D 2.1 – Assessment of Relevant Technologies

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Executive Summary

This deliverable is part of the INSPIRE project. The focus of the INSPIRE project is the development of innovative business models for flexible and demand-driven manufacturing and processing. The goal of these business models is to create more local business opportunities in Europe, reduce environmental impact and take the customer needs into account. The project approach in which this deliverable is a component is depicted in the figure below. The rationale is that INSPIRE provides business model archetypes, and an overview of assessed relevant technologies, that should help the owners of specific cases to consider and configure new technologies and flexibility enabled new business models.

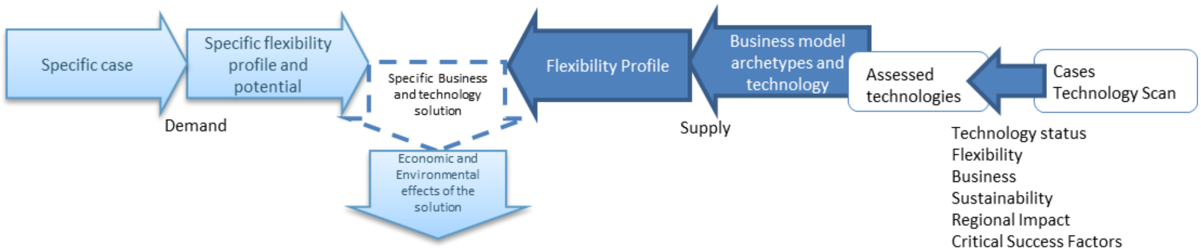

Figure 1: Schematic approach of WP2

This deliverable focuses on the role of technologies in new business models that aim to support the companies in the European processing and manufacturing industry to achieve resilience with respect to opportunities and the many changes that affect its context. The role of technology is crucial, yet on its own insufficient, in creating resilience for companies and industries. This report illustrates the contribution of a large set of technologies to improved resilience. It can help companies to consider new technologies in context of new business models that are enabled by flexibility.

Based on the work of Rohrbeck et al. (2006) we devised the INSPIRE Technology Assessment Framework that consists of the following dimensions

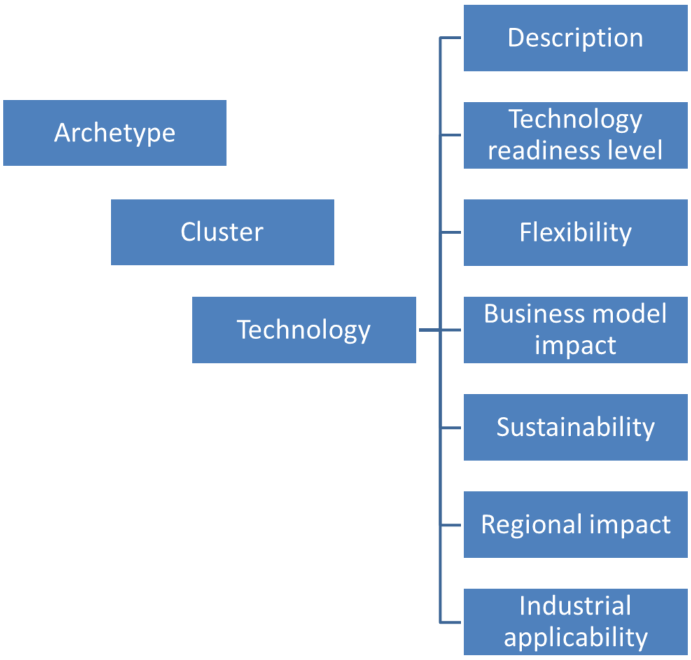

Figure 2: Dimensions in the Technology Assessment Framework

We assessed some 80 technologies in clusters over the five INSPIRE business model archetypes: Decentralized or Modular Production; Emerging Energy Carriers; Servitization; Reuse & Sustainability and Mass Customization.

We observe the following dominant flexibilities associated with each of the archetypes: Servitization and Mass Customization technologies typically apply technologies that enable product and innovation flexibility, whereas Reuse technologies enable feedstock flexibility. Emerging Energy Carriers and Decentralized or Modular technologies enable capacity and location flexibility. One could say that the technologies in the archetypes display a complementary and complete profile of flexibilities.

Based on this and the other elements of the assessment we summarize the archetypes as follows: Servitization and Mass Customization typically change the *relations and processes within the supply chain* but not so much its structure (and hence potentially limited regional impact). The technologies assessed in the Reuse & Sustainability archetype can be seen as an "*add-on*" (or "*add-in*") to the otherwise intact supply chain. The analysis of archetypes leads to the following summarizing table:

	Decentralized or Modular	**Emerging Energy Carriers**	**Servitization**	**Reuse & Sustainability**	**Mass Customization**
Technology Readiness Level	Mostly market present	Ongoing R&D in power conversion	Ongoing R&D in equipment manufacturing	Mostly market present, some R&D in various clusters.	Mostly market present
Business model impact	Few market present highlights, mostly positive impact	Highlights both market present and R&D. Mostly positive.	Some market present highlights, some have clear barriers (negative Business Model Impact)	Highlights ongoing R&D, mostly low impact, positive exception.	Mixed business model impact. Very few broad impact technologies.
Flexibility	Broad flexibility, capacity and location stand out. Some all-round technologies.	Mostly feedstock and energy. Few all-round technologies	Very strong in product and innovation, not much in other categories. Very few all-round technologies	Strong in feedstock. Some all-round technologies. Overall low flexibility.	Varies positively. Mostly product and innovation flexibility. Some capacity flexibility to manage small lots. Few all-round technologies
Sustainability	Mostly positive. One negative exception.	Varies strongly	Doubtful, many have negative impact.	Varies, positively	Moderate, with strongly positive exceptions
Regional Impact	Varies positively.	Varies strongly, positively.	Varies, with positive exceptions	Moderate, with positive exception	Moderate
Industrial applicability	Some technologies are very generically applicable, others are domain specific	Some technologies are very generically applicable, but most are very domain specific	Varies, but mostly moderate.	Many technologies are generically applicable	Varies slightly, mostly broad applicability.

Table 1: Summarized conclusions from the assessment of technologies

By applying the INSPIRE Technology Assessment Framework on all these different technologies, we learned about the different ways in which these technologies enable new business models. Often, a technology is complementary to another (like automated process control and electrification) and thus the technology is part of a system set-up. It also needs prerequisites and affects simultaneously the business model and its supply chain. The insights above lead to the conclusion that individual technologies are best considered as a component in context of its encompassing technological system, its business model and its supply chain, rather than standalone. Based on the rich insights and considerations as evidence, the INSPIRE technology assessment framework provides relevant and independent dimensions. For a given technology, one cannot infer the impact on these dimensions based on its membership to a cluster or business model archetype alone. To find the correct impacts on these dimensions a complete assessment must be conducted, no shortcuts. Conversely, reviewing technologies in the context of clusters and business model archetypes on these dimensions does bring forward new considerations relevant to designing new specific business models.

With respect to the devised methodology, we observe some challenges for the methodology when applying it to such a large scope and working with distributed inputs. However, we feel it works and we are convinced it adds more value if the application context is more concrete. We feel that more explicit attention for the nature and system context of the technologies (e.g. complementarity, immediacy, …) could improve the methodology.

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1 Introduction

This report contains the findings from a study on innovative business models that PNO, TNO, ITIA and ZLC have conducted on behalf of the European Commission for WP2 “Assessing the value of technology developments and horizontal eco-innovation concepts that enable flexibility & delocalization” of the GA Nr.723748 - INSPIRE under H2020-IND-CE-2016-17/H2020-SPIRE-2016.

This deliverable focuses on the role of technologies in new business models that aim to support the European processing and manufacturing industry to achieve resilience with respect to the many changes that threat it. Think of energy availability and transitions, volatility in pricing or availability of feedstocks, changing and shifting product demand, geopolitical pressures. Technology, as manifested in the resources that a company or supply chain deploys, forms the backbone to Europe’s industry. It often requires substantial long-term capital investments. Consequently, choices in technology are crucial.

Yet, technology is not the only factor that determines a company’s or an industry’s competitiveness and resilience. Chesbrough (Chesbrough & Rosenbloom, 2002) clearly illustrated in his work that related choices in the business model determine its competitiveness. Think of choices in feedstocks and supplying partners, the chosen markets to supply to and the way the product or service is offered (e.g. pay per kilogram in advance or pay per use afterwards). And these choices both depend on and affect the context of the company; e.g. feedstocks need to be available in order to be able to integrate them into the business model. However, some of these choices in the business model are more changeable (e.g. production equipment vs. payment conditions), and some choices can be made to more changeable (e.g. leasing equipment vs. owning equipment). More easily changeable business model choices enable a company to respond more quickly to changes in its environment – and hence increase its resilience and probability of survival.

However, changeability, or flexibility, does not guarantee survival. And flexibility comes at a price too. That price may vary from the cost or efficiency of equipment, to the organization of information using ICT, to changing the organization, to investing in storage et cetera.

The text above illustrates the important, yet on its own insufficient, role of technology in creating resilience for companies and industries. These considerations introduce the rationale behind this deliverable. This report aims to illustrate for a large set of technologies how they can contribute to improved resilience. This is thus by no means a stand-alone deliverable – it is explicitly meant to be considered in context of WP1 and WP3 deliverables of the INSPIRE project.

1.1 Objective

The objective of this work package, as described in the description of work, is to identify and characterize 10 to 15 key flexibility enabling technologies that enable flexibility & delocalization such that parties who desire and consider flexibility and reshoring understand the characteristics, conditions and potential of the different options. In other words, it should help companies consider new technologies in context of new business models that enable flexibility. The approach is to assess the technologies in several dimensions and link them to the business model archetypes identified in WP1. The following figure intends to capture the approach.

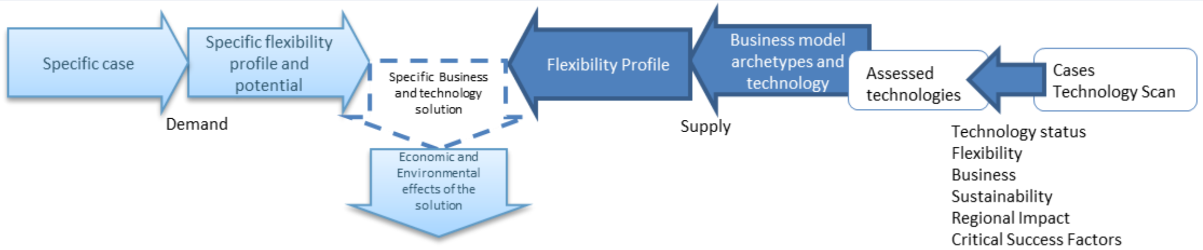


Figure 3: Schematic approach for WP2

The purpose of the project is to enable EU companies to increase their resilience by promoting new business model concepts. The INSPIRE project believes that business models are unique as companies' positions and contexts are unique. So specific cases require specific business model configurations. Nevertheless, INSPIRE believes that even specific cases can be supported with more generic and configurable information. In WP2 this information pertains enabling technologies for business model innovation. The approach of WP2 is to illustrate how technologies contribute to resilience by linking them to dimensions that are relevant to new business models and resilience. These dimensions are among others,

- Technology readiness level - how mature is the technology?
- Flexibility – what type of flexibility does the technology enable?
- Business model impact – how does the technology impact the business model?
- Sustainability – how does the technology contribute to sustainability?
- Regional impact – how does the technology affect the region in which it is applied?

By assessing these dimensions, it is believed that it is easier for companies to consider technologies for playing a role in a new business model that meets their specific needs towards resilience.

1.2 Objectives of this document

In line with the work package objectives indicated above, the objectives for this document are to provide the reader with insights in the high-level **technological** trends that are relevant to EU processing and manufacturing industry (Equipment manufacturing; Modularity; Intensification and cont. processing; Separation and recycling; ICT and Smart Industry; Electrification; Energy Carriers, etc.). The reader is also provided with more details and profiles for a large selection of enabling technologies organized in functional clusters. The reader thus should get a fairly good idea of what the enabling technology is, why it is (or could be) relevant and how it enables new business models.

Per enabling technology an assessment, including (but not limited to) flexibility profile, business model impacts and potential, was performed. The reader should get a fairly good idea of what it means to implement instances from the clusters and more importantly why she should consider these technologies. The reader should be able to identify challenges for a specific case at hand.

This document is intended for both innovation and business managers of the targeted industries to help them reconsider their innovation and business strategies with respect to technology deployment in new business model. It deserves noting that business model changes typically are of strategic nature and normally exceed the mandate of many R&D or innovation departments.

Consequently, this document also informs researchers, consultants and policy makers in the realm.

As indicated, the work package that produced this report is interdependent in the project. Below the diagram from the description of work is depicted.

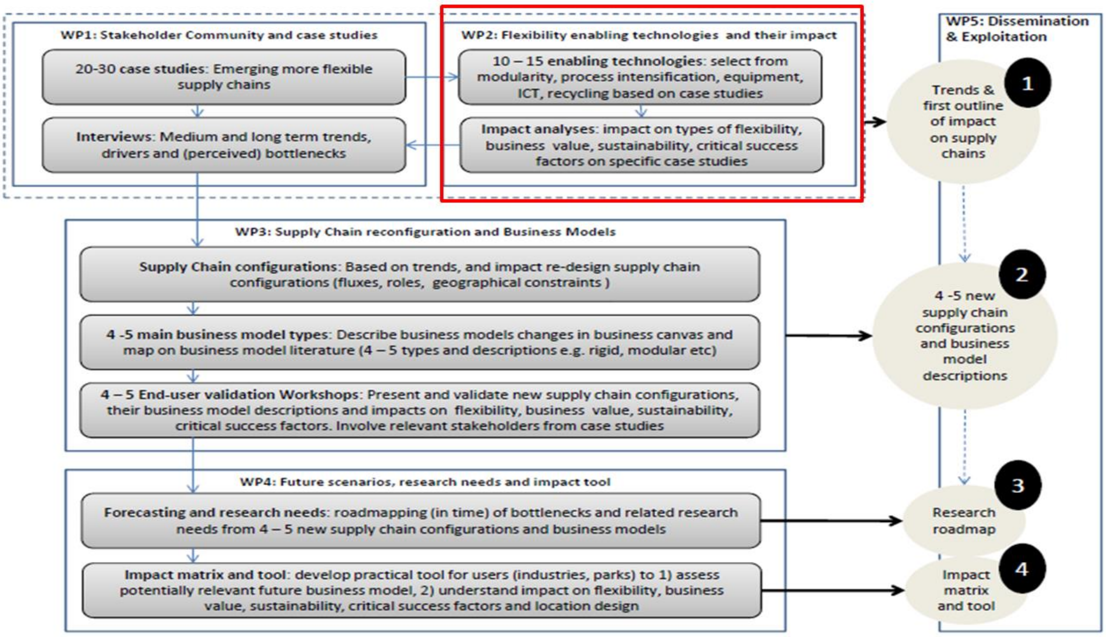


Figure 4: INSPIRE project structure and the position of WP2

Work package 1 (WP1) analyses 100 industry business cases for relevance to the project and analyzed a quarter in much more detail to derive the proposed INSPIRE business model archetypes. WP2 used these cases to identify different relevant technologies per archetype and appended more based on desktop search and industry expertise. The technology assessment will be used in WP3 to support the configuration of new business models as well as provide inputs to trends and the INSPIRE R&D roadmap in WP4.

The next chapter (2) describes the technology intelligence approach that INSPIRE devised. This is an adaptation of Deutsche Telekom’s Technology Radar. Chapter 3 provides the overview and analysis of the technologies and clusters per archetype. Chapter 4 presents conclusions from this work and the appendices capture the short descriptions of the analyzed technologies and the details of the assessments.

2 INSPIRE Technology Intelligence Approach

For this work we adapted the technology radar methodology by (Rohrbeck, Heuer, & Arnold, 2006). This method has become an industry standard throughout the years and therefore adopted in this project. The methodology consists of 4 major steps: identification of technologies, selection of technologies, assessment of technologies and lastly application of the technologies.

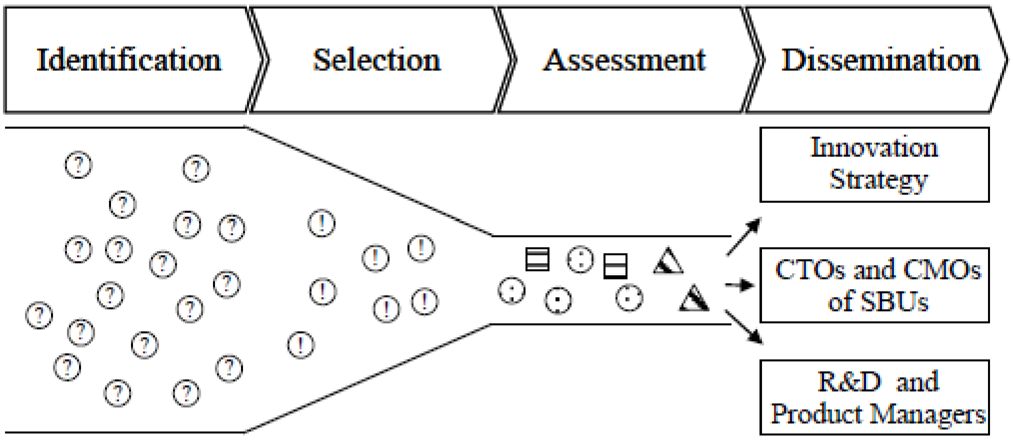


Figure 5: graphical representation of the methodology (Rohrbeck et al., 2006)

Application of technologies is well beyond the scope of this study. In fact, the lack of a clear application context makes for the adaptation of the methodology. Instead of concrete businesses or challenges we reverted to the scopes of the identified business model archetypes and related collection of cases as the scope of application.

Identification and selection. Based on the large collection of industry cases and business model archetypes derived in work packages 1 (WP1) and 3 (WP3) of this project, we identified a longlist of technologies that deemed relevant for realizing business models (in the archetype). The picture below illustrates how the project analyzed 100 business cases and derived the archetypes. This basis was used as input for this work package, but additional technologies were searched.

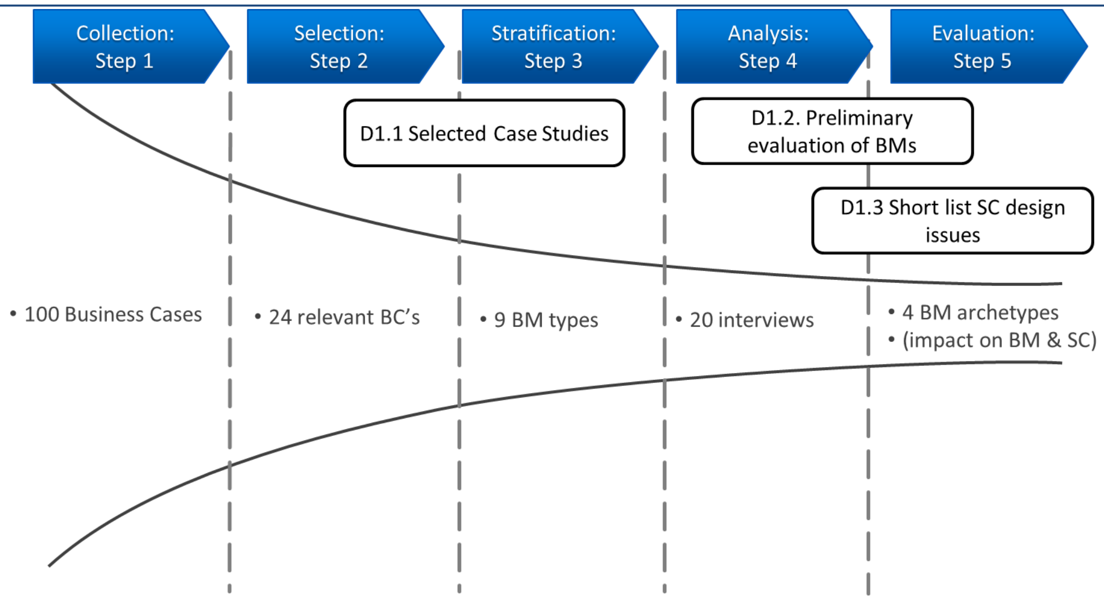


Figure 6: Elaboration of the business cases into INSPIRE Business Model Archetypes

These technologies were proposed by technological and domain experts. The project jointly reviewed the longlist and proposed the clusters to categorize the technologies. It should be clear that the resulting list of technologies merely reflects an overview of key technologies, rather than a complete listing of the technologies. The original objective of selecting (only) 10 to 15 technologies for highlighting falls short in meeting the demands from the varied collection of EU company's needs. The project team decided to allow for an increase of technologies, with an aim to illustrate an inspiring overview rather than strive for completeness or momentary prevalence.

Assessment. Next, these technologies were further detailed in descriptions and an assessment template. Extensive effort was spent in describing and assessing these technologies. In order to further analyze the assessment of the technologies overviewing graphics, such as the technology radar, were created. These analyses contributed to creating an illustration of how companies can navigate through the collection of technologies and learn about their profiles and differences.

Obviously, as indicated above, the step of application is lacking. This step is up to the considering companies (and supply chains). The methodology described above and further reported in this document is also considered as a blueprint for assessing new and emergent technologies that companies may wish to add to the collection. The lessons with respect to technology clusters and business model archetypes that can be drawn from this collection and assessment will feed into the INSPIRE R&D Roadmap, that will be developed within WP 4.

In the sections below, we describe the different elements of the process and the assessments.

2.1 Technology Intelligence in practice

We executed the following process steps in practice to create this document:

Figure 7: Illustration of the technology selection and assessment

1. *Creating common ground.* The approach and planning to achieve a set of assessed technologies was discussed and improved jointly
2. *Identifying clusters and technologies.* The initial task was for each of the partners to come up with a list of technologies relevant to their assigned archetype. During the work of WP1 a fifth archetype, Emerging Energy Carriers was introduced. This led to a **longlist per archetype**.
3. *Clustering, review and selection of technologies.* The partners jointly reviewed the proposed technologies and clusters. Additional proposals for clusters and technologies were made. The activity ended with a **shortlist per archetype.**
4. *Assessment template*. An assessment template to support the structured assessment of the technologies was developed. These criteria are described in the following subsections.
5. *Initial assessment.* An initial assessment was performed to pilot the assessment template.
6. *Updated assessment template.* Improvements were suggested and implemented in the final template. After these actions the **assessment framework** was agreed upon.
7. *Technology descriptions.* The selected technologies were described briefly.
8. *Technology assessment.* All selected technologies were assessed following the provided template.
9. *Description and assessment review.* The descriptions and assessments were jointly reviewed and brief improvement suggestions were made. This led to a full set of **assessed technologies**.

The assessed technologies were used for analysis of the archetypes during the following steps:

10. *Preliminary archetype assessment.* An initial analysis of one of the archetypes was provided to the partners to form an example to follow.
11. *Graphical representation.* Graphics to illustrate the technologies per archetype and clusters were produced to aid the analysis per archetype and cluster.
12. *Archetype assessment analyses.* The partners analyzed the assigned archetype and clusters using the graphics and the assessment, based on a preliminary example provided.
13. *Conclusions.* Conclusions were listed from the archetype assessments and the process that lead to it.

2.1.1 Technology selection and assessment

The focus of INSPIRE is on supporting the development of new business models, hence the contribution of this work is to support this. We believe this can be achieved better by exploring the relevant characteristics of a broad set of technologies. However, the scope of the relevant domains is so large that the resulting set of technologies would be immense and very diverse. And this set would be subject to constant change (trough development). It is not in the objectives or means of this project to achieve a complete or fully representative overview of relevant technologies. Therefore, INSPIRE had to apply a reasonable heuristic approach. The longlist of technologies was achieved by reviewing the cases developed in scope of WP1 and WP3. These cases themselves were already assessed for relevance to the domain (including SPIRE and manufacturing). Furthermore, the list of technologies was augmented by each of the partners. The partners in this project have an extensive experience in projects relevant in the domains as well as internal expertise on the matter. These partners are also well networked in both industry and innovation.

Before selection technologies were clustered. In this phase the clusters and technologies were subjected to cross-partner reviewing to use each-others' view and expertise on the matter. For the selection we focused on relevance to the archetype and representation of the cluster. The technologies with the higher TRL were prioritized to increase relevance to the business reader. We believe that the resulting set of technologies provides a strong basis to explore the different characteristics of technologies to understand the implications for developing new business models, in concrete cases.

2.2 INSPIRE Technology Assessment Framework

The INSPIRE Technology Assessment Framework is based on 6 dimensions, each with its own rationale. Central to our work is the project objective to support the development of new business models for the processing and manufacturing industry. Hence a business perspective is central to our reasoning. The focus of this deliverable is on enabling technologies. From a business perspective a new technology represents an investment. We included the following dimensions: Technology Readiness Level, Flexibility, Business Model Impact, Sustainability, Regional impact and Industrial applicability. The rationale behind incorporating these dimensions is:

- Technology Readiness Level (TRL) – This dimension reflects the time to market of the technology. It is important to understand whether opportunities that follow from applying the technologies can be seized right away or if the development of the technology still carries some level of risk.
- Flexibility – The European Industry and each business in it is confronted with several trends and changes. Think of the sustainability agenda, energy transition, energy prices and feedstock prices and volatility, geopolitical forces, changes and shifts in consumer demand. The ability to deal with such changes provides resilience. This calls for flexibility.
- Business Model Impact – Although technologies enable business models, they are just one facet of the business model. It is important to understand the impacts and prerequisites to seize the value that the technology enables
- Sustainability – Individual companies experience both internal and external pressures to shift to sustainability. It is one of the core values of the SPIRE PPP
- Regional Impact – One of the policy objective of the approach to develop new business models for EU Industry is reshoring of industry to (or continued residence), therefore it is of relevance to understand the potential contribution of technologies to this dimension.

- Industrial applicability – This dimension helps to navigate through the set of technologies as well as it is an indicator for vendor risk. Specific technologies carry in general more risk than generic ones.

2.2.1 Technology Readiness Level (TRL)

The technology readiness level (TRL) is an indication used in R&D and innovation of technologies to indicate the maturity stage in which the technology currently is. It can be seen as an indicator of how far the technology is from being commercially available. There are slightly different definitions available, but in general these vary from basic (or fundamental) research (level 1) to 'market availability' (level 9). The figure below provides a description of these levels.

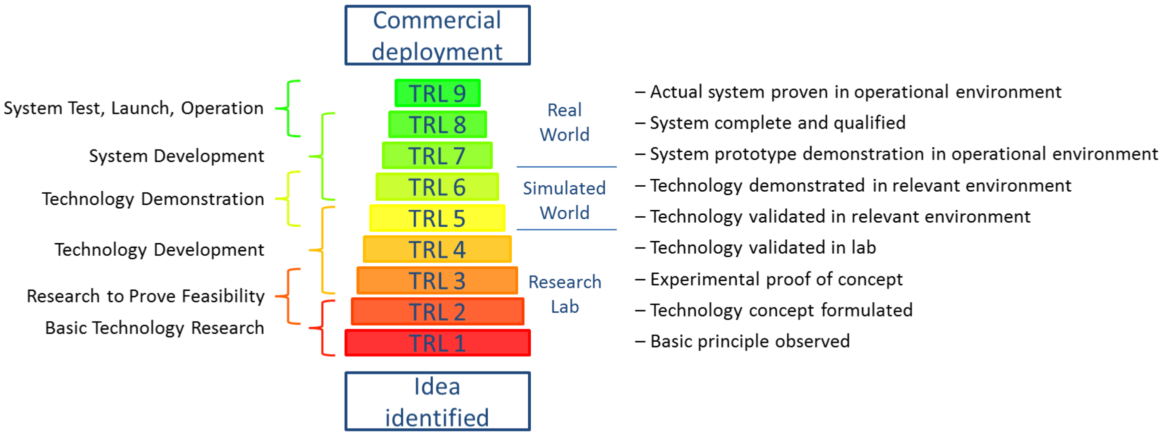


Figure 8: Technology Readiness Levels

It should be noted that the 'operational environment' in fact introduces the application context, which is a societal dimension. This means that technologies applied in aerospace can have TRL 9, but are not applied yet in, for instance, agriculture (TRL 6-7). In a new application domain, other requirements may apply. For example, when the technology needs to interact with systems that form an 'installed base'. It should also be noted that TRL does not describe actual uptake and use (thus impact) and that technological innovation still run substantial risks of failing despite being on the market.

For this study we simplified the levels of TRL into: *1-Basic Research, 2-Applied Research, 3-Market ready, 4-Market presence* following the table below.

TRL-EU	TRL-EU Definition	TRL-INSPIRE	TRL-INSPIRE Name
1	Basic principles observed	1	Basic research
2	Technology concept formulated	1	Basic research
3	Experimental proof of concept	1	Basic research
4	Technology validated in lab	2	Applied research
5	Technology validated in relevant environment	2	Applied research
6	Technology demonstrated in relevant environment	2	Applied research
7	System prototype demonstration in operational environment	3	Market-ready
8	System complete and qualified	3	Market-ready
9	Actual system proven in operational environment	4	Market presence

Table 2: Simplification of Technology Readiness Levels based on the EU Definition (http://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016_2017/annexes/h2020-wp1617-annex-g-trl_en.pdf)

2.2.2 Flexibility

A company or an industry can be challenged by different kinds of exogenous changes. Its ability to adequately respond to these influences its performance and probability of survival. In a previous study (Karin van Kranenburg, Sofra, Verdoes, & Graaf, 2015) five different types of flexibility were identified. A technology can enable a number of these. Usually deploying the technology itself is insufficient to achieve such flexibility. For example, to utilize the feedstock flexibility a company must have access to (supply of) different feedstock materials. Although energy is a specific type of feedstock, we felt that it is useful to distinguish the 'energy flexibility' to accommodate for the recent trends in renewable energy, electrification and storage of energy in materials.

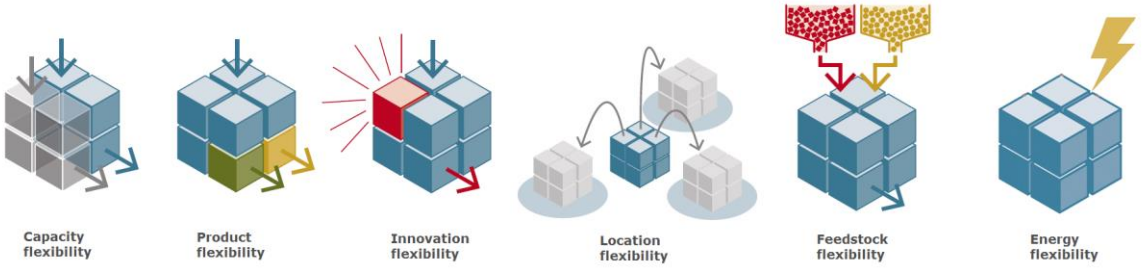


Figure 9: Different types of flexibility

The flexibility types are (adapted from (Karin van Kranenburg et al., 2015)):

- *Location flexibility:* The plant should be moveable from one place to another.
- *Capacity flexibility:* A plant should be able to produce small volumes in a cost-efficient way. When local demand grows or prices of feedstock or energy drop, it should be possible to scale the plant up or down easily.
- *Product flexibility:* A plant should be easily adaptable to switch to another product.
- *Innovation flexibility:* A plant should be very easily adaptable to try out innovative products and processes.
- *Feedstock flexibility:* The plant should be able to handle different kinds of feedstock.
- *Energy flexibility:* The plant should be able to easily scale-up or scale-down energy use by turning on and off operation, or change between energy sources.

For each of these types of flexibility we scored for each of the technologies whether the technology enables the type of flexibility. Response categories are: *0-No*, *1-Maybe*, *2-Limited*, *3-Definitely*, *4-Undesirable* with the following explanation

Scoring	Name	Description
0	No	No significant impact is expected
1	Maybe	It depends on […the application or circumstance] whether it has either positive or negative or limited impact
2	Limited	The technology will affect this element somewhat, but not dramatically
3	Definitely	The technology will significantly affect this element
4	Undesirable	The technology will affect this element in an undesirable way

Table 3: Definition of scoring in the technology assessment

We see levels 0-3 as ordinal as in general more flexibility is all else equal to be preferred over less. We did not consider the severity of a potential undesirable impact on flexibility.

In the graphs in Chapter 6 we plotted flexibility in several graphs. Therefore, we transformed these scorings into a single number. This is done by counting the assessments of the flexibility indicators (feedstock, location, etc.) calculated as: the number of definitely scores + 0.5 times the number of maybe scores – 1.2 times the number of undesirable scores. ‘A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

2.2.3 Business Model Impact

In the past decade the Business Model Canvas of Osterwalder et al. (Osterwalder & Pigneur, 2010) has gained strong attention in industry and it is regarded a reference model. In this project we use a simplified version of the business model canvas. This version was developed in the POLFREE (Lopez, Becker, Eris, Koers, & Bastein, 2014) project for presenting the impact of 100s of resource efficiency. We will first briefly introduce the business model canvas and its components. Although many other definitions are available, Osterwalder defines the business model as “A business model describes the rationale of how an organization creates, delivers, and captures value, in economic, social, cultural or other contexts.” (Osterwalder & Pigneur, 2010).

