH (Water, Sanitation and Hygiene) kits in Nepal, Syria and Lebanon.

Different companies and organisations, working in areas hit by disasters, have also looked at the development of specific 3D printers for such cases. An example is a team of researchers at the Penn State Humanitarian Engineering and Social Entrepreneurship program which set guidelines to produce a resilient, reliable 3D printer expressly created for use in addressing humanitarian crises. [148]

A good example of the application of AM during humanitarian crises has been revealed in the COVID 19 pandemic. All around Europe there was a lack of medical equipment to fight this pandemic, namely ventilators, Personal Protection Equipment (PPE) and other specific parts. Medical parts supply chain was not developed and prepared to the urgency of the needs in terms of specific parts since demand increased significantly, therefore AM industry replied to the urgency of these equipment. Due to AM unique production capabilities, the industry was able to manufacture the parts missing in the Health Sector. [149]

[150] [151] Furthermore, not only the industry was able to reply to this need of medical supply but also home AM/3D printing owners have come together and volunteered in many European Countries to develop PPE for Medical Personnel [152] [153] [154] [155]. In this context, AM potential was presented to the world, demonstrating its use to respond to some of the adversities caused by COVID 19 pandemic. Although the lack of knowledge about 3D printing by the home manufacturers, non-manufacturing professionals and end users was also visible with this scenario. These gaps were identified and will be addressed in the European AM Skills Strategy to tackle this lack of AM Awareness among different target groups.

Another application with great potential is the use of AM to ensure a fast rebuilt in areas hit by disasters.

The application of AM in construction has been increasingly studied and tested in recent years. In construction virtually every wall, floor, panel, partition, structure and facade are unique in dimension, which means either standard-sized materials are cut down to fit, or bespoke moulds are created to form each component.

Furthermore, it offers considerable freedom of design and extensive possibilities for automation. These benefits can be exploited by using digital planning methods. Particularly important is the integration of several different contracting parties already at an early design stage.

Lastly, using AM allows reductions in the quantity of materials used, through optimisation of form and the implementation of additional 'engineering function' within components. The computational design environment promises the freedom to design around individuals and the environment.

Despite the potential, there are still challenges to the application of AM in the construction sector. These are related to durability (typical required life span 50 years), safety and strength (compressive stress) of the part developed as well as the sizes of buildings. [156]

Deloitte considers five use cases that could be either created directly or improved by AM. [157]

- AM machines with plans downloaded from the Internet [158]
- Counterfeits: Goods or components designed and produced to mimic a trusted product from a trusted supplier; [159] products can range from counterfeit consumer goods, to credit card scanners, and even include false parts for military hardware [160]
- Improvised explosive devices: Non-traditional explosive devices [161]
- Advanced technology/weapons: A collection of advanced, usually export-controlled, technologies, including jet engine technology, missile technology, and advanced explosive systems such as explosively formed penetrators (EFPs) [162]

CBRNE threats: Chemical, biological, radiological, nuclear, and explosive (CBRNE) threats, as well as the means to produce or accelerate production/weaponization of such threats [163] A February 2017 report from the Stockholm International Peace Research Institute (SIPRI) concluded that AM machine cannot be used to develop all parts of weapon development, but can be used to print noncritical components.

