Webs of Innovation and Value Chains of Additive Manufacturing under Consideration of RRI

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D6.3 REPORT ON AM FUTURE SCENARIOS AND STRATEGIES

Four future scenarios for the AM webs of innovation value chains and their openings for RRI are co-created, described, discussed, and their chances and risks elaborated.

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EXECUTIVE SUMMARY

Developing futures within co-creation stakeholder workshops supports the implementation of RRI aspects into additive manufacturing webs of innovation value-chains (Spring et al., 2019). Foresight in combination with stakeholder involvement is an excellent foundation for accomplishing concrete strategies and action. When considering an innovation ecosystem, the developed strategies are more successful if the stakeholders are representatives from quadruple helix, such as industry & business, science & research, public administration, and civil society. There are various methodologies for accomplishing a foresight. In IAMRRI a scenario technique approach is applied because it is very structured, and it offers the possibility for engaging the stakeholders even in complicated analyses. When the process of the stakeholder co-creation actions should be successful, it has to be diverse & Inclusive, anticipative & reflective, open & transparent, and responsive & adaptive to change. Therefore, the RRI process dimensions are covered easily by our approach. The RRI policy agendas or RRI keys, such as ethics, gender equality, public engagement, science education, open access, are analysed and worked out for each scenario and accompanied the foresight process from the beginning.

Within IAMRRI the following four scenarios were co-created.

Table 1: The four future IAMRRI scenarios

	SCENARIO	What is it about	AM connection
(A)	Responsible Europe	Sustaining AM system in a well-structured Europe	"Service Provider", consumer purchasing remains in conventional sales channels
(B)	Self-organizing society	AM maker communities and individuals	"Content Provider", consumer purchasing shifts to online file-sharing repositories
(C)	Elites of money and knowledge	Powerful and mature AM industry	"Market Explorer", Use of AM to enhance existing business models
(D)	Robots world	Artificial Intelligence serves the world	"Mass Customizer", use of AM to create new business models

This foresight exercise wants to embed the AM webs of innovation value chain in a broader context. Besides technological aspects societal, economic, ethical, environmental, and legal aspects are considered by defining foresight influencing factors[1] in these categories and assessing them for future aspects in this AM webs of innovation value chain.

This foresight dialogue creates awareness in the stakeholders group (a) for AM in general and the AM webs of innovation value chain especially and how it works also in the wider context, (b) for RRI in this AM webs of innovation value chain, (c) for possible futures, its consequences, and appropriate measures, (d) for elements of this wider context for the simulation.

[1] In the context of IAMRRI we use "foresight influencing factors" and "foresight key factors" for distinguishing the work for the model and simulation, where there are a lot of other factors be discussed.

The applied scenario technique process is highly structured, and each step is built on the results of the previous one. Thus, ideally, the different foresight workshops are conducted with the same group of stakeholders. Since the future dialogue considers the broader context of society, environment, ethics, policy ideally stakeholders coming from science & research, industry & business, education, and public administration participate the workshops, and in the best case in all workshops, which are at least three. This was difficult in IAMRRI, since it is an EU project with partners spread over Europe (Norway, Finland, Denmark, United Kingdom, The Netherlands, France, Spain, Italy, Germany, Lithuania, Austria, Slovenia) with the emphasis on modelling and simulation of the AM webs of innovation value chain. Therefore, the foresight process is limited to three workshops in the six scenario development steps. These workshops were conducted in Metz in France for performing the context analysis, in Bilbao in Spain shaping the futures of the foresight key factors[2], and in Austria with the AM community for deriving consequences and measures.

These four IAMRRI future scenarios are linked to other published foresight studies of AM. The peculiarity of the IAMRRI scenarios is given by the wider context, the webs of innovation value chains, and especially the RRI context.

[2] See footnote 1.

1. INTRODUCTION

Scenarios are stories about the future, but their purpose is to make better decisions in the present.
(Ged Davis, Chair of World Energy Scenarios, WEC)

The **IAMRRI project** investigates, describes, and models the "webs of innovations value chains (**WIVC**) in the sector of additive manufacturing (AM) with openings for RRI (responsible research and innovation)" (see Spring et al. 2019). The project designs and builds an agent-based model for webs of innovation value chains in the AM industry. The model should allow simulation experiments enabling hypothesis generation and testing related to RRI locations and openings in the WIVC process and its associated webs. The work regarding foresight is embedded in the whole project and deals with stakeholder involvement and a scenario development process for these "webs of innovation value chains in AM with openings for RRI". The more general objectives of this task are generating a common communicable and well-structured picture within stakeholder groups about future shapes and strategies for AM and for webs of innovation value chains in AM with openings for RRI.

There are various approaches and methodologies for developing future studies for AM such as Delphi study, trend analysis, workshops with experts, roadmaps. The methodological approach applied for IAMRRI is a **scenario technique approach** with participation of relevant stakeholders in workshops combined with an underlying webs of innovation value chains view and interlinked with RRI. We apply a highly structured scenario technique approach with participation of stakeholders which leads to an anticipation of the future through co-creation stakeholder workshops. This approach is based on the link between WIVC and a participatory-anticipatory process.

The applied scenario technique approach needs well-defined groups of participants. At the best, relevant participating **stakeholders** have the power, the urgency, and the legitimacy (see Mitchell et al. 1997) to have an impact within the system. In this case of the AM WIVC triple helix actors (actors coming from science & research, from industry & business, and from public authorities) are involved.

The **concrete steps** within the applied process are well defined. The scenario process starts with defining a list and a description of foresight influencing factors of the "system of webs of innovations value chains in AM". Foresight influencing factors are trends, drivers, all aspects, which affect, boost, enhance and hinder directly or also indirectly the WIVC of AM. The assessment of these foresight factors leads to most relevant ones (foresight key factors), evaluate the openings for RRI, develop future alternatives of the foresight key factors, generate different future shapes, derive consistent scenarios, and investigate consequences and wild cards from the developed scenarios.

The **outcome** of the applied foresight process in IAMRRI are manifold. AM is put in a broader context and besides technological aspects also societal, economic, environmental, policy, and ethical factors are considered. Future strategies, future shapes, scenarios for the AM WIVC, for the AM dynamic webs of innovation value chains and their openings for RRI are developed. The emphasis is on RRI keys inside the developed scenarios and the innovation collaboration there. The result is an input for the AM simulation of the WIVC. The time horizon for the foresight outcome will be approximately 20 years.

The **recipient** of the foresight outcome, the future shapes of AM WIVC will be the EU AM Community, the European Commission, the RRI community, the stakeholder community, science

community of innovation systems and dynamics of innovation in emerging technologies, the consortium of IAMRRI.

The **structure of the deliverable** is divided into six chapters. The first chapter (1) Introduction provides the context and objectives. The second chapter (2) gives an overview about the applied methodology and procedure. Chapter three (3) is about the stakeholder workshops. In chapter four (4) the context to other AM future studies is drafted. Chapter five (5) presents the results in several subchapters (a) foresight key factors used, (b) future shapes of each foresight key factors, (c) the four scenarios with subchapter regarding consequences for the innovation phase and RRI in each scenario. Chapter six (6) concludes shortly the study.

2. THE METHODOLOGY AND PROCEDURE

The applied procedure for the whole scenario development in IAMRRI can be summarized in the following six steps.

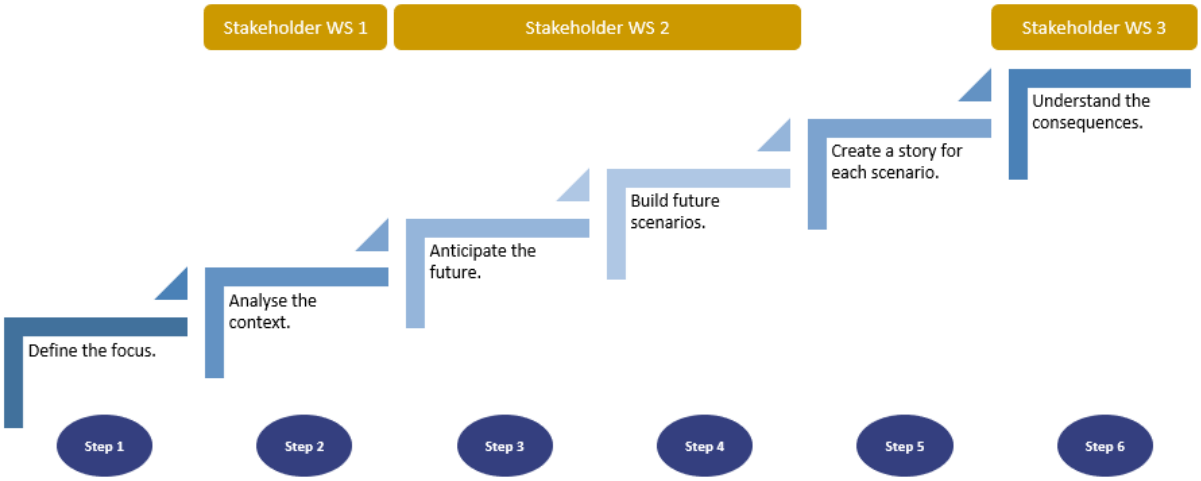

Figure 1: The steps in the applied scenario technique in the IAMRRI foresight.

There are different scenario techniques e.g., experts write various narrative future scenarios (Gaßner R.; Steinmüller K., 2018). The scenario development applied in this project follows the process introduced by Ute von Reibnitz (1992) and others. This highly structured process is conducted within co-creation workshops with stakeholders. There is a link to the RRI process dimensions because the applied co-creation stakeholder process for creating futures is diverse & inclusive, anticipative & reflective, open & transparent, and responsive & adaptive to change. This methodology should also help to reveal opening to the AM WIVC in addition to the study of the role of the political agendas like gender equality, ethics, science education, open access, public engagement, and government (6 RRI Keys).

The preparation of this work was conducted inside the consortium. A list of foresight influencing factors were defined and assessed inside the consortium based on the expertise in AM and based on other AM future studies. This assessment builds the basis of the foresight key factors and thus for the development of the scenarios. Several methods for the assessment of the foresight influencing factors were applied, uncertainty / impact analysis, cross-impact analysis, and social network analysis. These methodologies are explained and described in a lot of respective literature.

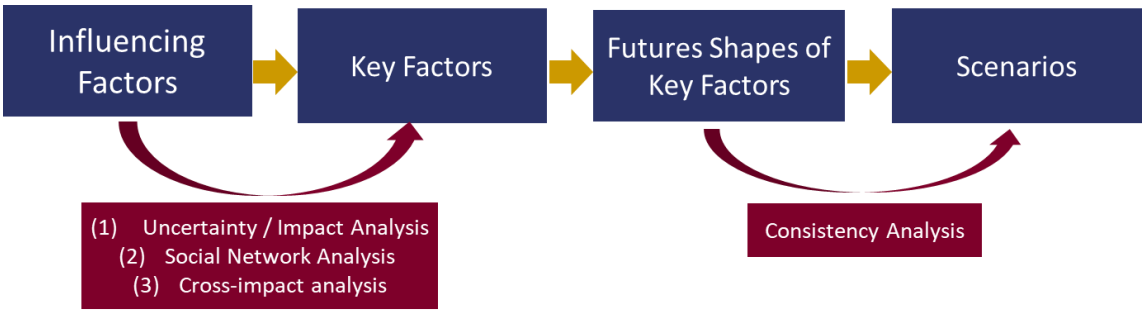

Figure 2: From influencing factors to future scenarios.