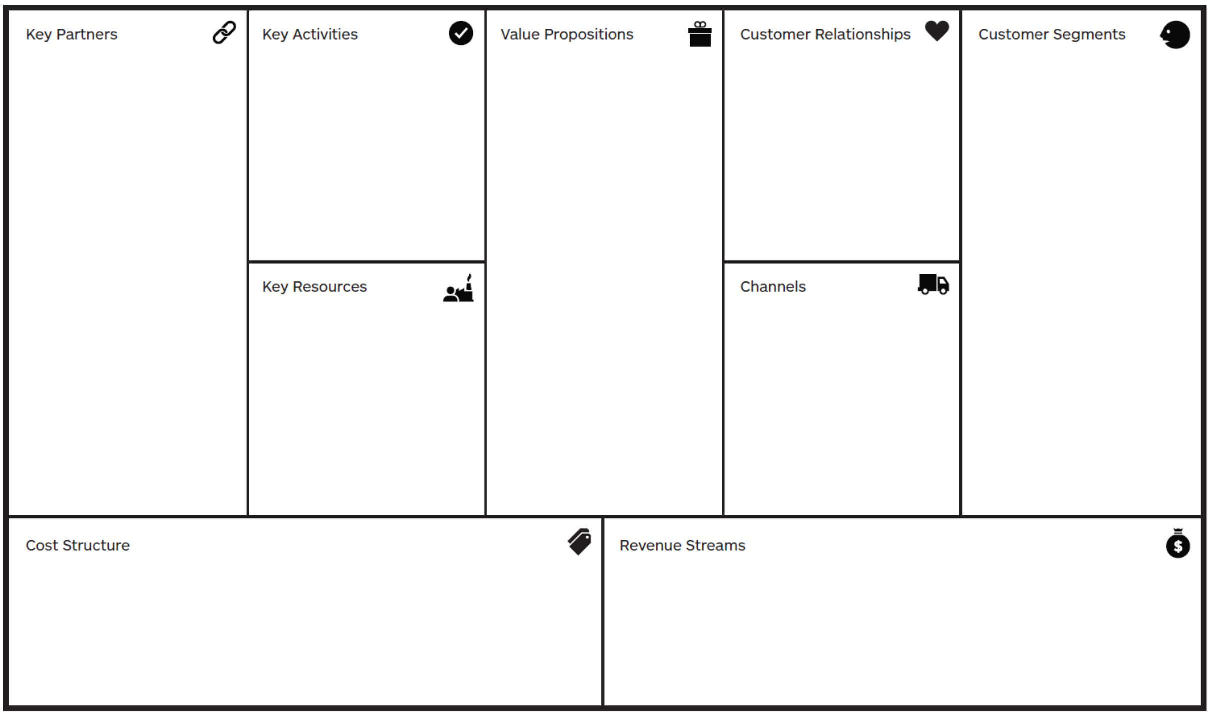


Figure 10: Business Model Canvas (Osterwalder & Pigneur, 2010)

The business model canvas describes in 9 building blocks a) which value (value proposition) is b) created (left: using resources and activities and supplies from partners – all at a certain cost (bottom)), c) delivered (right: to customers in segments via relations and channels) and d) captured (returning in revenues (bottom)).

The application of new technologies will typically affect the business model of the company *using* the technology. Technology typically is seen as a resource. Operating a new resource may require new or different operations (activities) and new partners or supplies (e.g. a 3D printer requires acquisition of digital designs and printable materials. This enables production of specific individual products or components. This affects the value proposition and thus how the customer is served. The introduction of new technology may thus affect businesses up- and downstream in the supply chain or even the level of the ecosystem, e.g. when applying extensive recycling schemes or disruptive platforms (like Über). We considered the following business model impacts with response categories similar to the ones used at flexbility (*0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable*):

- *Supply:* (to what extent) does the application of technology applied affect resources, activities, supplies, feedstock or energy or require new partners to do so
- *Demand:* does the application of technology allow to serve different segments with new products or services:
- *Chain:* does the application of technology affect the coordination of the supply chain
- *Ecosystem:* does the application of technology require coordination in the ecosystem
- *Cost:* does the application of technology enable a decrease in cost
- *Revenue:* does the application of technology enable increased revenues
- *Overall:* The number of categories scored Definitely minus the number of categories scored Undesirable

A new technology may not only affect the business applying it. It may even enable a new (type of) business and it may also affect the way equipment is realized (custom engineered or manufactured in large quantities).

In the graphs in Chapter 6 we plotted business model impact in several graphs. Therefore, we transformed these scorings into a single number. The color coding: The amount of definitely scores minus the number of undesirable scores is calculated. If the corresponding number is: 0-1: red – low; 2-3: yellow – medium; 4+: green – high

The other graphs: this is done by counting the assessments of the business model impact indicators (supply, demand, cost, etc.) calculated as: the number of definitely scores + 0.5 times the number of maybe scores – 1.2 times the number of undesirable scores. ('Overall' has not been considered here.). A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

2.2.4 Sustainability

Sustainability is a widely debated topic, with many different definitions. In this assessment we look specifically at the environmental part of sustainability. Social and economic parts of sustainability are partly assessed under Regional Impact. In this deliverable we do not mingle in this discussion but choose to follow the resource and energy efficiency dimensions that the SPIRE PPP sets by assessing the following sustainability criteria (again with the categories *0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable*)

- Material use: does the application of technology decrease the use of material
- Environmental footprint: does the application of technology decrease the environmental footprint (e.g. CO2, NOx emissions)
- Energy: does the application of technology decrease energy consumption or enable a switch to renewable energy

The previous criteria typically refer to the production process. We also asked for assessment of the sustainability strategy. This strategy is based on the R9 circularity strategies depicted below.

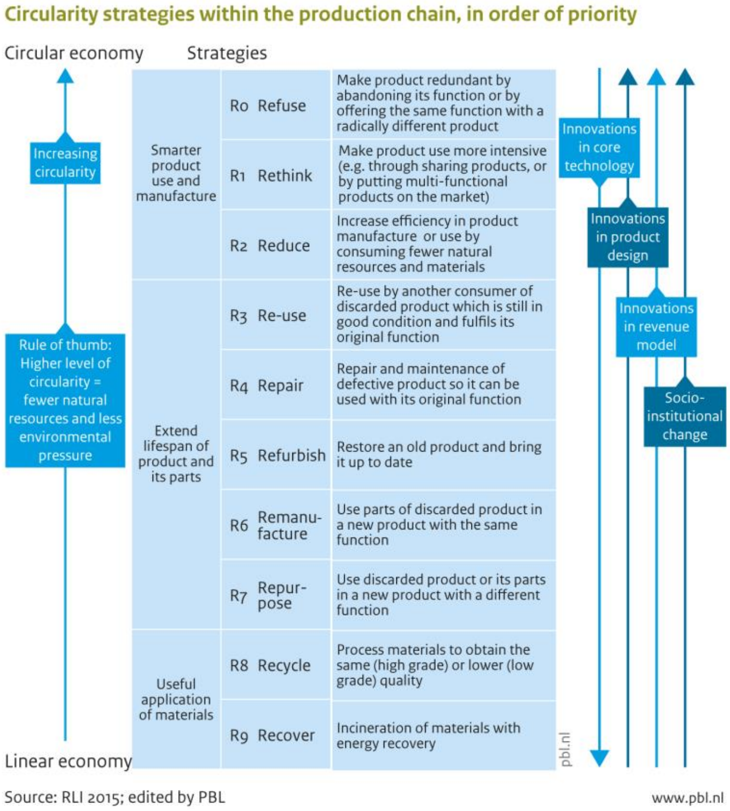


Figure 11: R9 circularity strategies (http://www.pbl.nl/sites/default/files/cms/afbeeldingen/001s_cem16-En.pdf)

The circularity strategies are converted to three categories: *1 - Useful after-life application of materials; 2 - Extend lifespan of product and its parts; 3 - Smarter manufacture and product use*. The following table shows how the R9 classification is converted.

R9 code	Name	Definition (PBL)	R9-INSPIRE Code	R9-INSPIRE Name
0	Refuse	Make product redundant	3	Smarter product use and manufacture
1	Rethink	Make the product used more intensively	3	Smarter product use and manufacture
2	Reduce	Increase the efficiency in product manufacture or use	3	Smarter product use and manufacture
3	Re-use	Reuse of discarded product or by-products which fulfills its original function	2	Extend lifespan of product and its parts
4	Repair	Repair and maintenance of defective product so it can be used in its original function	2	Extend lifespan of product and its parts
5	Refurbish	Restore an old product to bring it up to date	2	Extend lifespan of product and its parts
6	Remanufacture	Use parts of discarded product in a new product with the same function	2	Extend lifespan of product and its parts
7	Repurpose	Use discarded product or its parts in a new product with a different function	2	Extend lifespan of product and its parts
8	Recycle	Process materials to obtain the same or lower quality	1	Useful after-life application of materials

9	Recover	Incineration of materials with energy recovery	1	Useful after-life application of materials

Table 4: Conversion of the R9 circularity strategies to three categories for the technology assessment

In the graphs in Chapter 3 we plotted sustainability in several graphs. We transformed these scorings into a single number. This is done by counting the assessments of the sustainability, calculated as: the number of definitely scores + 0.5 times the number of maybe scores – 1.2 times the number of undesirable scores. 'Strategy' has not been considered here. A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

2.2.5 Regional impact

In order to understand the potential of the technology in reshoring industry we meant to assess the regional impact of application of the technology in 4 categories (*0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable*):

- Safety, Health and Environment: are these conditions potentially improved
- Material flow: to what extent can the technology contribute to a shorter supply chain, e.g. material sourcing or product use within the region
- Direct jobs: does application of the technology lead to new jobs in the company
- Business opportunities: does application of the technology provide opportunities for new businesses or services in the region

In the graphs in Chapter 6 we plotted regional impact in several graphs. Therefore, we transformed these scorings into a single number. This is done by counting the assessments of the regional impact indicators and the regional impact indicators Calculated as: the number of definitely scores + 0.5 times the number of maybe scores – 1.2 times the number of undesirable score. A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

2.2.6 Industrial applicability

To understand the applicability, we assessed in what sectors the technology could be applied. The SPIRE PPP associated sectors where taken into account, supplemented with some of the manufacturing sectors. The SPIRE PPP sectors are:

Figure 12: SPIRE PPP associated sectors

The considered manufacturing sectors are: *Food processing & beverages*, *Textiles including clothing*, *Paper and furniture*, *Electrical & electronic machinery*, *Vehicles & auto components*, *Leather & footwear*.

3 Overview and analysis of the technologies

In this section we reviewed the 78 technologies within their clusters and archetypes by plotting them in the multiple dimensions of the framework. This serves multiple purposes, including:

- Identifying overlaps and differences in the overarching profiles of the archetypes
- Identifying trade-offs in flexibility and business model impact, and for sustainability and regional impact
- Illustrating differences in technologies and how they enable flexibility and business model impact
- Illustrating how one can navigate through the different plots, technology assessments and descriptions to learn about the working of the technology

3.1 Selected technologies

INSPIRE selected the following technologies for further analysis (Table 5). The technologies are divided in clusters. The archetype Decentralized or Modular consists of 16 technologies divided over 6 clusters: Electrification, Equipment manufacturing, ICT, Modularity, Process intensification and Continuous processing and Recovery/Work-up.

Electrification	Equipment manufacturing	ICT	Modularity	Process intensification and continuous processing	Recovery/Work-up
Electrification of utilities	3D printing	Automated process control	Containerized construction	Continuous crystallization	Energy efficient solvent recovery
Electrically powered chemical technologies	Multilayer disposable plants	Big data	Skid based designs	Continuous reactors	In-situ removal of contaminants
		Process analytical technologies	Plate based equipment	HiGee process equipment	
		Remote control			

Table 5: Selected technologies from Decentralized or Modular

The Emerging Energy Carriers archetype has three clusters: Biomass based fuels, ICT and Power conversion. In total this archetype contained 14 technologies.

Biomass based fuels	ICT	Power conversion
Biochemical conversion	Automated process control	Carrier to power
Biomass gasification	Big data	Chemical looping
Product recovery	Process analytical technologies	Electrolysis low cost
In-situ removal of contaminants		Activation of carriers
		Hydrogen binding
		Carrier reconversion
		Hydrogen storage techniques

Table 6: Selected technologies from Emerging Energy Carriers

In the archetype Servitization two clusters have been defined, namely Equipment manufacturing and ICT. The overall amount of technologies in this cluster is 17.

Equipment manufacturing	ICT
Biosensors	Automation

Cold welding	Big data
Industry 4.0	Body scanner
Biodegradable materials	EHR
Micro- and nanomanufacturing	E-health
Microelectrochemical systems	Internet of things
	Robotics
	Telemedicine
	Elderly support
	Artificial Intelligence
	360-degree medical data

Table 7: Selected technologies from Servitization

In the archetype Reuse & Sustainability, 14 technologies have been considered. These technologies are grouped into 5 clusters.

ICT	Recycling	Remanufacturing, refurbishing and repair	Reuse, longer lifetimes	Simulation
Materials-process matching	Biodegradable materials	3D printing	Biomimicry	Business model simulation
	Chemical markers	IoT Smart Industry	Identifiers	Design for X PLM add-ons
		Automated disassembly	Materials mapping	Product-ageing simulation
			Well-aging materials	Reverse supply chain simulation

Table 8: Selected technologies from Reuse & Sustainability

The Mass Customization archetype consists of 5 clusters and 16 technologies.

Design and configuration	Equipment manufacturing	ICT	Supply Chain management	Sustainability
Product configuration	Additive manufacturing	Big data	Cloud based platforms	Life cycle assessment
Smart materials	Robotics	Internet of things	Data mining	Materials end-of-life
Virtual reality	Multi-purpose and hybrid processes	Modelling and simulation	Dynamic Supply Chain	
3D scanning	Adaptable and reconfigurable systems	Business intelligence		

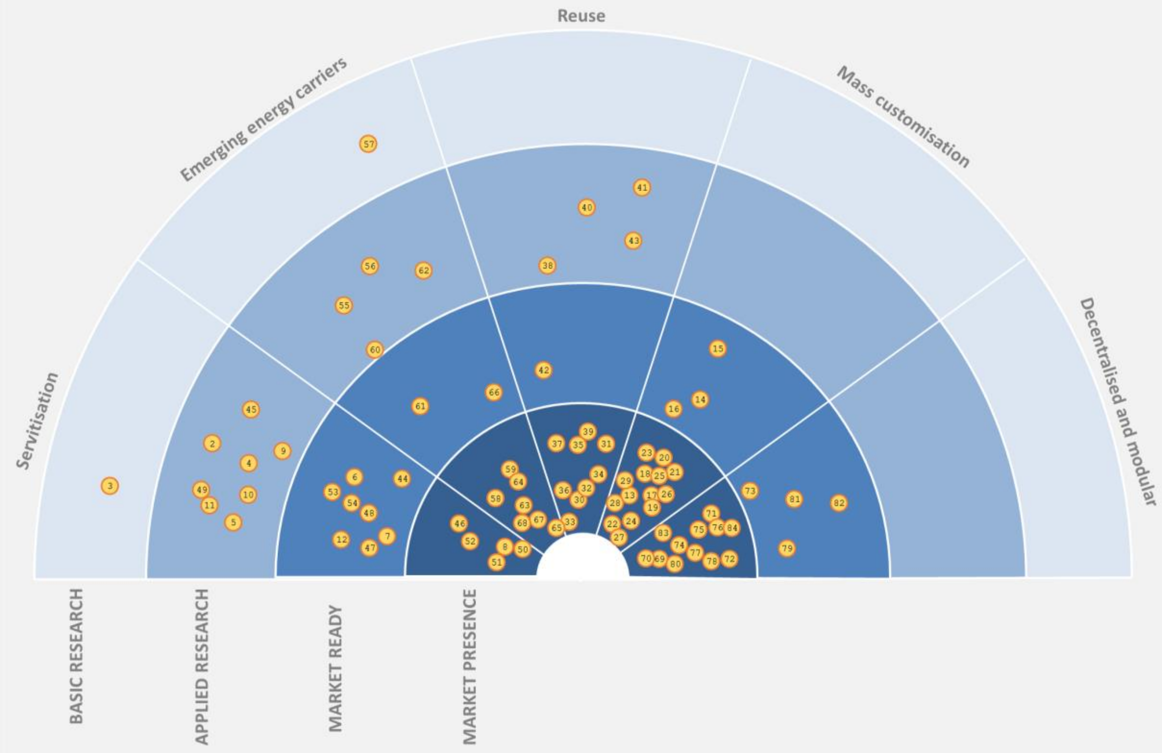
Table 9: Selected technologies from Mass Customization

In the overview it is visible that certain technologies appear in multiple archetypes and clusters. Although these carry the same names, in practice, when applied these appear to be somewhat different. E.g. big data for Emerging Energy Carriers relates to the application of predictive analytics in scope of grid load balancing, whereas big data technologies for Decentralized or Modular Production relates to the technologies used to learn about the performance and structure of processes. Therefore, we kept these within scope of the cluster.

3.2 Overview of archetypes

In this section we start the analysis with an overview of the assessment indicator scorings for all archetypes. The goal is to give a general impression of the scorings of the archetypes and the differences between these scorings. This section will be followed with a more detailed analysis per archetype.

3.2.1 Technology Readiness Level



Legend

Cold welding	1	Chemical markers	29	Hydrogen storage techniques	56
Biodegradable materials	2	3D printing	30	Biomass gasification	57
Micro and nano-manufacturing	3	Automated disassembly	31	Biochemical conversion	58
Biosensors	4	Biomimicry	32	Process analytical technologies	59
MEMS	5	Identifiers	33	In situ conversion of contaminants	60
Industry 4.0	6	Materials mapping	34	Big Data	61
Additive manufacturing	7	Materials-process matching	35	Automated process control	62
Sensors, monitoring and control	8	Reverse supply chain simulation	36	HiGee process equipment	63
Multipurpose and hybrid processes	9	Business model simulation	37	3D printing	64
Adaptable and reconf. systems	10	Elderly support	38	Containarised construction	65
Robotics	11	Artificial Intelligence	39	Multilayer disposable plants	66
Internet of things	12	Robotics	40	In situ conversion of contaminants	67
Modelling and simulation	13	Automation	41	Continuous reactors	68
Big Data	14	360-degree medical data	42	Plate based equipment	69
Life cycle assessment	15	Big Data	43	Electrification of utilities	70
Materials end-of-life	16	Internet of Things	44	Elec. powered chem. technologies	71
Cloud based platforms	17	Body Scanner	45	Skid based designs	72
Data mining	18	E-health	46	Remote control	73
Product configuration	19	E H R	47	Process analytical technologies	74
Smart materials	20	Telemedicine	48	Energy efficient solvent recovery	75
Virtual reality	21	Electrolysis low cost	49	Continuous crystallisation	76
3D scanning	22	Chemical looping	50	Big Data	77
Business Intelligence	23	Activation of carriers	51	Automated process control	78
Product-aging simulation	24	Carrier to power	52		
Design for X PLM add-ons	25	Hydrogen binding	53		
Well-aging materials	26	Carrier reconversion	54		
IoT Smart Industry	27	Product recovery	55		
Biodegredable materials	28				

Figure 13: Radar plot of the assessed technologies. The numbers in the legend correspond to the different technologies.

In Figure 13 the TRL levels of all technologies are shown per archetype. Most technologies are market present. This can partially be explained by a selection bias. In assessing technologies with specific cases in mind one tends to assess a technology with a high TRL level. On the other hand, this shows that a lot of technologies applicable to the archetypes are at least market ready in some form and thus have a lower time to market.

In the archetypes Emerging Energy Carriers, Reuse, and especially Servitization, there are still a lot of development possibilities. This are archetypes that also need more specific technologies that are to be developed and some R&D investment is needed to improve the TRL. Mass Customization and Decentralized and Modular appear to be well-developed already.

3.2.2 Business Model Impact

The figure below presents for each archetype the Business Model Impact (BMI) dimension by counting the number of technologies that have been indicated with a ‘definitely’ for the business model aspect.

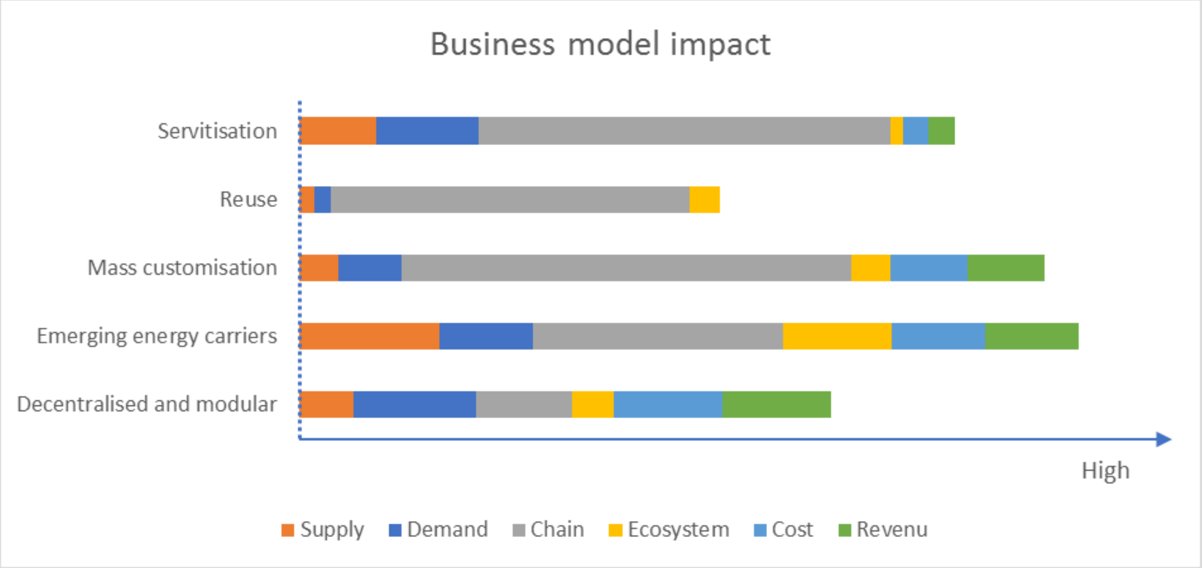


Figure 14: The percental of technologies assessed with “Definitely” on business model impacts.

The figure above immediately draws attention to the large, but varying, expected impact of the technologies on the chain (grey). The impact on the chain implies that, in order to realize a business model according to these archetypes it is expected that one must also coordinate with the companies up- and downstream in the supply chain. The archetype Decentralized or Modular is more modest on this aspect. This archetype is more focused on the Demand and Revenue side of the business model. In the Reuse & Sustainability archetype the impact on revenues is lacking from Figure 14. This indicates that potential barriers are foreseen for revenue generation. (based on the technology alone). Remarkably, this archetype also does not indicate definite impacts on cost. Also, large variations on the aspect of supply are observable. The archetype Emerging Energy Carriers probably requires the most intense coordination on that aspect. This refers to the acquisition of renewable energy sources. It is also Emerging Energy Carriers that indicates the need to coordinate within the ecosystem. This refers to the required coordination with renewable energy suppliers, grid operators and energy buyers for implementation of these energy carriers.

3.2.3 Flexibility

The figure below presents the number of technologies with a definite impact on the different flexibility types per archetype.

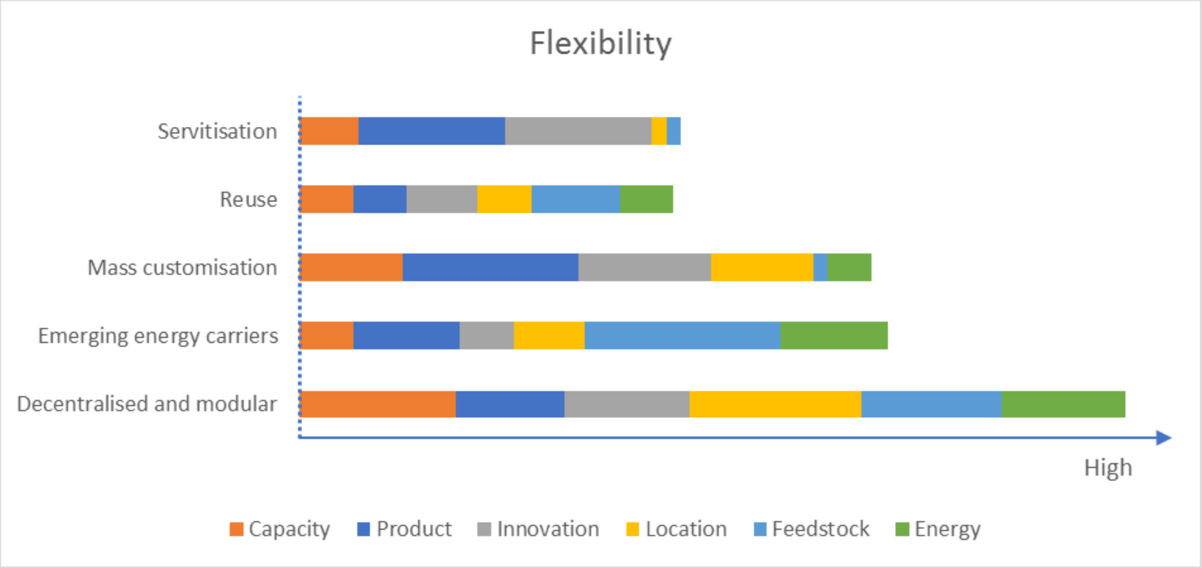


Figure 15: The percental of technologies assessed with “Definitely” on flexibilities.

The strong overall scoring of the Decentralized or Modular archetype immediately stands out. One could argue that this archetype is designed for flexibility, specifically location and capacity. Remarkably, the technologies considered in this archetype perform equally on energy flexibility as the Emerging Energy Carriers archetype. This is because of the definition of energy flexibility (“easy scale-up or scale-down of energy use”). Modular plants can more easily scale up or scale down their energy use, however the impact will also be lower than for Emerging Energy Carriers technologies. Emerging Energy Carriers also presents itself as an archetype with high feedstock flexibility, this is because it creates new ways to use energy. The Reuse & Sustainability archetype presents itself as somewhat modest in flexibility and with an emphasis feedstock. Mass Customization is mainly product flexible, which is completely in line with the scope of the archetype. Also, capacity flexibility is relevant to properly manage small production lots. Servitization focusses on product flexibility and innovation flexibility.

3.2.4 Sustainability

The figure below shows the technologies with definite impact on the three aspects of the sustainability criterium.

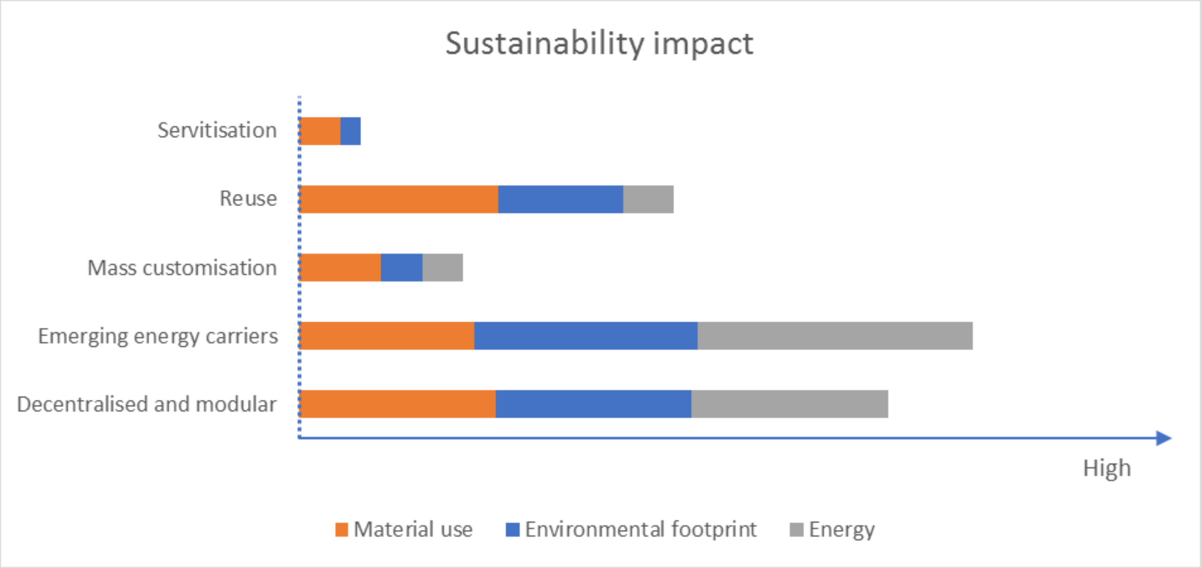


Figure 16: The percental of technologies assessed with “Definitely” on sustainability impact.

The limited definite impacts of the technologies in Servitization and Mass Customization immediately stand out. The assessed technologies of the Servitization archetype do not provide definite impact on energy consumption. Servitization is however associated with the Product Service System (PSS). Explanations for this are twofold: i) the PSS is a *system*, composed of multiple technologies; in this study we assessed only individual technologies, ii) the technologies studied under the archetype are not related to energy related service systems (consequence of selection). As compared to Emerging Energy Carriers and Decentralized or Modular, the Reuse & Sustainability provides a high score on material use, but a surprising lower score on environmental footprint. Again, the focus in selection here was not on energy related cases. In Decentralized & Modular capacity and specifically location flexibility was pertinent – affecting environmental footprint and energy consumption immediately through savings in logistics.

3.2.5 Regional Impact

The figure below illustrates the aspects of regional impact that were scored Definitely for the technologies in the archetype.

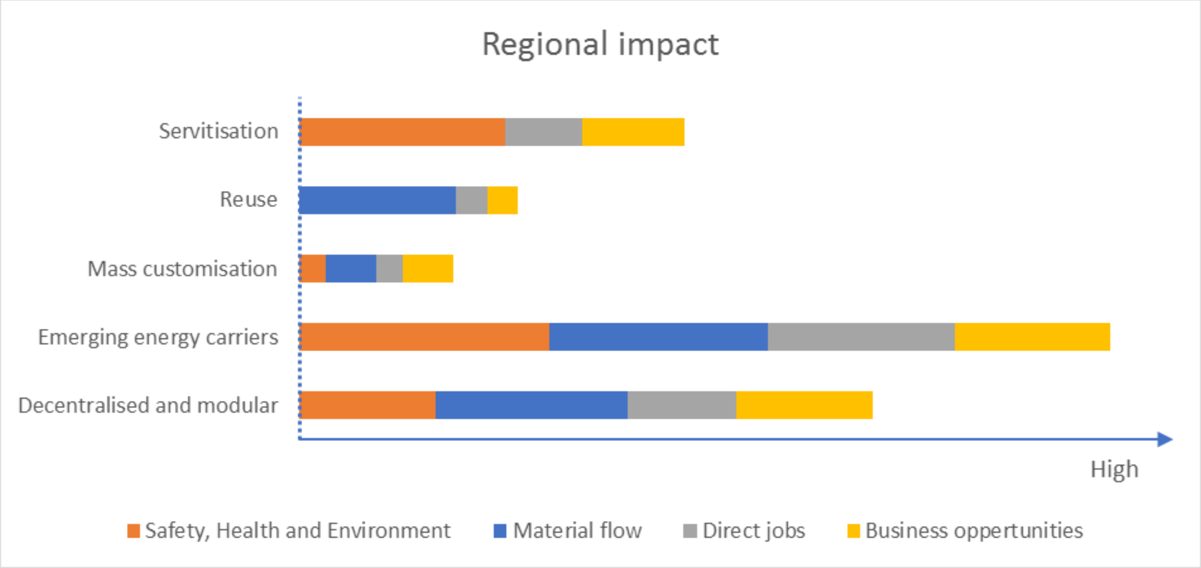


Figure 17: The percental of technologies assessed with "Definitely" on regional impact.

The Reuse & Sustainability archetype immediately stands out. Firstly, SHE aspects are not impacted (or require certain preconditions). Secondly, the relative weight of the material flows is substantial. The latter is clearly a direct reflection of the scope of the archetype. The strong rated impacts of the Emerging Energy Carriers are clearly related to the impacts of an associated local energy transition. Emerging Energy Carriers actually link the regular production supply chain, with the energy grids. And these energy grids are in transition to decentral and renewable. The low expected regional impacts of the technologies of the Mass Customization archetype can be explained by the cases studied for this archetype and the concept itself. The latter is focused on a stronger influence of demands in the otherwise unchanged supply chain (location wise). The regional impacts of the Decentralized and Modular concepts are directly related to the fact that decentralized production obviously affects regions. However, assessment of the underlying technologies show that this varies a lot. Combining this perspective with the insights of business model impact analysis, we can derive the suggestion that Emerging Energy Carriers and decentralized or modular typically install new technologies that affect the structure of the supply chain (and hence may affect regional production), whereas Servitization and Mass Customization typically affect the relations within the supply chain (and hence limited regional impact). The Reuse archetype can be seen as an "add-on" to the otherwise intact supply chain.

3.2.6 Industrial Applicability

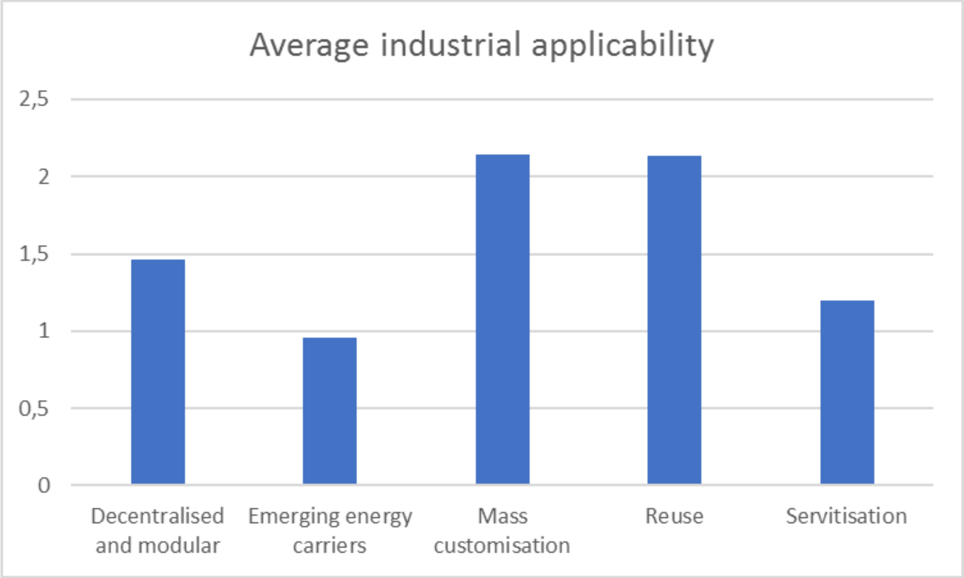


Figure 18: Average industrial applicability of archetypes. The technologies were scored on applicability in 14 industries. The average score (0 to 3) is shown in the graph.

In Figure 18 we see the average industrial applicability per archetype. The industrial applicability of Mass Customization and reuse is scored high, which means it has a relatively broad applicability. The industrial applicability of Emerging Energy Carriers is low. This can be explained by the fact that this mainly has chemical applications, so the applicability is not necessarily low, but narrower.

