UiT The Arctic University of Norway

Promoting Metal Additive Manufacturing in the Kolarctic Region

- Report on work package A2 in Kolarctic project “From Idea to Products” (I2P)

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1 Introduction

It is an undisputed fact that SMEs are basic elements that constituents the backbone of the global economy and playing a vital role in regional, national, and global economies and significantly affecting growth and wealth of a nation [1]. Statistics reveal that SMEs represent 90% of businesses, more than 60-70% of employment, and 55% of GDP in developed economies [2].

It is commonly agreed that the global competition is getting fierce, especially for those Small and Medium sized Enterprises (SMEs). Lack of finance, infrastructure, network connections, knowledge and production facilities are just some challenges SMEs face on a daily base [3]. The countermeasures at SMEs for sustaining in such competitive area are continuously increased responsiveness, agility, sustainability, and supply resilience for tackling current global business challenges. An increasing number of SMEs is seen to focus on lowering the cost which necessitating to benefit from advancement in technological development. Unfortunately, even more SMEs are missing out new opportunities with lost value and competition as consequence. To date, the gap between SMEs with modernizing technological oriented value proposition to those are conservative grows rapidly.

Metal Additive Manufacturing (MAM) is one of these technical advancements which are receiving exponentially growing attention and has been associated with potentially strong stimuli for revenues and cost saving [4]. Advantages of the MAM techniques are many, and main drivers for increased application are increased design freedom, reduce production and logistics waste, promoting digitalization in manufacturing system and their corresponding economic gains to a large extent [5] [6]. As shown in Figure 1, the global MAM market has been steadily increased in 2016-2019 and it is expecting significant growth towards 2024 [7], An estimated Compound Annual Growth Rate (CAGR) is 27.9% and it is predicted that MAM will evolve from being a prototyping tool to become one of the main technologies in manufacturing business.

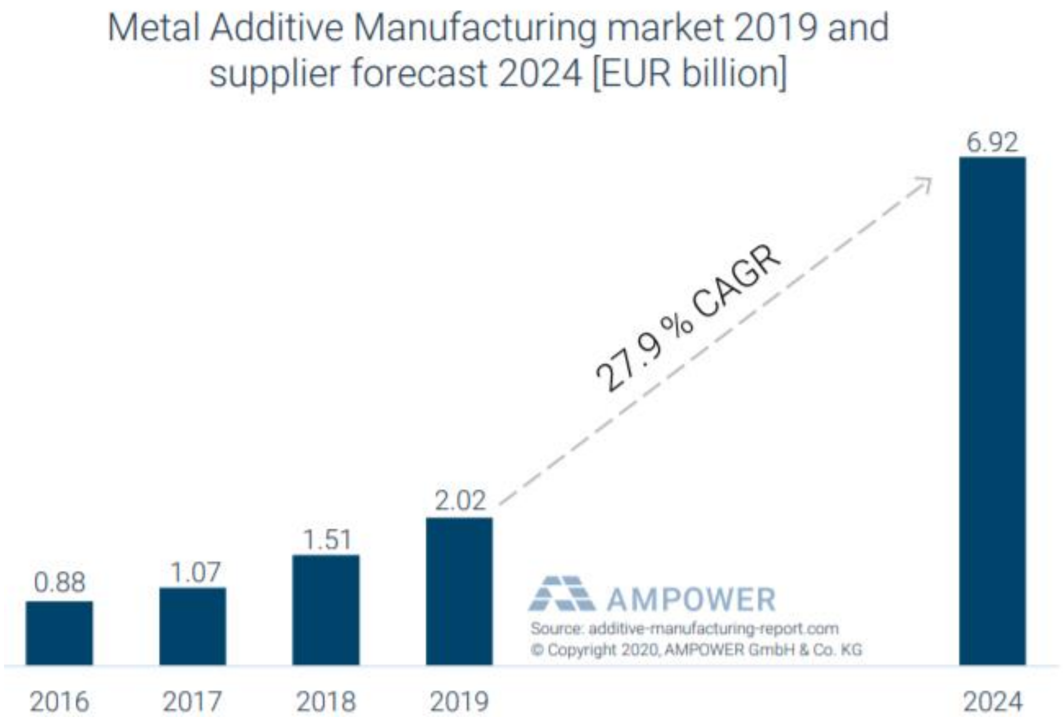

Figure 1 Metal additive manufacturing market *[7]*

However, fully benefitting from these techniques are challenging, and not least, very costing. The most of MAM concurrent application is therefore on high value product for niche markets, i.e., aerospace and defense, automobile[1], and medical sectors, as shown in Figure 2 [7] [8]. Trends and opportunities found within the aerospace and automobile industry are easy to justify, such as light weighting objectives, topology optimization and reduction of waste [6] [9] [10], while in the medical sector has seen different uses such as utilizing the techniques towards customized implant design, prosthetics and mechanical bone replicas [11].

Figure 2 shows also several other industrial sectors (i.e., oil and gas, mechanical and automation and energy) have signed up for MAM. With continuous development of technologies in MAM and those that enabling its adoption, it is confident to predict that MAM will have profound impact on how manufacturing industry conducts production activities and potential savings it

[1] The automobile sector faced a challenging business year in 2019 and the effects are mirrored in the AM investment. However, supplier forecasts expect high growth rates [7].

can bring to total supply chain costs. In short, the adoption of MAM will significantly influence global manufacturing SMEs in terms of competitiveness, profitability, and sustainability.

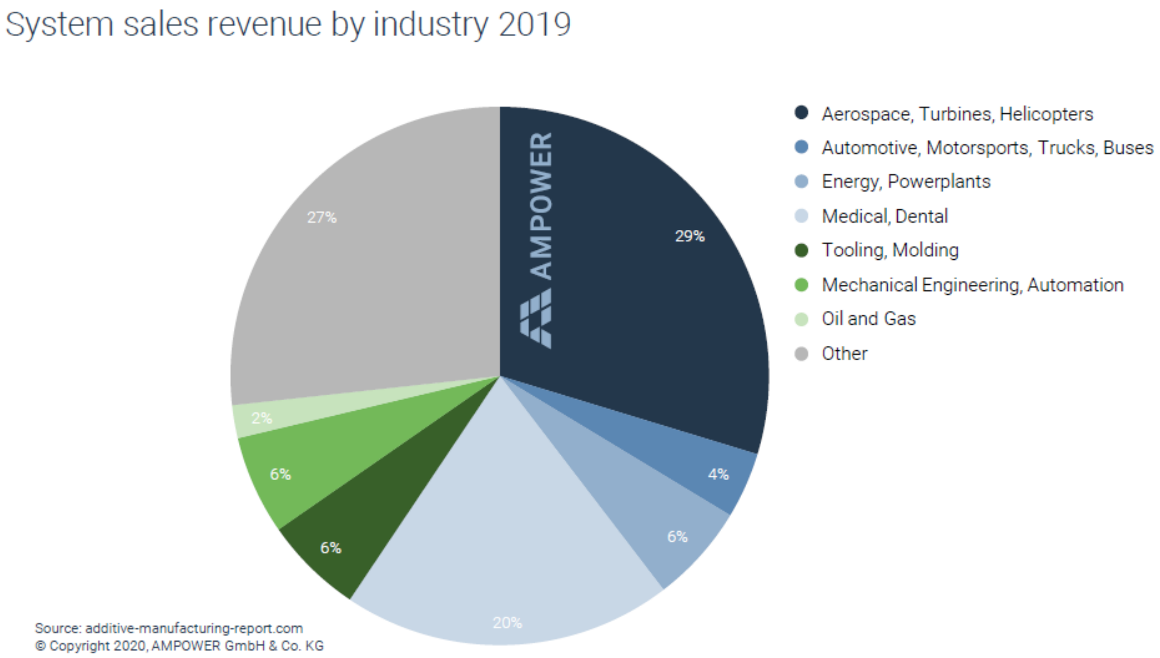

Figure 2 Global 3D printing metal market share, by application *[7]*

However, benefiting from MAM is particularly a challenge to SMEs. This challenge is even severe for those operating in sparsely populated regions that suffer from a reduced regional employment (comparing with central regions), lower job attractiveness for young people, geographical seclusion from major markets, and a lower capital turnover rate [12]. As MAM is expected to become future-oriented technologies in maintaining business advantage and increasing competitiveness of SMEs, assisting SMEs with a clear roadmap for the purpose of motivating and facilitating their adoption of MAM so that they can be fully benefited becomes an emergent task.