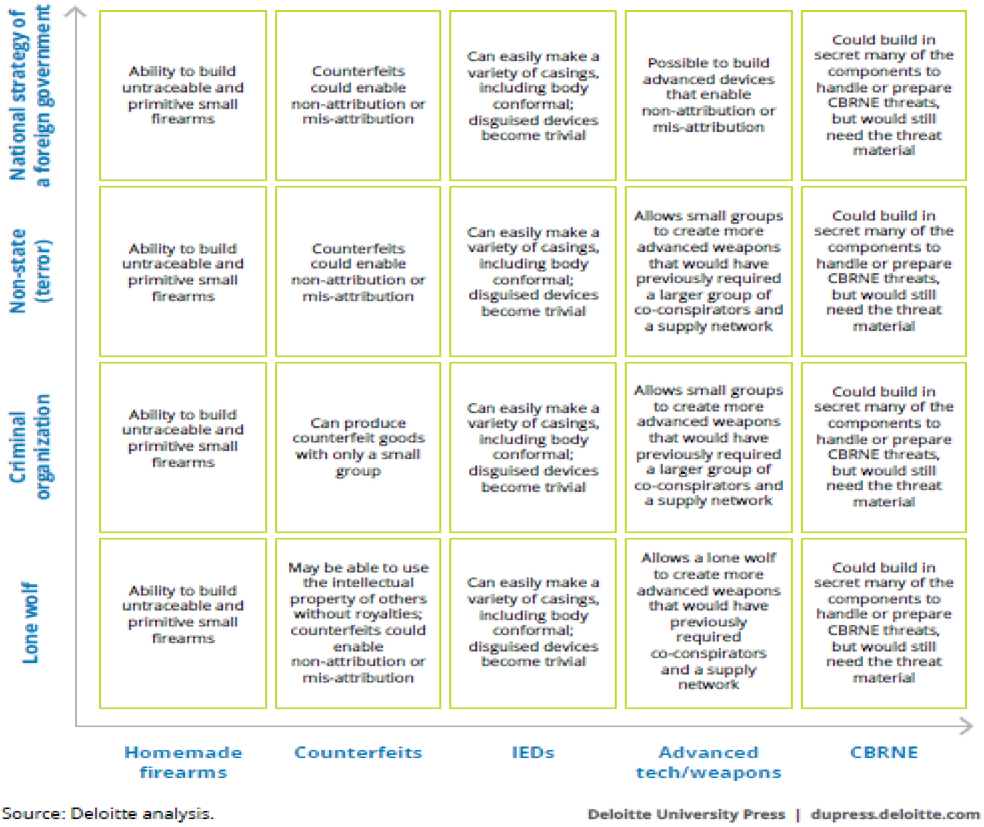


Figure 14 - Overview of AM related threats (Deloitte University)

Defence

The use of AM to develop defence products can bring innovation to a new level while taking greater control over product quality and security.

Today the defence industry outsources the production of thousands of replacement parts and tools for military equipment to external companies. The ability to eliminate several of the design limitations associated with traditional manufacturing technologies as well as the rapid, localised and flexible manufacturing capabilities offered make AM an ideal technology for this industry.

The defense sector relies on quick innovation and technological advancements. AM has the potential to meet these essential needs. There are several applications in which AM can increase the capacity of defence resources deployed in a situation or theatre of operations:

- Customised equipment
- Field assistance
- Monitoring of information

The flexibility of AM represents a one of the most significant paradigm shift allowing on-demand production either on a small scale (e.g. ad-hoc spare parts) or on a large scale (accelerating the development of new devices, vehicles, parts, etc.) which are essential for planning aid.

Furthermore, the opportunity to expedite the deployment of new products, making supply chain more efficient (reducing storage and logistics costs) have significant impacts on the value chains involved in strategic and tactical defence processes. Such characteristic is particularly important for units that are deployed on operations in remote locations that are difficult to supply by sea, road or air. [164]

There are also certain types of deployment applications which could be used to obtain planning intelligence and area exploration, for instance, the construction and customisation of simple drones and unmanned aerial vehicles (UAV), which together with suitable electronic means.

Although the adoption of AM can improve mission performance and increase operational efficiency and effectiveness, it still has some challenges that need to be addressed. For instance:

- Parts testing and qualification: The unique benefits of rapid build time and unique microstructural control offered by AM processes cannot be fully realised with existing long certification times.
- Training and skills development: lack of the skills required to develop, operate and maintain the AM into military operations [165]

7.3 Resulting milestones estimation

Global and Societal milestones and related skills have been identified until 2030 to overcome the identified challenges related to Citizens Security. These Milestones are categorized in 2 distinct groups: Production Process, Strategy and Security, as follows:

1) Production process

Milestone: **Development of resilient, reliable 3D printer expressly created for use in humanitarian crises**

AM/ 3D printing has unique properties that can be an advantage during specific out of ordinary situations. The fact that AM industry can rapidly overcome urgent needs in terms of very specific parts allows the industry to have a fast response to humanitarian crises. On the previous chapter was explained the example of the role of AM during COVID 19 pandemic. In a nutshell, industry and home manufacturers got together to help manufacturing, in short notice, specific parts to aid the battle against the pandemic. This was only possible due to AM unique capabilities that with the correct machine and a CAD file that can be shared all over the world, citizens could get together and produce parts to help people on the front line of the battle with this pandemic.

With continuous efforts of increasing the quality of AM machinery and the increase of industries using AM it will be possible in a short future to have more companies ready to help producing parts during humanitarian crises.