Anticipating the future(s) – co-creating future shapes of foresight key factors

For each feasible foresight key factor, however, extreme projections are formulated, which should be as distinct as possible. The timeframe is approximately 20 years ahead. The timeframe should be long enough so that stakeholders are forced to think a little "out of the box". These futures shapes build the basis for scenarios. The better the different futures of one foresight key factor are described, the better disjoint these future shapes of one and the same foresight key factor, the clearer the different scenarios will be.

Building future scenarios

Several methodologies can be implemented to get meaningful and consistent future scenarios. Generally, there is the intuitive holistic way, or there are systematic analytical methodologies. For the systematic analytical ways there are various software tools available.

When we work with stakeholders we reach for an intuitive holistic approach. For that, we use the morphological analysis. The foresight key factors and the future shapes are subject to a morphological analysis. Morphological analysis was designed for multi-dimensional, non-quantifiable problems where causal modelling and simulation do not function well or at all. Fritz Zwicky developed this approach to seemingly non-reducible complexity (Zwicky 1969).

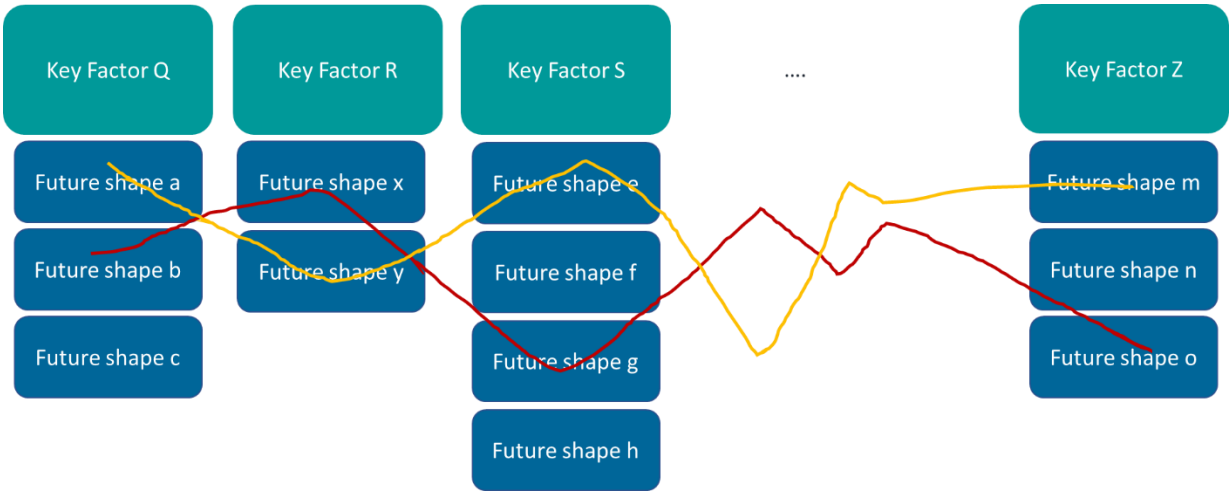

Figure 3: Deriving consistent bundles of future shapes of foresight key factors. *Source: own representation (AIT, Center for Innovation Systems & Policy).*

Here in this scheme, there are two possible scenarios indicated. Our experience shows that two to four distinct and consistent scenarios are possible under discussed conditions (10 foresight key factors each with two to 4 disjoint future shapes).

Developing a story for each scenario

The bundles of futures shapes (one from each foresight key factor) tells us already the core content of a scenario. Sometimes a story of e.g., a family or fictional person in a considered scenario is described.

Understanding the consequences

For this step in our procedure the opportunities and risks in each scenario are discussed in the third stakeholder workshop. Since this is an RRI project, RRI aspects in the innovation process are specifically worked out for each scenario.

Special focus was put on the design of the workshop aiming to work out consequences of the developed scenarios with respect to the innovation process of the AM system and RRI aspects, also delivering additional input for the simulation in IAMRRI. For this, stakeholders were asked to discuss and define the AM WIVC in terms of collaboration structures, actors, their roles, and the network structure (managers, promoters, knowledge brokers, etc.) and stakeholders discussed, where and how are ideas generated in this kind of AM innovation process. Furthermore, RRI aspects were discussed specifically with reference to this kind of AM innovation process, by asking, where ethical aspects are seen and how public engagement and science education impact the output of innovation. Also, the roles that gender aspects, transparency or open access play in this AM innovation process were investigated specifically.

3. THE STAKEHOLDER WORKSHOPS

The involved stakeholders in this IAMRRI foresight represents actors especially from the WIVC mainly regarding actors from triple helix (science, research and education, industry, public authorities).

Workshop 1- Metz Workshop, context analysis, for the discussion and assessment of the foresight influencing factors was organised by partner MATERALIA in Metz in France on 26th March 2019. There were 53 participants in this workshop (18 from universities, 8 from research & technology organisations, 14 from industry & business, 12 from public authorities, 1 from a venture capital organisation).

Workshop 2 – Bilbao Workshop, creating future shapes and drafting scenarios, was organised by partner TECNALIA in Bilbao in Spain on 9th October 2019. There were 22 participants developing the future shapes (12 from industry & business, 2 from universities, 8 research organisations).

Workshop 3 – Austrian Workshop, understanding the consequences in the scenarios, was organised as online workshop by partner MUL in Austria on 18th February 2021. 40 participants, European experts in additive manufacturing, innovation management, and RRI came mainly from Austria but also from France, Finland, Spain, Italy, Slovenia. The event was organized via Web and offered a bilingual workshop, in German and in English.

4. CONTEXT TO OTHER AM FUTURE STUDIES

The frame of the IAMRRI scenario development covers a broader analysis perspective by integrating many other future studies on AM. Additive manufacturing is already a reality in many industries. AM has a high potential for innovative solutions. Compared to traditional production methods, AM offers lower needs on tooling and assembly for instance. Serval advantages have already investigated in many other studies. The emphasis of all these studies is mainly on technical and/or business aspects and models. They deal with the technical potential of AM and we learn about the business opportunities and market possibilities. IAMRRI, however, underlines also the societal, ethical, and policy point of view. IAMRRI works out the openings for RRI, for responsible research and innovation and thus provides a holistic way of consideration. Each of the considered studies makes available a specific point of view. Gebler et al. 2014 investigate the cost-effectiveness and sustainability of AM. AM has a manifold application potential. For instance, there are studies for the application of AM in cultural heritage (Balleti et al. 2017). Considering the various futures of all these different possibilities goes far beyond this report. We focus on AM in general and especially with application potential in automotive and medicine. Bhattachrjya et al. 2014 investigates prospects of AM and discusses perspectives in healthcare, automotive, aerospace, consumer durables, and special consumer products, tools for assembly. Johnston et al. 2018 emphasis on security issues. They firstly draft the history of AM in complex structures such as for weapons and work out the doubtless progression in AM. They also state the strong link between AM and digital tools and data. Security is discussed as well as the possibility for weapon production and the consequences. Johnston et al. involved experts in workshops and discussed the industrial impact and dimensions of disruption. However, they result that there was a wide range of responses from the involved experts about impact and disruption of AM in future. They also state the need of a comprehensive regulatory approach with involving national and international actors, public and private sectors. In long-term, AM will change the value chains, which already starts with the innovation phase (Bromberger & Kelly, 2017). Digital technologies highly impact AM. These two technology approaches interact and promote each other. Riemer et al. 2019 developed three scenarios for Germany in 2025. They talk about “revolution from the niche”, “interlinked digital manufacturing succeeds” and “system providers under increasing pressure”.

Gausemeier et al. 2011 describe futures in AM based on scenarios which match technology push and market pull. Thus, this study emphasis on technology and economy. It is a DELPHI study with well recognized companies in Germany. They start with a short overview about the AM technologies and the challenges for the breakthrough to broader application areas. They further describe the competences of 15 research institutes in AM in Germany. They authors come from Heinz Nixdorf Institute and University of Paderborn. Ryan et al. 2017 study the literature (carried out on both academic and trade publications) about scenarios for supply chains. They find that existing future scenarios are particularly concentrated on job shop applications and pull-based supply chain processes, some constrains on the geographical concentration of AM manufacturing. Home printers are decentralized. And large-scale factories are also working. It shows the broad operating scale of AM.

Caviezel et al. 2017 (Technikfolgen-Abschätzung beim Deutschen Bundestag, TAB) deals with technological, economic, and ecological issues of AM and illuminates the technologies and experiences regarding possible health effects as well as risks for internal and external security. Also, legal aspects and regulations (protection of intellectual property, questions of liability) are discussed. Furthermore, they work out the potentially of the enormous importance of AM for international competitiveness and innovative strength of the manufacturing industry.

Trevor et al. 2018 study security implications in AM and summarize them in scenarios. This covers aspects regarding IPR, data, employment, and education level there, applications in the weapon industry.

Jiang et al., 2017 for instance, have studied the AM literature and have characterized and prepared the results for conducting a DELPHI study and a DELPHI projection. The outcome of this study are four scenarios. These four scenarios are (1) “Market Explorer”: Use of AM to enhance existing business models; (2) “Content Provider”: Consumer purchasing shifts to online file-sharing repositories; (3) “Service Provider”: Consumer purchasing remains in conventional sales channels; (4) “Mass Customizer”: Use of AM to create new Business models. These four scenarios are built on 18 projections coming from “production, supply chain”, “business models and competition”, “consumer and market trends” and “intellectual property and policy”.

The IAMRRI scenarios are linked to the studies of Gausemeier et al. 2011, Ryan et al. 2017, Caviezel et al. 2017, Trevor et al. 2018 respectively. Jiang et al 2017 is connected to each of the IAMRRI scenarios from an AM technical aspect. The following figure shows that the IAMRRI scenarios are developed on the sectoral innovation system and therefore, on a meta level. The scenarios of Jiang et al. describe more technical and economic aspects. Therefore, they enrich the IAMRRI scenarios in this aspect.

Figure 4 shows the link of the context of the scenarios in Jiang et al. with the IAMRRI scenarios and unveils the broader scope of consideration n IAMRRI.

Considering these studies here of the different authors uncovers also that the **whole scope of RRI is only considered in this IAMRRI scenarios.** The study by Jiang et al. gives input to each of the IAMRRI scenarios, although the scope of the analysis are consumer and market trends, production and supply chain, business models and competition, and policy and IPRs.

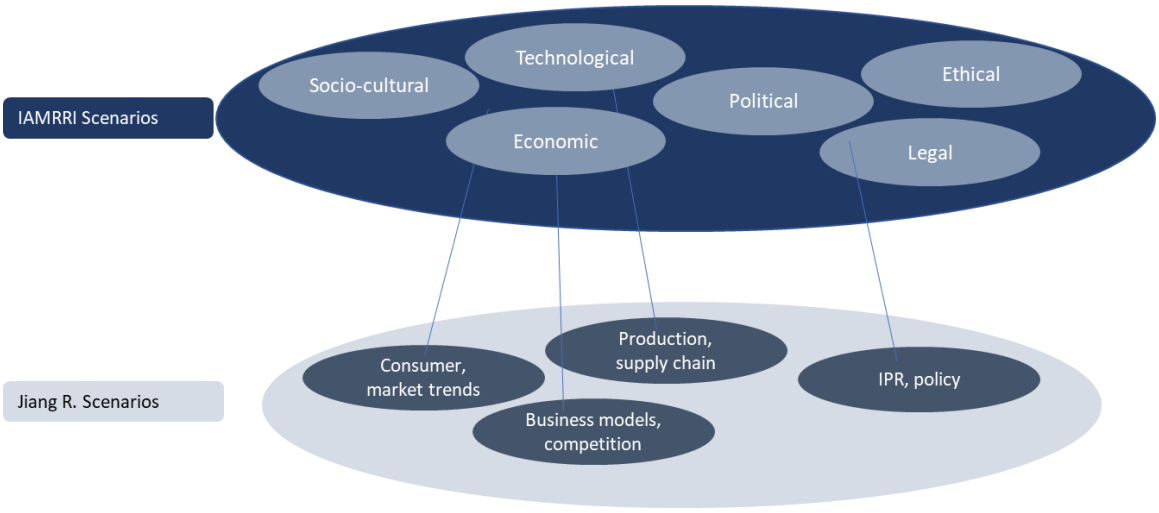

Figure 4: The scope of IAMRRI scenario linked to Jiang et al. scenarios.