This report documents the activities conducted in work package 2 (A2) in InterReg Kolarctic project I2P. Through the A2, the project consortium aims to cumulate knowledge as well as develop a thorough understanding on the economic and environmental status of the Kolarctic region in order to provide an analysis on the main challenges towards adoption of MAM for manufacturing businesses in the Kolarctic region. Guidelines for assisting SMEs' adoption of MAM technologies are designed thereafter. All these outputs will serve as input to other work packages in the same project.

2 The Kolarctic Region

The Kolarctic region is a geographical area in the northwestern part of Europe. The area consists of the circumpolar Arctic region of Russia, Sweden, Norway and Finland as depicted in green as shown in *Figure 3* – with dark green illustrated the core regions while greenish-yellow represents adjoining areas. Similarity for all the regions is that all areas are within or close to the Arctic. The closeness offers high potential for resource exploitation, yet with a high financial, social, and environmental cost in an environment remaining financially very risky [13].

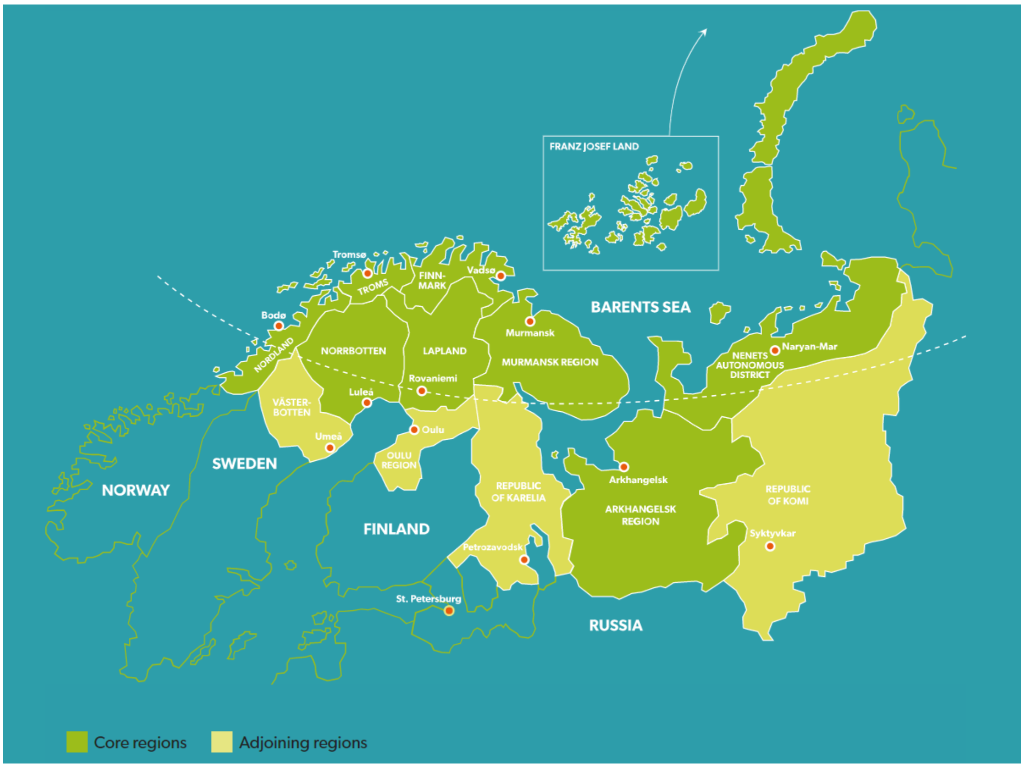

Figure 3 Kolarctic CBC program region [41]

The population in the Kolarctic regions is significantly lower than their respective country average. According to the 2020 BIN report, all Kolarctic regions, except North Ostrobothnia and Nenets, have had a lower population growth than the country average in a ten-year-period from 2009 to 2018. More worries can be directed to the Kolarctic Russian regions (except Nenets) due to negative population growth in the same period. As a whole, the Kolarctic region suffered from a population reduction of 200 000 people between 2009 and 2018 (see figure 4).

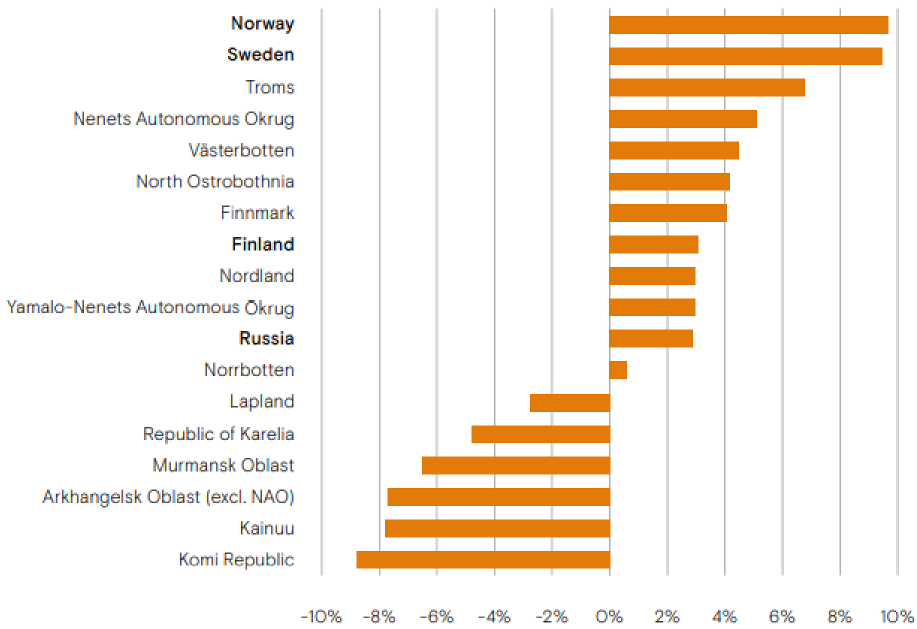

Figure 4 Change in population 2009-2018 [14]

The Kolarctic region is also notably sparsely populated comparing with their respective country. Table 1 presents the population density of the Kolarctic region comparing with its respective country average.

Table 1 Demographic statistics Kolarctic regions 2020

Region	Population	Density	Density rest of country	% of country
Norway	486 252	4.3/km^2	15/km^2	8.9 %
Sweden	520 651	3.4/km^2	25/km^2	5%
Finland	589 991	4.55/km^2	18/km^2	9.35%
Russia	3 312 476	2.5/km^2	9/km^2	2.3%

The negative population trends might be tied to the lower education level in the region. The education in the region is slightly lower than respective country average for higher education, particularly for the Russian region [14]. Considering that the adoption of advanced technologies usually is closely related to technical innovations competence that derived from higher education, the lower educational level in the regions can be one of the major challenges.

3 The Economy of and the Industries in the Kolarctic

The economic development of the Kolarctic region can only be realized through sustained innovation, better infrastructure, activities that lowers costs, increased education and opportunities for more fruitful exchange [15].

In the following sections, we present a general economic status of the Kolarctic together with an overview of the region's main industries.

3.1 The general economic status of the Kolarctic

While considering the Kolarctic economy, comparing and tracking of economic performance and measuring regional wealth and growth potential are of high relevance. At the macroeconomic level, comparing economic data from different regions in different countries can be challenging. For the purpose of this project, gross domestic product (GDP) and gross regional product (GRP) based on Purchasing Power Parity (PPP) are used for measuring price differences in domestic markets in project member countries. The application of GDP PPP provides tool for comparing economic performances of the countries. The data presented in this report are based on information collected from Organisation for Economic Co-Operation and Development (OECD) and the BIN reports.

Figure 5 presents GDP PPP per capita in 2016 for all partner countries. The red bars represent data on country level while the blue bars on province level for those in the Kolarctic region. Most noteworthy is the inequality found between the countries and regions. There is a distinct difference between the Northern regions and the southern metropolitan areas. Recognised from the Kolarctic regions GDP levels. All of which have lower GDP than the country level, except Nenets region (Merged with Arkhangelsk in 2020).