Milestone: **Part qualification and certification for defence sector**

The use of AM to develop defence products is expected to bring innovation to a new level, mainly for the production of replacement parts and tools for military equipment. AM technologies presents interesting advantages for the defence sector as allowing to eliminate several of the design limitations associated with traditional manufacturing technologies and on-demand production. However, to take full advantage of this capabilities, it is needed to ensure that the parts produced have passed performance tests and quality assurance tests to and meet the requirements of the sector. Part qualification and certification will thus be addressed in order to do not compromise the AM benefits of low lead times and mechanical properties that can be obtained.

2) Security

Milestone: **Improve security in the additive process and minimize any possible malicious actions by third parties**

As Additive Manufacturing is constantly increasing, and more and more industries are turning to this technology it is strictly important to improve digital security of the all manufacturing process, and more and more industries are moving their efforts to fill in this gap. [166] AM is still in its infancy and therefore there is still the need to implement robust security processes in the areas of ideas, design, prototyping, production and delivery. [167]

Furthermore, Additive Manufacturing takes a significant role in Industry 4.0 and is a must in this industrial revolution. [168] Cyberphysical security has also a significant role in Industry 4.0 and combined efforts in application of Cybersecurity in Additive Manufacturing will significantly impact the overall sectors affected by Industry 4.0. This topic is foreseen in the agenda of Industry 4.0 and therefore was considered a Milestone for Citizens Security field. [169]

Milestone: Development of authentication steps to protect designs from digital file's vulnerability

While previously we considered the overall impact of security in Additive Manufacturing, this Milestone is directed improve security and reduce vulnerability of design digital files. As explained previously in this document Design takes a significant role in Additive Manufacturing and the security of design files is rather important in this new industrial world we live in. Being so, industry is focusing on keeping Additive Manufacturing design files secure and there has already been developed features to ensure the security of additive manufacturing design files. [170] Furthermore, on the upcoming years it is foreseen that current security processes, such as authentication steps and application of a digital design flow for secure integrated circuits, are applied to the wide range of manufacturing production.

Table 15 includes some critical areas indicated in this chapter where additional research could lead to significant improvements.

List of challenges in the Citizens Security fields: Reacting and recovering from natural and man-made disasters; Digital Security, privacy and data protection; Consistent and secure production achieved through certification of parts and standards

Table 15 - Milestones and related skills for Citizens Security

Milestones (technology related)	**Timeline (3 scenarios)**	**Related technological skills**	**Other skills (e.g transversal, digital green)**
Development of resilient, reliable 3D printer expressly created for use in humanitarian crises	[2020-2021] Short-term (Identification of reliable solutions) [2022-2030] Foresight – (Integration of 3D printer for on-site use)	AM processes Design for AM Quality for AM Inspection of AM parts Structural integrity Materials Science Logistics and Transportation	Spotting opportunities to create value Vision Working with others Problem Solving Communication Planning and Organisational skills AM Software
Improve security in the additive process and minimize any possible malicious actions by third parties	[2020-2021] Short-term [2022 – 2030] Foresight (Global implementation of process security for the prevention of malicious actions)	Quality for AM Inspection of AM parts Materials Science Process Monitoring tools Metallurgy Standards for security	Working with others Planning and Organisational skills Communication
Development of authentication steps to protect designs from digital file's vulnerability	(2020-2021] Short-term [2022 – 2030] Foresight	Design for AM Quality for AM Inspection of AM parts Structural integrity	Encryption standards for AM digital files Spotting opportunities to create value Problem Solving
Part qualification and certification for defence sector	2020-2021] Short-term	AM processes	Spotting opportunities to create value

Milestones (technology related)	**Timeline (3 scenarios)**	**Related technological skills**	**Other skills (e.g transversal, digital green)**
	[2022 – 2030] Foresight	Design for AM Quality for AM Inspection of AM parts Certification and Standardization of AM parts	Problem Solving

The above identified and justified milestones in this section reflect the important achievements to be done in the future in terms of skills development to assure AM potential deployment within Citizens Security. Looking at the challenges and set of skills required by professionals of this sector, it is possible to infer that the AM skills strategy to be adopted shall address key driving actions linked to: standardisation, quality control, implementation of AM training for the identified skills and raise awareness.