3.3 Decentralized or modular production

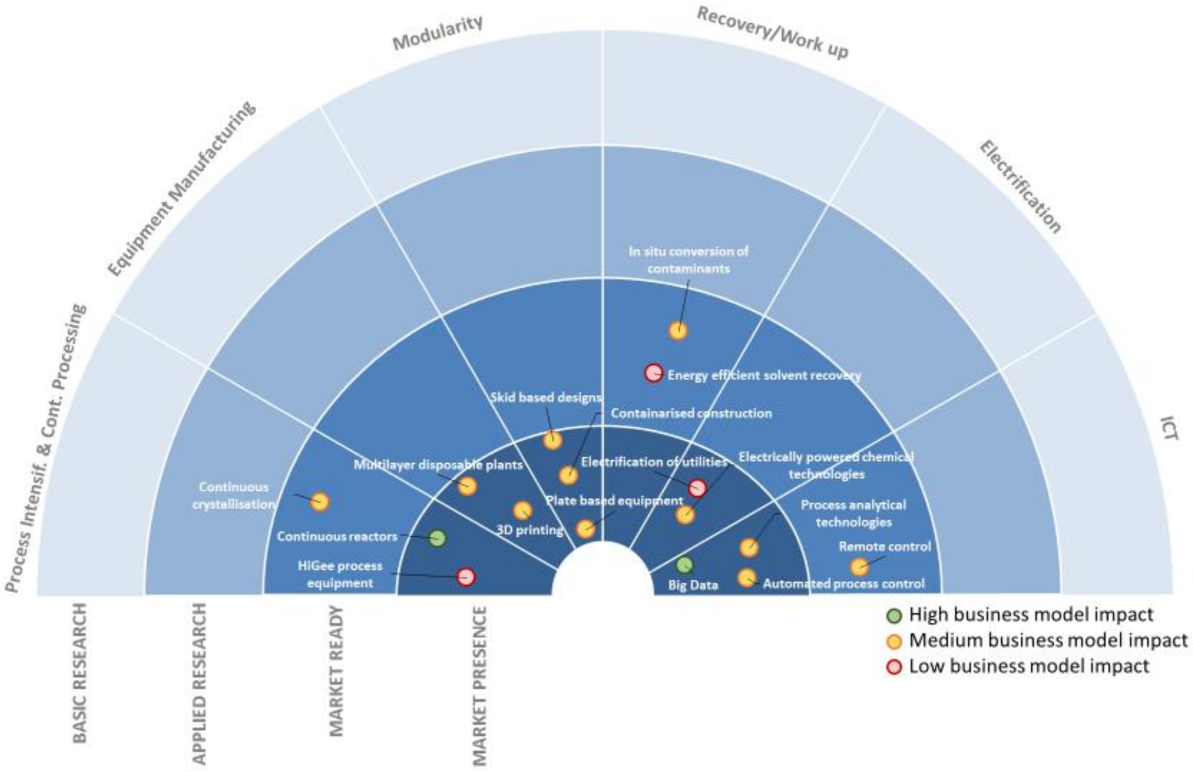


Figure 19: Radar plot of the technologies for the Decentralized or Modular production archetype (Business Model Impact in color)

The plot above shows the distribution of the assessed technologies of the Decentralized or Modular production business model archetype. From the outside to the center, the four half circles represent increased Technology Readiness Level (TRL)[1]. The radials represent the different clusters of technologies identified specifically in this archetype. The radar thus reflects the maturities of the different clusters. The colors indicate three levels of business model impact[2].

The first observation for this plot is the relative high maturity of the technologies. This is an artefact following from the selection process. Since we identified more technologies for this archetype than could be considered, it was decided to focus on the most relevant ones. If we had to make specific choices between examples of technologies (e.g. variants of 3D-printing) we included the one with highest TRL, so that the reader is presented as much as possible with available options. Nevertheless, the TRL distribution provides insight between the clusters. The clusters Process Intensification and Continuous Processing and Recovery/Work-up include very specific technologies that refer to specific steps in a process rather than a larger subsystem, such as ICT or Equipment Manufacturing. This, along with the mentioned

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[1] We made a simplification of the TRLs: 1-Basic Research, 2-Applied Research, 3-Market ready, 4-Market presence The position of technologies within one cell is arbitrary, to avoid overlap.

[2] The color for Business Model Impact is calculated as follows. The amount of definitely scored technologies minus the amount of undesirables is calculated. If the corresponding number is: 0-1: red – low; 2-3: yellow – medium; 4+: green – high

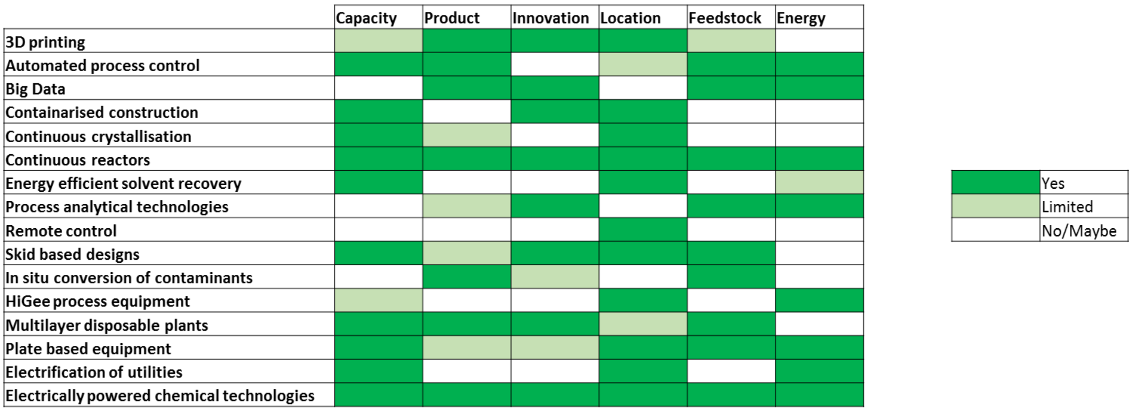
'selection bias' explains the relative lower levels of maturity. Still it reflects the activity in R&D of these fields. One could say that clusters like Modularity contain technologies that could also be assigned to other clusters. This can be observed when comparing the technologies Plate based equipment with HiGee process equipment. Plate based equipment are essentially a separation technique, but due to its nature these can be produced in a modular format. This implies a large potential for scaling (capacity flexibility) and easy replacement (product flexibility). HiGee process equipment uses gravity as a means of separation, and although continuous it is (currently) not 'encapsulated' by the modular paradigm.

One of the technologies that meets the eye is the Remote control technology in the ICT cluster. Remote control has a TRL scoring of "Market ready" although in general it is "Market Present". Although Remote control is applied in general, it is not commonly available to technologies within the archetype Decentralized or Modular. So, the scoring is more related to lack of interfaces and complexity of the processes that need to be controlled remotely (rather than the technologies that enable the remote controlling, once the process controls have been disclosed). This example also shows how the radar plot drives the navigation between different technologies: By seeking for explanations for a specific assessment or characteristic of a given technology or cluster, one needs to dive into the details of this. (At the moment of writing this deliverable an online system is developed to support this navigation.)

The business model impact coloring of the technologies has three different colors and is ordinal and positive, in the sense that green dots indicate, in general, desirable impacts for the business model. Red dots indicate that the technology has some identified barriers. This does however not imply that this technology should be red flagged. For example, the technology Energy efficient solvent recovery is simply a technology that works as an add-on to an existing process. Consequently, the core business model is not severely impacted, but the total process is somewhat more complex, and costs are added. Without a specific case in mind, it cannot be judged whether the related cost savings would justify it economically. Obviously, that would apply to any technology; there is no technology with a guaranteed positive business case. This example goes to show that it is useful to seek for the rationale behind the assessment.

In the ICT cluster, Big data presents itself as a winner on business model impact. Although this technology on itself only enables the creation of either ad-hoc or continuous insights, the assessors assumed that the action following the insight would also be implemented.

Another remarkable aspect can be observed in the electrification cluster. The technology Electrification of utilities has a lower Business Model Impact as compared to its peer Electrically powered processes. This is due to the nature of utilities versus processes. Processes tend to represent the core of the production, whereas utilities clearly are a commodity and a prerequisite. As such, these will not affect the downstream supply chain or the value proposition essentially.



	Capacity	Product	Innovation	Location	Feedstock	Energy
3D printing	▨	🟩	🟩	🟩	▨	
Automated process control	🟩	🟩		▨	🟩	🟩
Big Data		🟩	🟩		🟩	🟩
Containarised construction	🟩		🟩	🟩		
Continuous crystallisation	🟩	▨		🟩		
Continuous reactors	🟩	🟩	🟩	🟩	🟩	🟩
Energy efficient solvent recovery	🟩			🟩		▨
Process analytical technologies		▨	🟩		🟩	🟩
Remote control				🟩		
Skid based designs	🟩	▨	🟩	🟩	🟩	
In situ conversion of contaminants		🟩	▨		🟩	
HiGee process equipment	▨			🟩		🟩
Multilayer disposable plants	🟩	🟩	🟩	▨	🟩	
Plate based equipment	🟩	▨	▨	🟩	🟩	🟩
Electrification of utilities	🟩			🟩		🟩
Electrically powered chemical technologies	🟩	🟩	🟩	🟩	🟩	🟩

🟩	Yes
▨	Limited
	No/Maybe

Figure 20: Detailed overview of the flexibility profile of technologies of the Decentralized and Modular production business model archetype

The figure above displays the assessed flexibility profile of the different technologies in the archetype. Clearly, there are two technologies that enable all round flexibility: Electrically powered processes and Continuous reactors. Continuous reactors allow for component replacement and consequently allow for innovation flexibility. Easy component replacement also has positive implications for gradual improving quality, system lifecycle and maintenance, since these components can be replaced. We observe also a high level of flexibility of Electrically powered processes. This is due to the increased selectivity of the technology and its continuous control and electrical control (energy use flexibility). As compared to Automated Process Control (a complementary technology) its flexibility is much higher. This is because the electrification is basically the ‘actuator’ and the APC represents the controlling function. But this function ‘only’ optimizes within the confines of a given process (i.e. it cannot automate innovation).

Remote control stands out with quite low flexibility. The first is explained by its nature that it separates control and process over distance. In this case it means that either the production or the control is location flexible and thus could be moved towards either customer or feedstock (whichever provides benefits). Any flexibility (other than centralized capacity allocation) is essentially enabled by the characteristics of the process itself.

While looking at the type of flexibility, obviously capacity and location flexibility stand out. This is clearly associated with the use cases that are part of the archetype and provide the basis for identifying the technologies. As mentioned earlier, remote control, basically only enables location flexibility. Other technologies with a relatively weak flexibility profile are Energy efficient solvent recovery (“add-on”); In-situ conversion of contaminants and HiGee process equipment. The value of this overview is basically to provide a comparison in flexibility profiles.

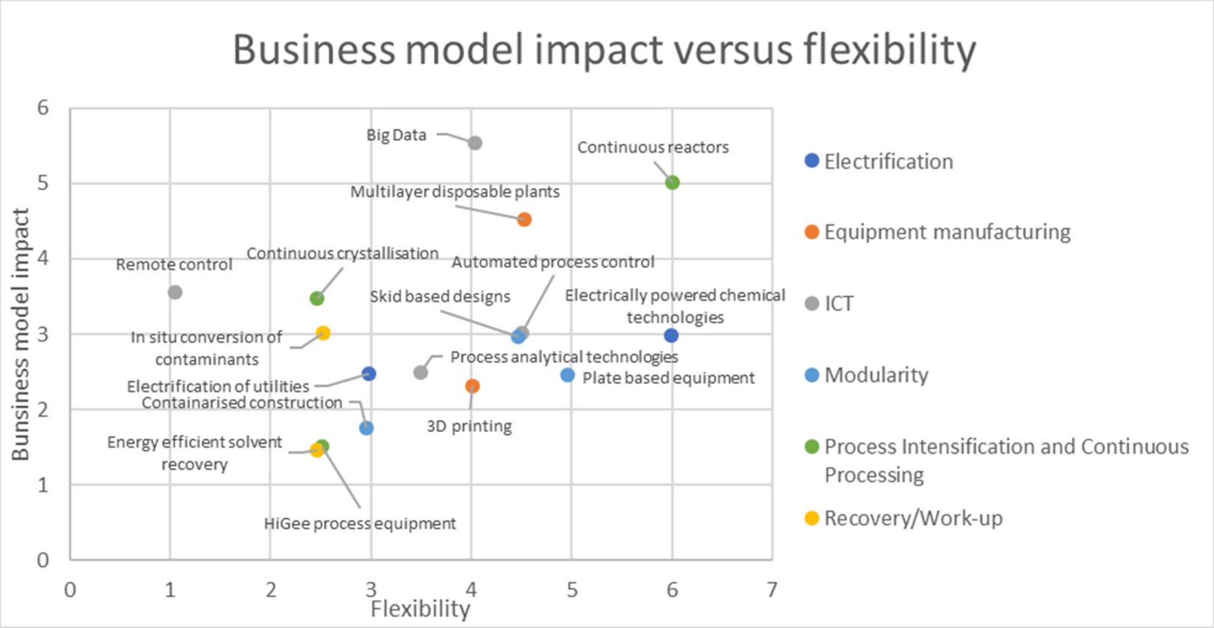


Figure 21: Distribution of technologies in the D&M archetype by cluster, flexibility and business model impact

The figure above illustrates the distribution of technologies in the Decentralized or Modular production business model archetype by technology cluster (color), flexibility[3] (x-axis) and business model impact (y-axis).

As in the previous diagram we see big data analysis stand out on business model impact. It has however currently limitations in applicability and requires new processes. On the bottom left we see two technologies with limited flexibility and business model impact. Energy efficient solvent recovery was already discussed above as an ‘add-on’ process. The relatively low business model impact of HiGee process equipment is due to its still uncertain impact downstream combine with a more certain cost and equipment supplier impact.

The technology Relevance: High
TRL: market ready / market present

- Plate based equipment refers to equipment in which functionality of process (for instance, filtration) can be easily extended just by adding the same equipment in the series. This technology enables capacity changes for a process which can be dealt with by increasing /decreasing the number of elements in a skid. Thus, connected to modularity business technology cluster.
- Broadly all kind of equipment that can be / has to be scaled in in capacity by numbering-up – so also hollow fiber membrane modules or spiral wound membrane modules can be categorized as plate based equipment.
- Characteristic is that elements can be produced according to standards in series production.

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[3] This is done by counting the assessments of the flexibility indicators (feedstock, location, etc) and the BMI indicators (revenue, supply, etc). Calculated as: the number of definitely scores + 0.5 times the number of maybe scores – 1.2 times the number of undesirable scores. ‘Overall’ has not been taken into account here. A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

- Plate based equipment include typical examples such as heat exchangers (plate-type alfa laval), filtration equipment, continuous micro-structured reactors, membrane units, and thus are market ready.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Membrane based filtration equipment for chemical/ water purification.
Flexibility			
	Capacity	3	Membranes are small and can easily be added if larger production is needed
	Product	2	Other products can be produced using a different filtrate-permeate combination/ membrane pore size.
	Innovation	2	By changing pore size
	Location	3	Truck based system can be designed to make easy movement.
	Feedstock (or Input)	3	Different feedstocks can be used (eg. Organic membranes can be designed to handle a variety of organic feedstock)
	Energy	3	Yes. Adding modular layers can help scale up/ down.
Business Model Impact			
	Supply	2	Membrane suppliers are needed for change/ maintenance.
	Demand	3	Modular production based on filtration can be operated on demand.
	Chain	1	Maybe because of added responsiveness to demand.
	Ecosystem	0	
	Cost	1	Depending on the application; some membranes are expensive than others.
	Revenue	3	Compared to concentration based filtration, membrane based separation can be OPEX friendly and using membranes can generate more/new markets.
	Overall	2	
Sustainability			
	Material use	1	Depending on selectivity this can be lower/ higher.
	Environmental footprint	3	Because evaporation/concentration based literature is energy intensive compared to membranes.
	Energy	3	
	Strategy	3	Materials can be re-used after reworking them/ changing of membranes and membranes are less energy intensive.
Regional Impact			
	Safety, Health and Environment	3	Filtration mostly have lesser impact than concentration.
	Material flow	2	Local high salty water can be used instead of fresh water from far away.
	Direct jobs	3	Local business opportunities for maintenance/ sales of membranes.
	Business opportunities	3	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	2	Water purification is partially applicable to several sectors,
	Ceramics	1	
	Chemicals	3	
	Engineering	2	New membrane modules and equipment's
	Non-ferrous metals	2	Water purification is partially applicable to several sectors,
	Minerals	2	Water purification is partially applicable to several sectors,
	Steel	3	
	Water	3	

	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	1	Cannot say for sure. Maybe
	Vehicles & auto components	2	Water purification is partially applicable to several sectors,
	Leather & footwear	3	

Containerized construction appears rather low on the business model impact. This is because - in general- containerized processes are typically less efficient and costlier. However, in specific cases, the ratio can be overcome by the cost savings in for instance logistics.

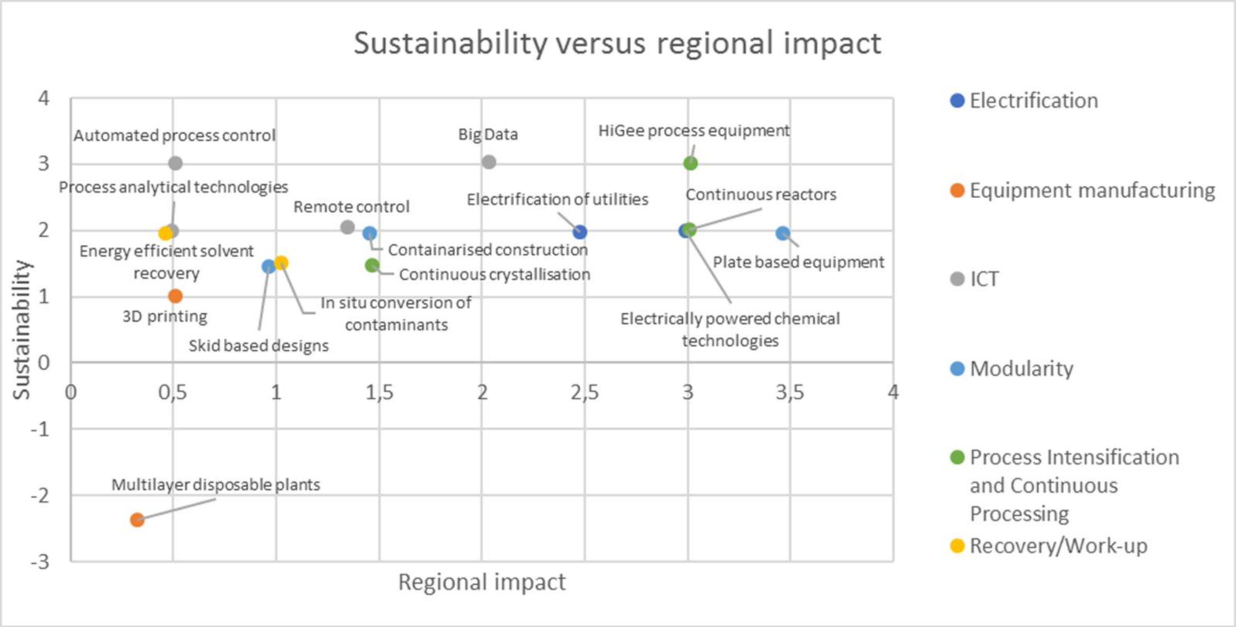

Figure 22: Distribution of technologies in the D&M archetype by cluster, sustainability and regional impact

The figure above illustrates the distribution of technologies in the Decentralized or Modular production business model archetype by technology cluster (color), regional impact[4] (x-axis) and sustainability[5] (y-axis).

Overall, we observe a nice spread over this plot. However, the multilayer disposable plants clearly stand out, in a negative way. Multilayer disposable plants provide many benefits in flexibility (and replacement, maintenance etc.). However, the equipment on its own, in general, is not very sustainable. Furthermore, in the assessment safety, health and environment (SHE) impacts are expected from the plastic plants based on potential safety risks. On upper right HiGee process equipment appears. This technology has a relatively low footprint. If it is provided in a mobile plant, it can provide for local jobs. Due to its continuous (scalable) nature, it also allows for smaller hold-ups of risky material, which positively impacts SHE.

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[4] This is done by counting the assessments of the sustainability indicators and the regional impact indicators Calculated as: the number of defenitely scores + 0.5 times the number of maybe scores – 1.2 times the number of undesirable scores. ‘Strategy’ has not been taken into account here. A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

[5] See above

3D Printing of spare parts thanks its modest impact on sustainability on the fact that material use can be tuned very specifically. Currently its regional impact potential is unclear. The ICT driven technologies process analytical and automated process control allow for central knowledge building and control. For Big data also more local jobs are expected as that has much more 'degrees of freedom'. Electrically powered processes has relatively high scores on limited HSE impact, reduced feedstocks, low fuel usage. As compared to Electrification of utilities the former has more impact on the energy use. As compared to batch processes the continuous reactors provide higher selectivity and less waste /-water and potentially also skilled jobs.

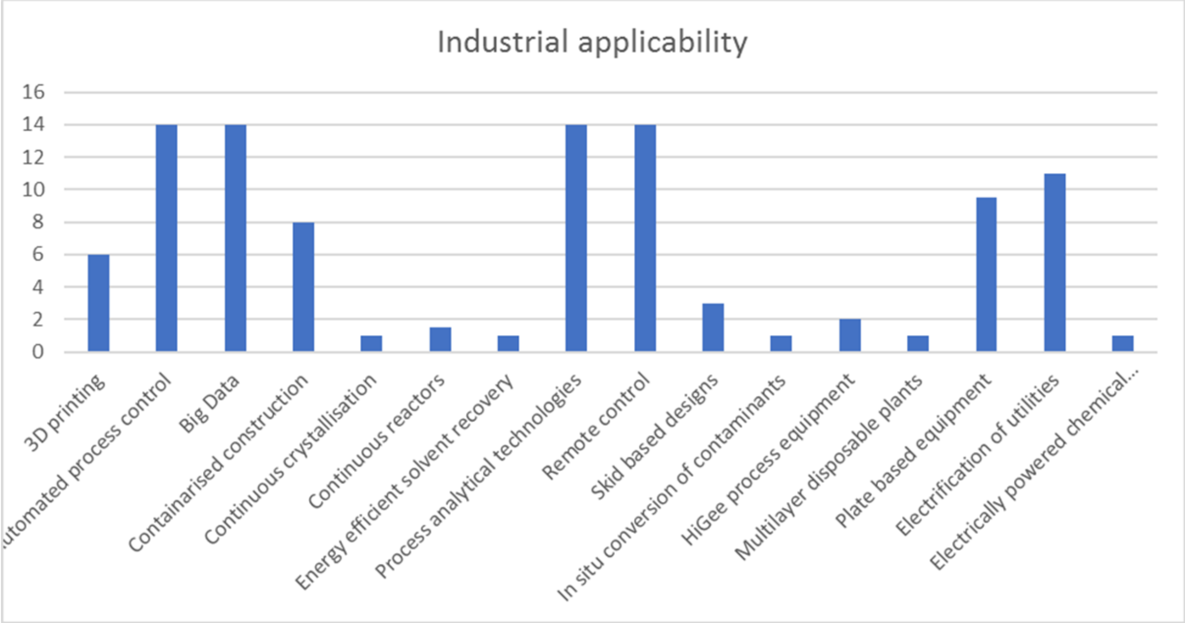

Figure 23: The number of industries in which the technology is applicable

The figure above illustrates the number of industries in which the technology is applicable. Figure 23 clearly reflects how generic a technology is, and obviously ICT related technologies stand out. As many industries need energy, to Electrification of utilities also has a high applicability. Conversely, Electrically powered processes have limited applicability outside the chemical sector.

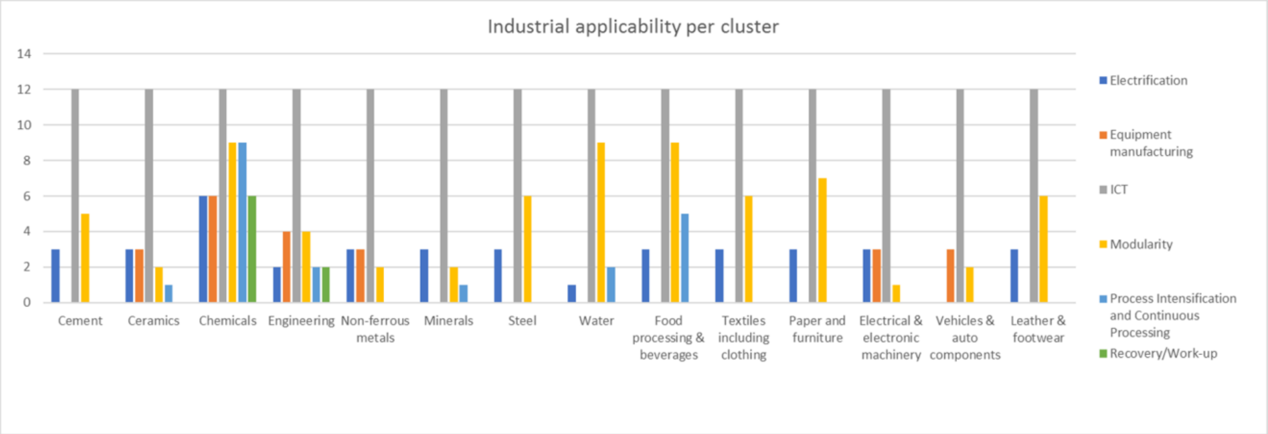

Figure 24: Applicability of technologies in processing and manufacturing sectors by cluster

The figure above illustrates the applicability of technologies in processing and manufacturing sectors by cluster. A selection bias towards chemical industry and consequently engineering (equipment manufacturing) is visible. Chemical industry however is a provider to multiple other sectors. This industry structure and material flow is not visible here. ICT has been recognized as generically applicable and electrification (of utilities) in general also has potential. There are many industries in which the modular technologies seem applicable. However, the modular concept has been dominant in equipment and electronics already for a long time.

Figure 24 also illustrates that the modular and decentralized concept might potentially be hard to apply in steel and cement, for instance. The recovery and workup cluster was in this exercise specifically tailored to chemical processes.

3.4 Emerging Energy Carriers

Figure 25: Radar plot of the technologies for the Decentralized or Modular production archetype (Business Model Impact in color)

The plot above shows the distribution of the assessed technologies of the Emerging Energy Carriers business model archetype. From the outside to the center, the four half circles represent increased Technology Readiness Level (TRL)[6]. The radials represent the different clusters of

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[6] We made a simplification of the TRLs: 1-Basic Research, 2-Applied Research, 3-Market ready, 4-Market presence The position of technologies within one cell is arbitrary, to avoid overlap.

technologies identified specifically in this archetype. The radar thus reflects the maturities of the different clusters. The colors indicate three levels of business model impact[7].

The first observation for this plot is the relative high maturity of the technologies in the cluster ICT. This is an artefact following from the selection process. Since we identified more technologies for this cluster than could be taken into account, it was decided to focus on the most relevant ones. Again, through the selection criterium, this figure is biased towards higher TRL technologies.

The cluster 'Power Conversion' contains technology of a lower TRL (1 or 2). This cluster contains technologies that are relatively new and need to be developed more to gain market presence. This cluster mostly consists of technologies that create or store new energy carriers and are not present in the current market. The high TRL technologies are the hydrogen based technologies and the last step of the energy carrier process, "conversion to power". Biomass based fuels are more present in the current market (pyrolysis, biogas) and therefore these technologies are ranked on a higher TRL level. A technology that stands out in this archetype is In-situ removal and conversion of contaminants. This technology is here specifically clustered for Biomass based fuels because it is used to purify the biomass feedstock/product and enhance the quality of the fuel.

Based on this radar plot one would start to consider ICT, but this is only a complementary technology. The other technologies in this archetype are specific as there are no general technologies available on the market yet. The first step is to develop these technologies. This illustrates that the radar plot drives the navigation between different clusters: By seeking for explanations for a specific assessment or characteristic of a given technology or cluster, one needs to dive into the details of this. (At the moment of writing this deliverable an online system is developed to support this navigation.)

The business model impact coloring of the technologies has three different colors and is ordinal and positive, in the sense that green dots indicate, in general, desirable impacts for the business model. Red dots indicate that the technology has some identified barriers. This does however not imply that 'green' technologies are standalone impacting the business model. For example, the technologies Hydrogen binding to carriers, Hydrogen storage techniques and Carrier to power all add to each other. When all are implemented successfully, the business impact is large. Because all these technologies imply the possibility of this impact they are all scored on that (with a discounting). However alone they will probably not achieve this impact. Furthermore, without a specific case in mind, it cannot be judged whether the related costs savings would justify it economically. Obviously, that would apply to any technology; there is no technology with a guaranteed positive business case. This example goes to show that it is useful to seek for the rationale behind the assessment.

In the ICT cluster, Big Data presents itself as a winner on business model impact. Although this technology on its own only enables the creation of either ad-hoc or continuous insights,

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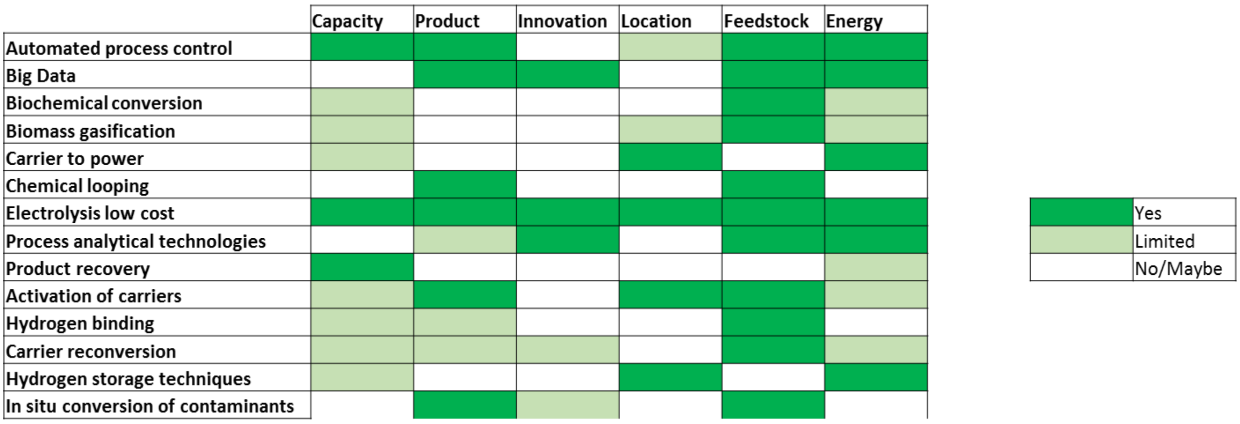
[7] The color for Business Model Impact is calculated as follows. The amount of definitelys minus the amount of undesirables is calculated. If the corresponding number is: 0-1: red – low; 2-3: yellow – medium; 4+: green – high

the assessors assumed that the action following the insight would also be implemented. The technology with the lowest business model impact is Chemical looping. This is a complex technology (power storage through oxidation) with some barriers and limited impact on business model as the product (heat) has low revenue.



	Capacity	Product	Innovation	Location	Feedstock	Energy
Automated process control	🟩	🟩		▨	🟩	🟩
Big Data		🟩	🟩		🟩	🟩
Biochemical conversion	▨				🟩	▨
Biomass gasification	▨			▨	🟩	▨
Carrier to power	▨			🟩		🟩
Chemical looping		🟩			🟩	
Electrolysis low cost	🟩	🟩	🟩	🟩	🟩	🟩
Process analytical technologies		▨	🟩		🟩	🟩
Product recovery	🟩					▨
Activation of carriers	▨	🟩		🟩	🟩	▨
Hydrogen binding	▨	▨			🟩	
Carrier reconversion	▨	▨	▨		🟩	▨
Hydrogen storage techniques	▨			🟩		🟩
In situ conversion of contaminants		🟩	▨		🟩	

🟩	Yes
▨	Limited
	No/Maybe

Figure 26: Detailed overview of the flexibility profile of technologies of the Modular or Flexible production business model archetype

The figure above displays the assessed flexibility profile of the different technologies in the archetype. Clearly, there is one technology that enables all round flexibility: Electrolysis low cost. The technology is capacity and location flexible because it can be made in small modules, that easily stack and can be moved. Different feedstock and products can easily be made by changing the voltages and it is energy flexible, by definition. So, the nature of electrification is again showing large flexibility. Automated Process Control (APC) is the next high flexibility technology, but it works as a facilitator and the electrolysis is the actuator technology. Automated Process Control 'only' optimizes within the confines of a given process (i.e. it cannot automate innovation) while electrolysis is the technology that ensures the flexibility. Note that this is the same as in the Decentralized & Modular archetype. The application of ICT technology can be the same in different archetypes.

Product recovery stands out with quite low flexibility. This technology group contains for separation processes like membranes of affinity separations. In the specific case of Emerging Energy Carriers, it can only be used to improve the quality of the feedstock (or product) such that more can be produced with the same equipment. An example is bio based pyrolysis oil which contain acidic compounds that degrade equipment. By recovering the energy carrier from the mixture, the capacity can be increased. This assessment is specific for the application in the archetype. In other applications the assessment of flexibility might be larger (e.g. location flexible).

Note that feedstock and energy flexibility stand out in this archetype. The archetype considers energy technologies, so therefore it is expected that most technologies contribute to energy flexibility. The feedstock flexibility however is because a lot of technologies are allowing new energy sources (feedstock) to be used. Instead of being fixed to the usual sources one can choose flexibly which source to use.

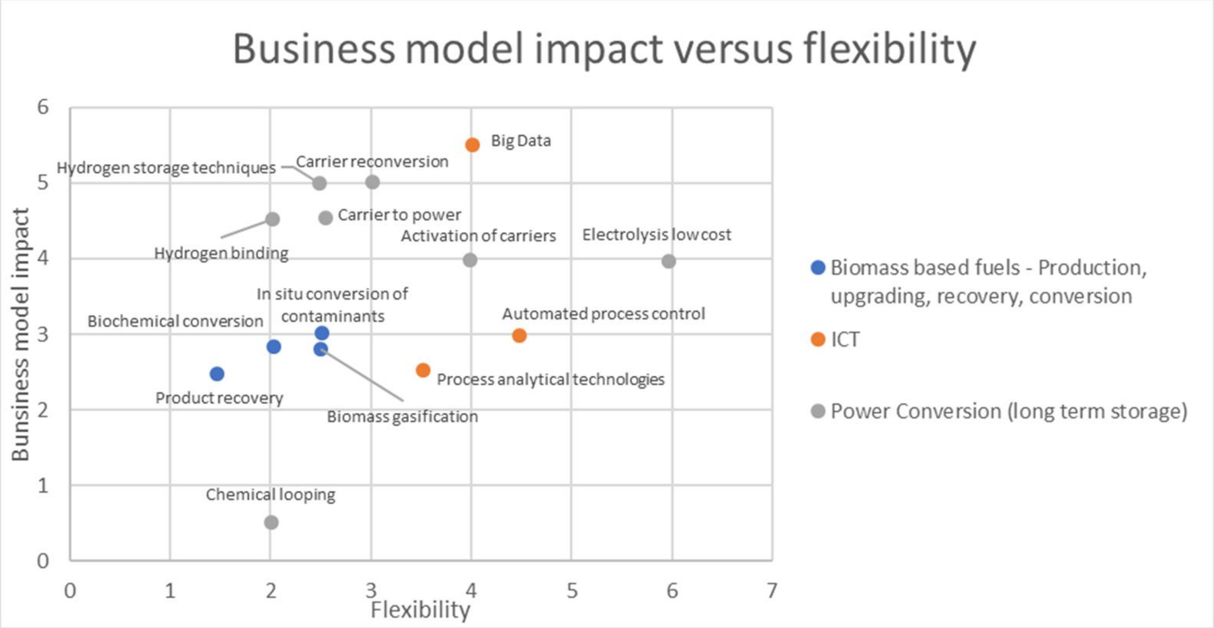


Figure 27: Distribution of technologies in the D&M archetype by cluster, flexibility and business model impact

The figure above illustrates the distribution of technologies in the Emerging Energy Carriers business model archetype by technology cluster (color), flexibility[8] (x-axis) and business model impact (y-axis).