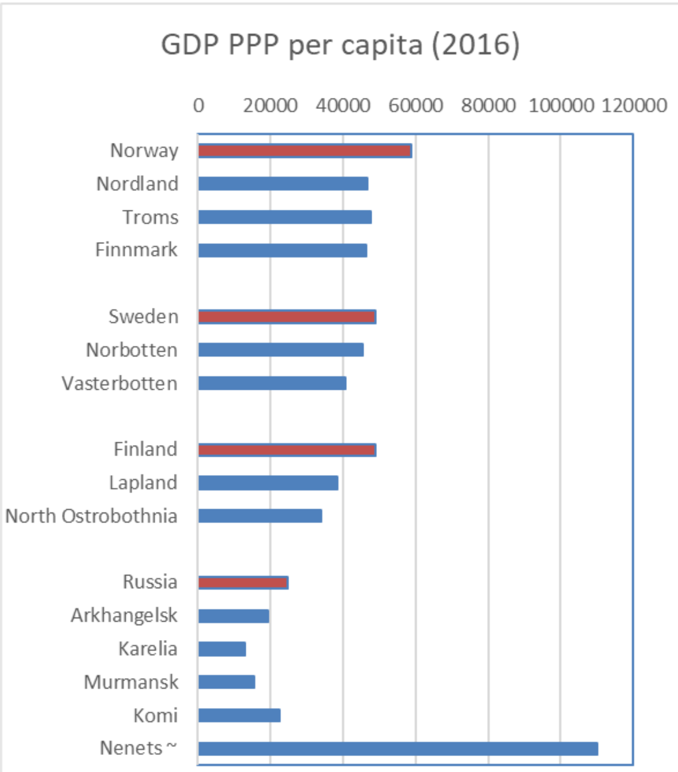

Figure 5 GDP PPP per capita 2016 (in $)

Figure 6 illustrates average GDP growth rate for the period of eight years for three the Scandinavian countries, while figure 7 illustrates the average GDP growth rate for the Russian area. From the figures it seems that the economic activity is unequally distributed, and those regions that have embraced the exploitation of natural resources, especially, non-renewable resources, shows high economic growth [14] [16]. However, these inequalities can limit development of new partnerships both cross-regional and cross-border. The poorer members of society have less resources for investment in technologies, and higher education in these societies can be challenging.

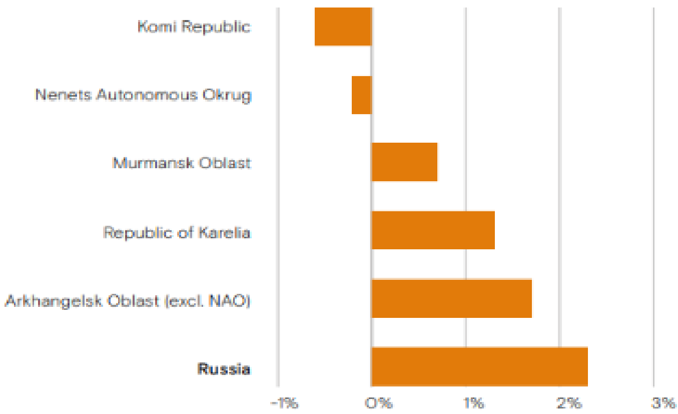

Figure 7 GDP average annual growth rate 2009-2017 [14]

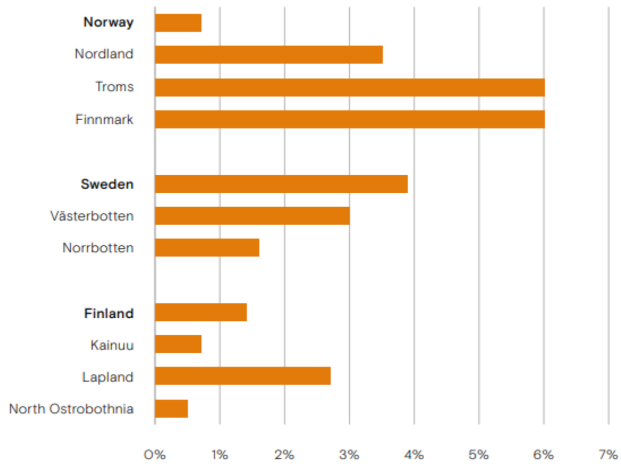

Figure 6: GDP average growth rate 2008-2016 [14]

3.2 The industries in the Kolarctic

The overview presented in this section is based on information mapping from the BIN reports. Due to the lacking of necessary data, the Russian regions of Komi and Karelia and Kainou in Finland are excluded in this overview.

Kolarctic area is diversified in terms of industrial development. Business in the region is dominated by activities tied to the extraction, refining, energy transformation, and harvesting of natural resources – accounting for 54.3% of all turnover in 2018 [17]. As illustrated in Table 2, typical industrial activities are related to fishing and forestry, mining (oil, gas, minerals), shipping, manufacturing, tourism, hydro power and other associated to the service sector, just to mention a few [18].

Table 2 Main industrial activities in the Kolarctic (based on BIN reports [19] [20] [17] [14], SSB [16])

Norway	Petroleum industry, maritime, mining, mineral production, hydro power
Sweden	Mining, wood, hydropower, refining of materials, heavy construction
Finland	Metal industry, forestry, tourism, trade and mining industry, technology (IT and software)
Russia	Fuel and energy industry, forestry, mining and metallurgy, Fishing, machine building, agricultural

The manufacturing industry is the largest industry as it is the main supplier to these industrial activities. The extent of the manufacturing industry can be illustrated by its turnover as shown in Figure 8 (for Norway, Sweden and Finland accumulated. Russia is excluded as due to lack of data).

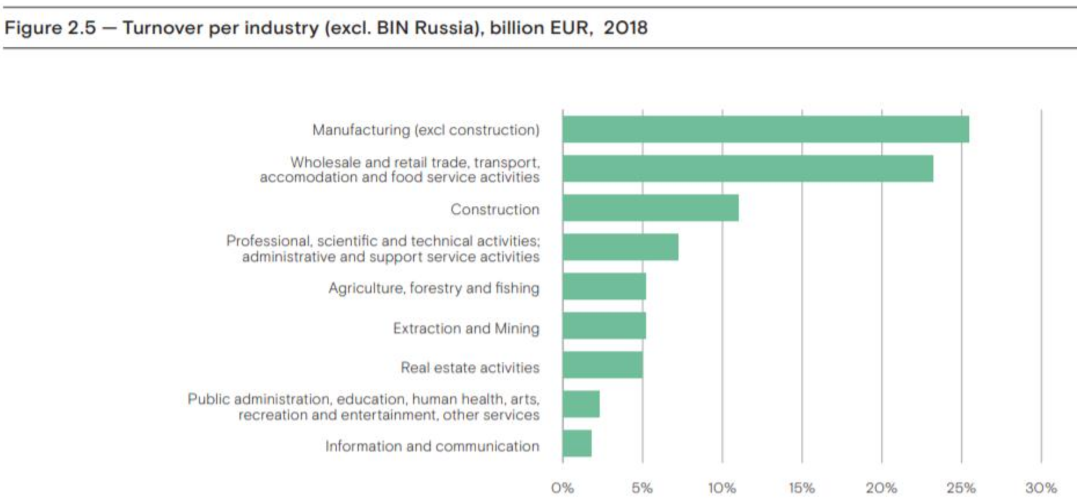

Figure 8 Turnover per industry BIN regions excl Russia [17]

Based on the analysis on BIN reports, it is clear that although manufacturing industry are the largest measured by turnover in the Northern regions there are large variations country wise. *Table 3* shows the manufacturing industry as % of GDP on national level in 2019. Sweden, Finland and Russia are all situated around the European average of 14%, while Norway significantly lag behind at 6.25% [21].

Table 3 GDP in the manufacturing industry [21]

Manufacturing % of GDP (2019)	**Norway**	**Sweden**	**Finland**	**Russia**
	6.25%	13%	14.4%	13.1%

Nevertheless, the 2019 BIN edition, reports stronger economic cycles than previously observed. A positive signal indicating increased competitiveness in the regions, with high activities in traditional manufacturing and construction industries (as seen from figure 5).