The required EUROPEAN AM SKILLS STRATEGY shall consider…

- linking training development and standardization activities to guarantee the quality, and security achieved through the certification of parts produced, thus aligned with the defined
- linking stakeholders of the AM value chain, in order to tackle the range of skills needed.
- implementation of different training methodologies and tools for different levels of AM qualifications, in order to tackle the diversity of skills required, including technological, green and digital.
- involving non-sectoral stakeholders (e.g. ISO and ASTM) in the identification and validation of necessary skills/qualifications
- continuous monitoring of AM technology developments and it is impact for citizens security
- raising awareness of the general public, including children, non-manufacturing professionals and students towards the AM advantages /contributions for the overall citizens security.

8. Additive Manufacturing and the general public

This report is mainly focusing on the skills related to the employment issues. This is in fact the focus of the SAM project as a whole. What is often forgotten in policy documents, is the understanding and acceptance of AM by the general public. It is true that basic understanding of a technology and the consequential acceptance is not a skill in the strict sense. Yet, it can play an important role in getting people curious and maybe even interested in acquiring AM skills. So, it is relevant for the SAM-ERASMUS+ Blueprint project.

Furthermore, lack of awareness on AM can lead to unmet expectations, misunderstanding and even fear. Most experts that have addressed more general audiences came across surprising reactions and worrying questions and remarks. Just some genuine examples:

- I will not let my child become a bricklayer because in the near future, all houses will be 3D-printed.
- There will be no more jobs in manufacturing because 3D-printing requires no manual intervention.
- On the high-end printers, is it possible to print an atomic bomb?
- Why don't we print new hearts instead of working with organ donors?

The problem is not new and is not specific to AM. People are afraid of being replaced by robots. In the 19th century, the *Luddites* were a secret oath-based organization of English textile workers protesting against the use of machinery in a "fraudulent and deceitful manner" to get around standard labour practices. Then as well as now, this can be easily debunked. *The 2019 World Manufacturing Forum Report, skills for the future of manufacturing* states:

> *…, while there are many things that must be addressed and considered in the manufacturing world, nothing is possible or made without people who know how to get the job done.*

The media focus on the spectacular research results, often exaggerating them, creates these false assumptions. In 2000, at Wake Forest Institute for Regenerative Medicine, a miniature blood filter was 3D-printed. In a sectorial report (*Challenges of Additive Manufacturing, Why companies don't use additive manufacturing in serial production* by Deloitte) this appears as one dot on a historic timeline: First 3D printed functional kidney. This is only a mild exaggeration.

To overcome this knowledge gap, SAM project can actively take part in giving the general public a better understanding of AM, it’s advantages, applications and disadvantages through its targeted awareness campaigns.

9. Conclusions

Am is an increasing technology which several industries are adopting. Market forecasts predict that between 2031 and 2038, AM is expected to reach 50% of the market potential, while reaching 100% of the market potential between the year 2058 and 2065 (Thomas, 2016) [171]. The technology has several advantages when comparing it with basic manufacturing. With AM there are less production wastes, less amount of material used and therefore it is better for the environment and the parts produced can be lighter, which is aligned with the major **Global and Societal challenges and priorities** addressed by European strategic programmes and corroborated in technical reports and both skills and technological roadmaps. Furthermore, AM allows a higher freedom of design, more precise and effective parts and a production of parts customized to consumers' needs that could not be produced in any other way. Moreover, in some industries AM manufacturing allows reduction of lead time and in some cases the final part has superior mechanical properties than if produced in normal production. The advantages above apply to all sectors defined in the previous chapters of this report.

In all reports analysed on the evolution of AM (and even manufacturing in general), there were many different opinions on what the future brings, but there was the consensus on one of the major threats being the lack of skilled people. This illustrates the necessity of the project as a whole.

Along the document, global and societal challenges of the different sectors were identified as priorities by the European programmes and recent technical reports, in order to understand how external elements, relate to AM technology and influence the skills development. Another point achieved with the milestones report, was the clarification whenever the identified challenges could lead /relate to specific AM technological or other skills needs in a certain period of time and for a certain sector, or if it could rather lead/relate to cross- sectorial skills needs covered in limited scenarios, i.e. Real case (2019); Short -term (2020-2021) and/or Foresight (2022 – 2030).

Based on the literature review, it is expected that the use of AM within different sectors will be strongly influenced by common technological trends such as: smart/autonomous and digital systems; artificial intelligence; optimization of resources (reduction of energy, waste, manufacturing steps and overall times), hybrid manufacturing, zero defects, improvement of quality performance in the entire AM value chain). Nevertheless, there are skills that will be required throughout the different scenarios analysed, with different levels of knowledge and consequent depth as time progresses, in order to enlarge the spectrum of application of AM technologies. Consequently, the training delivery in terms of new skills and knowledge about the updated developments requires to follow this rapid process, either by the provision of full qualifications or short-term training periods.