One can observe that Big Data and Electrolysis low cost stand out in this graph. Big Data has a high business model impact, however currently it has limitations in applicability and requires new processes. Electrolysis low cost is discussed as a technology with high flexibility, now we also see that it has a moderate business model impact. This is because electrolysis technology is needed to drive electrification of chemical industries and disrupt the existing business model.

On the bottom left we see again that chemical looping and product recovery score low. Where chemical looping has both low flexibility as business model impact. From the assessment speaks that it is a specific technology with low revenues. Product recovery has a very specific application, and therefore can only specifically improve the business model on a few points. Applications can exist without Product recovery, it only improves the process.

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[8] This is done by counting the assessments of the flexibility indicators (feedstock, location, etc) and the BMI indicators (revenue, supply, etc). Calculated as: the number of definitely scores + 0.5 times the number of maybe scores – 1.2 times the number of undesirable scores. ‘Overall’ has not been taken into account here. A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

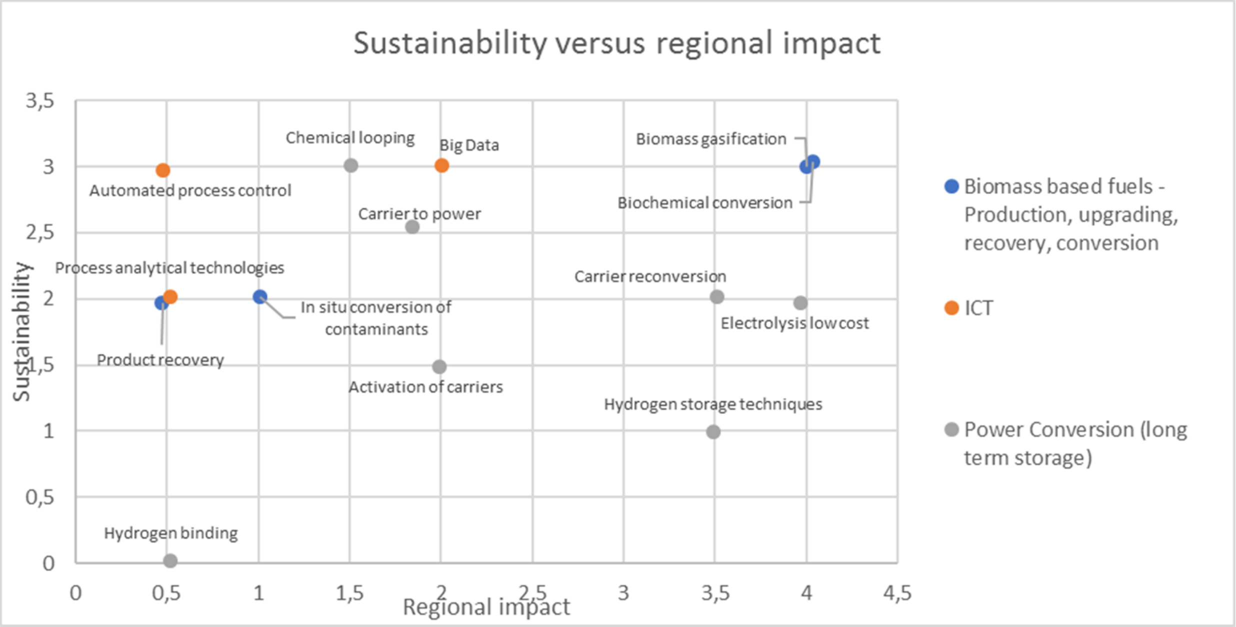

Figure 28: Distribution of technologies in the D&M archetype by cluster, sustainability and regional impact

The figure above illustrates the distribution of technologies in the Emerging Energy Carriers business model archetype by technology cluster (color), regional impact[9] (x-axis) and sustainability[10] (y-axis).

The first thing that stands out is the low score of Hydrogen binding to carriers. This is because the process for hydrogen binding to ammonia is assessed (Haber-Bosch) as highest TRL technology. This is a global process which benefits from economies of scale, so it will have low impact on the region. Furthermore, in assessing we have to look at the situation where we apply it somewhere we did not before. In that situation we will produce ammonia which is possibly hazardous and thus we will not have a positive sustainability impact. Also, hydrogen storage does not improve sustainability greatly, as it only creates more hold-up. The only positive is the possibility to use it as renewable energy storage.

The highest scoring technologies are biomass based technologies. This is because these technologies use (local) waste to produce new energy carriers. This is both a local process as a process that has a positive sustainability impact. Also, chemical looping has a high sustainability impact as it supplies a novel way to store energy and use it as heat. Also, ICT applications score high on sustainability as they may enable more sustainable business (but do not need to).

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[9] This is done by counting the assessments of the sustainability indicators and the regional impact indicators Calculated as: the number of definitely scores + 0.5 times the number of maybe scores – 1.2 times the number of undesirable scores. ‘Strategy’ has not been taken into account here. A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

[10] See above

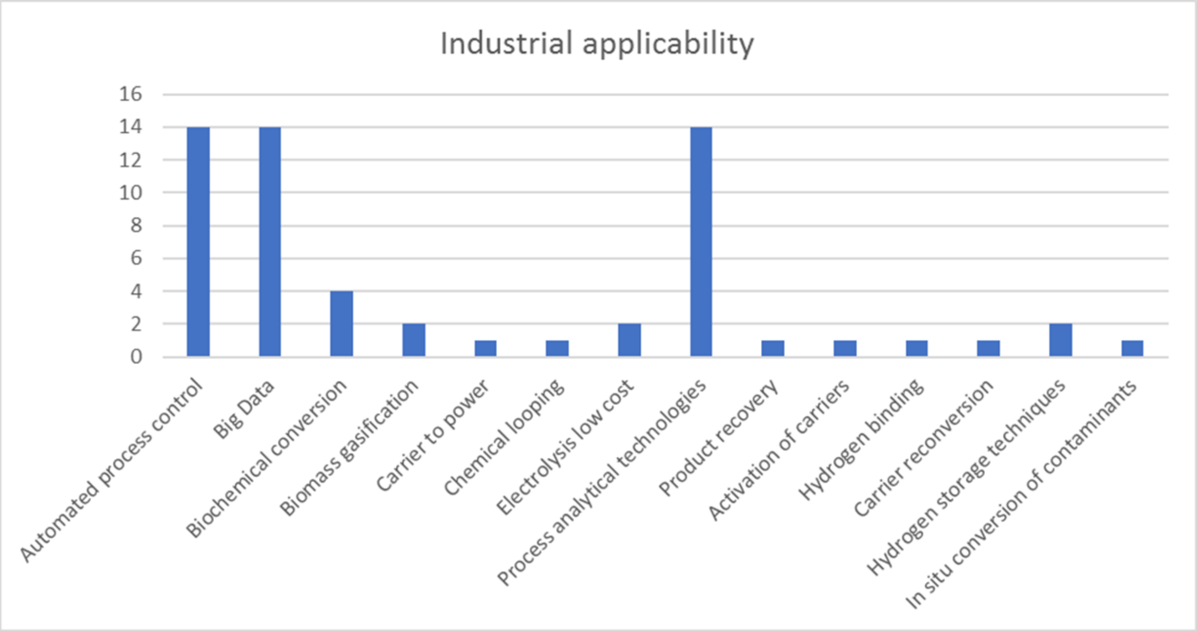

Figure 29: The number of industries in which the technology is applicable

The figure above illustrates the number of industries in which the technology is applicable. Figure 29 clearly reflects how generic a technology is, and obviously ICT related technologies stand out. Also, biochemical conversion is applicable in more industries. This is because bio feedstock can be found and applied in different industries.

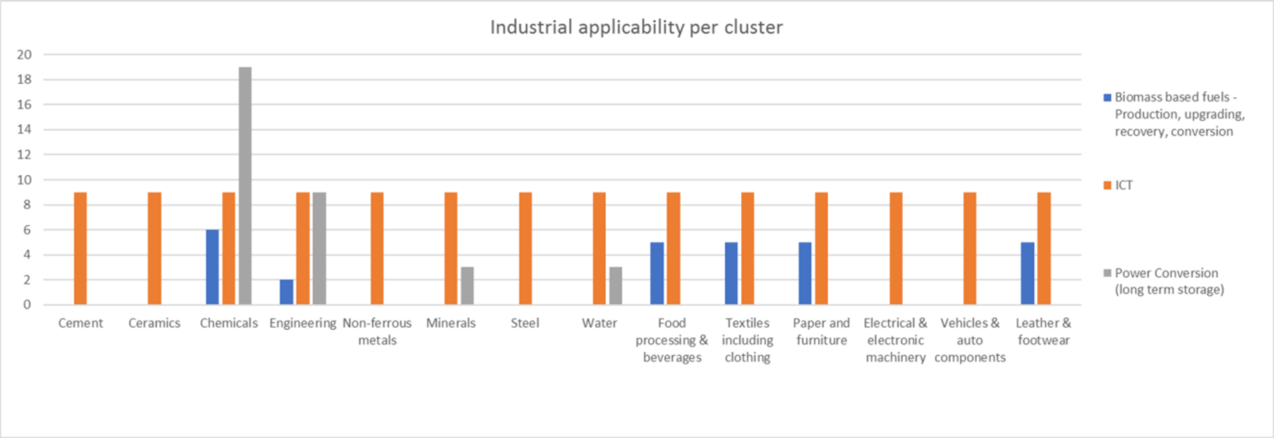

Figure 30: Applicability of technologies in processing and manufacturing sectors by cluster

The figure above illustrates the applicability of technologies in processing and manufacturing sectors by cluster. A selection bias towards chemical industry and consequently engineering (equipment manufacturing) is visible. Chemical industry however is a provider to multiple other sectors and the application of storing and using renewable energy has impact on many other industries. This industry structure and material flow is not visible here. ICT has been recognized as generically applicable and electrification (of utilities) in general also has potential.

Figure 30 also illustrates that in the Emerging Energy Carriers concept for bio based fuels can be applied in other industries. As in multiple industries bio based feedstock can be found and applied. The biggest impact however can be found in applying power conversion technologies at the chemical industry.

3.5 Servitization in the processing industry

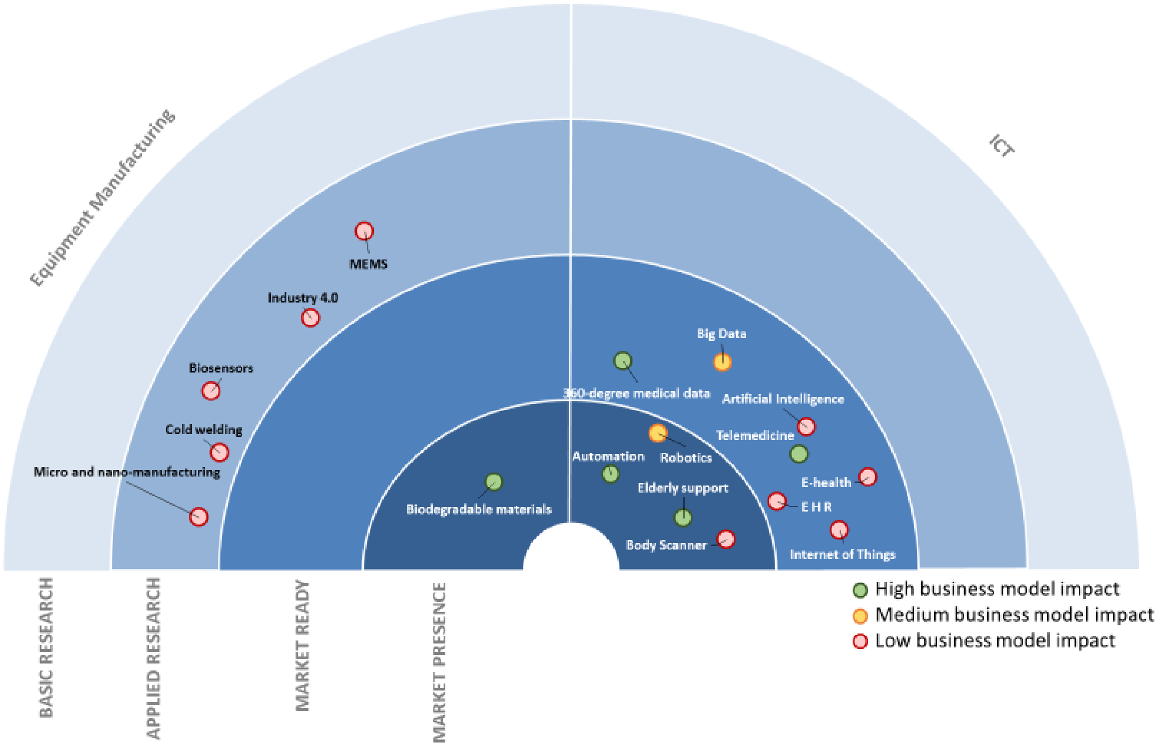

Figure 31: Radar plot of the technologies for the Servitization (Business Model Impact in color)

The plot above shows the distribution of the assessed technologies of the Servitization business model archetype. From the outside to the center, the four half circles represent increased Technology Readiness Level (TRL)[11]. The radials represent the different clusters of technologies identified specifically in this archetype. The radar thus reflects the maturities of the different clusters. The colors indicate three levels of business model impact[12].

At first sight it is possible to observe the relative high maturity of the technologies in the ICT (Information and Communications Technology) cluster, while in the Equipment Manufacturing cluster, the technologies are mostly under applied research. This is a consequence of the selection process of the technologies, their current applications and how they could be related to the Servitization Business Model.

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[11] We made a simplification of the TRLs: 1-Basic Research, 2-Applied Research, 3-Market ready, 4-Market presence The position of technologies within one cell is arbitrary, to avoid overlap.

[12] The color for Business Model Impact is calculated as follows. The amount of definitely minus the amount of undesirables is calculated. If the corresponding number is: 0-1: red – low; 2-3: yellow – medium; 4+: green – high

In the analysis we included different technologies for both clusters to make the identification current TRL possible. We included as much as possible all the trends and technologies that are currently under development for both clusters.

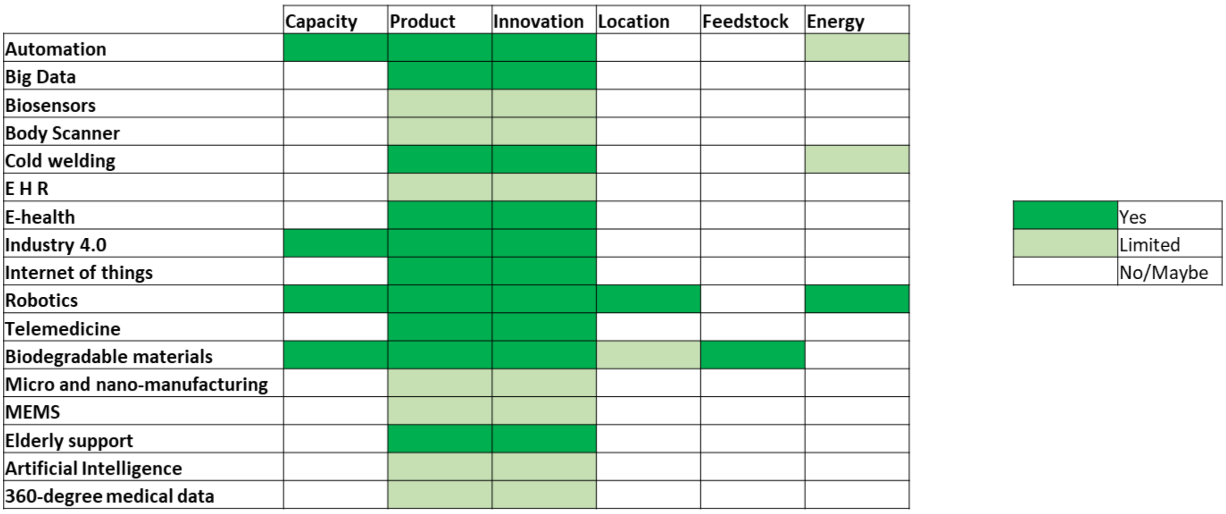
In the case of the ICT, it is possible to see that the technologies are more mature, being applied in some industries or even currently available in the market. For example, the technologies with the highest readiness level, such as Automation or Robotics, are both technologies which have been already in the market for several years, but in different industries and with other applications. Therefore, the application under the ICT cluster is made in a rather "simple" manner than developing all the systems around the technology. In the case of those in the Market Ready technologies there are some applications available already for each of them, but they require a deeper applied research to spread the applications on different fields. For example, Artificial Intelligence (AI) has been around couple of years now. Examples of this are Siri (from Apple) or Cortana (from Microsoft), two AI assistants already available in your mobile phone or computer, with learning curves to adapt and adjust to each user needs. However, if you think about AI, you might think about some more "technology-edge robots or computers" ready to help you and support you on more diverse daily tasks. In the case of Internet of Things, there is still many ground to be covered. However, many devices that take part in our daily decisions are "online" (connected to internet) without the user even realizing how much information we are sharing with those devices.

On the other hand, we have the Equipment Manufacturing cluster, where technologies are in an Applied Research stage, having developed some prototypes for a particular (or diverse) industry and tested the model into "real world" conditions, but the technology still requires further development. An example of this is Cold Welding, a technology that could be used for many high-precision industries, but so far has developed only aerospace applications due to complexity and cost involved in the development.

As a controversial example, we could argue that many different sensors have been in the market for, relatively, quite long time. The application of these sensors in biosciences is recent and under development. Moreover, the servitization of these devices is still under research. With this example we show how, even when it is possible to think about a technology that is applied to certain industries, the results differ widely from one industry to another and on how difficult is to find a technology that "fits all" the defined archetypes. We invite the reader to make a conscious reading for each of the archetypes and understand how each of the technologies applies on each particular case, and not to generalize application through different industries.

Regarding the business model impact, we have defined three different colors for the technologies and is ordinal and positive, in the sense that green dots should indicate, in general, desirable impacts for the business model. Red dots indicate that the technology has some identified barriers. This does however not imply that this technology should be red flagged. To give a specific example, if we consider the technology based on the Internet of things it is clear for us that there are many devices currently online, however there are many others that are part of our daily life that yet are not massively online (i.e., cars, kitchen appliances, etc.). This means that there exists an impact from the technology, but it adds complexity and extra costs, which can easily overcome the benefits. As a note, is not possible to judge the technologies based on a case as each one has its own particularities and introduces different challenges and risks. There is no technology with a guaranteed positive business case impact.

On the other hand, we have different cases where the impact could be possible. For the sake of argument, we select the Biodegradable materials as a case example, as it is at Market Presence level, providing different and large benefits for the industries where the technology is applied, not incurring high cost nor adding any other complexity layer to the business model. However, we cannot immediately jump to conclusions without interpreting each individual case and its specific assumptions.



	Capacity	Product	Innovation	Location	Feedstock	Energy
Automation	🟩	🟩	🟩			▨
Big Data		🟩	🟩			
Biosensors		▨	▨			
Body Scanner		▨	▨			
Cold welding		🟩	🟩			▨
E H R		▨	▨			
E-health		🟩	🟩			
Industry 4.0	🟩	🟩	🟩			
Internet of things		🟩	🟩			
Robotics	🟩	🟩	🟩	🟩		🟩
Telemedicine		🟩	🟩			
Biodegradable materials	🟩	🟩	🟩	▨	🟩	
Micro and nano-manufacturing		▨	▨			
MEMS		▨	▨			
Elderly support		🟩	🟩			
Artificial Intelligence		▨	▨			
360-degree medical data		▨	▨			

🟩	Yes
▨	Limited
	No/Maybe

Figure 32: Detailed overview of the flexibility profile of technologies of the Servitization business model archetype

The figure above displays the assessed flexibility profile of the different technologies in the Servitization archetype. Is it possible to appreciate that no technology in the archetype can achieve an all-round flexibility, as specially only one of them (Biodegradable materials) shows an impact in the Feedstock flexibility. Robotics and Biodegradable materials are both technologies with the most positive impacts and wide on flexibility, leaving out only one part of the all-round flexibility (feedstock and Energy, respectively). On the other hand, there are several technologies that offer limited impact on the flexibility profile and are mainly focused on the product flexibility and innovation flexibility (for the definition of each flexibility, please refer to the definition section).

Please note that as mentioned beforehand, some specific case study analysis is necessary for each of the technologies to suggest conclusions based on the findings presented here.

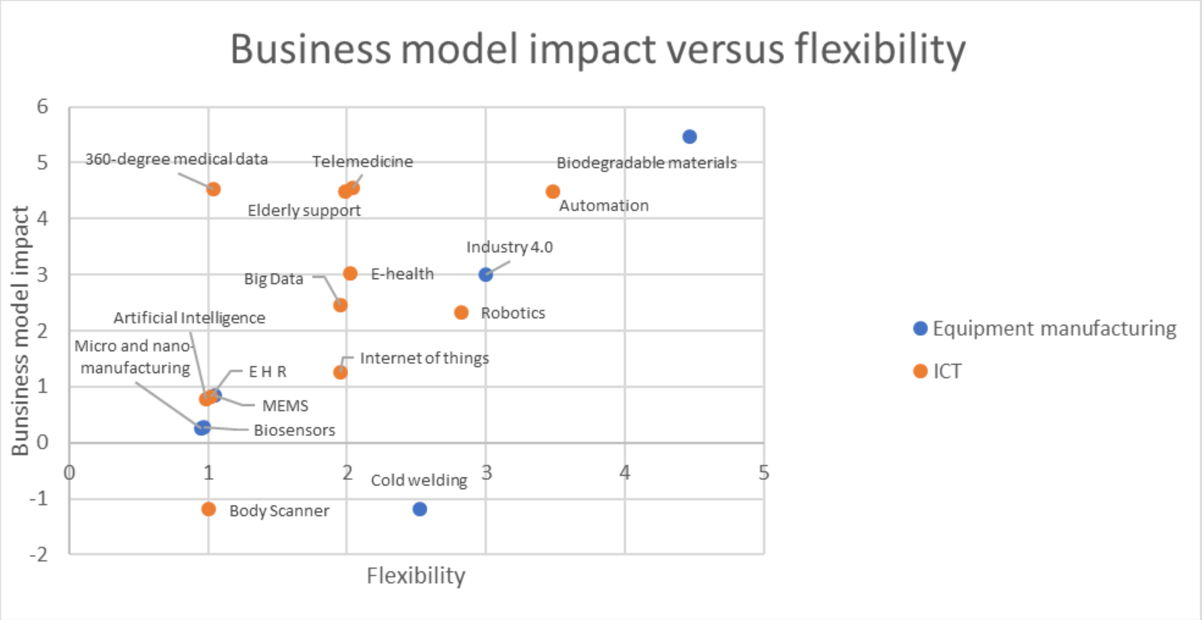


Figure 33: Distribution of technologies in the Servitization archetype by cluster, flexibility and business model impact

The figure above illustrates the distribution of technologies in the Servitization business model archetype by technology cluster (color), flexibility[13] (x-axis) and business model impact (y-axis).

As in Figure 31, it is possible to see that biodegradable materials stands out on business mode impact. Surprisingly, compared to the previous graph, Automation and Elderly support are surpassed by the high business impact from Telemedicine and 360-degree view of medical data, both of them which were not in a market presence stage. The main reason for this is the potential that both technologies have under development on the ICT under the Servitization archetype. When we bring flexibility to the equation, both of the health-related technologies (Telemedicine and 360-degree view of medical data) lack of higher degrees of flexibility, while Automation proves to be highly flexible and also providing high impact at business model level.

In the opposite area of the graph, we find Body Scanners and Cold Welding technologies as those who have a potential negative impact on the business model by adding higher degrees of complexity and incurring in additional costs. Body Scanners as well, offer the most limited flexibility among the different technologies analyzed. In the specific case of Cold Welding, the reasoning behind its score is related to the fact that it adds larger costs to the industry, becoming a highly expensive process with limited applications on daily basic technologies.

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[13] This is done by counting the assessments of the flexibility indicators (feedstock, location, etc) and the BMI indicators (revenue, supply, etc). Calculated as: the number of definitely's + 0.5 times the number of maybe's – 1.2 times the number of undesirabless. 'Overall' has not been taken into account here. A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

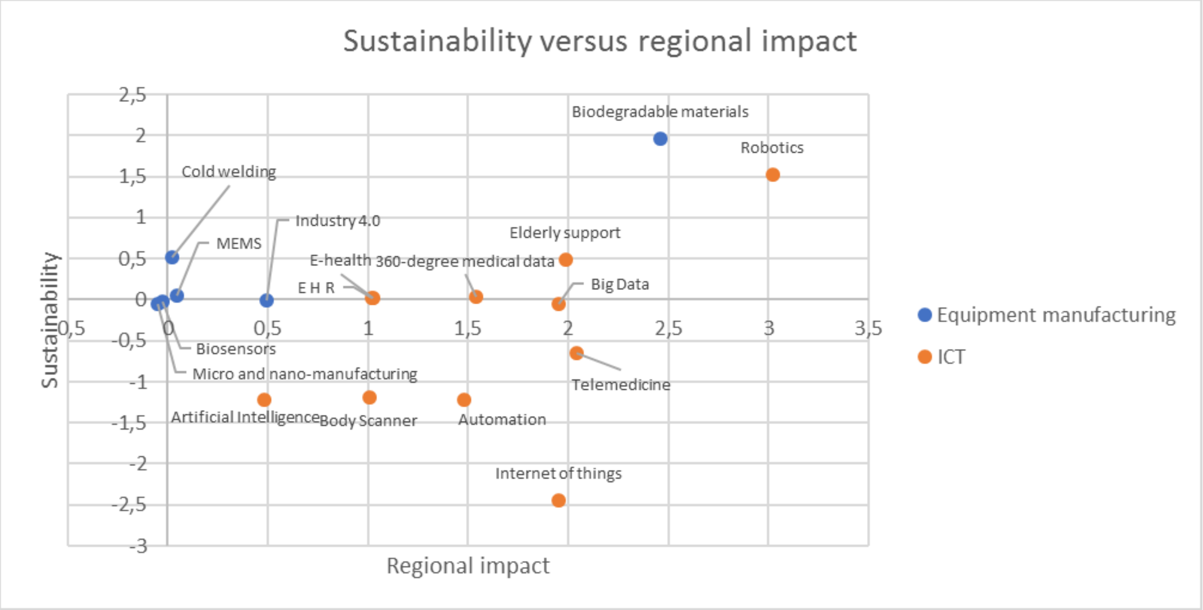

Figure 34: Distribution of technologies in the Servitization archetype by cluster, sustainability and regional impact

The figure above illustrates the distribution of technologies in the Servitization business model archetype by technology cluster (color), regional impact[14] (x-axis) and sustainability[15] (y-axis).

Overall, we note that almost 50% of technologies (8 out of 17) have little to no impact on the sustainability goals for the region. Unfortunately, there are five (5) technologies who go on potential detriment of the sustainability, supposing large impacts on natural resources and incurring in high intensive energy production processes. On the other hand, there are four (4) technologies that support the sustainability initiative for the region and could provide a large positive impact. We must note here that we are dealing with individual technologies here, whereas the Servitization itself is a concept in which several technologies and services are coordinated (e.g. pay-per-lux). This system approach allows for integrating sustainability incentives, but this is not visible directly at the individual technology level.

The case of the Biodegradable materials is remarkable. This technology has been traditionally seen as without major importance, but it could potentially benefit the European region by providing positive regional impact and also being the most sustainable technology to employ at different industries under the Servitization archetype umbrella. As well, Robotics are another technology that could offer a high positive regional impact, even showing sustainable outcomes (almost as high as Biodegradable materials technology). This last result is somewhat surprising as the reasoning behind the inclusion of robotics could be interpreted as an increment in the unsustainable impact, but the results illustrate the opposite. On the other hand, we can see that Internet of things, one technology that has a large impact in the regional objectives, also has its downside by being the one with a potential negative impact in sustainability by the creation and implementation of new devices, outdating previous versions and increasing the consumption and pollution trend.

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[14] This is done by counting the assessments of the sustainability indicators and the regional impact indicators Calculated as: the number of definitely's + 0.5 times the number of maybe's – 1.2 times the number of undesirables. 'Strategy' has not been taken into account here. A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

[15] See above

As a general conclusion on the regional impact, most of the technologies have a strictly positive impact, potentially showing that any of them can help to meet the regional goals in different percentages.

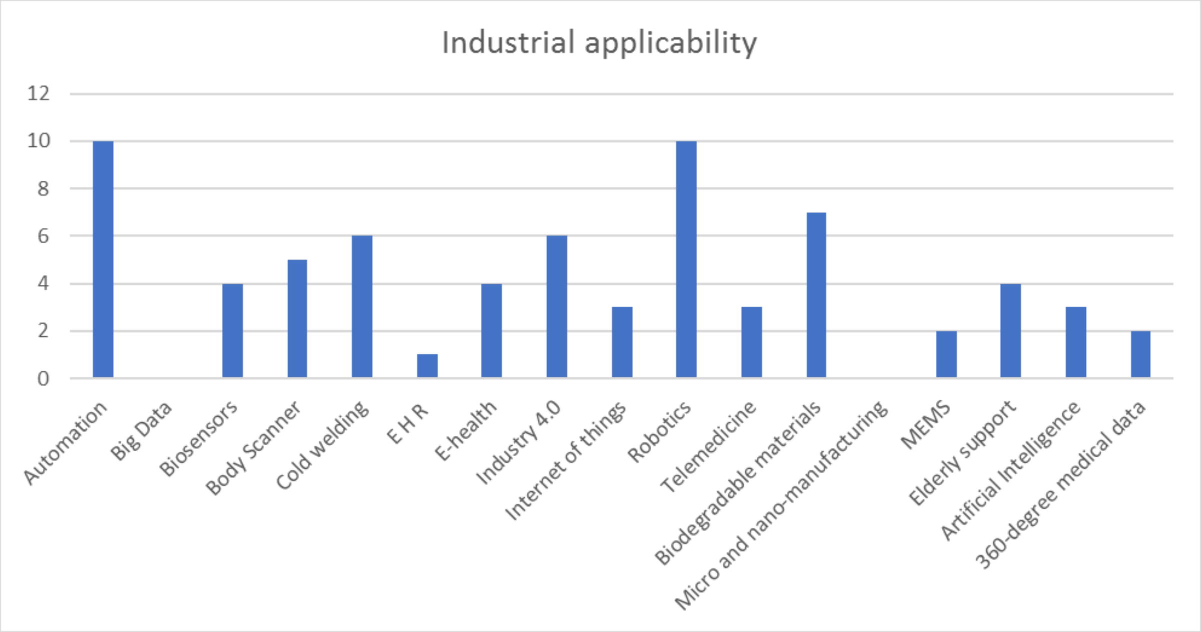

Figure 35: The number of industries in which the technology is applicable

The figure above illustrates the number of industries in which the technology is applicable. Figure 35 clearly reflects how generic a technology is, and obviously ICT related technologies (Automation and Robotics) stand out, while from the Equipment manufacturing related technologies only one stands out (Biodegradable materials). This is possible to be understood from the principle that industries look to incorporate cutting-edge technology into their processes but are also aware of the importance of environmental impacts as well.
Contrariwise, health related technologies have no applicability outside this sector.

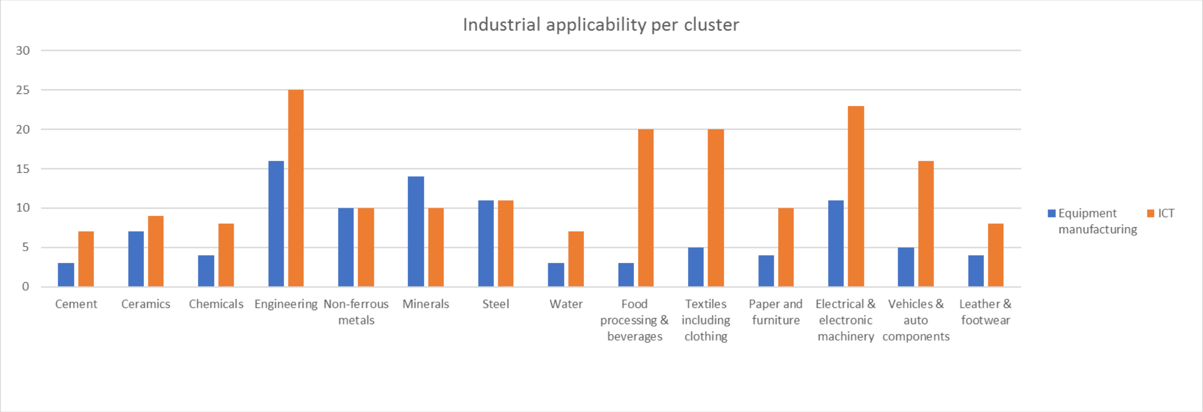

Figure 36: Applicability of technologies in processing and manufacturing sectors by cluster

The figure above illustrates the applicability of technologies in the Servitization archetype by cluster. Is possible to observe that ICT applications are largely related to engineering and highly intensive technological engineering related processes, such as electrical & electronica machinery, vehicles & auto components, textiles including cutting, and food processing & beverages.

Conversely, we can note that Equipment Manufacturing technologies have a lower number of applications in the selected industries and under the Servitization archetype umbrella. This is not a conclusion that these technologies cannot be applied under different perspective with better results. As evidence of this, Figure 36 illustrates that ICT technologies present a larger number of applications than Equipment Manufacturing technologies, except in the Minerals case, where ICT seems less applicable.

3.6 Reuse – Sustainability

Figure 37: Radar plot of the technologies for the Reuse – Sustainability archetype (Business Model Impact in color)

Figure 37 above shows the distribution of the assessed technologies of the Reuse – Sustainability business model archetype. From the outside to the center, the four half circles represent increased Technology Readiness Levels (TRL)[16]. The pie slices indicate the different clusters of technologies identified for this archetype. The colors indicate three levels of business model impact[17].