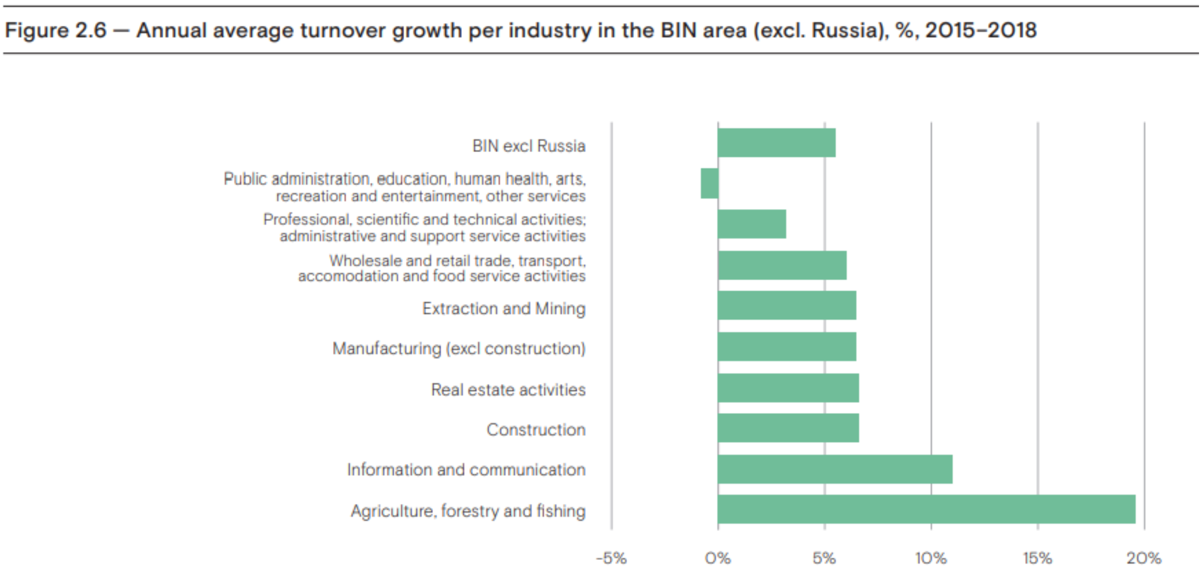

Figure 9 Annual average turnover growth per industry in the BIN region [17]

The findings from the general mapping the key regional findings relevant to the regional business market can be summarized into the following key points:

- It is observed that the industries in the Kolarctic region are thriving – with positive economic cycles and high activity in traditional manufacturing and construction. All of which indicating a large potential for MAM adoption and a fitting market.
- Population growth are far inferior to the average country level. All regions have a negative population growth trend. This is a troublesome trend that can lead to recession unless reversed.
- The regional GDP growth is lower than the average country level except all regions in Norway and Lapland region in Finland. As GDP growth rate is an indicator for investor for decision making for future investment, the current GDP growth in the Kolarctic region indicates large potential for attracting new business.

- Higher education in the regions is differing. All over it is falling behind the overall country level. Especially in most of the Russian regions. Higher education is essential for a sustainable development, and especially for new technical advancement. For succeeding with the adoption of 3DMP that has a high knowledge and competence requirement, the education access in the regions needs to be increased.
- There are high inequalities in the regions, both economic and social. Thus, knowledge transfer between the different regions is highly advantageous. Giving struggling region the opportunity to learn from regions that succeeds.

4 The Potential of MAM in the Kolarctic

As summarized in the last session, there are definitive potential of MAM in the Kolarctic regions due to their current status and need for economic growth as well as their current industrial structure indicates.

To our knowledge, there are no companies or providers of metal additive manufacturing services in the Kolarctic area at present time. Country wise in Norway, Finland and Sweden, there are only a handful of companies providing MAM services or operates with a 3DMP in house. One obvious explanation is that the early adopter of MAM is mainly found within aerospace and some within automotive which none of the Northern Scandinavian countries really have (except automobile production in Sweden), especially in the Kolarctic regions.

During this project work, the team hasn't managed to find any relevant or recent mapping on the manufacturing industry in the Nordic/Kolarctic regions in such extend that the project can build further on for an in-depth analysis. The project consortium has therefore decided to carry on a two-steps process.

Table 4 Selected manufacturing sectors (producers of metal products.)

Manufacturing industry	
C24	Manufacture of basic metals
C25	Manufacture of fabricated metal products, except machinery and equipment
C26	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers and semi-trailers
C30	Manufacture of other transport equipment
C32	Other manufacturing
C33	Repair and installation of machinery and equipment

In the first step, each partner is asked to create a picture of its respective manufacturing industry. For the purpose of comparison, the project is applying categorization regulated by Statistical Classification of Economic Activities in the European Community, commonly referred to as NACE [22]. A template was created by A2 lead (UiT) and distributed to all partners to gather information about the regional manufacturing industry *(Appendix A)*. Table 4 shows nine groups identified with their respective NACE codes. The project consortium deems these industrial groups are the representatives with the largest potential for adopting MAM.

In the second step, the project consortium members are interviewing a number of their respective manufacturing business based on predefined survey (Appendix B). The survey aims to, among which, provide an upfront information of how the industry experience the MAM technique and their perception of adoption potential.

The following sections are organized, firstly, to provide a general overview of current industry division in the Kolarctic in terms of industries that are using MAM contra those that still not applying MAM. The second section presents the current market share distribution of metal and non-metal manufacturers. This section also illustrates country wise distribution of current metal manufacturers. The result of company survey is presented in the last section.

4.1 Aerospace, automotive and medical sector in the Kolarctic

As mentioned in the section 1, the most widespread application for metal AM are within the aerospace, automobile and medical sector. These industries are well represented by NACE classification C29, C30 and C32 as below:

- C29: Manufacture of motor vehicles, trailers and semi-trailers
- C30.3: Manufacture of air and spacecraft and related machinery
- C32.5: Manufacture of medical and dental instruments and supplies

As already stated, the aerospace, medical, and automotive sectors are not large in the Kolarctic. Estimated from the partners input (*figure 10)* only 4% of the companies in the manufacturing industry are found within these sectors, while figure 11 shows the exact amount of companies within the Aerospace, automobile, and medical sectors in the Kolarctic region based on the collected data from all partners.

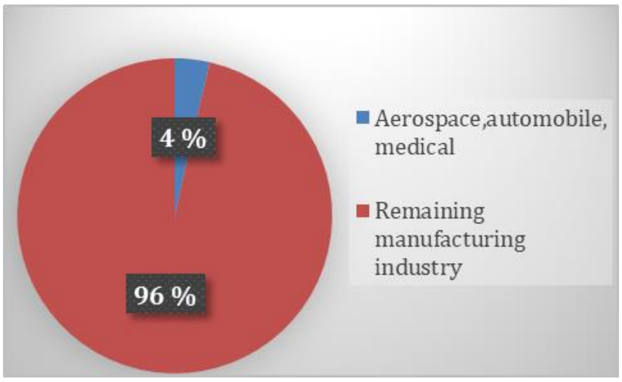

Figure 10 Kolarctic manufacturing industry compared to selected industries.

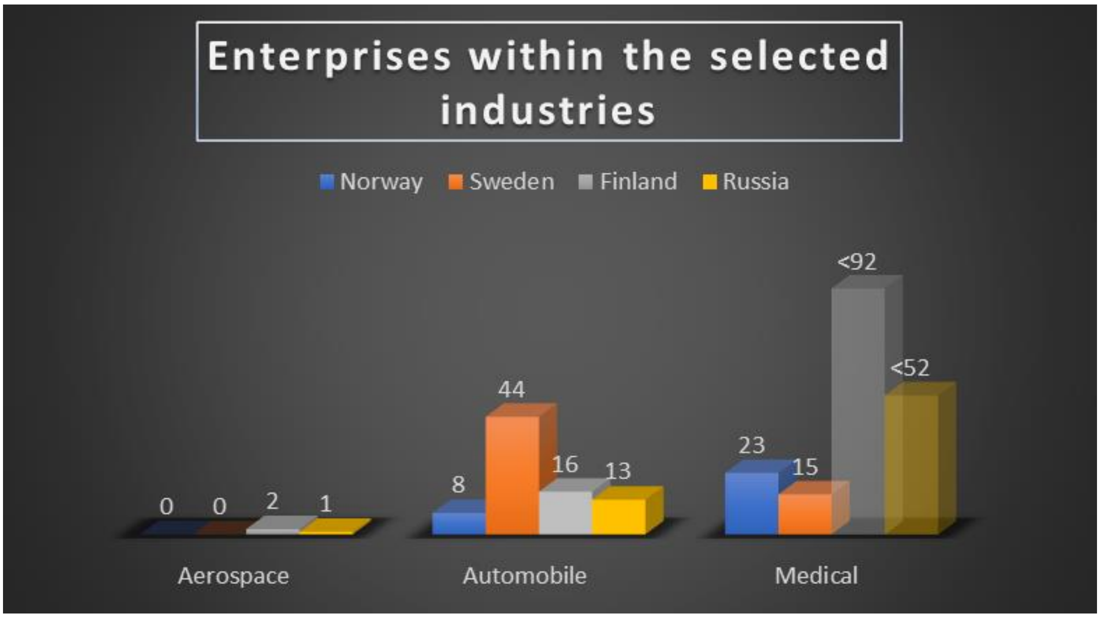

Figure 11 Enterprises within aerospace, automobile and medical sector in Kolarctic