5. RESULTS

There are several steps of results starting with the assessment of the 56 foresight influencing factors till the consequences in the four developed scenarios.

5.1 Importance-uncertainty rating

The Importance - Uncertainty Rating reduced the list of 56 foresight influencing factors to 45 foresight influencing factors. The foresight factors with the biggest influence on AM webs of innovation value chain and with the greatest uncertainty regarding the AM webs of innovation value chain were taken.

5.2 Cross-impact analysis

The results from the importance - uncertainty rating give the input for the cross-impact analysis. The interaction analysis or cross-impact analysis enables the depiction of relationships between different foresight influencing factors. How does one foresight factor affect / influence the other? This makes relationships of foresight influencing factors visible.

The cross-impact analysis result in active and passive sums, which are put into a grid. By this analysis the foresight key factors become visible. The following figure shows where foresight key factors can be found in this grid. The yellow area marks good candidates for foresight key factors which have high active and passive sums.

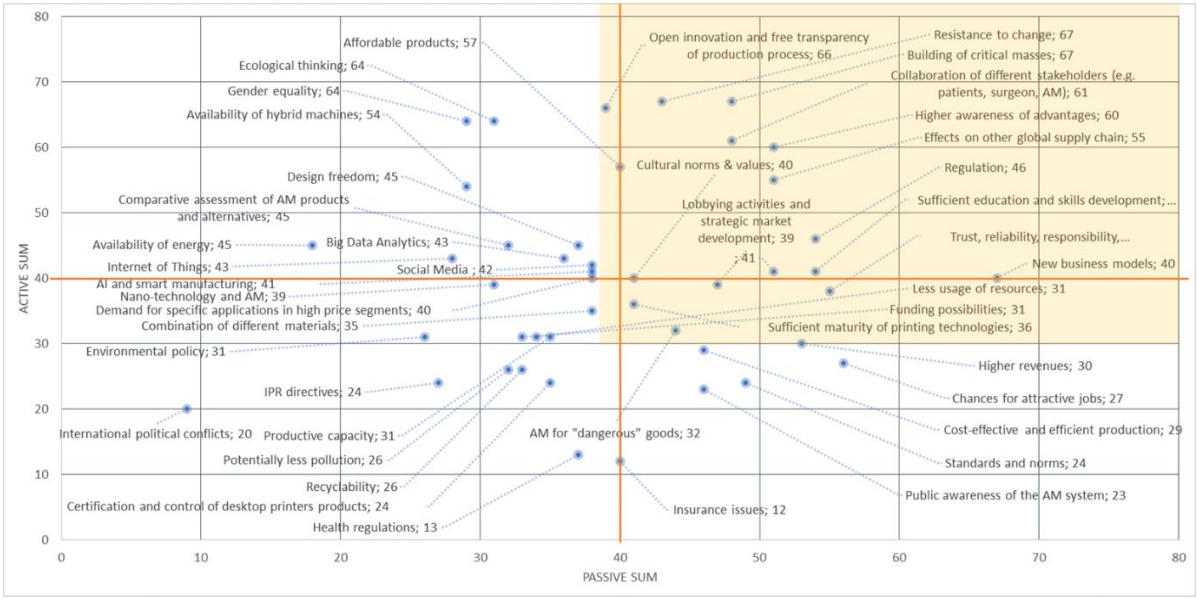

Figure 5. Active and passive sum grid of the cross-impact analysis derived by IAMRRI project.

5.3 Social network analysis (SNA)

Additionally, based on the results of the cross-impact analysis all foresight key factors are shown in a two-dimensional graph positioning each foresight influencing factor in relation to each other based on the. The system of foresight influencing factors, their interactions, and colours according to STEEPLE[3] is visualized and a top view on the system is established. In this way the system of foresight influencing factors is reviewed, and previous assumptions are made visible and are being considered again. This is a tool of creating transparency and awareness.

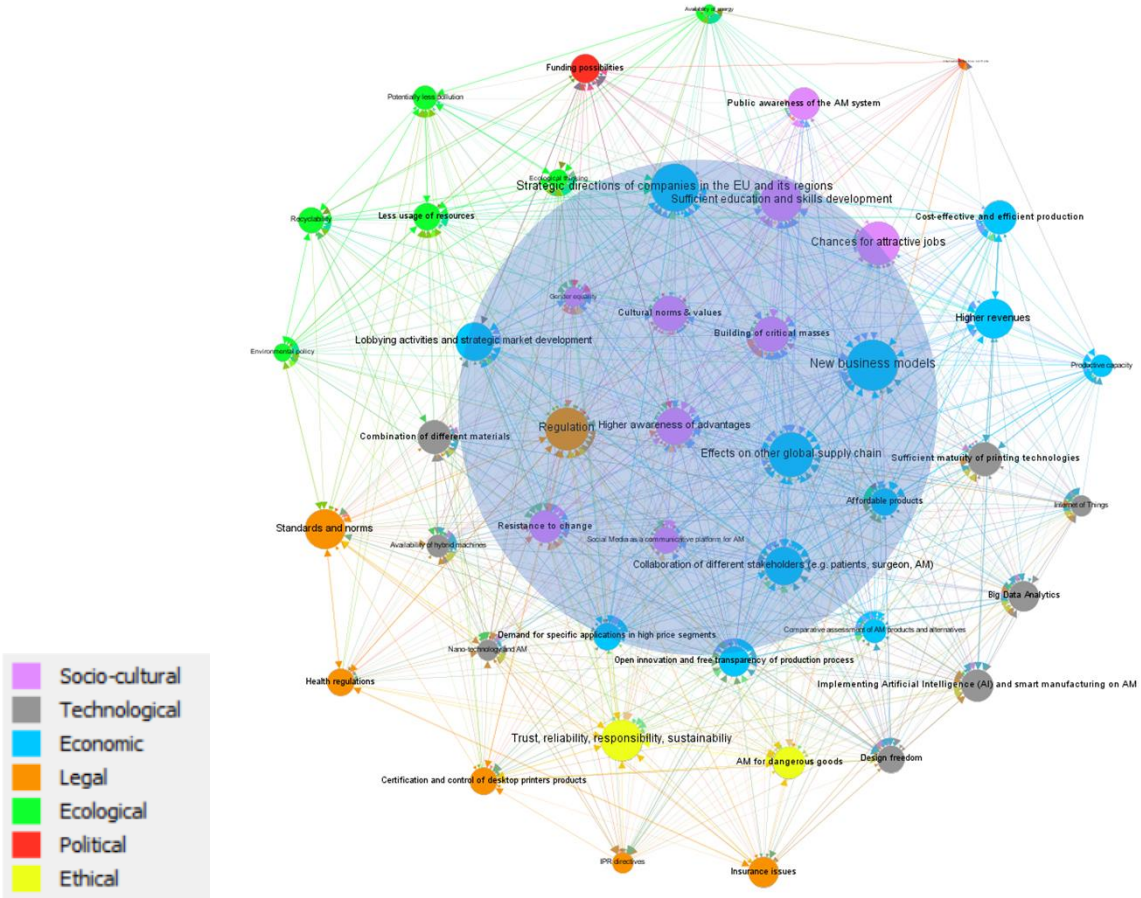

Figure 6: IAMRRI result of cross-impact analysis represented with SNA-tool Pajek.

Nodes in Figure 6 represent foresight influencing factors of the system, their colours correspond to STEEPLE categories, and their sizes correspond to their number of neighbours influencing each other. Arrows indicate the relationships between foresight influencing factors based on the conducted cross-impact analysis

Figure 6 is a graphical representation of the system based on the result of the cross-impact analysis. It shows the system of foresight factors influencing each other, which is indicated through arrows. Large

[3] STEEPLE stands for socio-cultural, technological, economic, ecological, political, legal, ethical.

nodes have more neighbours and nodes in the centre have more impact on the network. Therefore, the nodes in the centre are good candidates as foresight key factors. However, for a balanced view on the system, at least one foresight factor from each STEEPLE group was taken into account for the selection of the foresight key factors.

5.4 List of foresight key factors

The described three steps (important-uncertainty rating, cross-impact analysis, and SNA) lead to the list of 14 foresight key factors. The foresight identified key factors build the bases for shaping the future of the AM WIVC. Table 2 lists the 14 selected foresight key factors for the IAMRRI AM WIVC. Each foresight factor is given by its STEEPLE category, name, and description.

Table 2: IAMRRI foresight key factors as basis for the future shapes.

No.	Category	Name of foresight key factor	Definition/Description of foresight key factor
1	Economic	Business models	AM technology system needs new business models that could leverage the latent value of these technologies, also addressing all various aspects of traditional business models, such as the value proposition, cost structure and value chain. A business model is a system of interdependent activities within and across the organizational boundaries that enables the organization and its partners to create value and capture part of that value.
2	Economic	Effects on other global supply chain	AM is shortening the supply chain, closing the gaps between sourcing, manufacturing, and distribution. Thus, AM supply chain impacts the whole supply chain structure, customer centricity, logistics and supply chain capability.
3	Legal	Regulation	Typically, regulation means agreements of the delegated legislation which is drafted by subject-matter experts to enforce primary legislation. Regulation in the social, political, and economic domains can take many forms: legal restrictions promulgated by a government authority, contractual obligations, third-party regulation, certification, accreditation, or market regulation. Power to regulate should include the power to enforce regulatory decisions. Monitoring is an important tool used by national regulatory authorities in carrying out the regulated activities.
4	Socio-cultural	Education and skills development	AM requires new skills for all tasks in the AM value chain, e.g. thinking in a holistic way regarding engineering, data and parameter management, operation.
5	Ethical	Trust, reliability, responsibility, sustainability	Design of products, process, and value chain to minimise negative environmental and social impact, while achieving economic benefits by going align with responsibility, reliability, and with sustainability.