The first observation for this plot is the relative high maturity of all technologies. While most technologies are already present on the market, none of the technology is in the basic research level. This is an artefact following from the selection process. Since we identified more technologies for this archetype than could be taken into account, it was decided to focus on the most relevant ones. If we had to make specific choices between examples of technology, we included the one with highest TRL, so that the reader is presented with available options. Also, technologies at the basic research level are often not published, consistently labelled, or attributable to a specific application. Nevertheless, the TRL distribution provides insight between the clusters. While material and production process oriented technologies tend to have a high TRL, and are – at least in similar applications – readily available on the market, ICT

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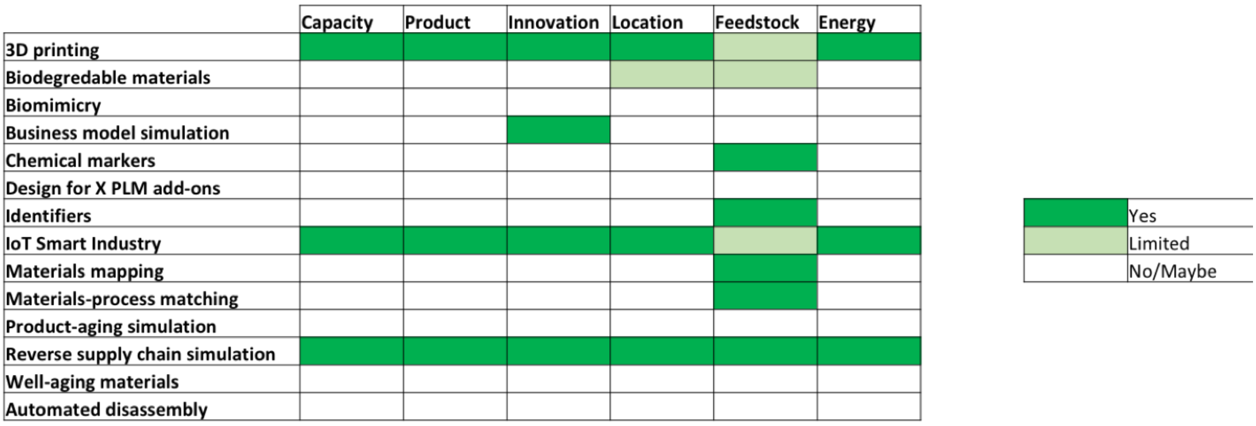
[16] We made a simplification of the TRLs: 1-Basic Research, 2-Applied Research, 3-Market ready, 4-Market presence The position of technologies within one cell is arbitrary, to avoid overlap.

[17] The color for Business Model Impact is calculated as follows. The amount of definitelys minus the amount of undesirables is calculated. If the corresponding number is: 0-1: red – low; 2-3: yellow – medium; 4+: green – high

based technologies are considerably less mature and seldom applied in the context of the circular business models of this archetype.

The business model impact coloring of the technologies has three different colors and is ordinal and positive, in the sense that green dots should indicate, in general, strong impact of the technology on the different elements of the business model considered in our analysis. Red dots indicate that the technology has no systemic influence on the business model, or that the influence on the different business model elements depends on the default configuration before implementation of the new technology. This does however not imply that this technology should be red flagged or might not have considerable impact on an individual organization. For example, the technology Automated disassembly can considerably improve the efficiency of re-X production processes. However, the impact of the technology highly depends on the previous amount of mechanization and achieved levels of efficiency. Moreover, the technology only influences operations without influencing the value proposition or revenue mechanism. So, despite potentially high impact on the business, its business model stays basically the same. Since circular economy technologies are mainly focused on operations, this rationale applies to most of the technologies of this archetype.

One noteworthy exception is the Business model simulation. This technology would allow to simulate different business model scenarios to support the business model innovation decision making. If the decision support leads to the selection and implementing of a new business model, or a substantial reconfiguration, the impact on the business model will be considerable.



	Capacity	Product	Innovation	Location	Feedstock	Energy
3D printing	🟩	🟩	🟩	🟩	▨	🟩
Biodegredable materials				▨	▨	
Biomimicry						
Business model simulation			🟩			
Chemical markers					🟩	
Design for X PLM add-ons						
Identifiers					🟩	
IoT Smart Industry	🟩	🟩	🟩	🟩	▨	🟩
Materials mapping					🟩	
Materials-process matching					🟩	
Product-aging simulation						
Reverse supply chain simulation	🟩	🟩	🟩	🟩	🟩	🟩
Well-aging materials						
Automated disassembly						

🟩	Yes
▨	Limited
	No/Maybe

Figure 38: Detailed overview of the flexibility profile of technologies of the Modular or Flexible production business model archetype

The figure above displays the assessed flexibility profile of the different technologies in the archetype. One can see that for technologies for which the flexibility gain can be estimated, this gain applies to all six types of flexibility for technologies that impact the entire production process and to the type affected by the specific value chain step that is influenced by the other technologies. The latter mainly applies to technologies that enable the substitution of feedstock. Business model simulation is the only technology that mainly affects flexibility in the context of innovation. While the other technologies improve efficiency and effectiveness regarding the archetype, they are not either not aiming at flexibility or the influence cannot be reasonably estimated.

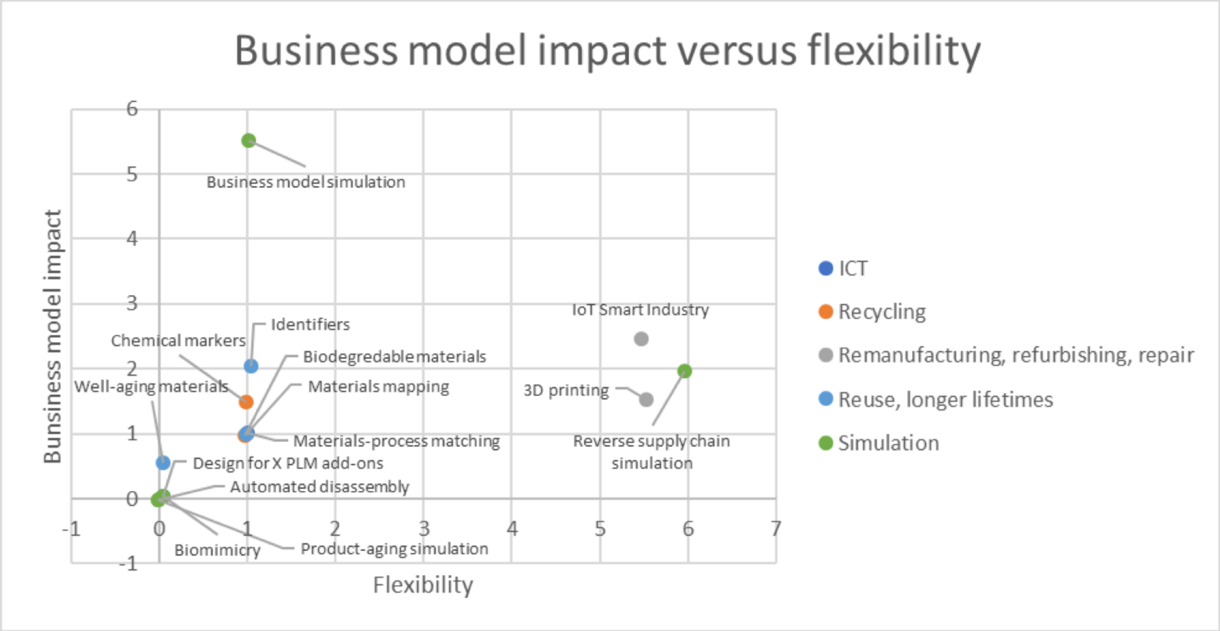


Figure 39: Distribution of technologies in the CE archetype by cluster, flexibility and business model impact

The figure above illustrates the distribution of technologies in the Reuse - Sustainability archetype by technology cluster (color), flexibility[18] (x-axis) and business model impact (y-axis).

Again, business model simulation stands out for its potential high business model impact, while the other technologies either impact only some elements, or their influence is hard to predict. Regarding flexibility, there are three technologies that we assumed to have a certain and high impact: IoT Smart Industry, 3D printing, and Reverse supply chain simulation.

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[18] This is done by counting the assessments of the flexibility indicators (feedstock, location, etc) and the BMI indicators (revenue, supply, etc). Calculated as: the number of definitely's + 0.5 times the number of maybe's – 1.2 times the number of undesirabless. 'Overall' has not been taken into account here. A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

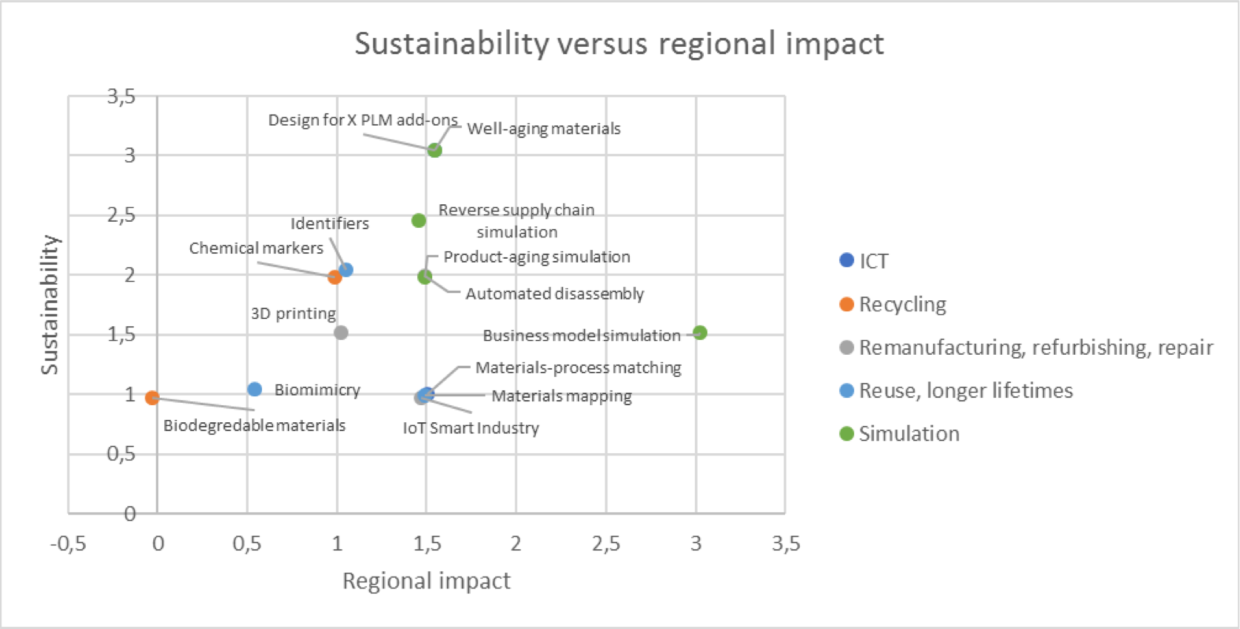

Figure 40: Distribution of technologies in the Reuse – Sustainability archetype by cluster, sustainability and regional impact

The figure above illustrates the distribution of technologies in the Reuse – Sustainability archetype by technology cluster (color), regional impact[19] (x-axis) and sustainability[20] (y-axis).

While the correlation between circular business models and sustainability remains underexplored, most researchers would expect a positive impact of circular business model supporting technology, especially on environmental effectiveness. Consequently, a better impact score of technologies associated to the Reuse – Sustainability archetype is to be expected compared to the other ones. However, our investigation has not measured the sustainability performance of the technologies but the likelihood of them having any actual impact. Figure 40 then shows an average of an accumulation of these scorings. Thus, a lower score can indicate a broad range of underlying mechanisms from a long causal chain from the application of a technology, e.g. a simulation of business model alternatives, to an increase in efficiency, e.g. less chips from a milling process, over a less clear understanding of the specific consequences of an eventual application of the technology in the context of this archetype, to high variability of impact depending on the specific organization and their previous processes.

The same applies to the second axis, regional impact, also because we have included some aspects like “Safety, Health and Environment” that have a strong overlap with the sustainability category, where they would normally be expected. The regional impact is particularly small, where technologies are involved that provide sustainable substitutes for production processes, like biodegradable materials. While this has a potentially strong influence on the overall sustainability of the products, this is largely independent from the local environment of the manufacturer.

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[19] This is done by counting the assessments of the sustainability indicators and the regional impact indicators Calculated as: the number of definitely’s + 0.5 times the number of maybe’s – 1.2 times the number of undesirables. ‘Strategy’ has not been taken into account here. A very small random number is added, to make sure you can distinguish dots that are on the same location in the plot.

[20] See above

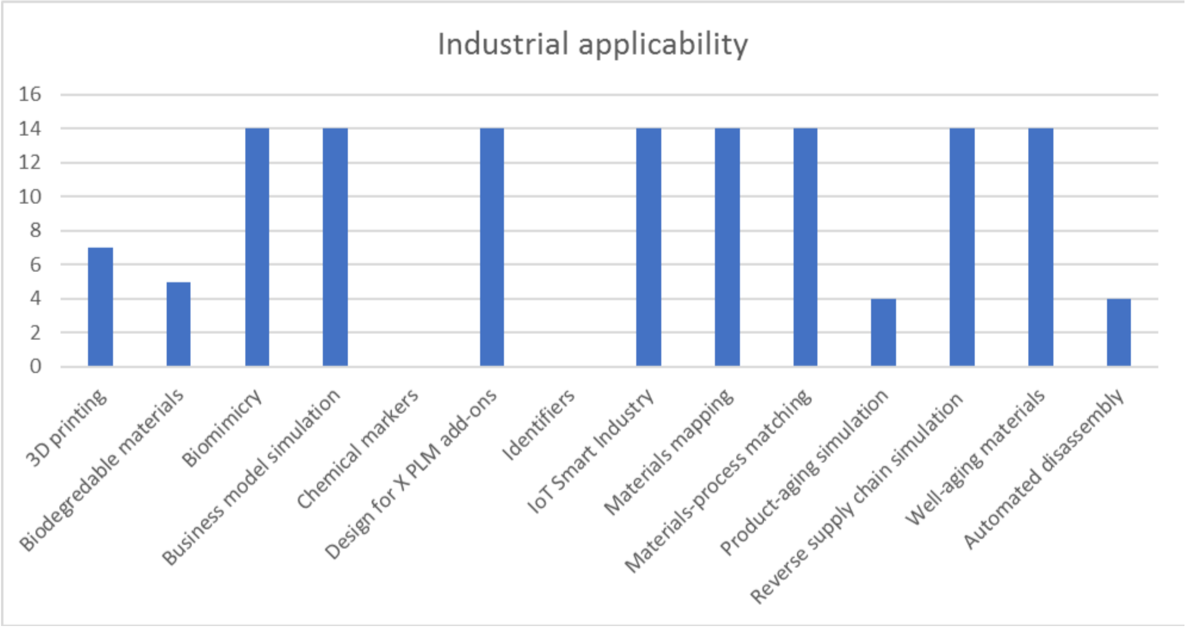


Figure 41: The number of industries in which the technology is applicable

The figure above illustrates the number of industries in which the technology is applicable. Since every technology is potentially applicable in industry, a value of zero indicates a lack of data rather than potential applications. Analogue to the business model archetype itself, most technologies are applicable to all industries.

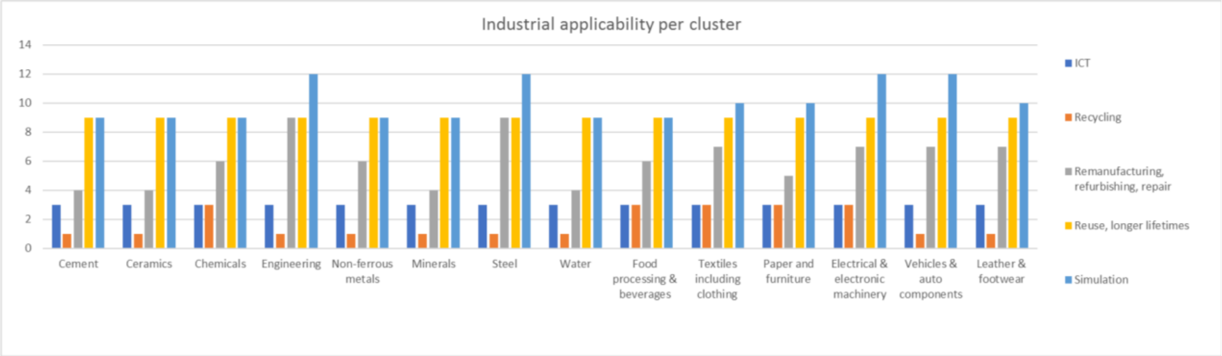


Figure 42: Applicability of technologies in processing and manufacturing sectors by cluster

This is also reflected in Figure 42, which illustrates the applicability of technologies in processing and manufacturing sectors by cluster. While simulation and longer lifetimes are applicable in all industries, remanufacturing, refurbishing, and repair is more pronounced in manufacturing. Analogue, these technologies apply to either to all or only to the manufacturing sector rather than the material producing and chemical industry.

3.7 Mass Customization

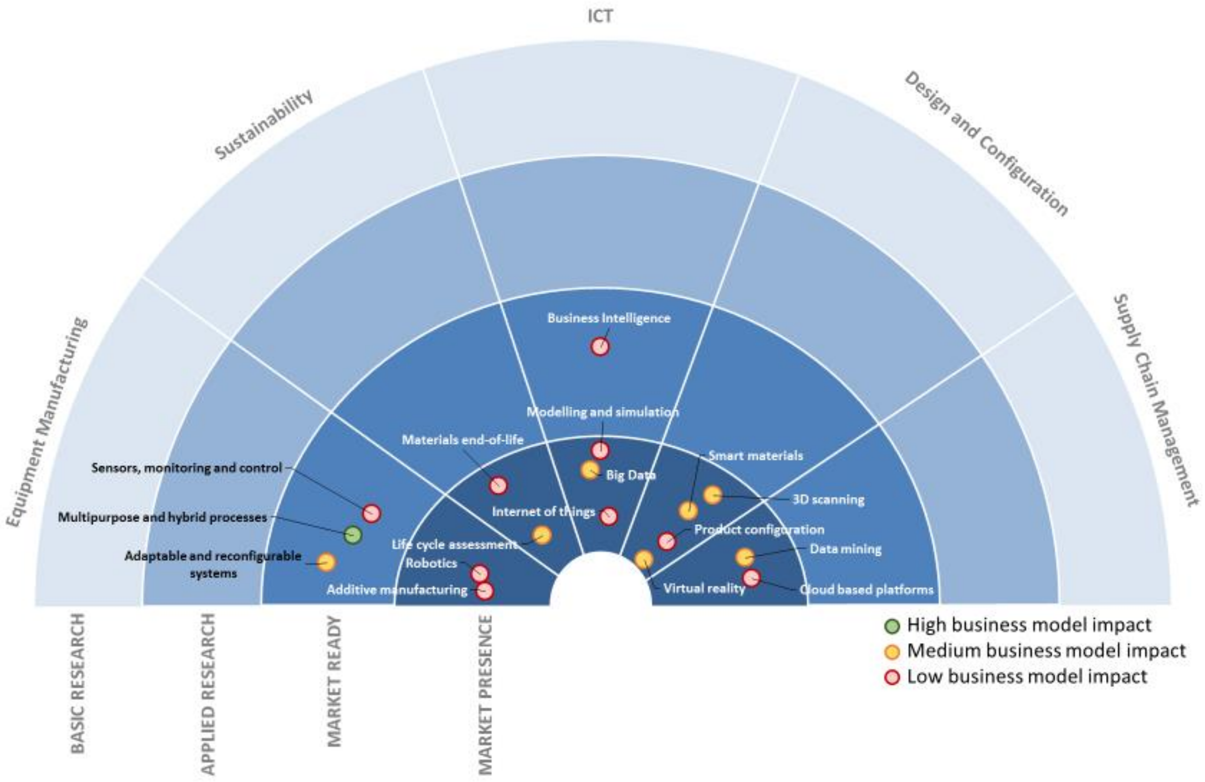


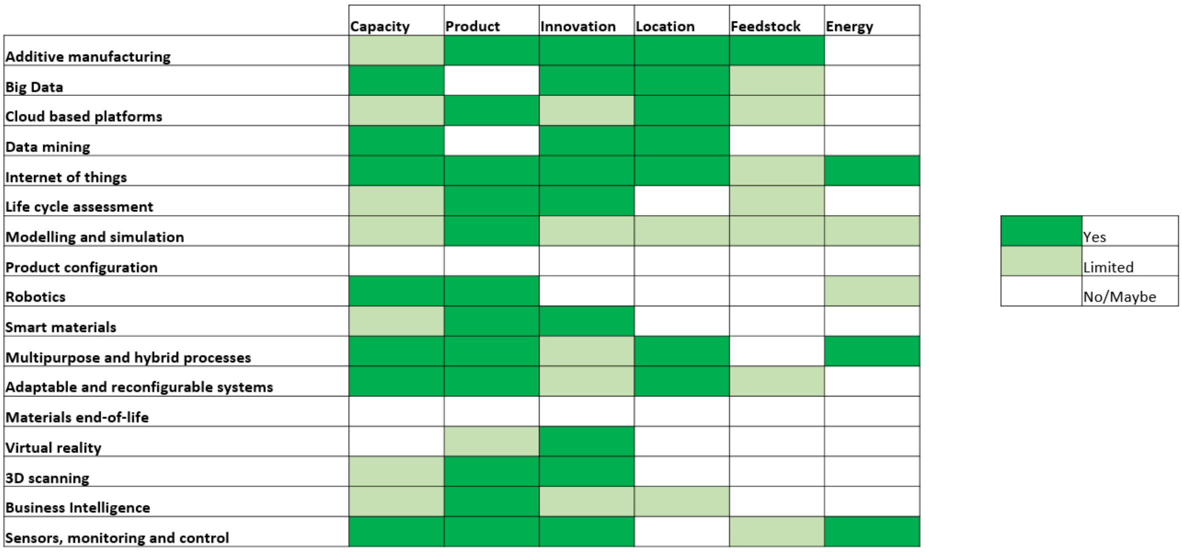
Figure 43: Radar plot of the technologies for the Mass Customization archetype (Business Model Impact in color)

First, we can observe a high maturity of the technologies: almost all of them are already present in the market, with some distinction between sectors, and only four of them are one stage behind, but ready to oncoming market applications and diffusion. Considering ‘sustainability’, ‘design and configuration’, and ‘supply chain management’ their BMI is low to medium, but considering single technologies, 3D scanning and Smart materials are on the way to affect companies’ business model more and more in the next few years. From the analysis held in the other WPs, automotive, textiles and leather are the sectors with major industrial applicability.

Internal processes of the industries applying Mass Customization (MC) have been positively impacted by 3D scanning, Virtual and augmented reality and Data mining to date; it also emerged that Smart materials and Life cycle assessment have growing impact even on the supply chain surrounding the companies, which means that the some technologies are changing the relationships between business partners. Some material suppliers are becoming technology providers; most of the smart material providers are subject to strict selection and performance evaluation.

Nevertheless, compared to the first three clusters already described, the TRL distribution is a bit different for ‘ICT’ and ‘equipment manufacturing’. On top, ‘Multipurpose and hybrid processes’ has the highest business model impact and it is market ready: companies will not have to invest a lot of effort to introduce them. Actually, they have to rely on new suppliers, the technology enables better responsiveness to customer demand and there will be costs for new machinery and even staff training, maintenance, etc. With respect to multipurpose and hybrid processes, we identify Robotics and Addictive Manufacturing as market ready and easier to be applied (hybrid is more tricky due to its complex nature).

We underline that modelling and simulation, business intelligence and sensors, even though they have a low BMI, will make life easier to companies when adopting them in the early future. Nevertheless, the introduction of sensors, monitoring and control makes it necessary to define interfaces and remote control, which may be challenging for some companies. Finally, Big data is market ready and has a medium BMI: it is important that companies learn how to manage and exploit this technology on short term. Big data can provide new and relevant opportunities to optimize data driven manufacturing, it enables better management of the innovation and the definition and analysis of the effects of location, which will lead to a properly configured supply chain.



	Capacity	Product	Innovation	Location	Feedstock	Energy
Additive manufacturing	▨	🟩	🟩	🟩	🟩	
Big Data	🟩		🟩	🟩	▨	
Cloud based platforms	▨	🟩	▨	🟩	▨	
Data mining	🟩		🟩	🟩		
Internet of things	🟩	🟩	🟩	🟩	▨	🟩
Life cycle assessment	▨	🟩	🟩		▨	
Modelling and simulation	▨	🟩	▨	▨	▨	▨
Product configuration						
Robotics	🟩	🟩				▨
Smart materials	▨	🟩	🟩			
Multipurpose and hybrid processes	🟩	🟩	▨	🟩		🟩
Adaptable and reconfigurable systems	🟩	🟩	▨	🟩	▨	
Materials end-of-life						
Virtual reality		▨	🟩			
3D scanning	▨	🟩	🟩			
Business Intelligence	▨	🟩	▨	▨		
Sensors, monitoring and control	🟩	🟩	🟩		▨	🟩

🟩	Yes
▨	Limited
	No/Maybe

Figure 44: Detailed overview of the flexibility profile of technologies of the MC business model archetype

The figure above displays the assessed flexibility profile of the different technologies in the archetype. Internet of things enables flexibility almost at all levels. The following three best performing technologies are Addictive Manufacturing, Multipurpose and hybrid processes and Sensors, monitoring and control. There are many technologies enabling capacity, product and innovation flexibility, which are strictly connected with the structural features of MC.
Concerning feedstock and energy flexibility, they are not supported as well as the others because these two dimensions have a minor impact and minor consideration for the MC.

The 'ICT' cluster has an average impact on flexibility. An exception is internet of things (IOT), which is one of the widest technology classes. The activities enabled by data collected by sensors create opportunities for more direct integration of the physical world, thus reducing human activity and, at the same time, improve efficiency, accuracy and economic benefit across a wide range of sectors.

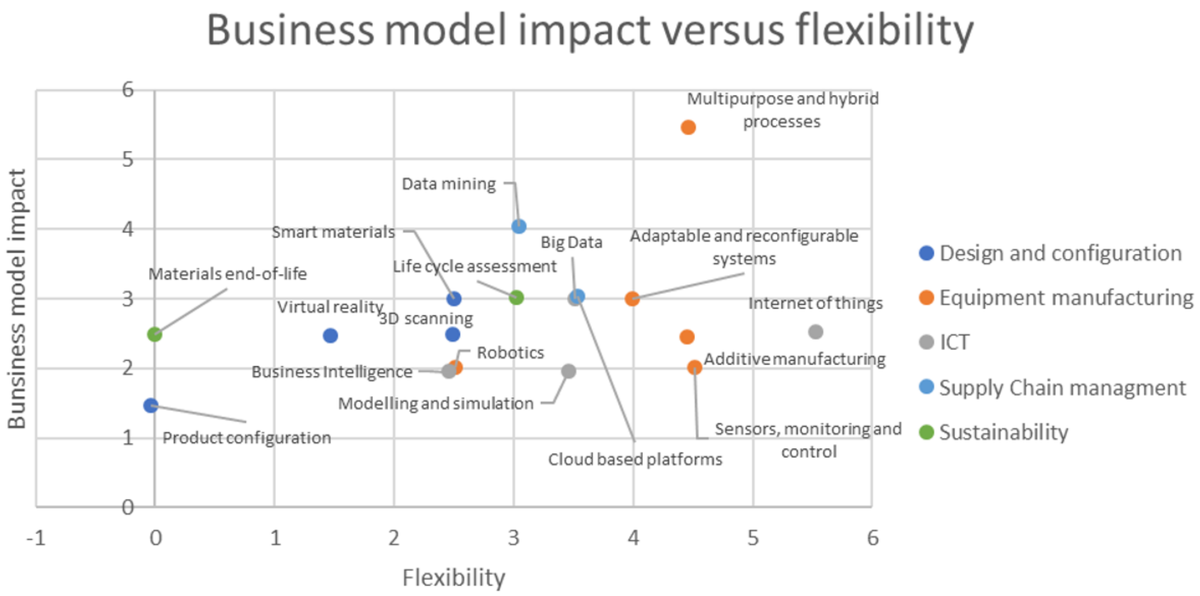


Figure 45: Distribution of technologies in the MC archetype by cluster, flexibility and business model impact

Figure 45 shows the impact of the technologies on flexibility and business model. Multipurpose and hybrid processes stand out with relatively high flexibility and high business model impact across a wide range of sectors, due to its adaptability and capability to enable different kind of working processing for different materials. The cluster ‘Design and configuration’ has a lower effect than ‘Equipment manufacturing’ but this is due to the considered dimensions of flexibility which are more linked to production than to the design phase. Smart materials and life cycle assessment have positive implications for gradual improving quality, maintenance and system lifecycle.

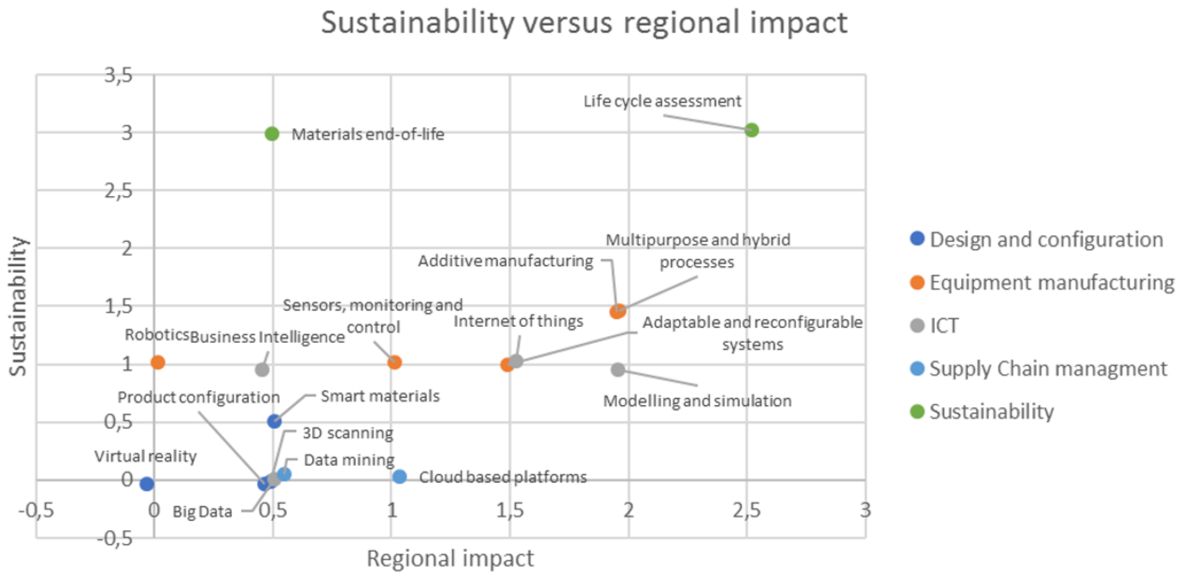


Figure 46: Distribution of technologies in the MC archetype by cluster, sustainability and regional impact

Considering single technology clusters, we observe similar features and clear distinctions among them. Reasonably Materials end-of-life and Life cycle assessment have a strong positive impact on sustainability, the former because of the impact on the decrease of the use of primary raw materials and the latter because of its impact on monitoring the carbon footprint.

The impact of 'Equipment manufacturing' and 'ICT' on sustainability is lower than in the previous case because some sub-categories are positively influenced (like for example the use of materials in case of additive manufacturing) while the impact on the carbon footprint of some technologies is still to be demonstrated. Robotics regional impact is near to zero especially because the creation of jobs, strictly correlated to the technology itself, is not demonstrated. Internet of things seems to have higher impact because it can create local business opportunities by exploiting local strength, and adaptable and reconfigurable systems is expected to create local business opportunities since innovation is facilitated and small batch production is enabled.

Modelling and simulation has a strong regional impact because local IT providers or consulting companies can find new business opportunities to support industrial companies in the implementation of these tools for MC. Then multipurpose and hybrid processes and additive manufacturing have similar regional impact, since they potentially enable to satisfy new market niches and it is expected to create local business opportunities, plus positive impact on local health and environment as well.

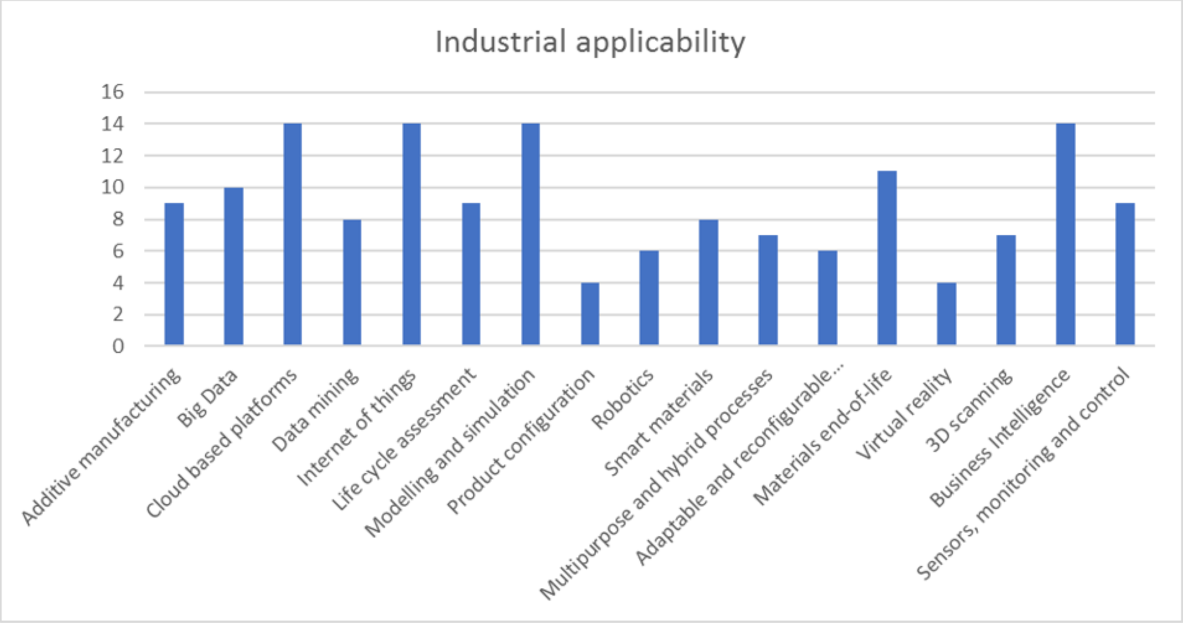


Figure 47: The number of industries in which the technology is applicable

Figure 47 presents the number of industries in which the technology is applicable. Most of technologies considered can be widely adopted by different kind of industries, even if ICT technologies appear as the most spread. Due to the increasing need to face sustainability issues, both Materials end-of-life and Life cycle assessment are rising. Product configuration and Virtual and augmented reality are strongly related to the customization process, in particular within the selling phase of B2C industries.