4.2 Kolarctic metal manufacturing industry

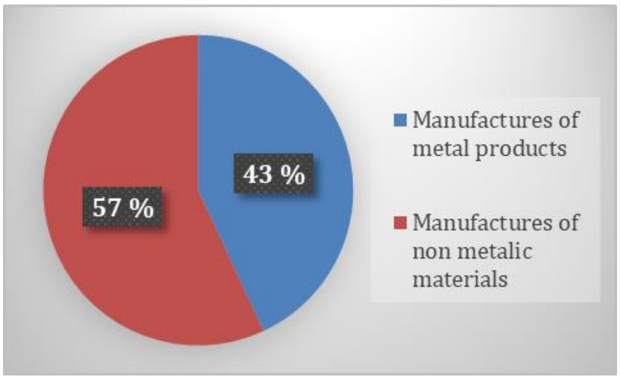

Figure 13 Kolarctic manufacturing industry and metal manufacturing industry

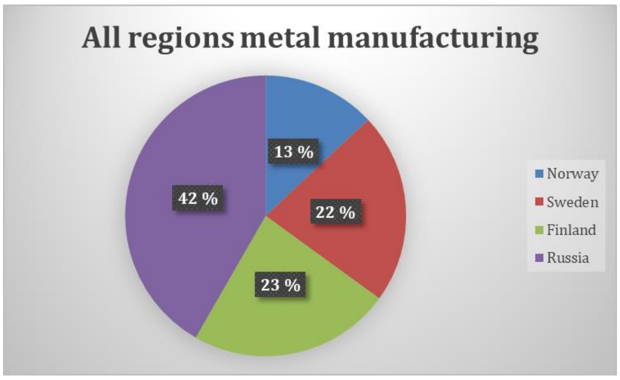

Figure 12 All regions metal manufacturing industry country distributed

Figure 13 illustrates Kolarctic manufacturing industries applying nine NACE codes identified. 43% of the companies are connected to the production of metal products, representing a far greater percent of the regional manufacturing industry than aerospace, medical and automotive industry do alone. These are potential MAM manufacturing – as the project consortium can expect.

From the general mapping we know Sweden, Finland, and Russia all have a developed manufacturing industry while Norway lag behind. This is further revealed for the metal manufacturing industry in *figure 12*. Norway have significantly less companies than the subsequent countries.

Figure 14 illustrates the distribution of metal manufacturing industry based on company size. Norway, Sweden, and Finland have a similar trend, dominated by micro and small companies. Russia, on the contrary, has mostly the larger SMEs and few smaller one.

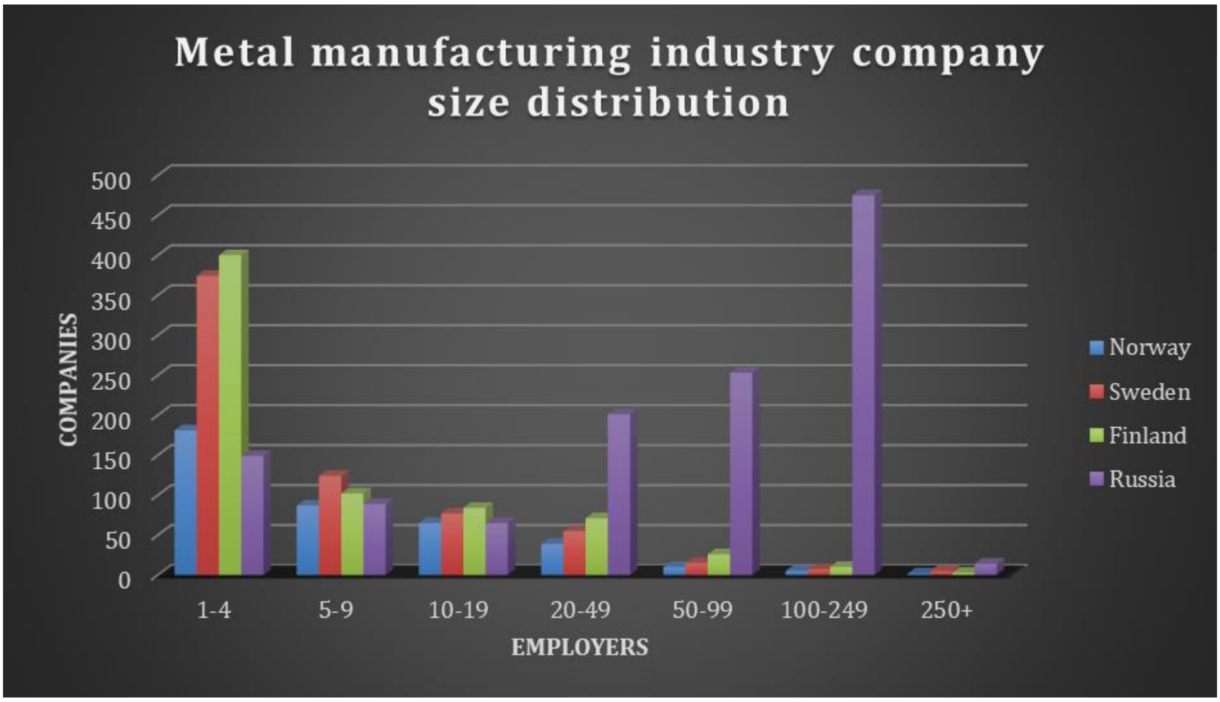

Figure 14 Metal manufacturing industry company size distribution

Although Russia doesn't have many large enterprises (LEs, with 250+ employers), the country is still dominated by much larger companies than the others. The Russian Kolarctic region possesses significantly more people, and company size might possibly be corresponding this. However, the fact that the larger SMEs are outnumber those micro and smaller ones in Russia Kolarctic might indicate that start-ups are more difficult to establish and succeed in the region.

Empirically, SMEs on average are less innovative than LEs [23]. Nevertheless, from a historical perspective large radical innovation, especially in the science-driven sectors tend to be produced by smaller companies [23]. Large established companies' current business environment often does not let them pursue new technologies. Suffering from many inhibiting factors such as the inability to unlearn obsolete mental models, a successful dominant design or business concept or the inability to develop mandatory internal or external infrastructure to mention a few [24]. While smaller companies often are more agile with less bureaucracy. In these regards, the Norwegian, Sweden, Finnish, and Russian manufacturing industry has great potentials for fostering MAM adoption.

4.3 Survey on industrial experience and potential for adopting MAM

Based on the general mapping of the regional manufacturing industry of metal products the consortium has drafted a survey to obtain a deeper understanding of the state-of-art of MAM from a company perspective (*see Appendix B*). The survey result provides a view of how the industry experience the MAM technique and adoption potential. The questions were selected to display the company's operations and their position in their respective industries and markets. Furthermore, showcase their impression of MAM within their internal operations and how it can change the current production methodology in the industry.

The interviewees were divided into four groups based on their ties and experience with MAM technologies. The groups were chosen to better understand how prior experience affects their impression of the technology. The groups were the following:

1. A company that owns one or more 3D metal printer (3DMP).
2. A company that does not own a 3DMP but is a customer of metal printed products from other companies.
3. A company that neither owns a 3DMP, nor purchases 3DMP products but recognizes a need for 3DMP products.
4. Business association.

The 11 questions provided as shown in *Appendix B* are compiled into three main areas.

- Generic questions
    - Gives background to the company, associated industry/market, and the challenges and opportunity they experience today.
- Company centered questions related to the adoption of metal additive manufacturing.
    - This section identifies how the company views MAM techniques related to their operations. Here we are looking into existing experience, how it can be implemented in their processes, possible challenges the technique offer for the company and requirements for adoption.
- Questions on the outlook on MAM in the general industry
    - This section we are interested in how the interviewee believe MAM will form the manufacturing industry in general, and the future potential of the technology. For many it can be difficult to envision the adoption of a new technology in their

own operations, therefore it is important to map their view from a general industrial view.

Figure 15 summarizes main input from all four groups. It is clear that all groups have a basic understanding of the AM technology and can envision a widespread adoption of metal AM in the future. All the groups mention the commonly known challenges of lacking competence, high cost, uncertainty etc. It is consensus for all four groups that the lacking awareness of opportunities and market is the main challenge to fully adoption and benefiting from MAM. Further, for those companies who are considering adopting, higher awareness should be achieved. Also, the majority of the companies know about the advantages MAM can offer, but they are so less competent that preventing them from a full benefitting. Together with the unfamiliar market, and unknown customers potential, the further implementation can be too risky for the companies.