No.	Category	Name of foresight key factor	Definition/Description of foresight key factor
6	Economic	Lobbying activities and strategic market development	Lobbying for AM in all aspects of the value chain would boost AM technologies and AM products beginning from software, powder, machine, till the end-user and through all social circles.
7	Economic	Collaboration of different stakeholders (e.g. patients, surgeon	Successful collaboration during the innovation process and the value chain leads always to improved results.
8	Socio-cultural	Cultural norms & values (including gender equality)	Cultural norms and values may either stimulate or hamper AM. Different regions or countries might adopt AM innovation system depending on their values and cultural norms. Compatibility of AM innovation system with the cultural values and norms affect the success of AM.
9	Socio-cul-	Building of critical	Critical mass is needed for all aspects along the innovation value chain of AM starting with powder producers and resulting in the acceptance in
10	Socio-cultural	(Public) Awareness of advantages	Awareness of AM refers to people's ability to recall and recognize AM. If people know AM, they can become familiar and comfortable with it. No awareness regarding the advantage, the potential, and the capacity of AM in research, industry, marketing, and society hinder the adoption of AM technologies.
11	Technological	Sufficient maturity of printing technologies	The AM manufacturing line has to be improved regarding printing time, printable size, printing results, e.g. resolution, precision, stability, reproducibility, etc. and improved combination of materials and efficiency.
12	Ecological	Less usage of resources	Additive manufacturing with intelligent lightweight design may maximize resource efficiency in manufacturing.
13	Political	Funding possibilities	Easy access to support from policy makers and EU funding supports necessary research and bridging the gap to economy and market.
14	Economic	Open innovation and free transparency of production	Open innovation system leverages the AM potential. Open innovation contributes to a faster development and therefore to a higher competition.

Figure 7: Foresight key factors on PowerPoint slides (see Appendix for details).

The work with the foresight key factors in the workshops takes place with each foresight factor on one slide (see the are presented in a better readable way in the appendix) as presented in Figure 7. Each foresight key factor is presented with its name, description, and graphic representation as used during the Bilbao workshop (2nd foresight workshop).

5.5 Future shapes of the foresight key factors

For each of the foresight key factor two to four different future shapes are developed in a co-creating workshop.

The better the different futures of one foresight key factor are described, the better disjoint these future shapes of one and the same foresight key factor, the clearer the different scenarios will be. Figure 8 shows the workshop, where these future shapes have been developed.

Figure 8: Second IAMRRI stakeholder workshop in Bilbao on October 10th, 2020.[4]

All foresight key factors got at least two future shapes. The following table represents this result.

Table 3: The foresight key factors and their various future shapes.

	Foresight key factor	Future Shape A	Future Shape B	Future Shape C	Future Shape D
1	Business models	Products on demand	Responsibility for application		
2	Effects on other global supply chain	One step supply chain	Tax disruption	Negative CO_2-footprint	Multicorporate enterprise acting on global
3	Regulation	Very strict regulation all over the world	Lose regulation all over the world	Different regulations regarding strictness, sector, and geography	
4	Education and skills development	No education and skills needed	Education focused on technical skills	Education focused on creativity	
5	Trust, reliability, responsibility, sustainability	"Capitunism" (this means capitalism & communism)	The lucky always wins (polarisation)	Democratic open societal makers	"Who cares!"

[4] Regarding the figure 8 - the participants agreed to taking and publishing pictures.

	Foresight key factor	Future Shape A	Future Shape B	Future Shape C	Future Shape D
6	Lobbying activities and strategic market development	Finished successful lobbying	On-going sustaining lobbying	Contra\backslash (too strong lobby, opposite effect, no support)	Closed down, AM prohibited
7	Collaboration of different stakeholders (e.g. patients, surgeon, AM)	Customer-centric collaboration (e.g. surgeon)	Artificial Intelligence defines collaboration		
8	Cultural norms & values (including gender equality)	Gender equality as a matter of fact	Sustainability and responsibility values	Neo-realist & plutocracy & nationalism (War/unrest)	
9	Building of critical masses	Education (existing critical masses)	Niches (no critical masses)		
10	(Public) Awareness of advantages	Science faction	Men's domains	Poisoning: Everybody is aware of toxicity and risks of materials for AM	Robot knows
11	Sufficient maturity of printing technologies	People-free factory	De-centralized production		
12	Less usage of resources	Expensive resources	Cheap resources		
13	Funding possibilities	EU top-down funding	EU bottom-up funding		
14	Open innovation and free transparency of production process	Mostly open	Mostly closed		

5.6 Morphological analysis

The morphological analysis supports to define consistent bundles of future shapes. There are several methodologies to create meaningful and consistent future scenarios. When working with stakeholders the holistic way seems to be appropriate. For conducting this a morphological analysis supports the work. Each foresight key factor is put on the top. Below each foresight key factor its different future shapes are posted. The next step is to across the future shapes, which means, take one future shape of each foresight factor, and combine it to a future shape of the other foresight key factor. These two future shapes should be consistent. Identifying a bundle of consistent future shapes, where each foresight key factors is represented is the basis for the scenarios. The lines (based on the coloured dots) form such bundles. Each of such a bundle leads to a future scenario.

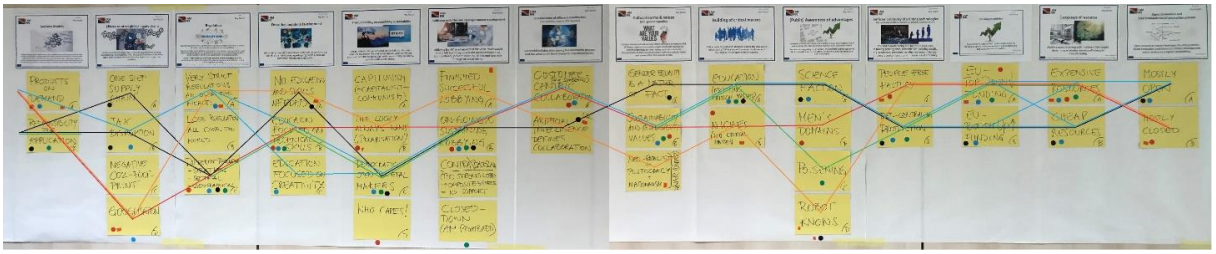

Figure 9. The lines in different colours define the different scenarios in this morphological box[5].

[5] The term morphology comes from antique Greek (morphe) and means shape or form. The general definition of morphology is "the study of form or pattern. (Fritz Zwicky, 1966).

General Morphological Box (analysis) is a method for investigating the totality of relationships contained in multi-dimensional, non-quantifiable problem complexes.

5.7 IAMRRI future scenarios

Based on the intuitive approach with the morphological analysis the following four future scenarios were identified and described. In the scenario development workshops we work with colours so that we can easier distinguish between the contributions and assign the results to the specific scenario. Therefore, also here the paragraphs are marked in colour corresponding to the respective scenario.

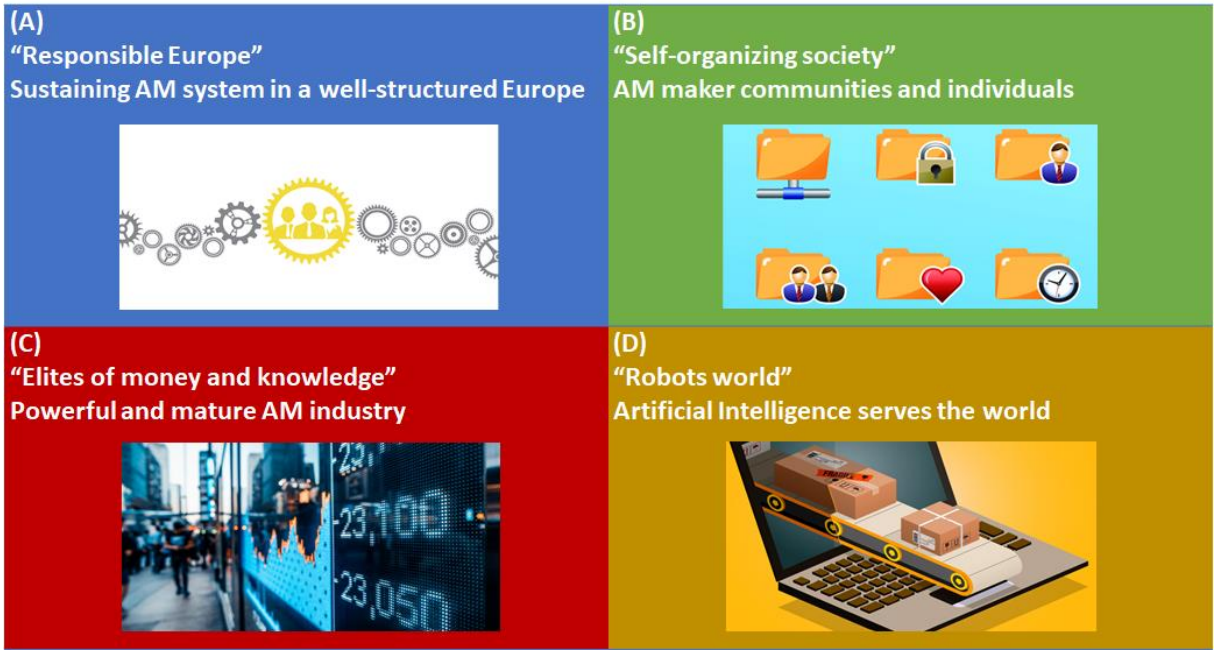

Figure 10: The names and pictures of the four future IAMRRI scenarios.

Table 4: The list of four future IAMRRI scenarios as developed in the project

	SCENARIO	What is it about	AM connection
(A)	Responsible Europe	Sustaining AM system in a well-structured Europe	"Service Provider", consumer purchasing remains in conventional sales channels
(B)	Self-organizing society	AM maker communities and individuals	"Content Provider", consumer purchasing shifts to online file-sharing repositories
(C)	Elites of money and knowledge	Powerful and mature AM industry	"Market Explorer", Use of AM to enhance existing business models
(D)	Robots world	Artificial Intelligence serves the world	"Mass Customizer", use of AM to create new business models

In the following the four scenarios are described in detail. Firstly, an overview to each scenario is presented. Secondly, the scenarios are described in detail with a link to already existing AM scenarios.

(A) **"Responsible Europe"** **Sustaining AM system in a well-structured Europe**	(B) **"Self-organizing society"** **AM maker communities and individuals**	(C) **"Elites of money and knowledge"** **Powerful and mature AM industry**	(D) **"Robots world"** **Artificial Intelligence serves the world**
GENERAL ASPECTS			
• Conservative scenario • Democracy, sustainability, openness and (science) education are high values within policy and society. • RRI principles are implemented as high values. • Incremental improvement of the AM production system which is mostly open and user-centred. • AM is a standard technology • Harmonized and strong regulations	• High degree of differentiation, democracy, individual solutions • Knowledge society; High education is available for everybody • AM products are printed at home or in maker spaces. • No common standards or rules. Tax on material/data and equipment • Generally high open access to knowledge, innovation, and science education. • Gender equality is a matter of fact, there is no loss of talents.	• Societal imbalances • Society is dominated by elites who own money and knowledge; High education for elites only • Economy is dominated by only a few powerful organisations • AM is a mature, highly automated and reliable technology • RRI principles are tried to be implemented top-down, but they are not of societal interest • No gender equality. • Resource efficiency due to resource scarcity	• Artificial intelligence (AI) and robots replace human beings in the production • The machines serve all humans for wealth and prosperity. • AM products mass customized • Data on humans is collected and used by AI, consumption is steered • High education and awareness are high values. • The state provides income for everybody. • Regulation makes sure that AI is controlled and RRI is part of the algorithms.
ADDITIVE MANUFACTURING ASPECTS			
"Service Provider" **Consumer purchasing remains in conventional sales channels** • Large companies dominating but system is also open to smaller players • Using AM to produce small batches (components) of products in an existing assortment. • Use of AM to service specialized products efficiently with spare parts. • Providing add-ons and upgrades to existing products, using AM as a "marketing story". 	**"Content Provider"** **Consumer purchasing shifts to online file-sharing repositories** • Manufacturers become pure content providers of digital product files, outsourcing manufacturing to consumers. • Strong shift in business models due to very different asset allocation, new capabilities, and different IP model. • Branding of files becomes central strategic resource. 	**"Market Explorer"** **Use of AM to enhance existing business models (exploitation)** • AM is mature and highly automated • AM industry is dominated by a few powerful organisations. • AM plants all over the world belong to the elites. • Using AM to set up an additional sales channel for data files for testing or entering secondary markets. 	**"Mass Customizer"** **Use of AM to create new business models (Exploration)** • Use of highly reliable AM to efficiently enable customized products for every customer, build-to-order. • Use of established online and offline channels for customer interaction. • Manufacturing remains in-house, AM is utilized to provide high variety at low complexity & cost. • High level of personalization 

Figure 11: Overview of the four IAMRRI scenarios compared with each other.