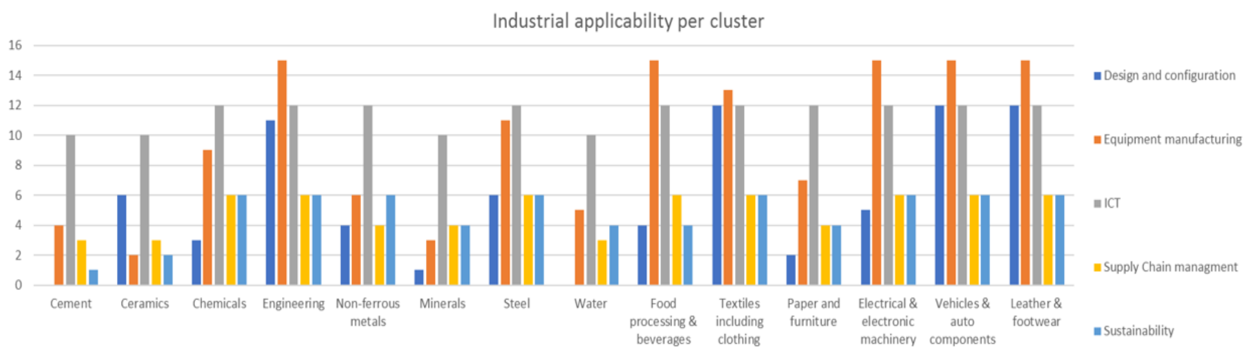


Figure 48: Applicability of technologies in processing and manufacturing sectors by cluster

In Figure 48 the applicability of technologies in processing and manufacturing sectors by clusters is shown. Mass Customization can be applied to many different sectors, in particular in textile & clothing, automotive and engineering industries. Other sectors are increasingly adopting this paradigm and related technologies as steel, non-ferrous metal and chemicals industries. Among technology clusters, ICT is the one that has been identified as applicable in most of all sectors. Also, equipment manufacturing has been recognized as highly adopted in different industries. Also in this case, the cement industry is one sector where the customization paradigm seems not easily adoptable.

3.8 Comparison of the archetypes

After the detailed analysis per archetype, in this section the conclusions that can be drawn for different archetypes will be compared. Where applicable we organized the graphics in the following structure. As we will only focus on the morphology of the graphics, these graphics are not intended to be readable.

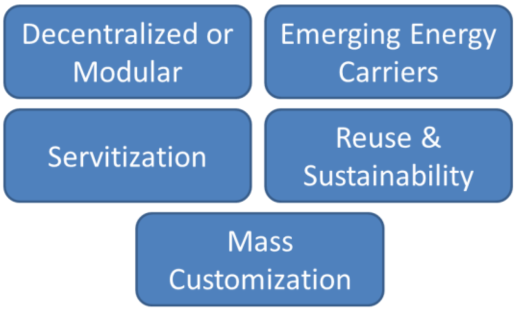


Figure 49 Structure and ordering of archetypes in the following analysis

3.8.1 Technology Readiness Level

The figure below represents the technology radars of the 5 BM archetypes according to the structure indicated in Figure 49.

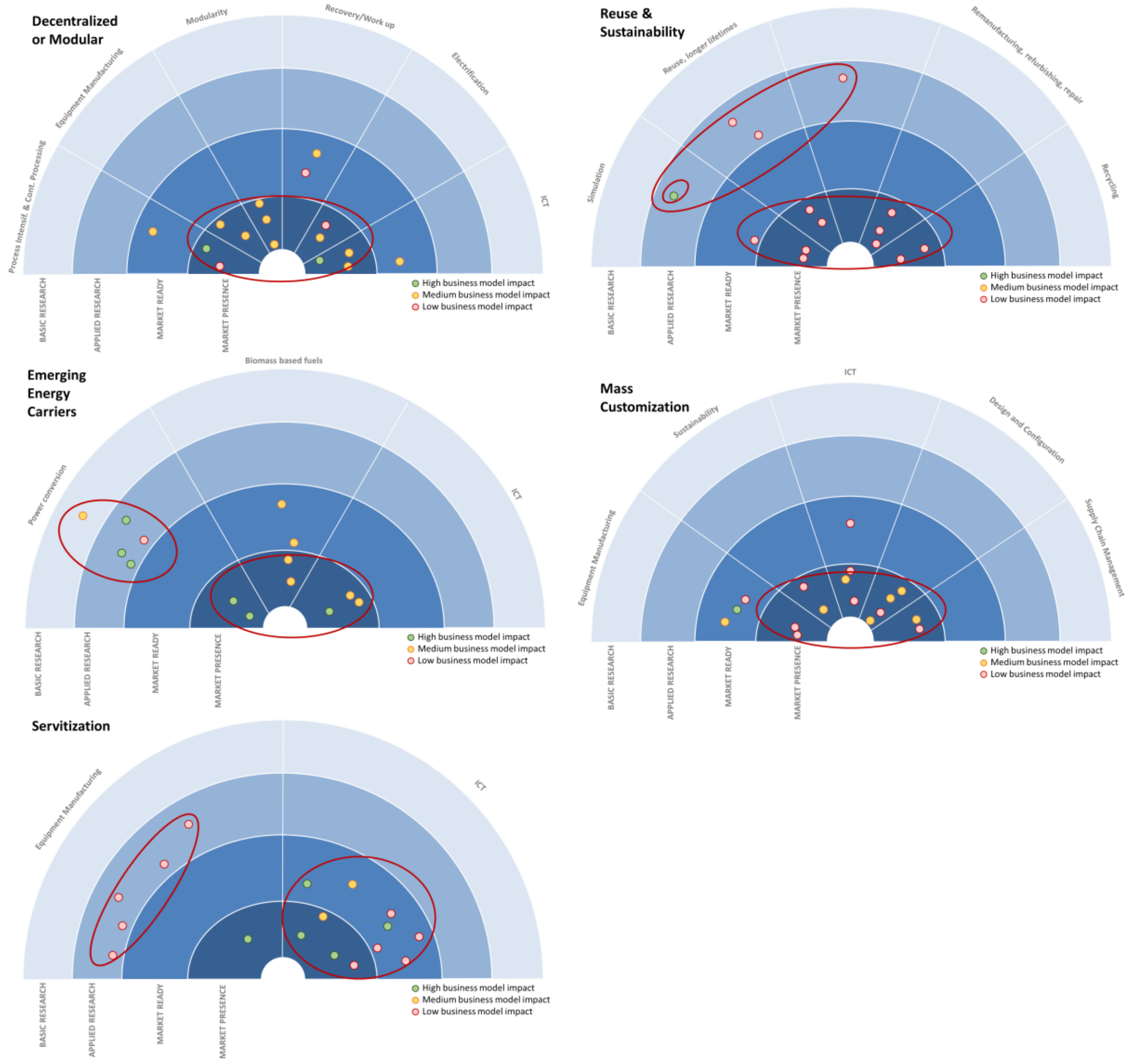


Figure 50: Technology Radars for the five BM Archetypes

In both Mass Customization and Decentralized or Modular we observe a rather crowded ‘heart’ of the radar. This indicates that there are a lot of technologies that are market ready or market present. These more mature technologies were prioritized in the technology selection process above technologies in an earlier development stage. In the other three archetypes we observe clusters of emerging technologies. For the archetype Emerging Energy Carriers there are ongoing R&D developments in the cluster of Power Conversion. In Servitization there are ongoing R&D developments in the cluster of Equipment Manufacturing. For the Reuse & Sustainability there are technologies under construction, but these are scarcely and scattered over different clusters.

3.8.2 Business model impact and flexibility

3.8.2.1 Flexibility

The figure below presents the flexibility profiles for each of the archetypes by technology, organized according to the structure reflected in Figure 51.

Figure 51: Flexibility profiles for the different Archetypes.

This figure clearly shows differences in density. The Decentralized or Modular archetype, being the densest one, shows an emphasis on Capacity and Location flexibility. It also contains the largest number of ‘all-round flexible’ technologies together with the Mass Customization archetype. The Emerging Energy Carriers and Servitization archetypes have the least number of all-round flexible technologies. The Emerging Energy Carriers and Reuse & Sustainability archetypes have an emphasis on feedstock flexibility, whereas both Servitization and Mass Customization emphasize the product and Innovation flexibilities. These are virtually absent in EEC and Reuse. In summary, one could say that the archetypes display a complementary yet jointly complete profile of flexibilities.

3.8.2.2 Flexibility & Business Model Impact

The figure below shows the plots in which business model impact is confronted with flexibility for each of the archetypes.

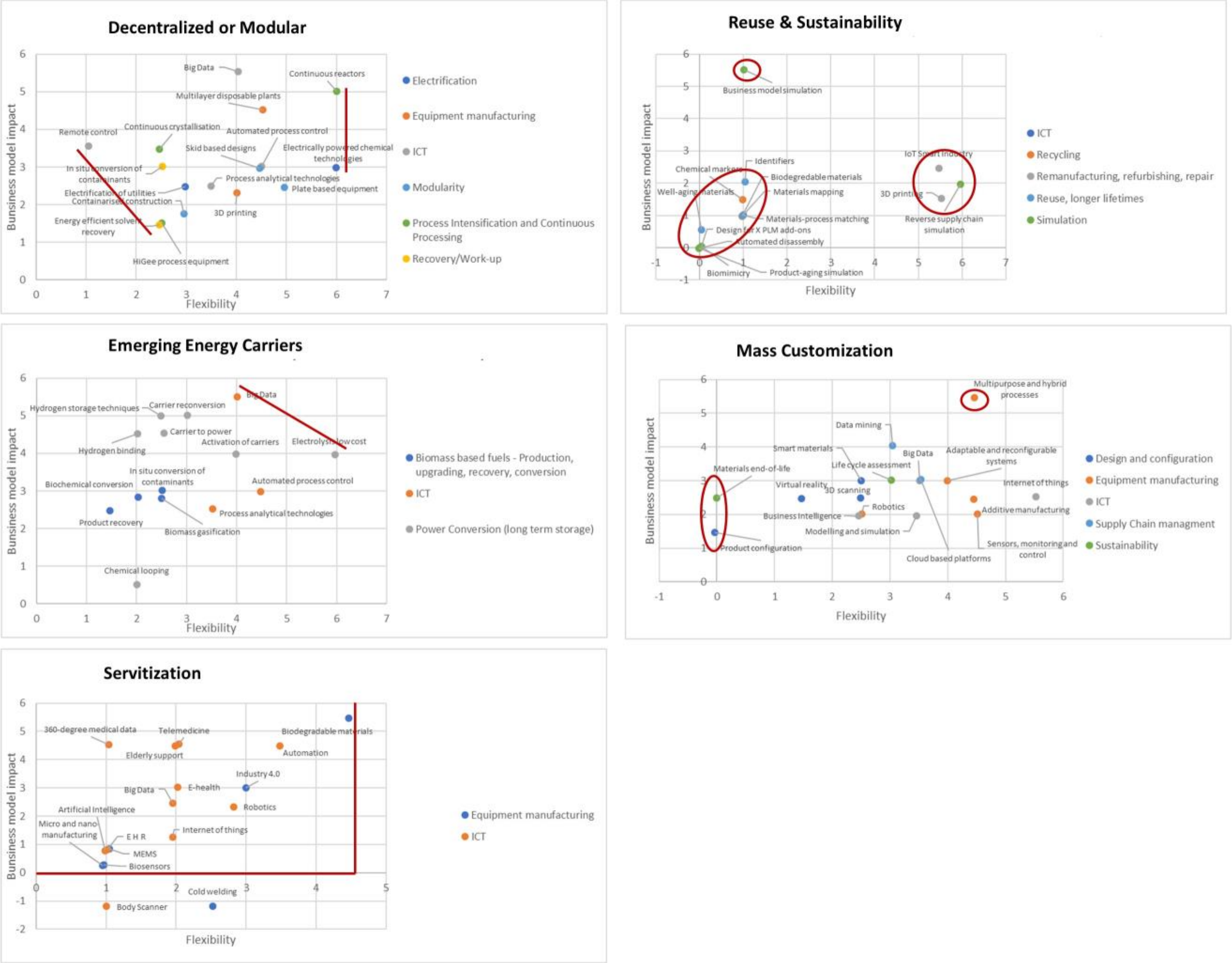


Figure 52: Business model impact and flexibility for the different Archetypes

These plots confirm the somewhat different patterns of the archetypes. A first remarkable pattern can be found in the Reuse & Sustainability archetype. This one shows two clusters and an ‘outlier’. One cluster is quite modest in terms of both flexibility and business model impact, while the other is mostly flexible. These are the all-round flexible technologies identified earlier. The ‘outlier’ merely has a high business model impact potential. The Mass Customization shows two remarkable outliers, one with high flexibility and high potential business model impact and two with no flexibility at all. The core cluster in this archetype shows varying levels of flexibility but with limited business model impacts. The Decentralized or Modular archetype shows a stronger coherence (i.e. one cluster, between the two red lines), with a consistent spread. A similar but slightly scarcer spread is displayed by the EEC archetype, left of the red line. The Servitization archetype even shows technologies with identified barriers (negative business model impact, below the horizontal red line) and a contained flexibility (left of the vertical red line). In general, we can conclude that positive business model impacts are not corresponding to high levels of flexibility in the technology and that these patterns differ per archetype.

3.8.3 Sustainability and Regional Impact

The figure below illustrates the confrontation of sustainability and regional impacts of the technologies in the archetypes.

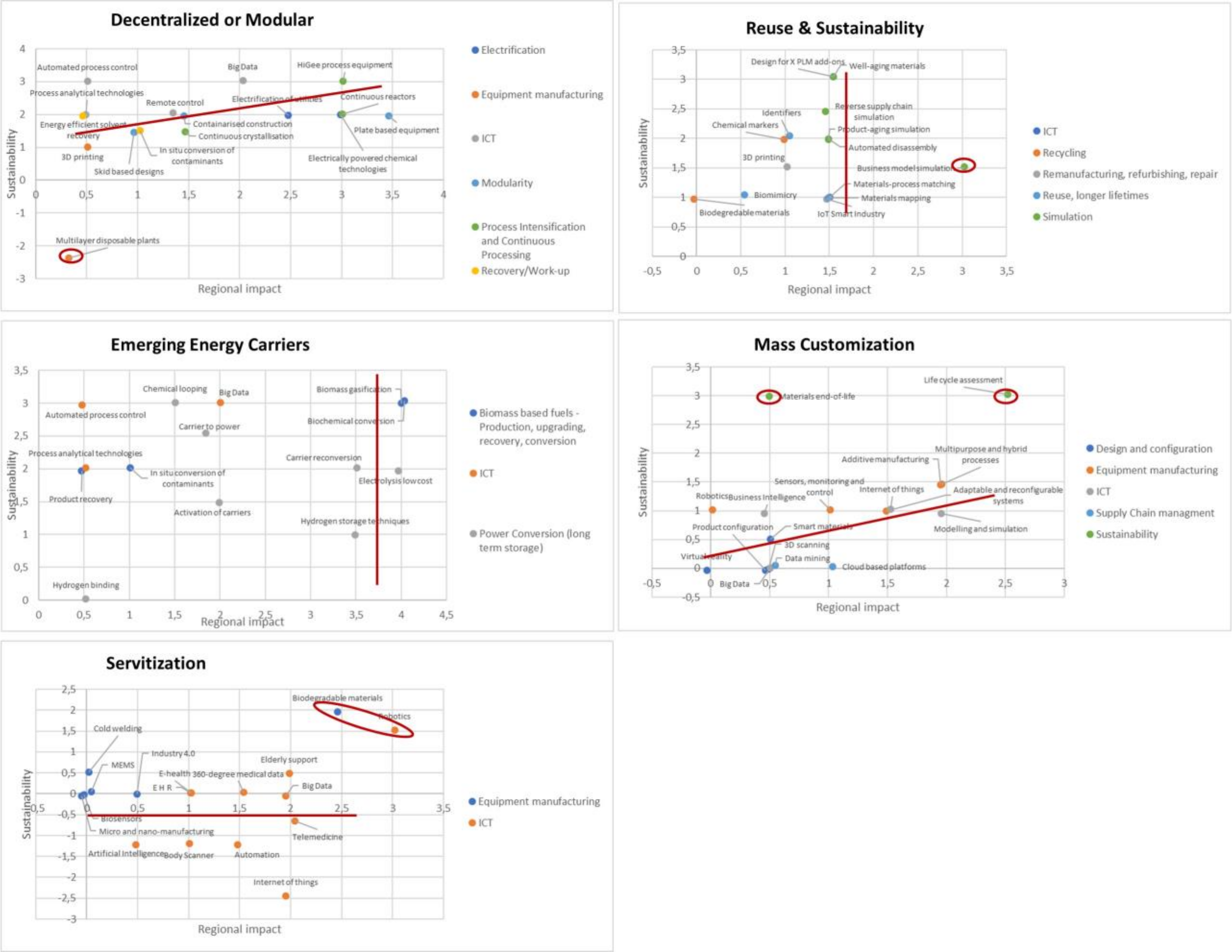


Figure 53: Sustainability and regional impact for the different archetypes

The figure above again shows differences in patterns between the archetype, suggesting different relations between sustainability and regional impact. A first observation can be found in the Servitization archetype, where the technologies revolve around the ‘no sustainability impact’ horizontal line (with two exceptions). This has to do with the focus of the servitization concepts studied (what is being servitized). The Reuse archetype shows a limitation in regional impact (with one exception), combined with varying levels of sustainability. The mentioned limitation can be explained by the “add-on” to an otherwise intact supply chain view of the archetype. Both Mass Customization and D&M show a positive ‘trend’ between regional impact and sustainability, although the D&M line is structurally higher. This reflects the conclusions drawn in the two previous sections (i.e. affected supply chain structure versus within supply chain change).

3.8.4 Industrial applicability

The figure below reflects the industrial applicability of the individual technologies within the archetypes.

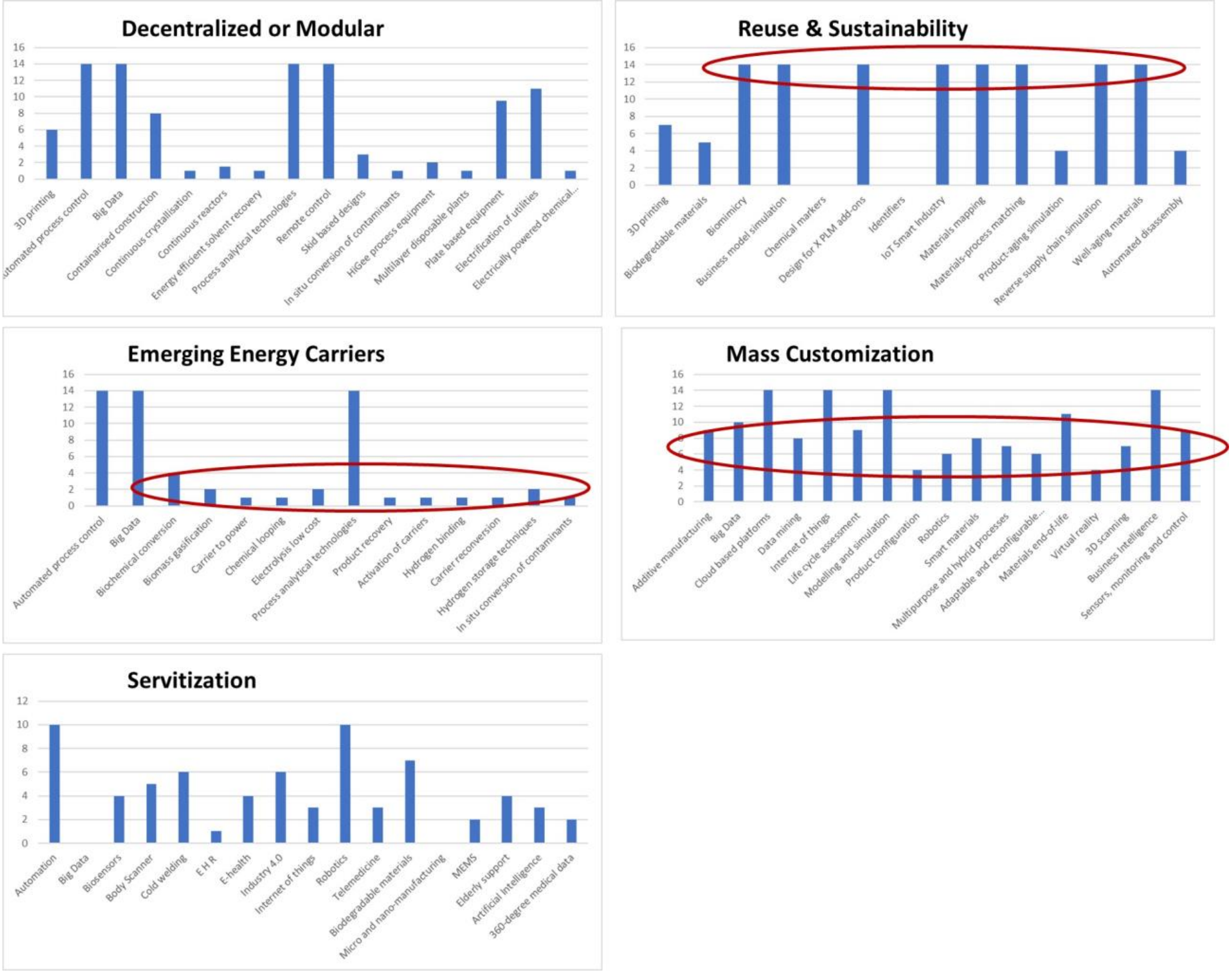


Figure 54: Industrial applicability of specific technologies for the different Archetypes

Overall, each of the profiles consists of both generally applicable ("horizontal") technologies and domain specific technologies, although the number of these generic technologies varies per archetype. The Reuse archetype includes many technologies that can be applied in many sectors, which reflects the "add-on" nature of the archetype. The EEC archetype technologies indicate the opposite of this pattern, with a few generic enablers – probably related to enabling controlling and linking energy sources and storage. The other three archetypes have more mixed profiles, but the 'minimum' of the Mass Customization archetype is somewhat higher. This indicates that those technologies are 'semi-generic'. This seems to suggest that Mass Customization technologies have a wide application potential.

The figure below shows the applicability of the clusters in the archetype to each of the sectors.

Figure 55: Industrial applicability per cluster of the five different Archetypes.

The figures show strong differences in applicability per cluster, suggesting that the ‘generic’ technologies typically belong to one cluster (such as ICT). This figure also reveals an emphasis of D&M and EEC on chemical industry and engineering. This is a consequence of the cases studied. These figures further reinforce the insights from the previous graphics.

4 Conclusions and Discussion

4.1 On the archetypes

In this section we summarize the conclusions from chapter 6. In Table XX the main conclusions per archetype are shown, this is explained in more detail below.

	Decentralized or Modular	**Emerging Energy Carriers**	**Servitization**	**Reuse & Sustainability**	**Mass Customization**
TRL	Mostly market present	Ongoing R&D in power conversion	Ongoing R&D in equipment manufacturing	Mostly market present, some R&D in various clusters.	Mostly market present
Business model impact	Few market present highlights, mostly positive impact	Highlights both market present and R&D. Mostly positive.	Some market present highlights, some have clear barriers (negative BMI)	Highlights ongoing R&D, mostly low impact, positive exception.	Mixed business model impact. Very few broad impact technologies.
Flexibility	Broad flexibility, capacity and location stand out. Some all-round technologies.	Mostly feedstock and energy. Few all-round technologies	Very strong in product and innovation, not much in other categories. Very few all-round technologies	Strong in feedstock. Some all-round technologies. Overall low flexibility.	Varies positively. Mostly product and innovation flexibility. Some capacity flexibility to manage small lots. Few all-round technologies
Sustainability	Mostly positive. One negative exception.	Varies strongly	Doubtful, many have negative impact.	Varies, positively	Moderate, with strongly positive exceptions
Regional Impact	Varies positively.	Varies strongly, positively.	Varies, with positive exceptions	Moderate, with positive exception	Moderate
Industrial applicability	Some technologies are very generically applicable, others are domain specific	Some technologies are very generically applicable, but most are very domain specific	Varies, but mostly moderate.	Many technologies are generically applicable	Varies slightly, mostly broad applicability.

Table 10: Summarized conclusions from the assessment of technologies

We did analysis on the relation between business model impact and flexibility (Figure 52). In general, we conclude that positive business model impacts are not corresponding to high levels of flexibility. We also analyzed the relation between sustainability and regional impact (Figure 53). Here the same conclusions can be drawn: very different patterns appear for different archetypes and no general conclusions can be drawn on the relation between sustainability and regional impact.

The findings lead to the conclusion that the different indicators on which the assessment was performed, are not (strongly) correlated and therefore it is important to take all these indictors into account when performing an assessment, to obtain a complete image.

4.1.1 Decentralized or modular

This archetype mainly features market present technologies. While looking at the type of flexibility, we see a wide flexibility. Capacity and location flexibility stand out, as we expected from the definition of the archetype. The industrial applicability of the ICT cluster is very high, while the other clusters show lower applicability.

4.1.2 Emerging Energy Carriers

The TRL of this archetype is relatively low compared to the other archetypes. Except for the ICT cluster. The strongest flexibilities for this archetype are feedstock and energy, because this archetype considers energy and technologies allowing a more flexible choice of energy (feedstock). The ICT cluster technologies clearly show a broad industrial applicability, while the rest of the technologies have a narrow applicability. The applicability of new energy technologies is mainly in chemicals and in industries that use bio feedstock.

4.1.3 Servitization

The Servitization archetype features many R&D technologies, especially in the equipment manufacturing cluster. Many technologies in this archetype have low or negative sustainability impact, because of large impacts on natural resources and high energy intensive production processes. The flexibility enabled by technologies for this archetype is very specific, and concentrates on product and innovation flexibility. The industrial applicability of this archetype is moderate, with, remarkably, also moderate applicability of the ICT cluster technologies.

4.1.4 Reuse

Reuse features many market present technologies and some ongoing R&D. The business model impact of the investigated technologies is low. The reason is that despite a potentially large impact on operations, the business model essentially stays the same, when technologies in this archetype are applied. As is to be expected, the sustainability scoring of this archetype is relatively high. The flexibility can mainly be found in feedstock flexibility, and the archetype contains some very flexible technologies: for technologies for which the flexibility gain can be estimated, the gain applies to all flexibility indicators. The industrial applicability of this archetype is very large.

4.1.5 Mass Customization

This archetype mainly features market present technologies, except for the equipment manufacturing cluster. This archetype mainly enhances capacity, product and innovation flexibility, and hardly any energy and feedstock flexibility, as these dimensions have minor impact and consideration for Mass Customization. Mass Customization technologies have a wide application potential.

4.2 On technology as an enabler of new business models

In the introduction of this document we presented briefly the approach of INSPIRE to technology enabled new business models for the European processing and manufacturing industry. We have assessed a great number of technologies in context of their clusters and archetypes following the INSPIRE Technology Assessment Framework. This has brought a number of insights of the complex relations of technology with new business models.

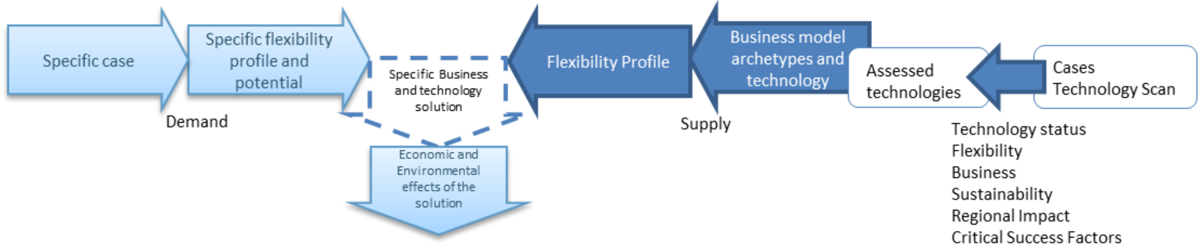


Figure 56: approach for WP2

A key observation is that each technology is different. We have observed *generic* technologies or approaches (such as Internet of Things, electrification or membranes) and *specific* technologies (such as biodegradable materials) as enablers of business models. And others *solve* a specific problem, such as energy efficient solvents, that add to the feasibility of decentralized concepts. And we have not been able to find whether one is better than the other.

The problem of *attribution* is also relevant for assessing *enabling* technologies. This was visible in the assessment of sustainability of the enabling technologies for the Reuse & Sustainability archetype. Although these technologies play essential roles in achieving sustainability: many of these technologies require extensive coordination via a business model or in the supply chain (e.g. recycling) in order to achieve the sustainability effects – application of these technologies in isolation (which is assessed) may not.

There's also the *immediacy* of the technology on the effect: Both big data analysis as well as chemical looping may enable (sustainability) effects, however the latter acts directly on the material flow, whereas the first provides intelligence to design or control operations in a (more) sustainable fashion. One can even see *delays* in effect, e.g. a long causal chain from the application of a technology, e.g. a simulation of business model alternatives to implementation to effect.

We have also found that technologies can be *complementary* (like electrically powered chemical technologies and automated process control for example), which implies that *systems of technologies* make for a higher level and more powerful enabler than either one of their sub technologies does. This implies that assessments of standalone technologies are less powerful if one cannot make assumptions on the overarching system. Without making such distinctions (in immediacy, complementarity, delays) it is impossible to infer up front for instance what type and magnitude of sustainability effects a technology may bring. For example, the product-service system (PSS) is a *system*, praised for its ability to align incentives of both manufacturers, owners and users (e.g. pay-per-lux). It is composed of multiple technologies and services; in this study we assessed only individual technologies, not system concepts.

With respect to business models, some technologies can be seen as a "component" (e.g. product-aging simulation) and some can be seen as the "heart" of the business model (e.g. continuous reactors). This means that some technologies only influence operations without influencing the value proposition or revenue mechanism and others shape the core production capacity and require redesigning the business model. Note that despite potentially high impact on the business, business model impact itself may be modest. Business impact and business model impact is not the same. Also, we have not seen that high levels of flexibility enabled by the technology correspond to positive business model impacts (or vice versa). This seems to suggest that *business impact, flexibility and business model impact are, from the perspective of the technology, independent dimensions*.

By inferring from the type of supply chain and ecosystem impact we derive different 'supply chain impacts' for each of the archetypes: cases in Emergent Energy Carrier technologies and Decentralized or Modular technologies typically install new assets that affect the *structure of the supply chain* and hence may incur changes in regional production. (EEC technologies converge conventional production and energy distribution). Servitization and Mass Customization typically change the *relations and processes within the supply chain* but not so much its structure (and hence potentially limited regional impact). The Reuse archetype can be seen as an "*add-on*" to the otherwise intact supply chain. Such changes are also reflected by the dominant flexibilities associated with each of the archetypes: Servitization and Mass Customization technologies typically enable product and innovation flexibility, whereas Reuse technologies enable feedstock flexibility. Emerging Energy Carriers and Decentralized or

Modular technologies enable capacity and location flexibility. One could say that the technologies in the archetypes display a complementary (yet jointly complete) profile of flexibilities.

The insights above lead to the conclusion that technologies are best considered in scope of the technological system, its business model and its supply chain. Consequently, the dimensions of the INSPIRE technology assessment framework provides relevant and independent dimensions. For a given technology, one cannot infer the impact on these dimensions based on its membership to a cluster or business model archetype. No shortcuts.
Conversely, reviewing technologies in context of clusters and business model archetypes on these dimensions does bring forward a wealth of considerations relevant to designing new specific business models.

4.3 On the INSPIRE Technology Intelligence Approach

The INSPIRE Technology Intelligence Approach is based on the Technology Radar as devised by Deutsche Telekom and adapted to fit in the INSPIRE project. One of the major differences with the original methodology is that the scope of application within the INSPIRE is largely undetermined. It should, in our view, in principle be made relevant to any business wishing to consider new business models in line with the objectives of increasing European resilience.
This large scope of applications brings forward a large scope of diverse and continuously emerging technologies. The archetype of 'Emerging Energy Carriers' that was identified during the work in WP1 and WP3 is a token thereof. It is not in the objectives or means of this project to achieve a complete or fully representative overview of relevant technologies. Therefore, INSPIRE had to apply a reasonable heuristic approach, described in Chapter 5.

While applying this approach in context of INSPIRE several learnings came forward.

The set of technologies included in this study is the result of a selection process. In this process some concrete cases were more prominent than others. At moments of selection technologies with the higher TRL were prioritized. Although the purpose of this study was not completeness, at moments some degree of '*bias*' could be felt in the selection of technologies and the assessments. This consequence was foreseen and accepted in favor of the improved insights that can be gained by studying objects in a *concrete context*. Within the archetypes we used clusters and in the selection process we attempted to balance the number of technologies in each cluster per archetype somewhat. Although these clusters were not formally derived, we feel that this balancing provided at least some level of generalizability towards the archetype and the scope of the study. And although a relatively high number of technologies were studied and to some extent numerically processed, the nature of this study remains largely qualitative (yet structured) because of the level of interpretation our experts deployed in the assessment tasks.

During the assessment some overlap in reasoning was experienced in for instance the dimension "Safety, Health and Environment" of the regional impact, more specifically the environment, and sustainability. Also, in cases similar reasoning in business model impact and flexibilities and direct job creation in regional impact was experienced. Overall, however, these dimensions appeared largely independent, which seems to confirm that these levels can be assessed in parallel. Furthermore, the actual value for assessing such dimensions would lie in the insights it brings for developing new business models. The experts also felt that in order to assess the dimensions, specifically sustainability and regional impact, but also the others, explicit reasoning was required to derive conclusions. It was observed that this explicit reasoning often leads to somewhat counterintuitive conclusions, e.g. in assessing the technologies for the Reuse & Sustainability archetype. While these have a potentially strong influence on the overall sustainability of the products, this is largely independent from the local environment of the manufacturer. An assessment can capture ‘a broad range of underlying mechanisms from a long causal chain from the application of a technology. The need for such explicit reasoning implies the nuanced understanding that the assessment indicates the *potential* for an impact in the assessed dimension when applying the technology (in context of the business model). And while the numerical processing of the assessment in its current state cannot reflect such interpretations, we feel it should be emphasized that such reasoning is extremely relevant when designing and evaluating a new business model.