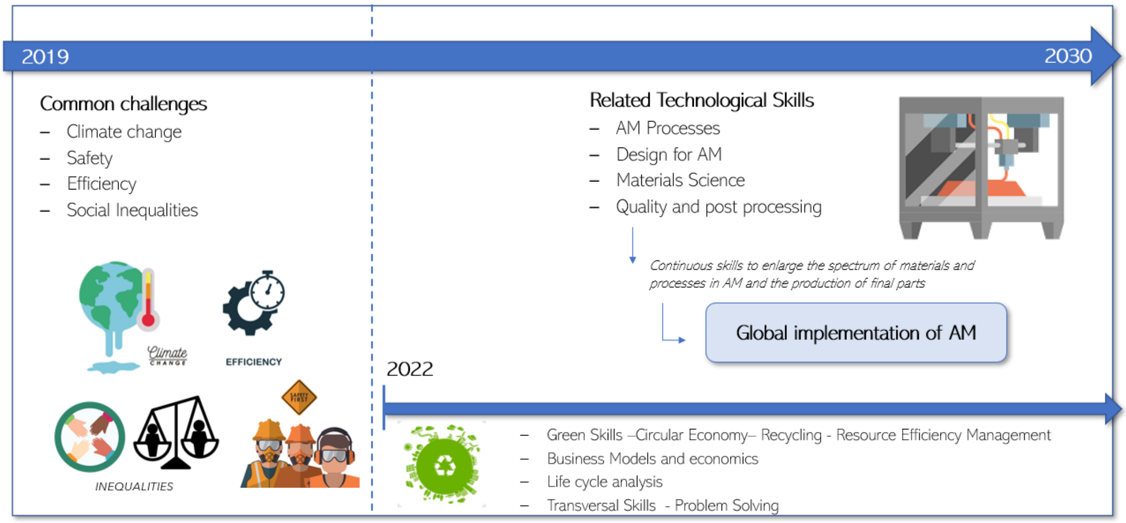
As mentioned along this report, Global and Societal Challenges were carefully depicted regarding the overall European strategies and proprieties addressed by H2020, Horizon Europe and also other international policies and agreements documents (e.g. Enable Development Goals (2015-2030), United Nations Framework Convention on Climate Change (UNFCCC)), enabling to relate the programmes objectives and working areas for different fields with the AM sector.

The analysis of the first stream of the strategy **Global and Societal Milestones**, points the climate change, safety, efficiency and inequalities as the common global and societal challenges for the health and demographic change, energy, transports, environment, citizens security, innovative and inclusive societal factors, thus corresponding to all addressed fields.

The outcome of this process led to the establishment of milestones defined in terms of technological priorities and its relationship with AM technological skills and other needs for the 3 scenarios. These findings will be an important factor to consider in the **development of the Methodology to review and design Professional Profiles / Qualifications** (WP3), as it will enable to identify the origin of the skills gaps related to the milestones. Moreover, these findings are the baseline that will enable to **define the European AM skills strategy. The following** key **drivers of action were considered to be** crucial to be adopted, namely: linkage of AM Skills with quality, standardisation, involvement of both relevant sectoral and non-sectoral players, implementation of training according with the priority of skills, as well as the promotion of raise awareness of the general public towards AM contributions to deal with the global and societal challenges.

The optimization of AM processes, AM design, AM materials science, quality and post-processing are the main key knowledge areas where skills demand is foreseen to have more impact on the AM sector and consequently on the global challenges. In general, it is expected a continuous development of these skills, at different levels, within the next 6 months, 2 years and 10 years in order to globally implement the AM technologies.

Particularly, there are skills on sustainability, circular economy, recycling, resource efficiency management, business models and economics in AM that appear as priorities from 2022 to 2030.



These are the common skills mentioned as the main influence to enlarge the spectrum of materials and processes in AM and the production of final parts, the common milestone for the different sectors.

However, specific challenges of the sectors may be addressed by specific skills. In case of health and demographic changes, aging population and personalisation are the main challenges that may be related with biomaterials and green skills for printing human body parts in bio-tissues. For the citizens security, the development of AM skills is foreseen to influence the global implementation of process security for the prevention of malicious actions.