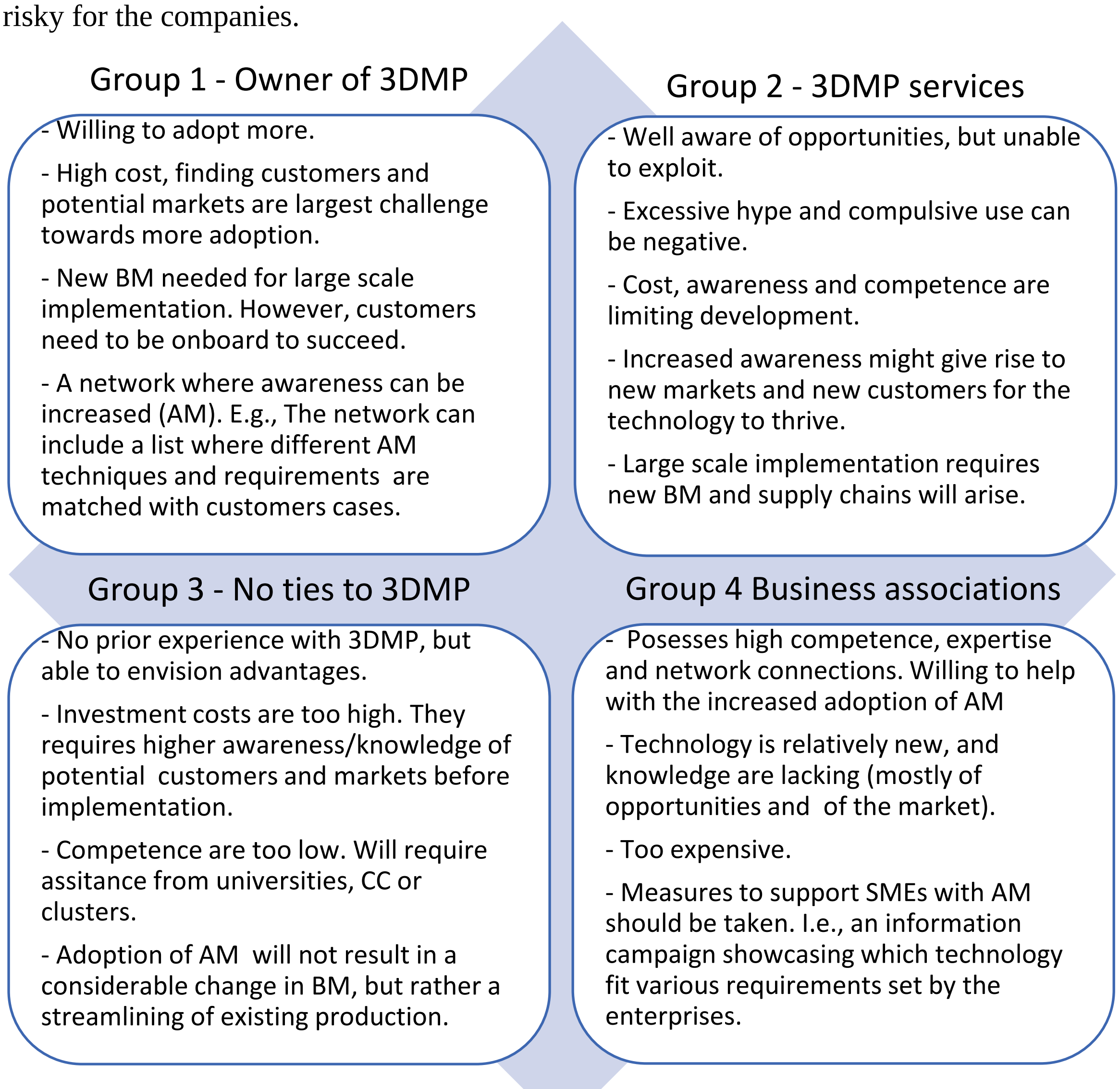

Figure 15 Challenges in applying MAM in the Kolarctic SMEs

An interesting tendency is that the third group, companies with no ties to 3DMP, emphasize costs are the largest hurdle. The other groups to a larger degree emphasize the need for competence in various degree depending on the extent of adoption.

In short, typical challenges to a SME in adopting MAM are therefore material, market, production, construction and competence. However, from the earlier studies, we noticed that researchers have mentioned an emergent need for creating new business models to enable, among which, a new mindset for speed-up quick adoption of evolving technology can be a challenge.

5 A Stepwise Guideline and a Readiness Model for Facilitating Increased Awareness and Adoption of MAM in the Kolarctic

Based on our observations it is clear that the manufacturing industry in Kolarctic has great potential in adopting MAM for exploring increased value generation and benefiting from this technological advancement. The survey conducted among current manufacturing industries in the region urges that a guideline should be developed for assisting manufacturing industry in adoption of MAM. A stepwise guideline can also offer manufacturing companies a tool to be more conscious of their opportunities in adopting MAM, identifying their limitation so that they can be more systematically in strategic development towards a full-scope MAM adoption. In the following sections, a five-step guideline for facilitating SMEs adoption of MAM is developed followed by a readiness model which a SME can apply to identify their current position in the adoption.

5.1 A stepwise guideline

Figure 16 shows a guideline for stepwise adoption of MAM in a manufacturing company.

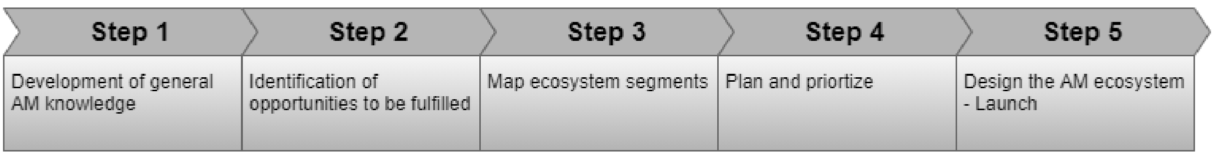

Figure 16 A guideline for SMEs to adopt MAM

Five simplified steps are proposed to help companies identify opportunities and positioning themselves for success along the AM value chain. The step by step method are based on the

Boston consulting groups (BCG) guidelines for designing business ecosystem, the regional assessment, and available literature towards structuring business ecosystems. [25] [26]

Step 1 – Development of general AM knowledge

The first step involves the development of competence and knowledge, a key consideration for business willing to ensure competitive advantage. As seen from the market assessment, current level of MAM knowledge in the region is still low. The awareness on technological advancement needs to be significantly increased before companies can set out to adopt the technique. Furthermore, the educational institutions and research centers and clusters will be essential stakeholders for local industries to develop the required knowledge although we can see more focus are put on the development of AM educational programs.

Step 2 – Identification of opportunities to be fulfilled

For adopters of MAM who are aiming at effectively benefiting from the technology and justifying the high cost of the initial investment the companies must first clearly understand and define their needs. Companies should have a clear understanding of what they want to achieve and their priorities. If it is to streamline an existing production line, remove an existing friction or address an unmet new customer demand.

Step 3 – Map ecosystem segments

Next, is the ecosystem segment mapping. The initial step after thoroughly evaluating the needs is to map the "value blueprint"; the activities required to deliver the value proposition. In simple terms it means a mapping of the partnerships. Specifying the flow of information, goods, services, and money between the different segments. Who are the most important stakeholders, their responsibilities, and the links between them? Whether it is a service provider, equipment/software provider, consulting, governmental, R&D etc.?

Step 4 – Plan and prioritize

Based on the initial three step the company should be in a position to start planning and building their business model. This step is broad and involves multiple subcategories. At a general level the following matters must be evaluated:

- Decide on the governance model[2]
- How they plan on capturing value
- How to reach critical mass
- Ensure sustainability of the business and ecosystem

Step 5 – Design AM ecosystem – execute plans.

Final step is the realization of the planning. The actually designing the ecosystem, structuring flows, connections and partnerships to ensure a successful adoption of AM. Create incubators, attending events, testing and refine.

All of the steps are at a general level and further elaboration will be needed to increase the relevance for the SMEs.

5.2 A readiness model

Based on our experience with interviewees, companies in different phase of MAM adoption might differ in their approach to more MAM adoption based on their maturity in MAM technology. The project consortium has developed a full-scale maturity measurement for facilitating SMEs identification of their current position in MAM adoption. As shown in Figure 16. The MAM readiness model is based on Timothy Simpsons preliminary version [27].

[2] The governance model is referring to the governance of the ecosystem, which defines the rules and boundaries of each participants operation within the ecosystem [25].