(A) Responsible Europe - sustaining AM system in a well-structured Europe

Sustaining AM system in a well-structured Europe. “Service Provider”, consumer purchasing remains in conventional sales channels.

Figure 12: Icons for presenting scenario (A) “Responsible Europe”.

In this scenario the “European” way is continued. In a well-structured world of openness and regulation ethical values, democracy, sustainability, and education are high values within policy and society. Society is built by democratic open societal makers. There are many options to choose for the individuals. Science education becomes more important. Also, public engagement and ethics become more important to individuals.

Gausemeier et al. (2011): “Europe sets the pace in a globalized world” fits into this scenario.

There is a strong tendency towards urbanization, slight population growth through migration. Living and working conditions are good and children and family have a high priority. Older people feel needed and are willing to work longer. Awareness for sustainable mobility is high and also the availability of modern digital forms of communication. High financial support of research institutions by the government pays off. Population is well skilled. Policy is efficient and highly effective. Free trade without borders is possible within the EU.

European economy grows due to value-creation-intensive enterprise functions, future- and high-quality-oriented as well as value-creation-intensive company divisions are settled in the EU, gross domestic product is growing by 2% annually. This development has been stable for years.

Efficient material use and regenerative energy prevent energy crisis, scarce energy fosters high efficiency, sustainable and intelligent processing of raw materials is applied worldwide. There are better recycling processes, a slightly increasing expansion of regenerative energy sources, and broad consensus for environmental protection has been emerging worldwide.

Education is focused on technical skills on knowledge and on creativity. It has undergone radical change as it also focuses on creative thinking. AM is also integrated into curricula, and there is an open access system. Society works closely together with engineers. Toolboxes are available for non-technical trained people to solve technical problems. Training of engineers are more holistic and integrates non-technical topics, such as RRI orientation.

Regulations are harmonized and strong. Regulation covers standardisation and legal requirements. They give a secure framework for broad applications of the technology. Some technologies and solutions may disappear due to strict environmental and safety and security regulations. Harmonized regulation worldwide makes global market grow. Ethical values are defined by the society. Ethical panels decide on the framework of these ethical values.

The highly esteemed RRI keys are implemented. Science education, public engagement, and ethics become more important to individuals. There is more open access and more gender equality. Sustainability and responsibility are high values, i.e. waste reduction, and less use of resources as well as circular economy.

There is high awareness in society, so everybody is aware of the risks of AM raw materials and the AM technologies, products. Also, resources are a high valuable good. AM could be a solution with e.g. innovative lightweight solutions and product designs. There is tax on pollution (material, equipment), e.g., taxes for those who will produce waste, and taxes on data.

In this conservative scenario there is only incremental improvement of the AM production system which is mostly open, and user/customer centred. AM is a standard technology used wherever needed. Harmonized and strong regulations give a secure framework for broad applications of the technology.

AM webs of innovation value chain had undergone a consolidation process. AM added webs of value chains and supply chains might be dominated by large global active companies. The monopoly on machine selling, licensed models, licensed designers etc. but the production and innovation process on new products is open for other players, with low barrier access to patents and user-centricity. RRI is reflected in the new products and manufacturing process because ethical aspects, gender, society needs are taken into account. There is still a great variety of possibilities for smaller companies and there is strong knowledge flow but limited by regulation.

AM business models are based on the principle of online ordering and production on demand, which requires know-how on the customer side. Factories are micro-factories, localized where it is needed (neighbourhood, city, etc.). AM production system is decentralized and can be globally.

This scenario matches with the AM "Service Provider" Scenario from Jiang et al. (2017): *Consumer purchasing remains in conventional sales channels. AM is mainly used to produce small batches (components) of products in an existing assortment and to service specialized products efficiently with spare parts. AM is also used for providing add-ons and upgrades to existing products and using AM as a "marketing story". AM is still, of course, important for prototyping and inspiring innovation.*

(B) Self-organizing society - AM maker communities and individuals

AM maker communities and individuals“Content Provider”, consumer purchasing shifts to online file-sharing repositories.

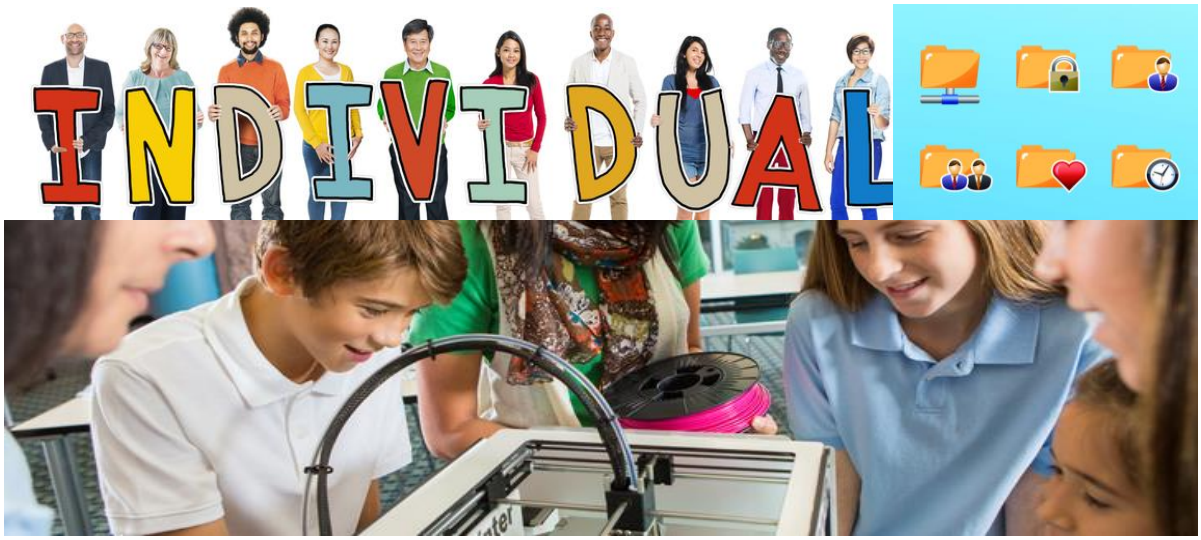

Figure 13: Icons for presenting scenario (B) “Self-organizing society”.

Differentiation, democracy, individual solutions, and knowledge society are the keywords in this scenario. In this colourful and diverse world individuality is the highest value of all. Individuals share a common understanding of high ethical values. Each are responsible for themselves, their education, and their jobs. They have so many possibilities that it is hard to find a “red line”. Regulation varies and is not well established everywhere. The innovation and education systems are open and transparent but not harmonized. Education is a good for everybody and a very high value.

Democracy, ethical values, and personal rights are very high values of society. Everyone aims at freedom for themselves and society. Therefore, there are built fair social conditions in a bottom-up way. Sustainability and social welfare and balance are principles on which society and individual decisions are based.

There are no common standards or rules. Regulations are very different regarding their strictness, the sector addressed and the geographical area. Concerning AM there would be a need of regulation and control of what is printed. Also, the taxes which apply tax on material/data and equipment are not harmonized.

The implementation grade of RRI is different based on the geographical area and sector but with a generally high open access to knowledge, innovation, and science education. Gender equality is a matter of fact, there is no loss of talent. Information and knowledge are shared and tools for collaborative work are common. Sustainability and responsibility are high values, i.e. waste reduction, and less use of resources as well as circular economy. Everybody is aware of the toxicity and risks of AM raw materials.

Government has increased possibilities, but the policy system is more complex. EU funding works bottom-up as there are open calls for all entities with high risk projects, market and entity driven. Interdisciplinarity is important.

There are many highly innovative specialists and experts. Critical masses on AM are already existing and AM is integrated into curricula. AM education is focused on technical skills.

Ryan et al (2017) reviewed various existing scenarios and developed plausible scenarios for what they called "white spaces". *One of the scenarios considers the options of mobile production: "By using mobile facilities, additional 3DP equipment can be added or removed to the production system, enabling the achievement of capacity flexibility for the firm. Alternatively, factory mobile 3DP could provide emergency cover for machine failures. For craft implementations, this ability to increase capacity though mobile 3DP might even serve to undermine some of the "print at home" scenarios, by eliminating the need for the customer to own a fixed resource. Just as domestic customers today may hire expensive capital equipment items for short periods (e.g. professional carpet cleaning machines), Mobile 3DP allows customers to increase their ability (from zero to whatever is required), without the need for long-term commitment. This is particularly sensible for home environments, where ownership of high-cost 3DP equipment with low utilisation is likely to be financially unviable." Other scenarios concentrate on craft business, where items are produced at home for sale on the market, and personal manufacturing, where both production and consumption would take place within the user's home.*

The AM production system is decentralized as AM products are printed at home or in maker spaces. Everybody has the capability to print at home and his/her own short supply chain. Not the products are sold but the value (e.g., orthoplastic versus warranty). There is a great variety of products. Everybody needs to take responsibility for the whole product life cycle (engineering, dismantling).

The production process is mostly open, with cheaply usable patents, open access to publications. There is great knowledge flow. Open innovation gives a high diversity and easy access to take part in innovation.

This scenario matches with the AM "Content Provider" Scenario from Jiang et al. (2017): *Consumer purchasing shifts to online file-sharing repositories and manufacturers become pure content providers of digital product files, outsourcing the manufacturing to consumers. There is a strong shift in business models due to very different asset allocation, new capabilities, and different IP models. The branding of files becomes a central strategic resource.*

(C) Elites of money and knowledge - powerful and mature AM industry

Powerful and mature AM industry “Market Explorer”. Use of AM to enhance existing business models.

Figure 14: Icons for presenting scenario (C) “Elites of money and knowledge”.

In this world of geographical and societal imbalances society is dominated by elites who own money and knowledge. Economy is dominated by only a few powerful enterprises. AM is a mature, highly automated, reliable, and efficient technology. RRI principles are tried to be implemented top-down, but they are not of societal interest. There is no gender equality. Only concerning resources, efficiency is a high value due to resource scarcity.

Caviezel et al. (2017) predict negative employment effects resulting from higher efficiency and degree of automated production steps. *Parts of these effects might be compensated by new opportunities for product improvements and more attractive services (e.g. faster delivery times, customised products). Higher demands for additive manufacturing products may lead to an increased employment of skilled workers, but only until the relevant markets reach saturation. If simpler manual work steps are automated with the help of additive manufacturing, this could result in a substantial need for qualification of company employees. However, skilled workers who have been working in manual production for a large part of their working lives, additive manufacturing, with its emphasis on screen work and equipment operation, could possibly create a feeling of alienation from their work, which could reduce their willingness to adapt to the new manufacturing processes.*

In this scenario society is split and there is a large gap between rich and poor. Most people live in crowded mega-cities in small flats or even around them in slums. They work on the few occasional jobs that are available. Most of the work is done by machines. Those who live at the countryside work for large farms together with machines earning their modest living.