The table below summarizes the relationship between the Global and Societal Challenges, the correspondent Milestones, defined as technical requirements, and related skills requirements for AM professionals in the identified sectors and scenarios, from which we highlight the following conclusions:

- For all sectors Skills and Know-how related with AM Processes, Modelling, Design, materials science and metallurgy and structural integrity, Quality control and Inspection of AM parts remain relevant for the next years;
- Health: Skills and Know-how related to Green skills and Recycling Processes were identified for a future perspective, being the sector focused on the expansion of the spectrum of materials and processes, as well as on the production of real human body parts;
- Energy: it is expected to increase large parts production after small components production steadiness;
- Transport: investment in Skills and Know-how related with post processing and business skills is expected to increase, being the sector focused on the expansion of the spectrum of materials and processes;

- Consumer Goods: throughout the next years skills and know-how related with Open innovation management, Production models and business models and IP management will be highly in demand;
- Environment & Efficient Resources: throughout the next years skills and know-how related with Life-cycle analyses methods and software will be highly in demand;
- Citizens Security: The overall expected AM service for the society's prosperity

HEALTH

Real case scenario / Short term scenario (2019, 2020, 2021)	Skills / Know how on	Foresight term scenario (2022 … 2030)	Skills / Know how on
Modelling methods of interaction between materials and living tissue	Modelling for AM; Design for AM; Simulation Software; Biomaterials; Materials science and metallurgy; structural Integrity; Transversal Skills.		
		Studying and modelling of the whole human body and its evolution over time	Modelling for AM; Design for AM; Simulation Software; Biomaterials; Materials science and metallurgy; structural Integrity; Transversal Skills.
Bio-materials applicable to AM	Modelling; Design for AM Biomaterials; Materials science and metallurgy; structural Integrity; Circular economy and transversal skills;		
Large production at lower costs	AM value chain; production industry techniques and methods		
Validation of mechanical and thermal properties of existing materials			
		Printing human body parts in bio-tissues	Modelling for AM; Design for AM; Biomaterials; Materials science and metallurgy; Structural integrity; Production industry techniques and methods; AM processes; Quality control in AM; Standards for Parts and Processes; Inspection of AM parts; Simulation and modelling of AM parts; Resource efficiency management; circular economy; Transversal skills;
		Recycling, reuse of precious materials and use of sustainable ones	Green skills; Integrated production; AM value chain; Production industry techniques and methods; AM processes; Recycling Processes; Interaction between several production processes; Design Modelling; Data Analytics; Simulation Software; Green skills; Transversal skills;
		Multi-material products with improved functionalities	AM processes; Quality control in AM; Modelling for AM Design for AM; Materials Science; Materials for AM; Simulation software Transversal skills;
		Novel skeletons	

Sector	Real case scenario 2019 / Short term scenario 2020, 2021	Skills / Know how on	Foresight term scenario 2022	2030 Skills / Know how on
ENERGY	Development and industrialization of more efficient small and complex components	AM processes; Simulation; Design for AM; AM quality and part inspection; Certification and Validation; Structural integrity; Standards for parts; Transversal skills; Eco-design of parts;	Development and industrialization of more efficient large size components	AM processes; Design for AM; AM quality and part inspection; Materials science; Structural integrity
ENERGY	Repair of components	AM processes; AM quality and part inspection; Materials science and metallurgy		
ENERGY	New sustainable and improved materials	AM processes; structural integrity; Materials analysis and characterisation Certification and validation Materials development (harsh environments, high temperature; Metallurgy Materials for AM; Problem solving.	Smart materials	AM processes; Structural integrity Materials analysis and characterisation Certification and validation Materials development (harsh environments, high temperature,) Metallurgy; Materials for AM; Problem solving.
ENERGY	On-site Production of small size parts	AM processes; Post-processing; AM quality and part inspection; Materials science and metallurgy New business models; Transversal Skills	On-site production of large size parts	AM processes; Post-processing; AM quality and part inspection; Materials science and metallurgy New business models; Transversal Skills
TRANSPORT	Optimization modelling for the most used materials and processes	AM processes; Design for AM Materials science; Structural integrity; Metallurgy; Structural integrity; Modelling for AM; Evaluation of defects and correlations; Software systems and transversal skills;	Development and optimization for other materials and processes reaching the market and industry	AM processes; Design for AM Materials science; Structural integrity; Evaluation of defects and correlations; Software systems and transversal skills;
TRANSPORT	Design optimization in the assembly of complex parts with main used processes	AM processes; design for AM; Structural integrity; Standards for AM Design; Design software; Problem Solving	Design optimization in the assembly of complex parts with all used processes	AM processes; design for AM; Structural integrity; Standards for AM Design; Design software; Problem Solving
TRANSPORT	Identification of feedstock properties to achieve powder production quality and consistency	Quality Systems for AM; Feedstock control and characterization; Resource efficiency management; Circular economy	Testing and validation criteria of feedstock properties to ensure part quality	Quality Systems for AM; Feedstock control and characterization; Resource efficiency management; Circular economy
TRANSPORT	Reliability of produced parts linked to new sustainable materials, processes, multifunctional materials, multi-materials with highly improved functionalities	AM processes; Quality control in AM; Inspection of AM parts; Simulation and modelling of AM parts; Materials for AM; Business models and economics for AM; Recyclability of AM parts; Transversal skills.	Reliability of produced parts during their lifetime and in accordance to different sectors requirements linked to new sustainable materials, processes and related characterization in the field of multifunctional materials, multi-materials with highly improved functionalities	AM processes; Quality control in AM; Inspection of AM parts; Simulation and modelling of AM parts; Materials for AM; Business models and economics for AM; Recyclability of AM parts; Transversal skills.