To provide the graphical plots as in Chapter 3, we had to make transformations of the multiple dimensions of the assessment to 1 or two numbers. Obviously, in such transformation a lot of nuance and information is lost. Nevertheless, we also felt that the different presentations trigger navigation and deep diving in the technology descriptions and assessments to find an explanation. By seeking for explanations for a specific assessment or characteristic of a given technology or cluster, one needs to dive into the details of this. This goes to show that seeking for the rationale and considerations behind the assessment provides a good method for learning about technology assessments in context of new business models.

The technology radar we provided resembles the originally proposed radar. However, one difference is the categorization of the dots in the plots originally reflects relevance to the business of the focal company. This focal company is absent in this study, and replaced by the archetype.

All considered, we observe some challenges for the methodology when applying it to a large scope and with distributed inputs. However, we feel it met the design requirements and are convinced that it adds even more value if the application context is more concrete. We feel that more explicit attention for the nature and system context of the technologies (Section 4.2) could improve its performance.

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A1 Description of technologies

A1.1 Decentralized or Modular

A1.1.1 Overview

The decentralized or modular production can be enabled by several technologies, which are classified into categories of modularity, ICT, electrification, equipment manufacturing, process intensification and continuous processing and recovery/work-up. This overview is adapted from van Kranenburg et al. (2015)[21].

Modularity is an approach that subdivides processes into separate parts (modules) that can be independently created and then connected either in parallel for copying plant parts[21], for instance to enable increase/decrease in capacity, or in series for connecting multiple process steps, for instance to enable modular plant construction or change to unit operations at a decentralized location Thereby enabling the use of resources (feedstock or energy) available at a decentralized location and at the same time minimizing logistics in the value chain.

ICT technologies refer to the gathering of inline (live, continuous and running) information of the production plants and making predictive and holistic process models for monitoring and control of continuous, remote controlled decentralized plants. As information technologies progress, production plants will be made more intelligent, more efficient and more independent. By integrating sensors and ICT in flexible production, more insight in the condition of assets is gained. This information can be used to prevent downtime, increase safety, maintain stocks efficiently, and to make the value chain more efficient. All these aspects contribute to increasing the robustness and the productivity, whilst decreasing maintenance costs.

Electrification refers to transformation of electrical energy to thermal, mechanical or chemical energy. The conversion to chemical energy in the form of fuel or chemical commodities (for instance, formic acid) is especially interesting as it enables the production, storage and application on demand at a centralized or a decentralized location. Thus, providing flexibility and new opportunities.

Equipment manufacturing in this section refers to novel inexpensive mass production technologies. These technologies should be able to produce complex parts that can resist process environmental conditions, are relatively easy and low-cost to make and that can be changed easily in geometry (shape, size and form). More specifically, possibilities of making custom designed geometry of custom application whenever required. Technologies here include 3D printing and disposable plastics aimed at decentralized application for chemical processing.

Process intensification is an approach in chemical engineering that can be described as ‘a strategy for making dramatic reductions in the size of a chemical plant to achieve a given production objective’. This approach is achieved by combining several steps or unit operations such as reaction step, separation step or size reduction step of a process into one step. When employed correctly, process intensification and continuous processing offer a huge increase in

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[21] Van Kranenburg, K., Sofra, S., Verdoes, D. et al (2015), Small scale flexible plants, towards a more agile and competitive EU chemical industry, TNO Innovation for life.

productivity at a much lower operational and capital costs and a much smaller plant footprint compared to employing traditional methods and technologies. Thus, enabling safer, time efficient, resource efficient and space efficient decentralized production.

Recovery and work up technologies refer to efficiently high recovery and separation of products and contaminants from a reaction mixture of chemicals and at the same time enhance the production of desired product. Inline (in-situ) separation of (by) products using low energy technologies like membrane separation can not only increase the yield of desired production but also reduce the energy requirement. Thus, reducing the need of large scale equipment and utility (boiler) sources and enabling decentralized production of chemicals.

The following section outlines the major characteristics of individual technologies which fall under the overall classification of technology categories described above.

A1.1.2 Modularity

A1.1.2.1Skid Base Design

Relevance: High
TRL: market ready / market present

- Skid based design refers to construction of chemical process and unit operations in a transportable skid/ box construction which can be stacked one of the other in a modular way thus falls in the technology cluster of modularity.
- Skid based design are most appropriate for small capacity process plants, for which complete plants can be manufactured on skid. For large capacity plants, skid based design can provide the advantage of parallel construction, where process systems are built off-site in a fabrication facility while civil site upgrades are completed at the plant site simultaneously.
- These designs can be made in series leading to standardized construction.
- Utilities (power / water / steam) are generic and easier to be offered as standard (range) skids than chemical specific reaction or separation. Flow skids (pump, flow meter, valves etc.) are commercially available and market ready.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	For utilities and fluids handling commercially available
Flexibility			
	Capacity	3	number of skids to be varied
	Product	2	change skid with product
	Innovation	3	rental skids
	Location	3	rental skids, skid based production can easily be moved
	Feedstock (or Input)	3	change skid with feedstock
	Energy	1	number of skids to be varied
Business Model Impact			
	Supply	3	Skids manufacturing/rental
	Demand	0	
	Chain	2	
	Ecosystem	2	Different business models for equipment providers
	Cost	3	Lower cost because the process can be set-up and changed more efficiently

	Revenue	0	
	Overall	1	
Sustainability			
	Material use	3	match demand (and material use) with capacity
	Environmental footprint	1	
	Energy	2	Better matched demand and capacity means less energy use
	Strategy	3	match demand (and material use) with capacity
Regional Impact			
	Safety, Health and Environment	1	
	Material flow	1	It has an impact because demand is matched with capacity, but not necessarily local
	Direct jobs	1	
	Business opportunities	3	Skid equipment and maintenance business models
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	0	
	Paper and furniture	1	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.1.2.2 *Plate based equipment*

Relevance: High
TRL: market ready / market present

- Plate based equipment refers to equipment in which functionality of process (for instance, filtration) can be easily extended just by adding the same equipment in the series. This technology enables capacity changes for a process which can be dealt with by increasing /decreasing the number of elements in a skid. Thus, connected to modularity business technology cluster.
- Broadly all kind of equipment that can be / has to be scaled in in capacity by numbering-up – so also hollow fiber membrane modules or spiral wound membrane modules can be categorized as plate based equipment.
- Characteristic is that elements can be produced according to standards in series production.
- Plate based equipment include typical examples such as heat exchangers (plate-type alfa laval), filtration equipment, continuous micro-structured reactors, membrane units, and thus are market ready.

Indicator	**Category**	**Score**	**Explanation**

Technology Readiness Level			
	Overall	4	Membrane based filtration equipment for chemical/ water purification.
Flexibility			
	Capacity	3	Membranes are small and can easily be added if larger production is needed
	Product	2	Other products can be produced using a different filtrate-permeate combination/ membrane pore size.
	Innovation	2	By changing pore size
	Location	3	Truck based system can be designed to make easy movement.
	Feedstock (or Input)	3	Different feedstocks can be used (eg. Organic membranes can be designed to handle a variety of organic feedstock)
	Energy	3	Yes. Adding modular layers can help scale up/ down.
Business Model Impact			
	Supply	2	Membrane suppliers are needed for change/ maintenance.
	Demand	3	Modular production based on filtration can be operated on demand.
	Chain	1	Maybe because of added responsiveness to demand.
	Ecosystem	0	
	Cost	1	Depending on the application; some membranes are expensive than others.
	Revenue	3	Compared to concentration based filtration, membrane based separation can be OPEX friendly and using membranes can generate more/new markets.
	Overall	2	
Sustainability			
	Material use	1	Depending on selectivity this can be lower/ higher.
	Environmental footprint	3	Because evaporation/concentration based literature is energy intensive compared to membranes.
	Energy	3	
	Strategy	3	Materials can be re-used after reworking them/ changing of membranes and membranes are less energy intensive.
Regional Impact			
	Safety, Health and Environment	3	Filtration mostly have lesser impact than concentration.
	Material flow	2	Local high salty water can be used instead of fresh water from far away.
	Direct jobs	3	Local business opportunities for maintenance/ sales of membranes.
	Business opportunities	3	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	2	Water purification is partially applicable to several sectors,
	Ceramics	1	
	Chemicals	3	
	Engineering	2	New membrane modules and equipment's
	Non-ferrous metals	2	Water purification is partially applicable to several sectors,
	Minerals	2	Water purification is partially applicable to several sectors,
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	

	Electrical & electronic machinery	1	Cannot say for sure. Maybe
	Vehicles & auto components	2	Water purification is partially applicable to several sectors,
	Leather & footwear	3	

A1.1.2.3Containerized construction

Relevance: Medium
TRL: market present

- Containerized construction refers to the use of processes/ unit operation in a container structure of standardized dimension. Several unit operations (e.g. compression system, pumping unit, water purification) can be stacked one after the other and hence connected to modularity technology cluster.
- Containerized construction enables easier transport of ready to use unit operations.
- There is containerized construction market ready example for several processes (e.g. compression system, pumping unit, water purification)
- This technology falls under decentralized or modular BT archetype and is market ready example for several processes (e.g. decentral water purification, compression/ pumping units)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Containerized Construction for pumps and compressors.
Flexibility			
	Capacity	3	Small scale containerized compressors (or other processes) can be used and easily scaled
	Product	0	
	Innovation	3	
	Location	3	Small scale containerized compressors can be used and easily relocated
	Feedstock (or Input)	0	
	Energy	0	
Business Model Impact			
	Supply	0	
	Demand	3	New on demand products can be manufactured local and generate market growth
	Chain	3	Containerized processes will be placed further downstream in the supply chain
	Ecosystem	0	
	Cost	4	More costs if done at small scale
	Revenue	3	Yes, as it promotes modular production and generates market growth using modular production
	Overall	3	
Sustainability			
	Material use	2	Not for the equipment, but the production process can better accommodate the market and reduce waste
	Environmental footprint	3	Using containerized production modular and local will reduce logistics
	Energy	2	Using containerized production modular and local can increase the use of local renewable energy

	Strategy	3	smarter manufacture
Regional Impact			
	Safety, Health and Environment	1	Smaller equipment contained safety. But the risks are moved locally.
	Material flow	3	The feedstock can be sourced more local
	Direct jobs	2	Modular multiple units can lead to more local on-site jobs.
	Business opportunities	1	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	1	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	3	

A1.1.3 ICT

A1.1.3.1Automated Process Control

Relevance: High
TRL: market present

- Automated process control combines the use of important process parameters such as pressure, temperature, etc. to make a predictive control of the process of interest. Thus, using information technology for process control and hence categorized under ICT technology cluster.
- High degree of automation is required for M&F production to be economically viable and competitive, and thus APC is highly relevant.
- Continuous flow at steady state conditions is type of process that favors APC; Liquid (mono) phase processes are less sensitive to disruption than multiphase processes and hence favor APC.
- APC is a market ready technology with several examples in process industry[22].

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	For instance, MyH2O2 (Industrial Internet of Things)
Flexibility			
	Capacity	3	The technology is easily scalable and facilitates scalability

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[22] https://www.proleit.co.uk/references/industries/chemistry.html

	Product	3	Easily adjust the production process for a new product
	Innovation	1	The technology itself does not have an impact on innovation flexibility but it can make innovation flexibility easier
	Location	2	The technology is location independent and facilitates the incorporation of remote control
	Feedstock (or Input)	3	Easy adjusting the process based on the feedstock
	Energy	3	Easier and faster control to adjust energy use
Business Model Impact			
	Supply	3	New equipment, new maintenance strategy
	Demand	0	No impact on the demand
	Chain	0	The control only has impact on the production plant
	Ecosystem	3	The technology needs professionals that are skilled in the production process and in ICT
	Cost	3	The technology will lower the production cost through more efficient control
	Revenue	0	No impact on the demand
	Overall	3	
Sustainability			
	Material use	3	The process can be easily adjusted for more efficient material use
	Environmental footprint	3	The process can be easily adjusted for less environmental footprint
	Energy	3	Controlling the energy source/input through automated process control (the technology is a prerequisite for using energy flexibility to DSO's)
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	1	When used correctly it has an impact, but this is not inherent in the technology
	Material flow	0	ICT technology
	Direct jobs	2	Does not need on-site jobs for operating, limited for equipment
	Business opportunities	0	Does create ICT SME opportunities but does not need to be local
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	

	Leather & footwear	3	

A1.1.3.2Process Analytical Technologies

Relevance: High
TRL: market present

- Process analytical technology is an enabler for automated process control adding additional level of functionality; these include FTIR, UV-VIS, NMR, Raman, laser diffraction. The collection and analysis of information from different sources using information technology tools and thus connected to ICT technology cluster.
- Gives additional information on composition of stream during operation (reaction, separation) next to conventional P, T and flow sensors and enables a greater control.
- High degree of automation is required for M&F production to be economically viable and competitive, and thus PAT is highly relevant.
- PAT is a market ready technology.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Sensors
Flexibility			
	Capacity	1	The technology itself is scalable but does not explicitly facilitate scaling up or down the volume
	Product	2	As prerequisite for data analytics
	Innovation	3	Innovation flexibility is easier when more digital information is available and measured
	Location	1	The technology is location independent but does not specifically facilitate location flexibility
	Feedstock (or Input)	3	Facilitates knowledge on different feedstocks and possibly adapting the process
	Energy	3	Facilitates knowledge on the state of the production process/buffer and the energy demand (both in the grid as in the process)
Business Model Impact			
	Supply	3	New measurement equipment
	Demand	0	
	Chain	3	More possibilities for information sharing in the supply chain
	Ecosystem	2	The technology needs professionals that are skilled in ICT
	Cost	1	The technology itself increases cost, but it facilitates cost reducing improvements
	Revenue	0	No impact on the demand
	Overall	2	
Sustainability			
	Material use	2	The technology gives more knowledge on material use, but it needs other technologies to create an effect
	Environmental footprint	2	The technology gives more knowledge on the environmental footprint, but it needs other technologies to create an effect
	Energy	3	More knowledge on the energy market immediately increases the potential of using renewable energy
	Strategy	3	

Regional Impact	Safety, Health and Environment	1	When used correctly it has an impact, but this is not inherent in the technology
	Material flow	0	ICT technology and thus not local materials
	Direct jobs	2	Does not need on-site jobs for operating, limited for equipment and maintenance (sensoring)
	Business opportunities	1	Does create ICT SME opportunities but does not need to be local
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.1.3.3Remote control

Relevance: Medium
TRL: market present

- Remote control of processes means control from a different location, as is practiced for example offshore gas fields, chlorine production. This technology deals with communication of information over distances and thus falls under ICT cluster.
- Remote control of utilities appears common practice (power, steam, water, gasses)
- Remote control initiatives concern nowadays also so called ‘chemical utilities’ e.g. supply of process chemicals like peroxide and chlorine, with suppliers owning and operating the equipment on the site of their customers but without physical presence of employees of the supplier in a control room
- Remote control is an enabler for the introduction of decentralized, highly automated processes e.g. based on electrochemical processing
- Chemical processes that are monitored and controlled from a distant location appear market present for low-hazard operations (utilities)

Indicator	**Category**	**Score**	**Explanation**

Technology Readiness Level	Overall	3	MyH2O2
Flexibility			
	Capacity	1	The technology is easily scalable but does not inherently facilitate scalability
	Product	0	
	Innovation	0	
	Location	3	The technology facilitates making remote production facilities
	Feedstock (or Input)	0	
	Energy	0	
Business Model Impact			
	Supply	2	New ICT supplier
	Demand	3	Closer to the customer may increase demand
	Chain	3	Has an impact on resellers and customers as the distance is shorten (or maybe at customer site)
	Ecosystem	0	
	Cost	1	Remote control increases the cost of the production process (it is easier to produce at existing facility) but it eliminates transportation costs
	Revenue	3	Closer to the customer yields higher revenue (higher price/market demand)
	Overall	3	
Sustainability			
	Material use	0	
	Environmental footprint	3	Less transportation
	Energy	3	Local generated (sustainable) energy sources can be easily incorporated
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	4	Moving the process locally increases risks and remote control also increases risks of communication errors
	Material flow	3	Local placement and remote control of the production process increases opportunities for local sourcing (feedstock/energy)
	Direct jobs	2	Needs less on-site jobs because of the remote control, but needs maintenance and steering locally
	Business opportunities	3	Remote control moves the entire process local and therefore increases the business opportunities
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	

	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.1.3.4Big data analysis

Relevance: Medium
TRL: applied research / market present

- Increased processing capacity of computer systems uses ’cognitive’ technologies for assessing and evaluating massive amounts of data with varying formats. This technology uses collection and analysis of information and falls under ICT technology cluster.
- First applications in process industries concern operations where large quantities of logged process data are available: e.g. optimization of processes and lowering maintenance cost, examples are prediction of process disturbances (compressor trip) and predictive maintenance.
- Further applications concerns finding correlations between feedstock quality, operational performance and product quality, again to optimize the process.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Business Information & Data Analytics, Machine Learning, Artificial Intelligence
Flexibility			
	Capacity	1	The technology is easily scalable but does not inherently facilitate scalability of the process
	Product	3	Analytics improve product flexibility by analyzing which product must be produced (optimization)
	Innovation	3	Improves innovation flexibility by analyzing the process and test results
	Location	1	The technology is location independent but does not facilitate location flexibility
	Feedstock (or Input)	3	Analyzing the (different) feedstocks to create insight on how it can be used in the process
	Energy	3	Analysis for demand patterns and when to adjust the energy use/production
Business Model Impact			
	Supply	2	New ICT supplier
	Demand	3	Analytics improve changing the product and deciding when to produce which product to match demand
	Chain	3	Optimizing collaboration in the supply chain through analysis

	Ecosystem	3	The technology needs professionals that are skilled in the supply chain and in ICT
	Cost	3	The technology will lower the production cost through better optimize the process based on analysis
	Revenue	3	Better adjustment to the demand
	Overall	5	
Sustainability			
	Material use	3	Better understanding of the process can be used to optimize raw material use and predictive maintenance to improve equipment lifetime
	Environmental footprint	3	Better understanding of the process can be used to reduce environmental footprint
	Energy	3	Controlling the energy source/input through automated process control (the technology is a prerequisite for using energy flexibility to DSO's)
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	3	Analysis can be used to optimize Safety, Health and Environment
	Material flow	3	Analysis can be used to optimize local material use
	Direct jobs	0	Does not need on-site jobs for operating
	Business opportunities	1	Does create ICT SME opportunities but does not need to be local
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.1.4 Electrification

A1.1.4.1 Electrification of utilities

Relevance: High
TRL: market present / market ready

- Technologies include electric heating – like electrode boiler for steam, microwave or infrared heating, heat pumps, electric air heaters, but also mechanical vapor recompression, electric cooling equipment and connected to electrification technology cluster.
- M&F operation will be often at small scale and at locations that have limited infrastructure while power grid will be generally available
- Electric utilities can be smaller and less complex (no water circuits) compared to thermal utilities (gas powered steam boilers) or cooling water towers
- Electric utilities allow for use of renewable power; Electric utilities are easy to turn on / off – to deal with availability of renewable power.
- The electrical utilities like steam generator, heat pumps etc. are market ready and highly relevant for M&F operations.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Electric heating/ cooling equipment high TRL technology.
Flexibility			
	Capacity	3	Electric heaters can vary from few watts to several KW.
	Product	0	
	Innovation	1	It can be in case of use of plasma/ microwave reactors.
	Location	3	
	Feedstock (or Input)	1	Plasma can be used to handle different feedstocks.
	Energy	3	Electrification increases the electricity use and thus the possibility to be active on the electricity market
Business Model Impact			
	Supply	0	
	Demand	2	Electrification enables modular production and thus responsiveness
	Chain	1	Maybe in case of plasma/microwave reactors.
	Ecosystem	2	Can be an impact if electricity is traded
	Cost	3	Electricity for small scale steam production can be cheaper than large scale plant.
	Revenue	2	Enabling modular production can lead to changes in demand.
	Overall	1	
Sustainability			
	Material use	3	No fuel requirements thus lower number of raw materials
	Environmental footprint	1	
	Energy	3	Because electricity can be renewable electricity supply.
	Strategy	3	Smarter manufacture in compact manner.
Regional Impact			
	Safety, Health and Environment	2	Lower fuel usage when supplied via renewable electricity.
	Material flow	0	
	Direct jobs	3	Electricity based jobs.
	Business opportunities	3	Local energy SME's
Industrial Applicability (SPIRE and			
	Cement	3	
	Ceramics	3	

Manufacturing clusters)	Chemicals	3	
	Engineering	1	because modular production of nh3 will involve equipment manufacturers/suppliers
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	0	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	0	
	Leather & footwear	3	

A1.1.4.2Electrically powered processes

Relevance: High
TRL: basic research - market present (application dependent)

- Technologies include electrically driven reactors: electrochemical and photochemical cells, microwave and plasma reactors. But also, electrically driven separations – ESP, electrodialysis. These technologies enable the use of electricity and thus connected to electrification technology cluster.
- M&F operation will be often at small scale and at locations that have limited infrastructure while power grid will be generally available
- Electric reactors / separations will be in general of the ‘plate based equipment’ type, capacity can be varied easily by numbering-up
- Electric chemical technologies are easy to turn on / off – to deal with availability (and use) of renewable power
- The first examples for electrical powered technologies are market present (e.g. Chlorine manufacturing) but a widespread application to several chemicals is under various levels of research (depending on chemical).

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Electrochemical reactor for Cl2 production using NaCl.
Flexibility			
	Capacity	3	More modules can be added.
	Product	3	An electrically powered process (e.g. electrochemical cell with carbon electrodes) can possibly handle production of one product at one voltage and with a different feedstock another product at another voltage.
	Innovation	3	New processes can be tested with similar equipment.
	Location	3	It can be truck based system.
	Feedstock (or Input)	3	Different feedstocks (e.g. Cl salts) can be used.
	Energy	3	

Business Model Impact	Supply	0	
	Demand	3	Electrification enables modular production and thus responsiveness
	Chain	1	Possible create more opportunities.
	Ecosystem	1	not significant as your electricity supplier is available.
	Cost	3	Can avoid large scale investments as required in traditional plants.
	Revenue	3	Enabling modular production can lead to changes in demand.
	Overall	3	
Sustainability			
	Material use	3	No fuel requirements thus lower number of raw materials
	Environmental footprint	1	
	Energy	3	Because electricity can be renewable electricity supply.
	Strategy	3	Smarter manufacture in compact manner.
Regional Impact			
	Safety, Health and Environment	3	Lower fuel usage when supplied via renewable electricity, also low hazardous process compared to traditional chlorine production.
	Material flow	1	
	Direct jobs	3	Electricity based jobs.
	Business opportunities	3	Local energy SME's
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	1	Handling of brine
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.1.5 Equipment Manufacturing

A1.1.5.1Multilayer disposable plants

Relevance: Medium

TRL: applied research - market ready

- Multilayer disposable (plastic) plants refer to single use vessels/ equipment/ plant for processing of food and (pharma) chemicals.
- Disposable plants require several vessels to be used for the same unit operations to enable parallel processing enabling increased manufacturing of equipment. Thus, it falls within the technology cluster of equipment manufacturing.
- This technology increases uptime for production by reducing or eliminating the cleaning time required in traditional steel equipment.
- Disposable vessels are market ready and used substantially in food and pharmaceutical manufacturing.

- Although, development is ongoing to extend this batch-configuration technology to complete automated systems.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Multilayer disposable (plastic) equipment/plants
Flexibility			
	Capacity	3	Easy to scale up and down of plastic plants if the margin is high enough (e.g. for pharma companies)
	Product	3	Every batch new plastic modules can be used, this also enables (slightly) new products
	Innovation	3	Every batch new plastic modules can be used, this also enables innovation
	Location	2	Still required to move the auxiliaries
	Feedstock (or Input)	3	Every batch new plastic modules can be used, this also enables the use of (slightly) different feedstock
	Energy	0	
Business Model Impact			
	Supply	2	New plastic based manufacturers are required
	Demand	3	New/ more products can be made due to short uptime and flexible facilities
	Chain	2	More on demand production can enable better delivery times to people downstream.
	Ecosystem	3	Yes, new parties involving plastic manufacturers.
	Cost	2	It is costly but saves on time/cost of cleaning.
	Revenue	3	The benefit of short cleaning times can increase production and hence revenues. And fast product to market/maybe new products
	Overall	3	
Sustainability			
	Material use	4	Plastic plants are used a few times and then disposed of
	Environmental footprint	4	Plastic plants are used a few times and then disposed of
	Energy	0	
	Strategy	1	Plastic plants are disposed of
Regional Impact			
	Safety, Health and Environment	4	Cleaning in semi-continuous manner. Safety of plastic plants.
	Material flow	3	Local sourcing of plastic vessels
	Direct jobs	2	In addition to running equipment, there is requirement of handling the used plastic equipment.
	Business opportunities	1	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	

	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.1.5.23D Printing

Relevance: Medium

TRL: applied research - market ready

- 3D printing is used as additive manufacturing technique for the metal spare parts, ceramics material and other small scale / specialized equipment used in the industry.
- This technology allows manufacturing of several products on location with the same machine. Thus, falls under the BT archetype of decentralized or modular within the cluster of equipment manufacturing.
- 3D printing can be beneficial and applied to industrial manufacturing for instance keeping low level of stocks/ warehouse for spare parts used extensively in the chemical industry. Thus, market ready for several applications.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	3D printing for metal spare parts/ tubing.
Flexibility			
	Capacity	2	Yes, small spare parts can be made on demand.
	Product	3	3D printing can make new parts and therefore generate easy adjustments to the process
	Innovation	3	3D printing can make new parts and therefore generate easy innovation to the process
	Location	3	Yes, small spare parts can be made on demand at the site.
	Feedstock (or Input)	2	The feedstock changes from spare parts to the raw materials for spare parts
	Energy	0	
Business Model Impact			
	Supply	2	New raw materials and not solid sheet products
	Demand	3	New/ more products can be made due to short uptime
	Chain	3	More on demand production can enable better delivery times to people downstream.
	Ecosystem	0	
	Cost	4	3D printing has higher costs for making the spare parts

	Revenue	3	The benefit of short order times can increase production and hence revenues.
	Overall	2	
Sustainability			
	Material use	3	3D printing can be very precise thus low waste
	Environmental footprint	1	Both reduction due to smarter
	Energy	0	
	Strategy	3	smarter manufacture
Regional Impact			
	Safety, Health and Environment	1	
	Material flow	1	
	Direct jobs	2	Specialized jobs for 3D printing and training.
	Business opportunities	0	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	0	

A1.1.6 Process Intensification and continuous processing

A1.1.6.1 Continuous reactors

Relevance: High
TRL: market present / market ready

- Continuous reactors refer to flow chemistry (e.g. micro-fluidics) manufacturing applied for batch scale processes to continuous processes.
- Enabler for steady state processing, reducing batch times and scaling down vessel size requirements., allowing for process automation and thus falls in the technology cluster of process intensification and continuous processing.
- Equipment for flow chemistry is commercially available e.g. Chemtrix, Ehrfeld, Syrris, Vapourtec in the domain of flow chemistry
- Mass- and heat transfer can be improved versus batch vessels => process intensification

- Domain is mostly pharmaceutical and fine chemicals with many examples of market ready applications.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Continuous reactors for fine chemicals.
Flexibility			
	Capacity	3	Speed of flow can change capacity
	Product	3	different API's can be made
	Innovation	3	different new products can be tested on small scale
	Location	3	Facilitates making production sites in smaller sizes and thus location flexible
	Feedstock (or Input)	3	Easier to change in small amounts, batch needs large amounts
	Energy	3	Can turn the process on and off/instead of batch which need to be on
Business Model Impact			
	Supply	2	New continuous equipment manufactures
	Demand	3	Portfolio can be expanded
	Chain	3	Responsiveness can impact business models, patent capture effects
	Ecosystem	2	
	Cost	3	Continuous processing is more efficient as batch processing
	Revenue	3	Reaching market faster (demand)
	Overall	4	
Sustainability			
	Material use	3	Higher conversion/selectivity as opposed to batches
	Environmental footprint	3	Less production of waste water
	Energy	0	
	Strategy	3	smarter manufacture
Regional Impact			
	Safety, Health and Environment	3	Less hold up of chemicals
	Material flow	2	
	Direct jobs	3	Creating direct jobs because of production in Europe
	Business opportunities	2	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	0	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	2	
	Textiles including clothing	0	
	Paper and furniture	0	

	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.1.6.2HiGee process equipment

Relevance: Medium
TRL: market present / market ready

- HiGee process equipment concerns use for processes that are normally operated with gravitation to drive mass flow, e.g. on a filter to separate liquid from solids or in a settler to phase separation two liquids with different density. By applying centrifugal forces, the acceleration can be increased to many times the gravitational gravitation, hence accelerating the mass flow.
- High forces enable to scale down the separation processes enabling process intensification and continuous processing, and thus this technology cluster.
- Centrifugal equipment has been around for a long time for applications like solids removal from liquid (centrifuge, decanter) and liquid-liquid phase separation (centrifuge)
- Since the 1980s research has been done on implementation of centrifugal forces on other equipment for gas absorption / desorption and for distillation ('column on a shaft'). Conventional equipment for such contacting processes consists of tall columns to provide sufficient contacting time between liquid film or droplets with gas films or bubbles.
- In higee equipment mass and heat transfer are accelerated because much thinner liquid films / gas films are feasible and hence contacting times can be shorter, allowing for more compact design of the equipment (smaller footprint). This works especially well on viscous streams.
- Higee equipment is particularly useful for use in places where surface area is scarce, e.g. offshore platforms or where height is limited like in containerized construction for mobile plants.
- Furthermore, because of compact construction the hold-up in the equipment is small, reducing risk when processing hazardous compounds.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	centrifuges, gas absorbers / strippers, distillation
Flexibility			
	Capacity	2	It is smaller as usual technologies and can therefore easier be modularized
	Product	1	
	Innovation	0	
	Location	3	small footprint (Risks, Space, CO2) - containerized
	Feedstock (or Input)	1	The technique is mainly beneficial for highly viscous liquids
	Energy	3	small hold up

Business Model Impact			
	Supply	2	other equipment manufacturers
	Demand	1	Can have an impact when used for location/capacity flexibility
	Chain	0	
	Ecosystem	0	
	Cost	3	higher cost equipment, savings of opex
	Revenue	0	
	Overall	1	
Sustainability			
	Material use	3	more effective mass transfer
	Environmental footprint	3	more effective heat/energy transfer
	Energy	3	more effective energy transfer
	Strategy	3	more effective transfer
Regional Impact			
	Safety, Health and Environment	3	smaller hold-up
	Material flow	3	localized production (mobile plant)
	Direct jobs	2	local jobs if used for localized production
	Business opportunities	2	logistics if used for localized production
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	2	
	Food processing & beverages	2	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.1.6.3Continuous crystallization / solids handling

Relevance: Medium
TRL: applied research / market present

- Continuous processing (or flow chemistry) in general is beneficial for flexible and modular production because it allows for a process to run at steady state conditions and hence allows for automation which is required to achieve low process costs for decentral production.
- Handling of liquids and gases in continuous processes is relatively easy and equipment for flow chemistry is commercially available (e.g. Chemtrix, Ehrfeld, Syrris, Vapourtec in the domain of flow chemistry).
- Many processes require, however, the handling of suspensions or solids that is feasible in batch operation (stirred vessels) or in large scale continuous flow equipment but not in small scale continuous flow equipment as would be required in many modular and flexible operations.

- Equipment for continuous processing of suspensions and solids is being developed and tested for implementation (for example from Nitech, AMtech) often based on keeping particles in motion by applying vibrations, oscillations or pulsating movements.
- The availability of (relatively) small scale equipment for continuous handling of suspensions and solids (powders) is an enabler for decentral, modular & flexible processing.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	Continuous crystallization / solids handling
Flexibility			
	Capacity	3	Enables small scale solids handling and therefore capacity flexibility for solids
	Product	2	Enables more options for production of solids instead of liquids
	Innovation	0	
	Location	3	Enables small scale solids handling and therefore location/containerized production
	Feedstock (or Input)	1	The technology might require new feedstock for solids handling
	Energy	0	
Business Model Impact			
	Supply	2	Equipment manufacturer
	Demand	3	Solids enabled instead of only liquids
	Chain	3	Solids can be produced decentralized or this needs collaboration
	Ecosystem	0	
	Cost	1	
	Revenue	3	Higher purity of solids and new product (local)
	Overall	3	
Sustainability			
	Material use	3	all steps enabled - efficiency of solids production goes up
	Environmental footprint	2	all steps enabled - efficiency of solids production goes up
	Energy	0	
	Strategy	3	also, solids and reuse
Regional Impact			
	Safety, Health and Environment	1	
	Material flow	3	enables local solids handling
	Direct jobs	1	
	Business opportunities	2	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	1	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	1	
	Steel	0	
	Water	0	
	Food processing & beverages	1	

	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.1.7 Recovery/Work-up

A1.1.7.1 Energy efficient solvent recovery

Relevance: High

TRL: applied research / market ready

- Separation of solvents based on new separation principles – mechanical methods, molecular separations (membranes), smart molecular methods (affinity separations). These methods enable low energy solvent recovery and thus categorized in recovery technology cluster.
- Often thermal separations based on phase change (evaporation, distillation). Solvent recovery account for major use of energy in chemical industries
- For energy efficiency large scale operations required (high temperature) – difficult to scale down and inflexible
- Decentral production would benefit from lower energy intensive separations

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	Energy efficient solvent recovery
Flexibility			
	Capacity	3	Usually large-scale operations required (high temperature), energy efficient recovery benefits small scale and thus capacity flexibility
	Product	0	
	Innovation	1	
	Location	3	Usually large-scale operations required (high temperature), energy efficient recovery benefits small scale and thus location flexibility
	Feedstock (or Input)	0	
	Energy	2	The energy use gets reduced and therefore (relatively) some more flexible
Business Model Impact			
	Supply	2	equipment manufacturer
	Demand	0	
	Chain	1	
	Ecosystem	1	
	Cost	3	lower cost of product
	Revenue	1	
	Overall	1	
Sustainability			
	Material use	1	
	Environmental footprint	3	Lower energy use

	Energy	3	Lower energy use
	Strategy	3	Lower energy use
Regional Impact			
	Safety, Health and Environment	2	less energy use
	Material flow	0	
	Direct jobs	0	
	Business opportunities	0	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.1.7.2In-situ conversion of contaminants

Relevance: Medium

TRL: applied research / market ready

- This technology refers to in-line/ in the vessel conversion of contaminants or side products to favor the production of main products or prevent poisoning of the main product. These methods enable high efficiency recovery and conversion and thus categorized in recovery/ work up technology cluster.
- Especially for processing of complex mixed feedstock (biomass, waste) beneficial to remove compounds present in small quantities that disturb the process
- For example, aldehydes in sugar-hydrolysates made by hydrolysis of (hemi)cellulose that are toxic to micro-organisms used in fermentation processes and have to be removed prior to fermentation.
- Molecular affinity type of separations to be applied: adsorption, extraction, membranes.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	In-situ removal of contaminants
Flexibility			
	Capacity	0	
	Product	3	selective auxiliaries

	Innovation	2	selective auxiliaries
	Location	0	
	Feedstock (or Input)	3	polishing allows for use of different feedstocks
	Energy	0	
Business Model Impact			
	Supply	3	polishing allows for use of different feedstocks and thus new suppliers
	Demand	0	
	Chain	1	
	Ecosystem	2	
	Cost	2	limited contribution to the total cost of the product
	Revenue	3	contaminant removal increases value of products
	Overall	2	
Sustainability			
	Material use	2	more efficient use of feedstocks
	Environmental footprint	3	more efficient use of feedstocks
	Energy	0	
	Strategy	3	contaminant removal increases value of products and increases efficient use of feedstock
Regional Impact			
	Safety, Health and Environment	1	
	Material flow	3	allows for wider variety of feedstocks and less polished feedstock, so more local possibilities
	Direct jobs	1	
	Business opportunities	1	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.2 Emerging Energy Carriers

A1.2.1 Overview

Emerging Energy Carriers refer to the new forms of energy carrying molecules and methods. Specifically, a shift to carrying energy in hydrogen based carriers in place of traditional fossil based energy carriers. This section covers the explanation of the technologies, methods and equipment to produce, store and transform these novel energy carriers to energy/ products. Below is a brief overview of classification of emerging carriers into two categories, power conversion (long term storage) and bio based fuels.