Most of the people don’t have access to higher education so they have no chances to get well paid jobs (poor science education). Only the rich and well-educated elites have the possibilities to provide higher education to their children. Their job is the development and control of machines. They have a

very good life which is well-assisted by robots. Those who have the luck to get a good job in a position where humans are still needed, e.g. in creative positions. They work all day and night, to be able to survive and earn the money they need and keep their jobs.

RRI principles are not implemented. There is no gender equality. Science education is underrepresented. Only concerning resources, efficiency is a high value due to resource scarcity.

Regulations are very different regarding their strictness, the sector addressed and the geographical area. Regulation is not harmonized at all. Big markets protect each other (US, Europe, Asia). Global market could fall apart into different protected markets.

EU funding functions top-down, in mission-oriented calls (TRL, segment, etc.) with medium-low risk. Big enterprises have the power to get funding, small players have no chance to be part of the innovation system. Public is not engaged in the innovation process at all.

AM Economy, AM value chains, and supply chains are dominated by only a few powerful organisations having the monopoly on machine selling, licensed models, licensed designers etc. AM is a mature, highly automated, and reliable technology. In the people-free factories no human input is needed for the manufacturing process because the technology is completely mature. Additive manufacturing is a standard technology for the wealthy society. It cannot be used by the masses as they don't have the financial, technological and know-how recourses. AM plants are in all places of the globe for producing the products needed there. These plants belong, of course, to the elites.

Innovation is mostly closed with stronger patent protection, proprietary standards, strong national interests, higher specialization, and efficiency.

AM education is focused on technical skills. The education system is like the status quo (today). It focuses primarily on technical skills than on knowledge and science education. STEM degrees are the most popular. Companies are full of highly specialized technicians. It is hard to find these profiles due to high demands, but the job options are limited.

Resources are exploited and therefore already rather expensive. AM could be a solution with e.g. innovative lightweight materials. The use of AM could help to preserve resources and support sustainability and responsibility which are not high values everywhere. AM players are aware of the risks of the material and technologies e.g. toxicity of some AM materials.

The scenario of "Market Explorer" from Jiang et al. (2017) fits into this IAMRRI scenario C: AM is used to enhance existing business models (exploitation). *AM is used also to establish additional sales channel of data files, supplementing established sales models and as a new export strategy: using of digital product files to test or enter secondary markets.*

(D) Robots world - Artificial Intelligence serves the world

Artificial Intelligence serves the world "Mass Customizer". Use of AM to create new business models.

Figure 15: Icons for presenting scenario (D) "Robots world".

In this scenario the world consists of smart systems everywhere. Artificial intelligence (AI) and robots replace human beings in the production process. The machines serve all humans for wealth and prosperity. Humans have more spare time as the machines do all the hard work. Data on humans is collected and used by AI, and consumption is steered.

RRI is part of the algorithm. Which RRI aspects are programmed into the AI and robots is defined by the people with force. However, the general education level is high. The machines and robots work for the human's wealth and prosperity. There are scepsis about implementing differentiated ethical values. It might not be possible to develop algorithm for a differentiated and broad ethical framework.

The system depends totally on the role of the state and its policies which define how the daily lives of the masses look like. With a strict regulation and high awareness of the system and its dynamics, AI and robots provide standardised wealthy and healthy lives for human mankind. The basis of wellbeing and peace for humans in this system is secured to a reasonable extent. (Higher/academic) education system and an unconditional basic income are available to everyone. AM products are mass customized.

Our houses are smart homes where e.g. the refrigerator is able to refill itself, and a lot of daily life products are identified as being able to be delivered by AM technology immediately and regionally either in our own houses or at AM manufacturing sites ordered and produced on demand. As we live our lives all our paths and actions are traced digitally, so we produce huge amounts of data which represents our daily needs, the decisions we make and the values we share. Our data is collected, and Artificial Intelligence algorithms use it to rule/control our world in a hidden way and our consumption is steered by AI systems. All areas of life are controlled by AI, medical services, car driving, shopping,

et. It is essential who controls the algorithms as society and the distribution of money and wealth depends on the definition of algorithms.

An unconditional basic income for everyone is a profound basis for wealth and peace in this system and is possible because of the efficient and responsible application of technologies for the wealth of humans. Therefore, we humans have more spare time and most of us a good life as the machines do all the hard work. However, human decisions are controlled by the AI system providing an environment that uses the data on us and steers our consumption.

This makes economy big and differentiated. We live in a world of strong economic rules. Not only the big players dominate and control the system as there are niches for clever programmers and those who have the best algorithms and data win the race. Only "big brains" are able to play within this system of AI and machines.

It is essential who controls the algorithms as society and the distribution of money and wealth depends on the definition of algorithms. Therefore, the system depends totally on the role of the state and its policies which define how the lives of the masses look like. Regulation makes sure that AI is controlled and RRI is part of the algorithms. All ethical and gender equality requirements are programmed into the machines, which is being enforced and controlled top-down. With this assumption of high RRI and ethical values this world consists of a wealthy society where the machines support and care for the humans and all humans get their part of the wealth. With a strict regulation and high awareness of the system and its dynamics, AI and robots provide wealthy and healthy lives for human mankind as the state provides income for everybody.

To be able to control such a system high education and awareness are needed and therefore very high values.

EU funding is policy driven and functions top-down, in mission-oriented calls (TRL, segment, etc.) with medium-low risk.

The presumption of an excellent enough (high) education system and an unconditional basic income were derived from security issued mentioned in other ***similar scenarios which were described by Trevor et al (2018):*** *"As the technology advances, fewer workers might be necessary to produce the same amount of output…..Unemployment, isolation, and alienation of middle- and low-skilled laborers could be exacerbated by AM, potentially leading to societal unrest in both developed and developing countries. The security implications of large masses of unemployed, disconnected people are substantial. Additionally, the large return to automated AM capital could further increase economic inequality, exacerbating the trend of the past 30 years and potentially leading to social unrest."*

AM technologies are highly automated and reliable. In the people-free factories no human input is needed for the manufacturing process as the technology is completely mature. Highly educated people are needed for the development and maintenance of the AI in the companies dealing with AI solutions. Less educated people lose their jobs. Human skills are needed only for the development and control of the AI as computers and machines are everywhere. Everything is automated and digitalized.

Business models are based on the principle of online ordering and production on demand, which is supported by AI. AM is used for all possible applications. AM high-end applications are used for physical or mental augmentations and medical use. Also, weapons research (drones, light weight equipment)

is important. Public engagement will be higher because of reliability and is also more common to talk about AM (science education).

Very strict regulations will be applied all over the world with AM processes and products highly regulated and certified. Some technologies and solutions may disappear due to strict environmental and safety and security regulations. Harmonized regulation worldwide makes global market grow.

The machines need a lot of energy. Therefore, AM is a solution. Innovation is mostly closed with stronger patent protection, proprietary standards, strong national interests, higher specialization, and efficiency.

AM added value and supply chains are relying on AI algorithms, licences etc. Artificial intelligence defines collaboration. Therefore, algorithms define the way and quality of collaboration.

This "robots world" is supported by the AM "Mass Customizer" Scenario of Jiang et al. (2017): Use of AM to create new business models (Exploration); *AM is used to efficiently enable customized products (mass customization) for every customer, moving from build-to-stock to build-to-order. Established online and offline channels are used for customer interaction and manufacturing remains in-house. AM is utilized to provide high variety at low complexity & cost.*

5.8 Understanding the consequences

On February 18th, 2021, approximately 40 European experts in additive manufacturing, innovation management and RRI met to discuss the developed IAMRRI future scenarios for additive manufacturing. The event was organized via Web and offered a bilingual workshop, in German and in English.

Figure 16: Screenshot from online workshop on the consequences of IAMRRI scenarios on Feb. 18th, 2021. (Source: Screenshot from the online workshop.[6])

Figure 16 shows 12 of the 40 participants in the third stakeholder workshop. Central topic of the workshop was the assessment of the developed scenarios with respect to their future opportunities and risks, innovation processes and networks and the role of RRI keys such as ethical considerations, scientific education, public engagement, gender equality, and open access to knowledge. The results delivered additional input for the simulation work in IAMRRI.

The 40 experts from the European science and research organizations, clusters, public authorities, and companies representing SMEs and industry built a representative stakeholder group for webs of innovation network in AM. Six workshop teams discussed the four scenarios, which were developed in the previous Foresight workshop and formulated by AIT – Andrea Kasztler and Marianne Hörlesberger.

The workshop had two main parts. The first part discussed the opportunities, risks, and specific innovation situation in each of the scenario. For this, stakeholders were asked to discuss and define the AM WIVC in terms of collaboration structures, actors, their roles, and the network structure (managers, promoters, knowledge brokers, etc.) and stakeholders discussed, where and how are ideas generated in this kind of AM innovation process. The second part worked out the linkages to RRI keys (policy agendas) in these scenarios.

[6] The participants agreed to taking and publishing pictures.

Consequences for Scenario A "Responsible Europe"

The scenario A "Responsible Europe" focuses on sustaining AM system in a well-structured Europe. "Service Provider", consumer purchasing remains in conventional sales channels.

Risks	In this scenario the regulations are very strong. The CE marking[7] for AM components has to be introduced, starting from component to production method, to certified operator. Consequently, the use of printers at home for products will no longer be permissible. Thus, only big players remain and implies market consolidation. It might demonstrate a "regulation to death". Taxes and data tax do not lead to a boost either, every megabyte is taxed. This leads to compulsion on efficiency, but also inhibits development. Everything where value is created is taxed. Interaction with international market, where might this be? There is high potential for tax evasion. AM remains a niche topic in Europe as it is in the current situation. There is no major further development. This might bring only very view big companies orchestrating the value chains. The innovation power in Europe will be lost especially because of the very strong regulations. Material development, or plant and machine development will be difficult because of the strong regulations and taxes. Design development for AM could work. However, certifying the continuous process chain would be necessary when working for aeronautics for instance. This would be hardly possible. In case the world outside Europe does not care about responsibility, it would be a big challenge for providing "responsible technology" from Europe to the whole world. The market will be very distorted from companies and actors outside Europe. It might be that companies buy smaller innovative companies because AM market is a worldwide market. Europe could move from a technology provider to a technology user. The concentration only on Europe is a limitation because European technology developers and providers are players on the globe. However, does not hamper innovation, as there is a periphery of smaller innovative companies.
Opportunities	• **Smaller companies** (idea generation) have more opportunities for innovation but might be bought by a big company afterwards. • **Innovation** will still be implemented by large **companies** (idea development and idea dissemination). The likelihood for success on the market is higher. • Standardised materials and equipment effect **higher quality in AM** (e.g. Stratasys works) through guarantees that it works.

[7] The CE marking is the manufacturer's declaration that the product meets EU standards for health, safety, and environmental protection. The CE mark indicates that the product may be sold freely in any part of the European Economic Area, regardless of its country of origin. (https://en.wikipedia.org/wiki/CE_marking#:~:text=The%20CE%20marking%20is%20the,of%20its%20country%20of%20origin.)

	• **Regulation** such as standardisation has a positive impact on stable technologies and AM processes, because research organisation, industry, and politics have agreed on a common understanding.

About the innovation process in scenario A "Responsible Europe"

Collaboration in the value chain

The collaboration will be the way as today, along the steps from material to the product, links the design developers and the customer need. It will depend very much on whether you can put your own designs into the open access system, or whether you can only use predefined things. In this scenario supply chains dominated by big players, however, small players might innovate well, because also of the decentralisation of AM. Smaller companies will collaborate among each other. There will be licensing agreements of the central company. There might also be a platform economy where smaller companies are part of the platform of a big company.