TRANSPORT

Real case scenario	Short term scenario			Foresight term scenario			
2019	2020	2021	Skills / Know how on	2022		2030	Skills / Know how on
				Sustainability and recyclability of AM parts			
				Development of processes to manage graded materials and to overcome the need of joining/Welding parts			AM processes; Post processing; Joining/welding of AM parts; Materials for AM; AM modelling with multi-materials; Resource efficiency management; Transversal skills.
Development of control mechanisms for optimized performance of the AM processes			AM processes; Quality control in AM; Inspection of AM parts; Data analytics related to AM; AM material testing; Structural Integrity of AM parts; Transversal Skills	Development of real time control systems and data for improved repeatability, reproductivity and performance of AM processes			AM processes; Quality control in AM; Inspection of AM parts; Data analytics related to AM; AM material testing; Modelling for AM Structural Integrity of AM parts; Transversal skills
Characterization on dynamic properties and residual stresses			AM processes; Post-processing; AM material testing; Material Science; Residual stresses control; Resource Efficiency Management				
Design capability of complex structures using "common" AM processes			AM processes Design for AM; Simulation and modelling of AM parts; Structural Integrity of AM parts; Evaluation of parts durability; Standards for AM Design; Resource Efficiency Management; Transversal skills	Design capability of complex structures using all the AM processes			AM processes Design for AM; Simulation and modelling of AM parts; Evaluation of parts durability; Standards for AM Design; Resource Efficiency Management; Transversal skills
Automation of repair processes through integration of AM robotics			AM processes Repair using AM; Robotics; Certification and Validation; Resource Efficiency Management; Circular Economy	Automation of repair of complex parts/structures			AM processes Repair using AM; Robotics; Design for AM; Simulation and modelling of AM parts; Structural Integrity of AM parts; Evaluation of parts durability; Standards for AM Design; Resource Efficiency Management; Transversal skills
Post-processing of AM parts			AM processes; Post-processing; Combined AM and Subtracting Manufacturing; Joining of AM parts; Hybrid Solutions; Transversal Skills	Combined post-processing, including subtractive manufacturing with AM			AM processes; Post-processing; Combined AM and Subtracting Manufacturing; Joining of AM parts; Transversal skills;
				Production of larger AM airframe structures			AM processes; Post-processing; Parts production; AM Machinery; Problem Solving
				Higher rates and cheaper systems linked to the production of larger AM parts			