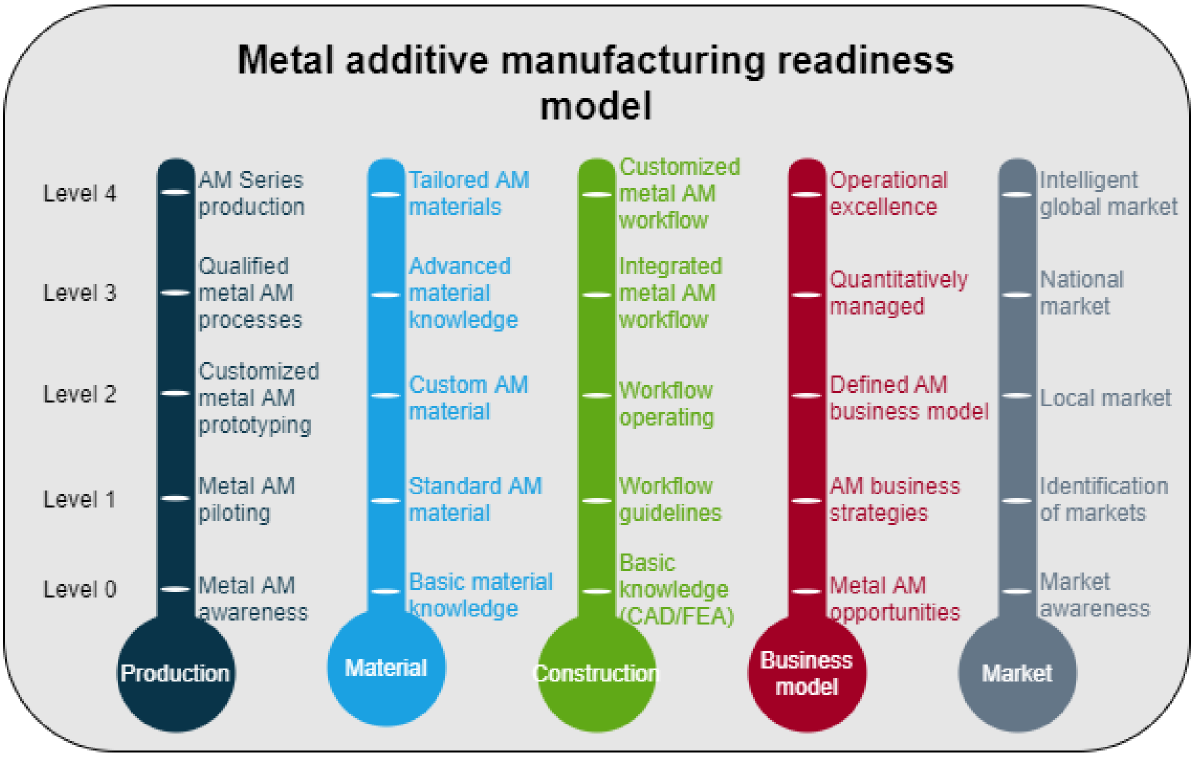

Figure 17 MAM readiness model

Production

- **Level 0**. Awareness of MAM techniques (BJ, PBF, MJ, etc). General knowledge of advantages/disadvantages.
- **Level 1:** MAM piloting. Testing AM production before more widely adoption.
- **Level 2:** Customized MAM processes (prototyping).
- **Level 3:** MAM operating at a certain standard during sustained commercial manufacturing**.**
- **Level 4:** Mass customization. Advanced system combining the low cost of mass production with flexibility of individual customization.

Material

- **Level 0:** Basic material knowledge.
- **Level 1:** Standard AM material. General material knowledge of various materials that can be used in AM processes (powder, wires etc.).
- **Level 2:** Custom AM materials. More detailed knowledge of material properties, understanding how material properties can be affected. (e.g., production, process variations, packing, storage, and repeated usage).
- **Level 3:** Advanced material knowledge: Use of what material for which processes. Understanding how to alter material properties.

- **Level 4:** Tailored AM materials. Understanding how material can be tailored to the print, and printer technology (e.g. what material for what print, and why it should be used).

Construction

The construction concerns the specific processes connected to the creation of the part. It consists of 5 stages: The design, build-prep, manufacturing, post-processing and certification.

- **Level 0:** Basic knowledge. Computer aided design (CAD), finite element analysis (FEA)
- **Level 1:** MAM workflow guidelines. At this level the company understand the five steps required for constructing MAM products.
- **Level 2:** MAM workflow operation. At this level the five steps are understood, but can also be operated by personnel without assistance.
- **Level 3:** Integrated MAM workflow. At this level the company at even greater detail understands the AM construction steps. Additionally, they can recognize improvement possibilities, and think "AM" when redesigning parts.
- **Level 4:** Customized MAM workflow: Optimized AM workflow, All the steps are operated and understood by the operators. They can easily design, produce, and deliver AM parts, from start to finish.

Business model

The business model is the company's core strategy connecting everything together, in short it involves the management of the business and how an organization creates, delivers, and captures value. Osterwalder Business model canvas act as a great starting point for companies developing their business towards additive adoption. Cost analysis whether an investment is viable, demand predictions and finding partners are just a few examples of activities needed to be carried while developing the business strategy. The business model is connected to the other pillars and the levels are the following.

- **Level 0:** MAM opportunities. The company should be aware of the business opportunities metal AM can offer, such as reduced lead time, reduced waste, cost effectiveness etc.
- **Level 1:** AM business strategies. At this stage knowledge whether a redefined business model is required should exist. Additionally, the company should understand the MAM

considerations required for implementation. I.e., if the production of parts will redefine or simply streamline their existing production. Are the company utilizing a printer technology inhouse or get it outsourced? Cost analysis for MAM etc.

- **Level 2:** Defined AM business model. At this stage the business model should be defined based on knowledge developed in the first pillar. Also, for this step the business model should be redefined accounting for changes in supply routes.
- **Level 3:** Quantitatively managed. At this level. All objectives are optimised based on the needs of the customers, end user organization and process implementation etc.
- **Level 4:** Operational excellence, a fully redefined business model optimized for customers, at this step the business continuously adopts and improves according to changes in the technology, market, and customers. Often utilizing continuous improvement strategies such as Lean, six sigma, and scientific management.

Market

The market and awareness towards potential customers are essential, especially for early adopter of the technology where the market can be hard to identify. Based on knowledge, and know-how accumulated the following levels are defined for the market:

- **Level 0.** Market awareness. Obvious industry trends, Emerging trends, Relationships between elements in the market and how they can create new markets and customers.
- **Level 1.** Identification of market. General understanding of the AM market and potential markets applicable for the companies/industries products.
- **Level 2.** Local market should be established applicable for the industry sector. Market analysis should have been conducted, and customer be onboard.
- **Level 3.** National market. A network should exist at this stage.
- **Level 4.** Intelligent global market. The company should have full view of the AM market, know exactly where the potential is and utilize it. Company should be active globally, deliver to a global network, and participate in a global AM network.

5.3 Applying the stepwise guideline and the readiness model in practice

Both the stepwise guideline and the readiness model are distinguishable from existing researches as well as the technological readiness level defined by EU. Due to the disruptive and dynamic nature of the AM this model can be tailored to the company's needs. Companies can utilize the model in conjunction with the step by step method as defined earlier. First to identify their current position on the scale. Then depending on the goal and ambition, they should in their planning phase analyse what they want to achieve with the technology and choose their path on the model. For most, the adoption should be gradually, starting with pilot projects, for instance. Then, depending on success rate and experience further adoption, climbing the scale is achievable. The university and competence networks are important stakeholders especially in the initial phase when companies are grasping the technique. They can for example provide showcases on the advantages of the technology as well as facilitating the adoption at the new beginners.

To illustrate an application of the model, an example is shown in Figure 17. Given a company, they have developed general knowledge within the technology illustrated with the black line. They want to adopt metal AM technology and have planned a pilot project (illustrated with grey lines). They, define the project according to their needs and find level 1 covers their requirements. However due to cost and resource limitations they do not have the capacity to invest in a printer on their own, neither do they have capacity to learn about all the material and construction requirements. They opt to outsource these services.