Actors

The actors in the WIVC in this scenario are universities, research organisations, and big companies and specific smaller companies for the idea generation. For the innovation development also, small companies are involved. The public is engaged in specific cases where a bigger society is affected. There are fab labs and makers (free lancers). However, they are forced to make their developments available as open access. The business models there is reimbursement through fees).

Network structure and economic opportunities

Networking is generally important in this scenario. Big companies need small companies and research organisation for being innovative. In medical application the networks are close with the patients because the products are personalised. Since there are strong regulations, the companies and research organisation have also a strong network with the policy makers.
Considering medical AM applications, a strong network between engineers, scientists, surgeons, patients is build. Europe could become market leader here because standards are also met. This experience could be extended to other areas, directly related to wearing comfort. Thus, there will be core and periphery network structures.

Innovation ideas generation

The more regulation, the less space for competition and business decisions. Ideas are generated by the whole network of the innovation value chain. The innovation is built upon the technology of the big company. There will be innovation ideas for personalised products especially for small number of parts ortoproducts where the mass of the individual products is not important for innovation.

AM could become more widespread if there are high fees on other productions where there is more waste ("waste tax"). In this case AM will be profitable again despite fees and taxes.
Europe might innovate rather from smaller sectors. However, this is quickly taken up by the big ones.
In the spare parts sector, costs can be saved if AM is used, especially if requirements are high. In the spare parts sector, costs can be saved if AM is used, especially if requirements are high.

Consequences for Scenario B "Self-organizing society"

The scenario B "Self-organising society" focuses on AM maker communities and individuals "Content Provider", consumer purchasing shifts to online file-sharing repositories.

Prototyping is an excellent possible for home printers however…

Risks	• Guarantee of the quality is not given. • AM production requires a lot of skills/knowledge to be able to produce a desired and certified product. • IPRs management is crucial in this scenario.
Opportunities	• Since AM production requires expertise, it might be an opportunity for setting up a good production and business for high-tech AM products. • Open innovation and open access in this scenario are a great opportunities. • High acceptance of the technology by the society. • Since encapsulated safe printing machines are available, the work in maker spaces and at home offers many possibilities.

About the innovation process in scenario B "Self-organizing society"

Collaboration

Openness might be limited to powerful actors, the ones who have the most resources. The innovation is faster than nowadays. It may start as decentralized but will concentrate in big companies by small ones (sliding into scenario C). A lot of sharing of knowledge is required. The collaboration actors need to know the expertise about the actors in order to cooperate. However, there are maker spaces and therefore, the collaboration is not contract based. The collaboration is thus not very stable or long lasting. There are more spontaneous networks. (The self-makers at home will only produce and will maybe not be so innovative.)

Actors

In this scenario, individuals with high skills and knowledge are central to innovation process. Maker spaces, innovation centres, communities play a central role of bringing skilled and motivated individuals together enabling more complex innovation. Then further, more facilities such as fab labs, innovation centres, innovations hubs, etc. are linked together to provide solutions. Companies still provide most of the machine and material innovations, maybe with co-operation with research organizations. Companies will still also provide a considerable amount of product innovations. However, the collective of individuals active in cooperatives, maker spaces, fab labs, etc. take up space in the innovation processes, individuals alone maybe not so much.

Network structure and economic statues

AM is currently driven by technologies, thus driven by limited number of companies. Due to technology development actors' landscape will be more heterogenic in the future. It would be possible that cooperatives, such as makers' communities are established to purchase expensive machines for their members.

Innovation ideas generation

Innovations are shared. There will be a shared economy at the beginning but might be commercialized and lose the openness later. Individuals will start the innovation. However, it might be limited as individuals have somewhat limited skills and knowledges.

Companies have a big responsibility in order to make scenario B possible. They need to open up to knowledge transfer and collaborations and need to allow individual AM manufacturers to step into AM market. The big companies will still exist up to this point, but they need to give up part of their market strength pretty much for this scenario to prosper.

It could happen that big companies are turning away from profit maximization for societal value maximizations.

Consequences for Scenario C "Elites of money and knowledge"

The scenario C "Elites of money and knowledge" focuses on powerful and mature AM industry "Market Explorer". Use of AM to enhance existing business models.

Risks	Basically, it is an anti-innovation scenario. The elites earn and optimise their money. Innovations happen only when pressure come to the system like resources are scarce and the elites are forced to innovate to keep their financial advantage. For the "normal population" there is hardly any access to resources. Here there is the risks of monopoly from a few actors (software, material, and machine providers). The monopoly situation induces also risks regarding agreement between material and machine providers, licence, etc. The big risk is inherent in the all-in-one solution providers. The biggest can absorb the whole industry). AM has a risk to follow "older" industry regarding the gender equality imbalance if no specific action is done. There will be no further steps in reuse of material and so there will be a lot of material waste. The consumption of energy, especially for raw material production (i.e. titanium powder) will increase. AM can remain a tech for advanced countries and companies. AM components can remain for advanced and developed products for "elite" people. Some might think that "from low-tech to high-tech" and especially from the simple idea "in a garage" to production for the "globe" in only possible with a lot of money. However, in this scenario, this example, this path of success created with little money will not be possible, because the elites will not allow it or buy it up.
Opportunities	There will be shadow economy with AM within the poor population. However, this is also an opportunity for ingenious ideas in the low- and high-tech sector (ideas of business and technologies "out of the garage"). Others counter, that development of high-tech is possible with little money. Really important is only that the product, the machine, and the process are ready for the market. However, some centralized major actors could simplify the value chain and rules the normative aspect of the market. They will be standardized and bring stability to the market. A decentralization of the manufacturing system is likely to happen with the democratisation of this mean of production (1000 people build 1 product instead of 1 factory build 1000 products).

	AM can develop low-budget production, high quality production with a low-budget equipment. It can also have an influence on the education. Since RRI is implemented more and more woman will work in R&D departments. The ratio of gender equality is increasing, 0,5% increasing each year. On the "new tech" area, not only in AM, there is an increase of consciousness of needs of equality. Since this scenario have also implemented artificial intelligent technologies, AM would have a good chance because AM is very digitalised and thus plays into the hands of robotics developments and AI. There will be algorithms that AM will also develop further. AM would have a chance to save resources in the low-tech sector.

About the innovation process in scenario C "Elites of money and knowledge"

Collaboration

The collaboration in this scenario is very much controlled top down. The elites of AM with their money and knowledge define the collaboration. Knowledge carrier are linked with the elites or the elites are themselves the knowledge carrier. Only big companies and elite research institutions collaborate. The funding is organised among the elites. The elites are concerned to maintain power and representation. AM is supposed to serve that.

Actors

Once large corporations, banks, insurance companies are the actors. However, also knowledge carrier play an important role.

Since there is a shadow world in the poor society with highly active people in AM, also they are actors, however with no power.

Network structure

The highly recognised elite universities and research organisations collaborate with the elite companies.

Networks exist in the non-elites (semi-official). These are very, very important to develop the low-tech innovations.

Innovation ideas generation

The focus of the innovation for elites will be for instance new skin on the face, preserving everything they have, e.g., big old cars, big house. So, these are innovation ideas for this scenario.

Furthermore, they maybe would like to travel to Mars and stay there. With AM it might be easier to build houses there. Elites also want to initiate unusual things. AM will innovate solutions in this direction.

Innovation is also split into those from the poor and those from the rich. Innovation is most likely much higher in the poor population (semi-legal).

Consequences for Scenario D "Robots world"

The scenario D "Robots world" focuses on artificial Intelligence serves the world "Mass Customizer". Use of AM to create new business models.

Risks	The direction of needs is controlled (manipulation of people). Freedom of choice will possibly be restricted. The question will be how freely we can decide what we want to have when the available resources (income) are limited. There might be no individualisation in the scenario. AI makes decision and might become critical for human beings because of lake of holistic ethical considerations). Ethical questions will increase significantly because competences and decision-making power will be handed over to AI. The high concentration of decision-making power on AI and algorithms will control and manipulate human beings and their decisions (competition of communities, hackers. The human beings are no more able to understand and reconstruct the AI decisions. Fears will also arise from the obvious realisation of the loss of control. Traceability of decision and transparency is not possible due to the characteristics and creation of AI. (Dualism complexity versus transparency). Robots and AI overshadows this scenario. AM gets covered. The challenge of retaining decision-making authority versus decision-making based on AI is seen critically.
Opportunities	In 2040, there will still be some developments that bring AM in the direction of "mass individualisation" and drive its use as a production technology. This demand requires an automated implementation of the constructive realisation of product ideas, which means that the AM software value chain is to be strengthened through AI. People will have access to knowledge, possibly there is less interest from society because there is a high basic supply, also AI can control the selection of topics and favour certain topics (bias for certain topics).

Power claims determine the degree of openness. AI itself is a partner in the innovation process. AM is driven by AI (construct products or process chain).

About the innovation process in scenario D “Robots world”

Collaboration and networking

Collaboration is and networking will remain. Both technologies, AM and AI, are further on the front end of science and research and will support and control collaboration formation.

AI and robots are important partners of the collaboration.

Actors

AI and robots are actors as well as companies, banks, universities, research organisations. No new actors are seen in AM unless AI is perceived as a new actor. Rather individual actions and individual actors bring themselves into the innovation system, and these are brought together in the background via data and AI.

There are operators and owners of supercomputers and software, due to the global claim and the high investment power. Primarily large corporations (business organisation) will be the owners.

Network structure

AI is also getting involved in networking and network building (link to IAMRRI SKIN model). Data volumes will be generated and available. These will be processed centrally. Networking is seen primarily via the existing data, rather than on the networking competence of people. The global networks offer new possibility of finding network partners. It is estimated that basic principles remain the same. Communication and data management is supported by AI.

Innovation ideas generation

AI plays an important role also in generating ideas. AI is an integrated part in the innovation process.

5.9 RRI in the innovation processes of these scenarios

RRI in the innovation process of scenario A
Responsible Europe - Sustaining AM system in a well-structured Europe. “Service Provider”, consumer purchasing remains in conventional sales channels.

There are very strict regulations in this scenario so open access, gender and ethics considered to be regulated.

Ethical values are implemented into regulations (standard and regal regulations). They protect the costumer, especially data protection, and offer safety.

The design of the regulations according to ethical aspects depends on the people and experts developing this. The group composition for developing the standards and norms considering ethics is crucial because of representing interest.

Since there is a strong dependence between design, material, printing process, etc. and so many different actors are involved for one product.

When considering the medical application of AM, there are strict regulation making more complex to bring in new materials, new applications to the field. This is an advantage and safety for the patient However, it hinders new innovative approaches. Only larger corporations can go through the bureaucratic process.

Public engagement could take place by involving smaller groups that develop ideas, which is encouraged thanks to good education. Impulses for innovation from the society will be possible in design phase, however, not in aspects of material, because a lot of expertise is needed here. If fab labs are established and AM will be taught in school, this will lead to increased interest and thus also to idea generation, starting with young people.

Governance perspectives in this scenario gives more opportunity to learn from each other, the market opens, the innovation rises. The market is easier to access from the public in this democratic scenario.

Large companies could be open to public engagement in the innovation process for marketing purposes.