INNOVATIVE & INCLUSIVE SOCIETY

Real case scenario 2019 / Short term scenario 2020 – 2021	Skills / Know how on	Foresight term scenario 2022 – 2030	Skills / Know how on
Cost effective printing assemblies linked to the design of parts	AM processes; Design for AM; Materials for AM	Cost effective printing assemblies linked to new design methodologies that align materials with functionality	AM processes; Design for AM; Materials for AM; Business for AM; Resource efficiency management; Transversal Skills
		Industrially relevant larger certified build envelopes	AM processes; Post-processing; Materials for AM
Development and validation of small and simple hybrid manufacturing systems	AM processes Post-processing; Design for AM and SM; Quality Control; Hybrid Solutions; Circular Economy; Transversal skills	Optimization of larger and more advanced manufacturing systems	AM processes Post-processing; Design for AM and SM; Quality Control; Hybrid Solutions; Circular Economy; Transversal skills
Multi-material parts	Materials for AM, properties and performance; Design and testing of new materials; Multi-material product design for AM; AM process; Problem Solving	Smart/4D multi-material parts	Materials for AM, properties and performance; Design and testing of new materials Multi-material product design for AM; AM process; 4D printing methods; Problem Solving
Mass customization of existing products	Design for AM Materials for AM; AM processes; Open innovation management; Production models and business models; IP management; Business for AM; Transversal skills	Mass customization, co-creation and fabrication platforms for new product-services	Design for AM Materials for AM; AM processes; Open innovation management; Production models and business models; IP management; Business for AM; Transversal skills
Improved aesthetics and surface quality linked to low post-processing	Design for AM Materials for AM; AM processes; Open innovation management; Production models and business models; IP management; Business for AM; Transversal skills	Improved aesthetics and surface quality linked to no post-processing	Design for AM; Materials for AM; AM process; Quality for AM; Post processing
		Predictive, self-learning and holistic multi-physical modelling approaches	Materials for AM; AM processes; Multi-physical modelling and simulation; Data Analytics; AI; Software platforms; Problem Solving
		3D capturing geometry/technologies	Modelling for AM ; Design for AM; Standards for AM parts; Standards for 3D scanning processes; Geometry algorithms and computer vision; 3D capturing tools and scanning ; AM files software

ENVIRONMENT & EFFICIENT RESOURCES

Real case scenario	Short term scenario			Foresight term scenario			
2019	2020	2021	Skills / Know how on	2022		2030	Skills / Know how on
				Hybrid manufacturing and Industry 4.0			Design and management of smart & hybrid systems and processes Value chain Digital manufacturing Industry 4.0 Design for AM Management of smart product lifecycle Production models Hybrid Solutions; Standards; Recyclability of AM parts IT/OT system integration; Data analytics; Resource efficiency management; Circular Economy
Identifying the advantages in terms of quality and durability of manufactured products with established AM technologies			AM processes; Materials science; Life-cycle analyses methods and software; Standards; Circular Economy; Resource Efficiency management; Business Model; Transversal Skills	Identifying the advantages in terms of quality and durability of manufactured products with emergent AM technologies			AM processes; Materials science; Life-cycle analyses methods and software; Standards; Circular Economy; Resource efficiency management; Business Model; Transversal Skills
Impact of different established AM technology in the sustainability ratios				Impact of different emergent AM technology in the sustainability ratios			
Studying life cycle analyses redesign processes for established AM technologies				Studying life cycle analyses redesign processes for emergent AM technologies			
Analysis of the impact of distributed production business models for established AM technologies			AM processes; Required sectorial Know-how; Life-cycle analyses methods and software; Design for AM; Standards for AM Design; Business for AM; Problem Solving	Analysis of the impact of distributed production business models for emergent AM technologies			AM processes; Required sectorial Know-how; Life-cycle analyses methods and software; Design for AM; Standards for AM Design; Business for AM; Problem Solving
Development of design rules for sustainability for established AM technologies				Development of design rules for sustainability for emergent AM technologies			

	Real case scenario	Short term scenario			Foresight term scenario	
	2019	2020	2021	Skills / Know how on	2022	2030 Skills / Know how on
CITIZENS SECURITY		Identification of reliable 3D printed solutions expressly created for use in humanitarian crises		AM processes; Design for AM; AM quality and part inspection; Structural integrity; Logistics and Transportation; AM Software; Transversal skills	Integration of resilient, reliable 3D printer for on-site use in humanitarian crises	AM processes; Design for AM; AM quality and part inspection; Structural integrity; Logistics and Transportation; AM Software; Transversal skills
		Improve process security and reduction of any possible malicious actions		AM quality and part inspection; Materials science and metallurgy; Standards for security; Transversal Skills	Global implementation of process security for the prevention of malicious actions	AM quality and part inspection; Materials science and metallurgy; Standards for security; Transversal Skills
					Development of authentication steps to protect from digital file's vulnerability	Design for AM; Quality for AM; Inspection of AM parts; Structural integrity; Encryption standards for AM digital files; Problem Solving
					Part qualification and certification for defence sector	AM processes; Design for AM ; Quality for AM; Inspection of AM parts; Certification and Standardization of AM parts; Problem Solving

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