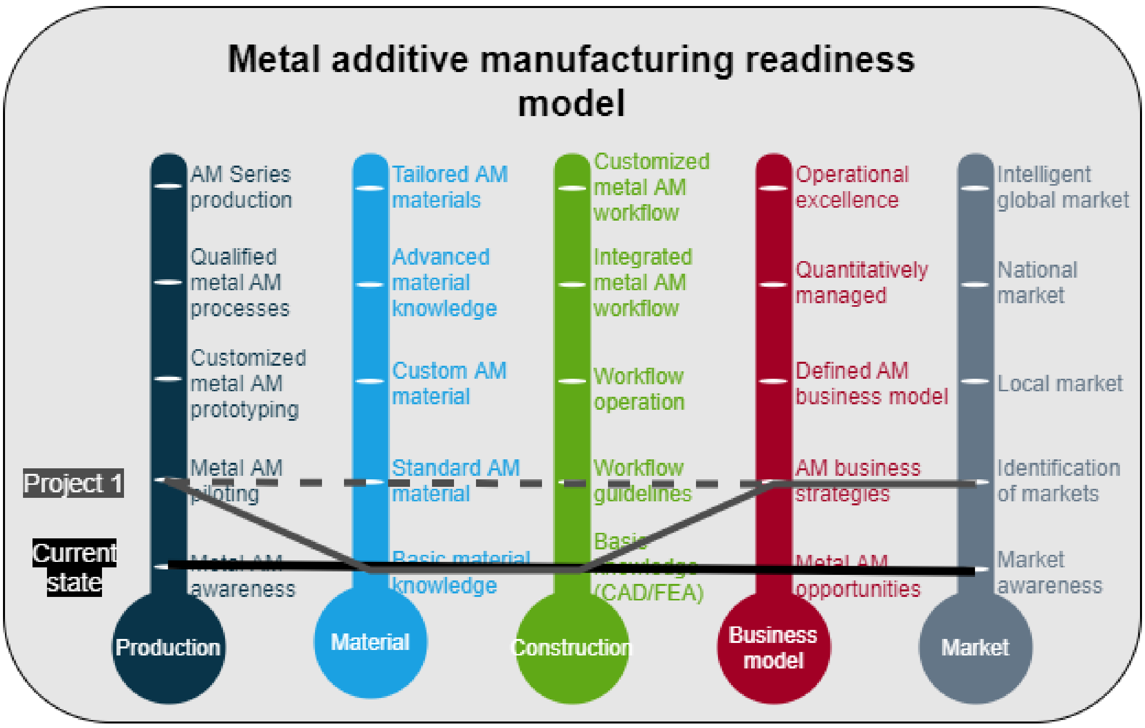

Figure 18 MAM readiness model - an example

Seen from the *figure 17*, the grey line illustrates the company's expertise, and the grey dotted line the outsourced services.

6 Summary

It's undoubtedly that SMEs consist the economic backbone for the Kolarctic. The SMEs are characterized with niche product and service and are suppliers to major national industries, i.e., petroleum, maritime, forest, mining, fish and aquaculture.

Technological development has always been a driving force for innovation and new value generation in this region. Among those enabling technologies maturing during Industry 4.0, MAM is the one has the greatest potential for supporting innovative product development with significantly shortened lead time and reduced needs for raw material. Promoting MAM in the Kolarctic represents a shift towards more environmentally sustainable production and this will help the Kolarctic SMEs to regain production sovereignty and sustain technological leadership in the region.

Despite that MAM has been a relatively matured technology, its full benefiting at the Kolarctic SMEs hasn't been observed. This report explores, firstly, general status of economy and industrial structures in the Kolarctic. It is followed by an in-depth mapping of manufacturing industries in Kolarctic regions in respective countries. It is addressed that as the Kolarctic region has currently limited business in those prevailed industries for current MAM application, promoting MAM in the Kolarctic has largest potential on existing metal manufacturers.

In order to understand why MAM hasn't been prevailed in the Kolarctic, the project consortium members have conducted interviews with their respective industrial representatives. Challenges in applying MAM in the Kolarctic SMEs are therefore identified in terms of six factors: material, market, production, construction, competence as well as business model.

A guideline is therefore developed aiming at leading the way for SMEs in adopting MAM step-by-step. A readiness model is further provided for SMEs to locate their competence in terms of five vital factors in adoption of MAM. An example is given for practical guide to use this model.

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Appendix A Collected data on manufacturing industry from project partners

Numbers of manufacturing companies - All										
Industry group	0	1-4	5-9	10-19	20-49	50-99	100-249	250+	Total numbers of company 1->	SMEs (1-249 employers)
C10	600	247	111	113	217	346	18	14	1066	1052
C11	61	46	21	23	35	2	0	1	128	127
C12	1	0	0	0	0	0	0	0	0	0
C13	175	48	15	22	6	1	0	0	92	92
C14	357	58	12	69	3	0	0	0	142	142
C15	49	9	2	2	1	1	1	1	17	16
C16	891	255	77	65	163	20	609	14	1203	1189
C17	12	11	18	3	1	2	2	9	46	37
C18	190	86	26	19	66	59	1	3	260	257
C19	2	5	1	0	0	0	0	1	7	6
C20	44	47	7	30	12	2	4	5	107	102
C21	5	4	0	1	1	0	0	0	6	6
C22	73	65	30	67	53	4	0	1	220	219
C23	155	115	33	46	155	8	195	6	558	552
C24	16	11	11	6	8	3	5	4	48	44
C25	700	388	140	102	147	167	5	1	950	949
C26	63	46	20	29	17	11	4	4	131	127
C27	32	37	16	12	8	3	4	0	80	80
C28	140	52	49	62	25	12	6	7	213	206
C29	54	19	23	7	10	6	0	3	68	65
C30	61	38	16	21	10	7	0	0	92	92
C31	361	85	33	21	13	217	3	2	374	372
C32	382	143	47	13	30	0	2	0	235	235
C33	859	453	116	80	136	109	479	9	1382	1373
Total all	5283	2268	824	813	1117	980	1338	85	7425	7340
Total Metal group	2212	1187	438	332	391	318	505	28	3199	2964

Figure 19 Compiled data on manufacturing industry from all project partners

Appendix B I2P industrial survey template

Company questionnaire:

General information (please notify us if you want to be anonymous)

Company name:	
Nationality:	
Numbers of employers:	
Yearly turnover:	
Type of industry:	
Associated to which sectors (NACE code):	

Type of your company:

1: ☐ 2: ☐ 3: ☐ 4: ☐

3DMP related questions

1	What are your current products and services? What industries do your company serve (in terms of supply chain and current business model)? What are your competitive advantages?
For example: which product in what industry? (In Norway: mechanic product for offshore industry) **In terms of supply chain: which position you have in a supply chain – as a supplier? With strong domination** **Competitive advantage: for example, low cost, high quality, short lead time etc.**	
2	What are your major challenges at present time? And what are the challenges you will be facing in future? (E.g. Qualified personnel, investment on machines, etc.).

3	How can an adoption of 3DMP contribute to increased competitiveness and sustainability (especially economic and environmental sustainability) in your company and your manufacturing supply chain at present time?
For example: reduced material use, fast delivery, reduced stock holding, reduced labor-intensive work, shortened transportation distance, recycled metal powder.	
4	At present time, does your company have a (or several) 3DMP(s) or do you rely on getting the service provided? In both cases, how large is the value of 3DMP generated in relation to total value of the business.
Remarks: the question is only applicable if company has some form of 3DMP.	
5	If you are a 3DMP owner, what material can you print out? If you are a 3DMP customer, in what material should products be printed?
Remarks: **Material: e.g., aluminum, stainless steel**	
6	At present, what do you see as the largest challenge(s) towards adopting or adopting more 3DMP technology in your company? Both managerial and operational.
Remarks: Operational: at design phase, 3DMP enables complicated product structure beyond traditional design. Managerial: Business model related, culture, others?	
7	Any other critical factors influencing your decision of adopting 3DMP? (E.g., economy and environment).

8	Do your company have necessary level of knowledge on 3DMP? If yes, could you explain which knowledge fields existing in your company that related to 3DMP? If no, what should to be done in order to increase knowledge level at your company?
Remarks: **Knowledge fields in terms of design, production, quality control etc.** **To increase knowledge level: course, tutorials, others?** **In which way: classroom lecture, webinar, physical lab, CyberLab, short session, continuous competence building**	
9	What is your outlook on adoption of 3DMP in manufacturing industry generally? And what is your opinion on enabling measures to increase this adoption.
Other enabling measures: **Cooperation with competent partners (I.e., universities and research institutions, other 3DMP companies in the Kolarctic region?)**	
10	What is the implication of increased adoption of 3DMP on new business models and creation of new supply chain for manufacturing industry?
Remarks: **Can current business model (which based on subtractive manufacturing) be used in an additive manufacturing cooperation mode?** **What need to be changed in current business model when 3DMP become major form of manufacture? What will be changed in terms of new supply chain (which will result in short-distant delivery and reduced inventory...)**	

11	Can you envision a Nordic/Kolarctic 3DMP network (at least one hub in each partner country) which will enable better utilization of 3DMP capacity in the region (to realize advantages as lower transportation costs, shorter lead time can be achieved, to mention a few).