Science education, training and education should not be geared towards gender. It should attract the interested and best students, however, should be inclusive. Maybe there could be courses for developing AM parts with the need of highly safety requirements and courses for AM development pars with low safety requirements. A trained society increases the success of AM innovation. Skilled people trigger collaboration, accelerates innovation and new ideas. Who does science education? University, high schools, companies are the candidates. Companies, training of workers.

Which role do **gender, open access**, or transparency play in this AM innovation process? The number of **women** in technology is always to low. However, women might be interested in the design field. Designs can be found often with short names in the internet, "artist names". Therefore, gender independent, income via use of design - see e.g. https://www.thingiverse.com/.

Open access and sharing of data are difficult for companies. Companies have to protect data. Data that can be shared by a company might be proprietary information on the formulation of the materials they are using. Only EU pursues open access, not EEUU or China. Open access can accelerate innovation, but it is a risk if not done worldwide.

Data able to be shared (transparency): Companies can refer to commercially available products or share information on the mixture, composition. Based on the public results others can build up, make other experiments.

RRI in the innovation process of scenario B
Self-organizing society - AM maker communities and individuals "Content Provider", consumer purchasing shifts to online file-sharing repositories

Ethics should be considered in the following way. Precautionary principle should be embedded into the innovation process. Innovators should try to think ahead about the possible negative side-effects. Being very precautionary or proactive could create competitive advantage for companies, and also desirable by the society. These kinds of mandatory principles need to diffuse among the innovators for this scenario to work in a first place.

Kyoto protocol or similar agreements are also influence and ensure the quality. It might create quality and sustainability issues to be covered in a very early in the process.

Long term thinking is required. Companies and individuals must commit to ethical thinking. Benefits of this thinking are realized in a far future, not immediately which makes it challenging. If AM is committed to engaging to ethics it might be even an advantage for the AM technology compared to other technologies. Highly ethical thinking is required for this scenario to work.

Public engagement is considered in the following. If public is active and aware of societal/environmental issues, it might condemn the companies or individual working against them. Public engagement is happening via the individuals developing innovations. There is a lot of discrepancies between manufacturer and customer currently, so public engagement will be needed, and it has to be realistic, not hype. Not too far-fetched ideas of what AM is capable of, discussions with public will dissolve the false expectations.

Science education is prerequisite for this kind of scenario as well as ethical thinking. Universities will play a big role at the beginning. Companies will have to open up and give away the knowledge and training. Thus, companies are more engaged to offering education in order to promote the technology and their responsibility will be high. We need home solutions that would work in some means where technology is developed that quality is so good that functional prototypes are possible to print at home.

Which role do **gender, open access**, or transparency play in this AM innovation process? Online platforms with open access are established, but also marketplaces. People would be more connected with such online platforms. This supports open access and transparency. You might share purchasable designs, but also to engage into the innovation processes. There will be no problem of disconnection by working isolated at home (Indian's portal). Everybody connected in a kind of AM platform shares 3D models, information on providers, new techniques.

RRI in the innovation process of scenario C
Elites of money and knowledge - Powerful and mature AM industry “Market Explorer”. Use of AM to enhance existing business models

Ethics regarding AM is defined by the elites in this scenario. There is freedom. “Just do it”, but without financial support. Freedom is an important argument for innovation. Anarchy is very important in the "lower innovation system", that of the poor people. Poor are treated badly. Protection of own class is essential. There is exploitation of the poor by the rich. (Such as already today - start-ups are bought out by big companies.

Influencers in social media play an important role because they can point out trends but also point out innovation opportunities.

Public engagement is basically not possible here. Public engagement is prevented because of the danger of upheaval. However, highly educated people will get engaged in the innovation process. Talents, geniuses, rich people will work for this system. The impact is that more innovation within the system is possible. The poor see this as an opportunity and increase their innovation. They strive to get into the "rich" group. However, these ideas are then used by the rich to make a profit. For the poor, this is an opportunity to rise through innovation, but also a danger of being exploited.

The elite has access to **science education, but not the majority of society**. The impact on innovation is low by this educated people because only a small circle is there. The poor population will acquire education, but with few resources, e.g. there are no laboratories. It can lead to a monopoly where only a few people own/use/access to the technology. People can share more easily knowledge through communities, social medias, etc. It becomes easier to use (plug and play) for youngsters. It becomes a tool than more and more people will have access to, to produce things.

Basic research will remain with the rich or will not take place at all. Just because of the image, it would be interesting for the rich after all. They deal with questions such as immortality, life on another planet. Health plays an important role.

Which role do **gender, open access**, or transparency play in this AM innovation process? Only when there is a benefit for the rich, gender and open access are considered. Open access has not a high priority for the most people, because they do not have the higher education to take advantage of that. You get a small compensation when providing an idea. Open innovation might play a big role in subculture, controlled by elite only.

A negative aspect is the unfair situation of who could benefits from this technology. People, the makers, have the knowledge needed to produce goods and to share it (for example masks during COVID crisis) and don’t care about the money. This is an example showing that it can help to struggle against elites/monopoly situations.

RRI in the innovation process of scenario D
Robot’s world - Artificial Intelligence serves the world “Mass Customizer”. Use of AM to create new business models.

Ethics is important in each stage of the innovation process. The needs of society are identical to those of customers and individuals. There is a conflict. AI enables individualisation (democratisation),

contradiction to the shaping of needs. So, AI must include an understanding of ethics. (By the way, transparency of knowledge and comprehensibility is different from acceptance.)

AI generates needs for society. The question arises how to deal with this from an ethical point of view. Thus, the option of manipulation is given.

Can AI decide only? Bias solutions are implemented in AI. The scope could be clearly defined for AM. Thus, AM is a differentiated service provider. AI and accountability are big questions. Who is to blame when something goes wrong?

AI can impact insights and optimises them. AI can also optimise innovation, can innovate incrementally in this scenario. What we consider radical today will be real in 2040.

There is no **public engagement**. Laws provide regulations for society standards (politics). The society is not always informed about all features of technology. There is a control function through politics, industry follows suit.

Even in **science education** AI and robots are implemented. AI regulates a lot, scientific interdisciplinarity declines. High specialisation in this topic is provided in higher education. New topics will occur. New scientific work will arise. There is easier access to knowledge, but better and more targeted evaluation (information overload). The nature of science will change.

There is no **gender** discussion in this scenario. The access to knowledge is easy. Admissions become more difficult. AI takes over the evaluation, " pseudo transparency".

6. CONCLUSION

IAMRRI develops a knowledge base and a model for the AM WIVC. The foresight work in IAMRRI project puts the AM WIVC in a broader context and develops futures with specific emphasis on the WIVC and RRI aspects there.

The developed four scenarios, one about “responsible Europe”, one about “self-organizing society”, one about “elites of money and knowledge”, and one about “robots world”, each in the field of AM and with RRI. The consequences for the innovation phase in each of the scenarios and especially the RRI consideration in the innovation phase in each scenario provide input for the AM model developed in this project.

Regarding some important technological aspects, the development in AM and in AI promote each other. Although, this dependency is worked out in the scenarios “elites of money and knowledge” and “robots world” especially, AI plays its role also in “responsible Europe” and in “self-organizing society”, because AM is also very much data, software, and design driven.

The IAMRRI scenarios are linked to future studies on Additive Manufacturing by other authors, such as Gausemeier et al. 2011, Ryan et al. 2017, Caviezel et al. 2017, Trevor et al. 2018 respectively. Jiang et al 2017 is connected to each of the IAMRRI scenarios from an AM technical aspect. Considering these studies here of the different authors uncovers also that the whole scope of RRI is only considered within these IAMRRI scenarios. The IAMRRI scenarios are developed on the sectoral innovation system and therefore, on a meta level.

From an innovation systems point of view basis for innovation is collaboration and networking. It must be ensured that all those involved also gain value.

Regarding AM value chains on a high geographical level we learn that if RRI was only implemented in Europe it could still be example for the world. However, when running a business on the globe, and AM works on the globe and is very divers, even in the two cases we consider in IAMRRI, automotive and medical application, further strategies must be developed for bridging RRI and global competitiveness. The developed IAMRRI simulation (WP5) might show some results about these aspects.

This exercise of foresight in this project should open up the scope of thinking, should enlarge possible directions. Foresight is not a prediction. It opens the possibilities for actions and reactions. In this IAMRRI case, and the scenario development is one of the foresight methods which are linked to stakeholder involvement. This combination is already addressing the RRI process dimension. The involvement of “relevant” stakeholders is crucial in such studies. The best results and the best impact are achieved if the affected stakeholders, who have also the power, the urgency, and the legitimacy for the transfer of the results into strategies. This is the limit of this study. The IAMRRI foresight was organized in three workshops, however with different stakeholders in each workshop mostly. Only the core team participated in each of the workshops. This is because of the limits of resources of IAMRRI.

Unless this fact, WP6 foresight process co-created a common communicable and well-structured picture and awareness within stakeholder groups about future shapes and strategies for AM and for webs of innovation value chains in AM with openings for RRI through a diverse & inclusive, anticipative & reflective, open & transparent, and responsive & adaptive to change process.

The outcome of the applied foresight process in IAMRRI are manifold. AM was put in a broader context and besides technological aspects also societal, economic, environmental, policy, and ethical factors are considered. Future strategies, future shapes, scenarios for the AM WIVC, for the AM dynamic webs of innovation value chains and their openings for RRI were developed with a time

horizon of approximately 20 years. In addition, the developed scenarios and their consequences delivered input to the simulation work here and will be compared with the developed model.

The recipient of the foresight outcome, the future shapes of AM WIVC will be the EU AM Community, the EU Commission, the RRI community, the stakeholder community, science community of WIVC and dynamics of innovation in emerging technologies, the consortium of IAMRRI.

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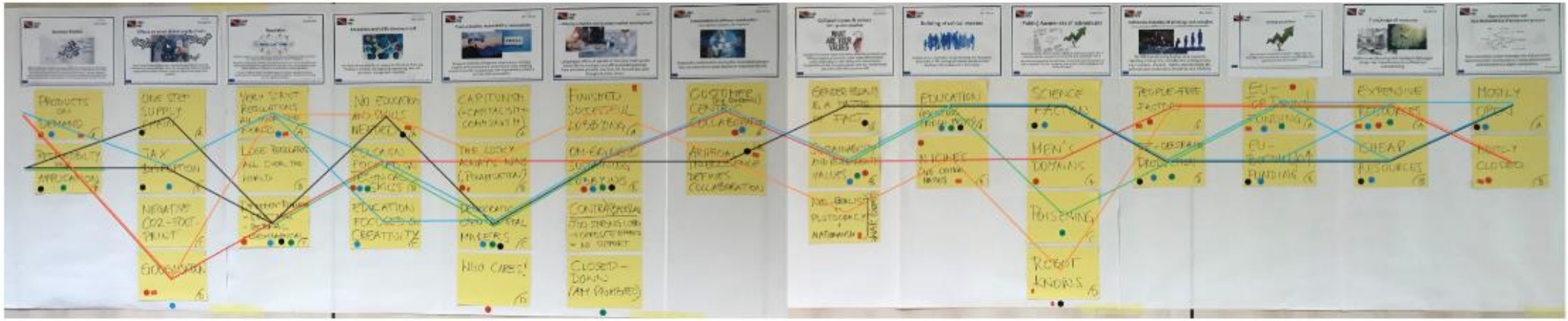
APPENDIX

Morphological analysis

Figure 9 in Morphological analysis gives a first idea. This figure is presented here so that is maybe better readable.



Foresight key factors

For the development of the various future shapes the foresight key factors were prepared in the following way so that they could easier be discussed in the group work.