Power conversion for long term storage refers to conversion of electricity (renewable) into energy sources such as H_2, methanol, NH_3 and others, which can be further stored and used on demand even after a long duration. This method of conversion of electricity to highly energetic chemicals like H_2 enables the use of “extra” electricity available during the peak times for renewable energy. Additionally, there are several technologies which focus on different aspects of the value chain from efficient/ new ways of production, to large scale storage to the transformation and regeneration technologies. These technologies are discussed below in more detail.

Bio based fuels refer to conversion of biomass into low density fuels which can be achieved from basic processes of pyrolysis or digestion. New developments in this field target the use of advance methods such as plasma torch, electrochemical conversion, in-situ/ in line separation of products and contaminants for enhanced productivity and lower foot-print of the bio based processes.

A1.2.2 Power Conversion (long term storage)

A1.2.2.1 Electrolysis low cost

Relevance: High
TRL: applied research / market ready

- Low cost electrolysis refers to standardized low-cost material use for electrochemical conversion of reactants to products. This technology is needed to drive electrification of chemical industries and is an enabler for Emerging Energy Carriers (H_2, NH_3)
- Starting with lower cost hydrogen made from renewable power – for reacting with CO_2/CO or N_2 from air to produce chemicals and energy carriers that are not based on fossil resources
- Cells of the types Proton Exchange Membrane (PEM) and Solid Oxide Electrolyser (SOEC) are expected to be the technologies for electrolysis with lowest overall cost (compared to alkaline cells).
- A dual use cell combining battery function with water electrolysis may (Battolyzer) may be a different approach to lower overall process cost

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	Electrolysis low cost H2 for reacting CO2/ CO or N2 to form chemicals; or direct.
Flexibility			
	Capacity	3	More modules can be added.

	Product	3	electrolysis cell with carbon electrodes can possibly handle production of one product at one voltage and with a different feedstock another product at another voltage.
	Innovation	3	New processes can be tested with similar equipment.
	Location	3	It can be truck based system.
	Feedstock (or Input)	3	Different feedstock can be used at different voltages to produce different products.
	Energy	3	New cells can be added in parallel/series to scale up-down.
Business Model Impact			
	Supply	3	New suppliers of CO2
	Demand	3	Electrification enables modular production and thus responsiveness
	Chain	1	Possible create more opportunities (green)
	Ecosystem	3	CO2 suppliers, water suppliers
	Cost	1	Yes, but dependent on scale
	Revenue	3	Enabling modular production can lead to changes in demand.
	Overall	4	
Sustainability			
	Material use	1	Depending on application in may increase/decrease
	Environmental footprint	3	Change the process from possible hazardous or polluting feedstock to renewable (clean) electricity
	Energy	3	Because electricity can be renewable electricity supply.
	Strategy	3	Smarter manufacture in compact manner.
Regional Impact			
	Safety, Health and Environment	3	Lower fuel usage when supplied via renewable electricity, also low hazardous process compared to traditional chlorine production.
	Material flow	3	
	Direct jobs	3	Electricity based jobs.
	Business opportunities	3	Local energy SME's; Green jobs
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	3	Supply of water
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	

	Leather & footwear	0	

A1.2.2.2Hydrogen storage techniques

Relevance: High
TRL: basic research / applied research / market ready

- This technology refers to conversion of excess renewable source power to hydrogen for (long term) storage and in a later stage re-conversion to power in fuel cell or by combustion. Thus, a technology enabling energy carrying by storage effect.
- Reduction of hazards (explosion risks) is required for long term storage
- Hydrogen leaks through many materials by diffusion, for risk reduction and for efficiency should be limited
- Technologies include chemical binding of hydrogen in metal hydrides, storage of hydrogen as compressed gas or after liquefaction in small scale lightweight composite hydrogen tanks or in large scale storage in abandoned salt caverns

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	Hydrogen storage techniques in metal hydrides, light compression
Flexibility			
	Capacity	2	high energy density storage at low scale.
	Product	1	Metal hydrides can be possibly used to store other gases?
	Innovation	0	
	Location	3	Compressed h2 storage cylinders/ tanks can be transported.
	Feedstock (or Input)	1	Metal hydrides can be possibly used to store other gases?
	Energy	3	More larger volumes of metal hydrides can store more H2.
Business Model Impact			
	Supply	3	Yes. New partners for h2 storage.
	Demand	0	
	Chain	3	You need less fossil fuels production
	Ecosystem	4	Have to impact the energy ecosystem
	Cost	3	Hydrogen and ammonia production from cheap electricity
	Revenue	3	Can sell as an energy carrier
	Overall	2	
Sustainability			
	Material use	1	Depending on what you process is
	Environmental footprint	1	
	Energy	3	Because we use it as energy carrier
	Strategy	3	Use as energy carrier
Regional Impact			
	Safety, Health and Environment	3	Leakages of h2 is an issue
	Material flow	2	It will need metal hydrides as materials of storage.
	Direct jobs	3	New market so more production
	Business opportunities	3	Local energy SME's
Industrial Applicability (SPIRE and			
	Cement	0	
	Ceramics	0	

Manufacturing clusters)	Chemicals	3	
	Engineering	1	because modular production will involve equipment manufacturers/suppliers
	Non-ferrous metals	0	
	Minerals	3	For metal hydrides
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.2.2.3Chemical looping

Relevance: Medium

TRL: basic / applied research

- Chemical looping refers to conversion of excess renewable source power to hydrogen, followed by using the hydrogen for reduction of a hot metal-oxide bed to metal (water vapor is formed) for long term storage. In a later stage followed by oxidation of the metal bed to metal-oxide with air (or oxygen) to produce heat to generate power (e.g. by steam boiler). Thus, categorized under the technology cluster of Emerging Energy Carriers.
- Chemical looping poses an alternative to long term and large-scale hydrogen storage – instead a metal bed is formed posing little risks to surroundings.
- Elevated temperature is required to operate the bed, so either the bed must be kept at elevated temperature during the storage period or the bed must be heated up prior to charging/discharging, these are challenges to be overcome.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	1 to 2	Chemical looping of metal to metal oxides and back.
Flexibility			
	Capacity	1	Possibly with use of electrochemistry
	Product	3	Oxidation can be applied to making different products. E.g. oxidation of fuel, oxidation of chemicals (in future)
	Innovation	1	too low TRL to accurately predict the ease
	Location	1	Possibly with use of electrochemistry
	Feedstock (or Input)	3	Different feedstocks gases can be used
	Energy	1	Possibly with use of electrochemistry
Business Model Impact			
	Supply	2	new limited feedstocks of metal (oxides) needed
	Demand	0	it’s an enabler to produce same products
	Chain	1	
	Ecosystem	0	

	Cost	1	too low TRL to accurately predict
	Revenue	1	too low TRL to accurately predict
	Overall	0	
Sustainability			
	Material use	3	Limited used of fuel
	Environmental footprint	3	Limited used of fuel
	Energy	3	Limited used of fuel
	Strategy	3	smarter manufacture
Regional Impact			
	Safety, Health and Environment	3	Inherently safe way for oxidation reaction
	Material flow	2	Local sourcing of metal oxides required
	Direct jobs	1	
	Business opportunities	1	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.2.2.4Activation of carriers

Relevance: Medium
TRL: fundamental research

- This technology refers to conversion of excess renewable source power to hydrogen, followed by using the hydrogen for reduction of hydrogen carrier molecules like CO_2 and N_2 to CH_3OH and NH_3. In a later stage re-conversion to power by combustion (steam turbine) or in a fuel cell. Thus, categorized under the technology cluster of Emerging Energy Carriers.
- Plasma technology can be used to break up stable molecules like CO_2 to CO and N_2 to N-atoms, to lower the activation energy (milder conditions) for reduction with hydrogen to CH_3OH and to NH_3.
- This technology enables power conversion for long term storage of energy from electricity.

- Use of H_2 to bind N_2 is a conventional process (Haber Bosch) for producing ammonia for fertilizers that is economical at large scale (1 Mta) but that is not applied for long term power storage, certainly not at smaller scale (subject of applied research).
- Use of plasma to do activation of potential hydrogen carrier molecules is in fundamental research stage.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	1	Plasma activation of carriers.
Flexibility			
	Capacity	2	Small scale production possible
	Product	3	Different products can be produced using different catalyst/ voltages/feedstocks
	Innovation	1	
	Location	3	For plasma location flexibility due to power availability.
	Feedstock (or Input)	3	Different feedstocks gases can be used
	Energy	2	Scaling up-down will require careful distribution of charges.
Business Model Impact			
	Supply	2	New feedstocks can be used and thus limited need of other suppliers.
	Demand		
	Chain	3	You can produce activated carriers for energy which will affect downstream.
	Ecosystem	2	With energy supplying companies
	Cost	0	Not cost intensive. e.g. Use of plasma of activating N2 can limit high cost for large scale units.
	Revenue	3	Localized production can enable new demand
	Overall	3	
Sustainability			
	Material use	2	Limited used of fuel for heat activation
	Environmental footprint	0	Currently, it is more energy intensive/ kg product.
	Energy	3	Renewable electricity can be used
	Strategy	3	smarter manufacture
Regional Impact			
	Safety, Health and Environment	3	Because it eliminates use of high pressure activation reactors.
	Material flow	2	Local sourcing of electricity
	Direct jobs	2	For electrical setup and connections
	Business opportunities	1	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.2.2.5Hydrogen binding to carriers

Relevance: High
TRL: market ready

- This technology refers to conversion of excess renewable source power to hydrogen, followed by using the hydrogen for reduction of hydrogen carrier molecules like CO_2 and N_2 to CH_3OH and NH_3. In a later stage re-conversion to power by combustion (steam turbine) or in a fuel cell. Thus, categorized under the technology cluster of Emerging Energy Carriers.
- Reactors to bind hydrogen to carrier:
  - for long term (seasonal) storage of power
  - co-producing feedstock for chemical supply chain
- TRL of technology is application based.
  Catalytic bed reactors e.g. Haber-Bosch for $NH_{3,}$ MeOH from syngas (CO/H_2) or from CO_2 and H_2.
  TRL: HB large scale industrially applied (1 Mta NH_3) , small scale demo-level (Minnesota, Proton Ventures),
  TRL: MeOH large scale from syngas industrially applied, small scale from CO_2 demo-level (Mitusi Chemical)
- NB Electrochemical-reactors for direct conversion of power with carrier molecules like e.g. HCOOH from CO_2 and H_2O or NH_3 from N_2 and H_2O are subject of fundamental research.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Haber-bosch for ammonia
Flexibility			
	Capacity	2	
	Product	2	
	Innovation	0	
	Location	0	The process itself does not help in location flexibility
	Feedstock (or Input)	3	The hydrogen can be obtained from methane or electrolysis
	Energy	0	The technology itself does not facilitate energy flexibility. It cannot be easily shut down.
Business Model Impact			
	Supply	1	We need hydrogen, but we don't know if this is new.
	Demand	3	New products for hydrogen binding such as methanol or formic acid
	Chain	3	You need less fossil fuels production
	Ecosystem	2	If used as an energy carries, you need burners and energy buyer
	Cost	3	Hydrogen and ammonia production from cheap electricity
	Revenue	3	New products for hydrogen binding such as methanol or formic acid
	Overall	4	
Sustainability			
	Material use	1	Depending on what your current process is
	Environmental footprint	1	Depending on what your current process is
	Energy	1	Depending on what your current process is
	Strategy	1	Depending on what your current process is

Regional Impact			
	Safety, Health and Environment	0	Maybe an impact before and after in the supply chain
	Material flow	2	Hydrogen can be produced from (local) water
	Direct jobs	1	Dependent on where to use the h2 carrier for
	Business opportunities	1	Dependent on where to use the h2 carrier for
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	because modular production of nh3 will involve equipment manufacturers/suppliers
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.2.2.6 Carrier reconversion

Relevance: High

TRL: applied research

- This technology refers to conversion of excess renewable source power to hydrogen, followed by using the hydrogen for reduction of hydrogen carrier molecules like CO_2 and N_2 to CH_3OH and NH_3. Thus, categorized under the technology cluster of Emerging Energy Carriers.
- Reconversion/decomposition of hydrogen carriers (e.g. HCOOH, NH_3) back to hydrogen.
- Hydrogen can be combusted or can be oxidized in a fuel cell to produce power.
- For decomposition catalytic reactors are studies and developed, technology is in applied research stage.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	Carrier conversion to hydrogen.
Flexibility			
	Capacity	2	Enabler for less hazardous alternatives to large scale hydrogen storage
	Product	2	Product is always hydrogen, but this can be a new product

	Innovation	2	Product is always hydrogen, makes innovation in energy market possible
	Location	0	
	Feedstock (or Input)	3	The technology itself is selective per carrier but when applied it enables using different feedstocks for producing hydrogen
	Energy	2	This process contributes to energy flexibility by converting to an energy carrier. The process itself is not energy flexible.
Business Model Impact			
	Supply	3	Carrier recycling, H2 further conversion to power
	Demand	2	If not already done, create a new product: Hydrogen (as energy carrier)
	Chain	3	The technology affects Hydrogen users as they can use new feedstock
	Ecosystem	3	Either the process is going to use a new feedstock (e.g. Hydrogen carrier) or the process is going to produce a new product (Hydrogen) and thus new collaborations are needed
	Cost	3	yes, when used for new feedstock it reduces costs to buffer hydrogen
	Revenue	2	When used to create a new product it creates a new market (possibly energy market)
	Overall	6	
Sustainability			
	Material use	3	carrier can be recycled too and can get a new purpose
	Environmental footprint	2	Compared to traditional power making (when hydrogen used as energy source).
	Energy	2	If hydrogen used as energy carrier
	Strategy	3	New purpose for the carrier
Regional Impact			
	Safety, Health and Environment	3	Avoids large scale hydrogen storage
	Material flow	3	Carrier recycling / logistics
	Direct jobs	3	New market - equipment
	Business opportunities	2	Local energy SME's (if used as energy source)
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	1	Requires catalysts
	Engineering	3	Reconversion technology will involve equipment manufacturers/suppliers
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	

	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.2.2.7Carrier to power

Relevance: High
TRL: Market present

- This technology refers to conversion of chemical energy stored in energy carriers like H_2 to power using fuel cells.
- Several types of fuel cells such as proton exchange membrane fuel cells, solid oxide fuel cells, methane reforming fuel cells and others with different levels of technical maturity.
- Several large demonstrations e.g. 2.8 MW fuel cell plant in California have been built to showcase the application of this technology at large scale.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Hydrogen carrier (including H2) conversion to produce power.
Flexibility			
	Capacity	2	high energy density storage at low scale.
	Product	0	Product is always power
	Innovation	0	Product is always power
	Location	3	
	Feedstock (or Input)	1	Maybe in future, currently mostly for H2.
	Energy	3	Can be used for flexible power production, based on other demand and storage options
Business Model Impact			
	Supply	3	Yes. New partners for h2 carrier supply.
	Demand	3	New market for on demand power.
	Chain	2	You need less fossil fuels production
	Ecosystem	3	Need of burners and energy buyer
	Cost	0	
	Revenue	3	Can sell as power on demand
	Overall	4	
Sustainability			
	Material use	2	Compared to traditional power making.
	Environmental footprint	3	Compared to traditional power making.
	Energy	3	Because we use it as energy carrier
	Strategy	3	Smart use of h2 to power.
Regional Impact			
	Safety, Health and Environment	4	Leakages of h2 is an issue

	Material flow	3	Sourcing of h2 carrier would be required , best solution is local sourcing
	Direct jobs	3	New market so more production
	Business opportunities	3	Local energy SME's
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	because modular production will involve equipment manufacturers/suppliers
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.2.3 Biomass based fuels - Production, upgrading, recovery, conversion

A1.2.3.1 Biomass gasification

Relevance: High
TRL: market present

- These technologies include conversion of raw biomass few into more refined and directly usable chemicals like syngas (H_2 + CO) etc., or different kinds of fuels based on the level of conversion from syngas to fuels. Thus, categorized under the technology cluster of bio based fuels.
- Technologies include: gasifier, oven, plasma torch, electrohydrogenesis
- Partial oxidation of long-chain biomass (lignocellulose)
- Byproduct formation must be handled (tar, salt)
- Supply of feedstock in economical way limits scale (capacity)
- Several examples of gasification all over the world have been market demonstrated[23].

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[23] Arjan F. Kirkels, Geert P.J. Verbong, Biomass gasification: Still promising? A 30-year global overview, In Renewable and Sustainable Energy Reviews, Volume 15, Issue 1, 2011.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Biomass based gasification
Flexibility			
	Capacity	2	Cost efficient dependence limited to scale
	Product	0	Energy/ syngas major product
	Innovation	0	
	Location	2	
	Feedstock (or Input)	3	Different kind of biomass feed stock can be handled
	Energy	2	
Business Model Impact			
	Supply	3	Yes. New partners for biomass supply.
	Demand	2	New localized markets for application.
	Chain	3	You need less fossil fuels production
	Ecosystem	4	When used as an energy carries, you need burners and energy buyer
	Cost	2	
	Revenue	3	Reaching new market (demand)
	Overall	2	
Sustainability			
	Material use	3	Looking at complete supply chain, it utilizes wastes.
	Environmental footprint	3	Yes, it improves circularity of waste
	Energy	3	
	Strategy	3	Use of waste streams
Regional Impact			
	Safety, Health and Environment	3	
	Material flow	3	
	Direct jobs	3	
	Business opportunities	3	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	0	
	Engineering	0	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	2	
	Textiles including clothing	2	
	Paper and furniture	2	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	2	

A1.2.3.2Biochemical conversion

Relevance: High

TRL: market present

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- Biochemical conversion refers to water based technologies such as fermentation, digestion and algae culture for conversion of raw biomass to usable chemicals like methane, which can be used as fuel. Thus, connected to the technology cluster of biochemical conversion.
- The rate of production generally low and hence large volumes is required.
- Other characteristics include Mild conditions (p, T); harvesting (recovery) of products may be laborious and energy consuming; Handling of minerals needed to close cycle;
- The biochemical conversion enables fuel options which can be used for energy/ chemical conversion purposes.
- Most of these processes are market ready with expansion to several large-scale plants.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Bio chemical conversion for fermentation biogas making
Flexibility			
	Capacity	2	Cost efficient dependence limited to scale
	Product	0	Biogas making
	Innovation	0	
	Location	0	
	Feedstock (or Input)	3	Different kind of biomass feed stock can be handled
	Energy	2	
Business Model Impact			
	Supply	3	Yes. New partners for biomass supply.
	Demand	2	New localized markets for application.
	Chain	4	Use of biogas can be of impact for lower supply chain processes and has an image impact
	Ecosystem	3	You need less fossil fuels production
	Cost	2	
	Revenue	3	Reaching new market (demand)
	Overall	2	
Sustainability			
	Material use	3	Looking at complete supply chain, it utilizes wastes.
	Environmental footprint	3	Yes, it improves circularity of waste
	Energy	3	It is a renewable energy source
	Strategy	3	Use of waste streams
Regional Impact			
	Safety, Health and Environment	3	Local biogas reduces waste streams
	Material flow	3	Local waste for biogas production
	Direct jobs	3	Local jobs for the biogas creation
	Business opportunities	3	SME opportunities in feedstock provision and use of the biogas
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	0	
	Engineering	0	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	

	Water	0	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	3	

A1.2.3.3Product recovery

Relevance: Medium
TRL: applied research/ market ready

- Energy efficient product recovery refers to technologies for enhanced integrated separation processes for recovery of product from a mixture of chemicals.
- Bio based pyrolysis oil contains e.g. acidic compounds that hamper use for internal combustion engines or use as drop-in feedstock in petrochemical plants. This technology is recovery of product in bio-specific conditions (e.g. bio-digestion) and thus under the technology cluster of bio based fuels.
- Conventional thermal separations based on phase change (evaporation, distillation) are too expensive and energy consuming for upgrading pyrolysis oil.
- Gasified biomass contains undesired compounds like e.g. H_2S and siloxanes that must be removed before combustion in gas engine or before feed-in to grid.
- Separation processes required: e.g. robust molecular separations (membranes), smart molecular methods (affinity separations).

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	Product recovery
Flexibility			
	Capacity	3	enabler for decentralization
	Product	0	
	Innovation	1	
	Location	1	
	Feedstock (or Input)	0	
	Energy	2	The technology reduces the energy use
Business Model Impact			
	Supply	2	equipment manufacturer
	Demand	3	Quality improvement
	Chain	1	
	Ecosystem	1	
	Cost	3	lower (energy) cost of product, because more efficient recovery
	Revenue	1	No demand side change
	Overall	2	
Sustainability			
	Material use	1	
	Environmental footprint	3	Lower energy use

	Energy	3	Lower energy use
	Strategy	3	Smarter energy use
Regional Impact			
	Safety, Health and Environment	2	less energy use
	Material flow	0	
	Direct jobs	0	
	Business opportunities	0	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.2.3.4In-situ removal and conversion of contaminants

Relevance: Medium
TRL: applied research

- In situ removal of contaminants and by products refers to a larger transformation of raw materials into desired products; also improves the volume used for the process.
- Production of biomass based fuels involve manufacture of by products which limit the efficient use of feedstock and results in the bulkiness of equipment. This technology is recovery of product in bio-specific conditions (e.g. bio-digestion) and thus under the technology cluster of bio based fuels.
- Example can be for the use of water selective membranes for removal of water during the production of methanol from biogas.
- For most biomass related process, in-situ removal of contaminants is on applied level of research and yet to be demonstrated on a commercial scale and thus TRL is applied research.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	In-situ removal of contaminants
Flexibility			
	Capacity	0	
	Product	3	selective auxiliaries
	Innovation	2	selective auxiliaries
	Location	0	
	Feedstock (or Input)	3	polishing allows for use of different feedstocks
	Energy	0	

Business Model Impact	Supply	3	polishing allows for use of different feedstocks and thus new suppliers
	Demand	0	
	Chain	1	
	Ecosystem	2	
	Cost	2	limited contribution to the total cost of the product
	Revenue	3	contaminant removal increases value of products
	Overall	2	
Sustainability			
	Material use	3	more efficient use of feedstocks
	Environmental footprint	3	more efficient use of feedstocks
	Energy	0	
	Strategy	3	contaminant removal increases value of products and increases efficient use of feedstock
Regional Impact			
	Safety, Health and Environment	1	
	Material flow	3	allows for wider variety of feedstocks and less polished feedstock, so more local possibilities
	Direct jobs	1	
	Business opportunities	1	
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.2.4 ICT

A1.2.4.1Automated Process Control

Relevance: Medium
TRL: market present

- Automated process control combines the use of important process parameters such as pressure, temperature, etc. to make a predictive control of the process of interest. Thus, using information technology for process control and hence categorized under ICT technology cluster.

- Automated Process Control can be used to control the energy input/output of the process quick and effectively. In this sense it is a prerequisite for using Emerging Energy Carriers besides the usual process and switching between products.
- Continuous flow at steady state conditions is type of process that favors APC; Liquid (mono) phase processes are less sensitive to disruption than multiphase processes and hence favor APC.
- APC is a market ready technology with several examples in process industry[24].

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	For instance, MyH2O2 (Industrial Internet of Things)
Flexibility			
	Capacity	3	The technology is easily scalable and facilitates scalability
	Product	3	Easily adjust the production process for a new product
	Innovation	1	The technology itself does not have an impact on innovation flexibility but it can make innovation flexibility easier
	Location	2	The technology is location independent and facilitates the incorporation of remote control
	Feedstock (or Input)	3	Easy adjusting the process based on the feedstock
	Energy	3	Easier and faster control to adjust energy use
Business Model Impact			
	Supply	3	New equipment, new maintenance strategy
	Demand	0	No impact on the demand
	Chain	0	The control only has impact on the production plant
	Ecosystem	3	The technology needs professionals that are skilled in the production process and in ICT
	Cost	3	The technology will lower the production cost through more efficient control
	Revenue	0	No impact on the demand
	Overall	3	
Sustainability			
	Material use	3	The process can be easily adjusted for more efficient material use
	Environmental footprint	3	The process can be easily adjusted for less environmental footprint
	Energy	3	Controlling the energy source/input through automated process control (the technology is a prerequisite for using energy flexibility to DSO's)
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	1	When used correctly it has an impact, but this is not inherent in the technology
	Material flow	0	ICT technology
	Direct jobs	2	Does not need on-site jobs for operating, limited for equipment
	Business opportunities	0	Does create ICT SME opportunities but does not need to be local
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	

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[24] https://www.proleit.co.uk/references/industries/chemistry.html

	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.2.4.2Process Analytical Technologies

Relevance: High
TRL: market present

- Process analytical technology is an enabler for automated process control adding additional level of functionality; these include FTIR, UV-VIS, NMR, Raman, laser diffraction. The collection and analysis of information from different sources using information technology tools and thus connected to ICT technology cluster.
- Gives additional information on composition of stream during operation (reaction, separation) next to conventional P, T and flow sensors and enables a greater control.
- The technology facilitates knowledge and estimates on the current and future energy demand of the production process and the energy market. This enables the effective use of Emerging Energy Carriers.
- PAT is a market ready technology.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Sensor systems
Flexibility			
	Capacity	1	The technology itself is scalable but does not explicitly facilitate scaling up or down the volume
	Product	2	As prerequisite for data analytics
	Innovation	3	Innovation flexibility is easier when more digital information is available and measured
	Location	1	The technology is location independent but does not specifically facilitate location flexibility
	Feedstock (or Input)	3	Facilitates knowledge on different feedstocks and possibly adapting the process
	Energy	3	Facilitates knowledge on the state of the production process/buffer and the energy demand (both in the grid as in the process)
Business Model Impact			
	Supply	3	New measurement equipment
	Demand	0	

	Chain	3	More possibilities for information sharing in the supply chain
	Ecosystem	2	The technology needs professionals that are skilled in ICT
	Cost	1	The technology itself increases cost, but it facilitates cost reducing improvements
	Revenue	0	No impact on the demand
	Overall	2	
Sustainability			
	Material use	2	The technology gives more knowledge on material use, but it needs other technologies to create an effect
	Environmental footprint	2	The technology gives more knowledge on the environmental footprint, but it needs other technologies to create an effect
	Energy	3	More knowledge on the energy market immediately increases the potential of using renewable energy
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	1	When used correctly it has an impact, but this is not inherent in the technology
	Material flow	0	ICT technology and thus no impact on local materials
	Direct jobs	2	Does not need on-site jobs for operating, limited jobs for equipment and maintenance (sensoring)
	Business opportunities	1	Does create ICT SME opportunities but does not need to be local
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.2.4.3Big Data

Relevance: Medium

TRL: applied research / market present

- Increased processing capacity of computer systems uses 'cognitive' technologies for assessing and evaluating massive amounts of data with varying formats. This technology uses collection and analysis of information and falls under ICT technology cluster.
- First applications in process industries concern operations where large quantities of logged process data are available: e.g. optimization of processes and lowering maintenance cost, examples are prediction of process disturbances (compressor trip) and predictive maintenance.

- Big data complements the APC and process analytical technologies by generating insights on energy use, production and demands and therefore contributing to the use of Emerging Energy Carriers.
- Further applications concerns finding correlations between feedstock quality, operational performance and product quality, again to optimize the process.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Business Information & Data Analytics, Machine Learning, Artificial Intelligence
Flexibility			
	Capacity	1	The technology is easily scalable but does not inherently facilitate scalability of the process
	Product	3	Analytics improve product flexibility by analyzing which product has to be produced (optimization)
	Innovation	3	Improves innovation flexibility by analyzing the process and test results
	Location	1	The technology is location independent but does not facilitate location flexibility
	Feedstock (or Input)	3	Analyzing the (different) feedstocks to create insight on how it can be used in the process
	Energy	3	Analysis for demand patterns and when to adjust the energy use/production
Business Model Impact			
	Supply	2	New ICT supplier
	Demand	3	Analytics improve changing the product and deciding when to produce which product to match demand
	Chain	3	Optimizing collaboration in the supply chain through analysis
	Ecosystem	3	The technology needs professionals that are skilled in the supply chain and in ICT
	Cost	3	The technology will lower the production cost through better optimize the process based on analysis
	Revenue	3	Better adjustment to the demand
	Overall	5	
Sustainability			
	Material use	3	Better understanding of the process can be used to optimize raw material use and predictive maintenance to improve equipment lifetime
	Environmental footprint	3	Better understanding of the process can be used to reduce environmental footprint
	Energy	3	Controlling the energy source/input through automated process control (the technology is a prerequisite for using energy flexibility to DSO's)
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	3	Analysis can be used to optimize Safety, Health and Environment
	Material flow	3	Analysis can be used to optimize local material use
	Direct jobs	0	Does not need on-site jobs for operating
	Business opportunities	1	Does create ICT SME opportunities but does not need to be local
Industrial Applicability (SPIRE and			
	Cement	3	
	Ceramics	3	

Manufacturing clusters)	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3 Mass Customization

A1.3.1 Overview

In the Mass Customization archetype five technology clusters are presented. The first one comprises all manufacturing technologies, systems and equipment that are necessary to realize the customized products according to a flexible and reconfigurable approach able to handle small volume products with short delivery times. The second cluster addresses all supporting ICT technologies that have to be integrated in order to properly handle the information flow and the related increased amount of data that have to be managed when dealing with customized production. Technologies included in the Sustainability cluster are the ones that can help to face specific challenges connected with the production and dismissal of customized products. The Supply Chain Management cluster is strictly related with the equipment manufacturing and ICT ones because it deals with technologies and tools supporting the monitoring and control of the production flow along all the actors involved in the customization process. Finally Design and configuration enable to enhance fundamental steps involved in customization as the product design, its configuration according to customer needs and the customer experience itself.

A1.3.2 Equipment manufacturing

A1.3.2.1Addictive Manufacturing

Relevance: High

TRL: market ready / market present

- Additive Manufacturing (AM) serves the production of small batches of prototypes: it builds 3D objects and it is used to fabricate end-use products in aircraft, cars, medical implants and mainly fashion industry. It implies the adoption of advanced computer systems.
- The AM equipment reads data from the CAD[25] file and adds layer-upon-layer of plastic, metal and other materials (liquid, powder, sheet material) to fabricate a 3D object. Rapid Prototyping, 3D printing and Direct Digital Manufacturing are subsets of the overall AM technologies that also leads to the reduction of production errors.
- Thanks to these technologies single items (the entire product or specific components) can be produced, based on high-level customization, without incurring the mould and tooling costs of traditional manufacturing, reducing the delivery time and enhancing product quality. This ensures that consumers are given the opportunity to have products with a unique design and style, along with functional and comfort-related aspects.[26]
- Consumer goods (clothing, footwear, sports items, glasses, etc.) and medical products (orthopaedic prosthetics, dental prosthetics, etc.) and durable goods (cars, kitchens, etc.) can benefit from this approach.[26]
- Consumer goods (clothing, footwear, sports items, glasses, etc.) and also medical products (orthopaedic prosthetics, dental prosthetics, etc.) and durable goods (cars, kitchens, etc.) can benefit from this approach.

- [25] Computer-Aided Design and Computer-Aided Manufacturing refer “to computer software that is used to both design and manufacture products” (http://onecnc.com.au/). In particular, CAD’s usage is on product design and design documentation and you can take advantage of “CAD/CAM applications both to design a product and program manufacturing processes”. (https://www.autodesk.com/)

[26] http://www.fabbricaintelligente.it/wp-content/uploads/Booklet-Fabbrica-Intelligente-2015-PAGINE-SINGOLE.pdf

- AM is changing the way organizations design and manufacture products: its diffusion is between the stage of market readiness and market presence, since many industries has developed pilot programs and a comprehensive introduction of 3D printing to be expected in additional sectors.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Some applications are already used in industry with a comprehensive introduction of 3D printing to be expected in additional sectors
Flexibility			
	Capacity	3,2	this technology allows the production of small batches of product or one-of a kind product.
	Product	3	the flow from design to production is integrated and one printer can produce a broad range of different product designs. The set-up of the machine for new products is very short
	Innovation	3	it is easy to produce innovative products while process is fixed.
	Location	3	Small-batch production close to the customer is one of the key advantages of additive manufacturing
	Feedstock (or Input)	3	To a certain extent, depending on the specific printer technology
	Energy	1	Depends on the specific process
Business Model Impact			
	Supply	3	The main change is that materials suppliers become technology suppliers
	Demand	2	The product can change, and the portfolio accordingly expanded, opening the doors for new market niches and faster delivery times
	Chain	2	Yes, additive manufacturing (AM) is a key enable for Mass Customization
	Ecosystem	1	Depending on how it is employed
	Cost	2	The cost structure of the production operations changes significantly with both advantages and disadvantages involved. The cost structure is expected to improve as the technology matures.
	Revenue	1	Depending on how the technology is employed
	Overall		Depending on how the technology is employed; it can be substantial in the short-medium period for some sectors
Sustainability			
	Material use	3	Yes, additive manufacturing involves less waste production during the manufacturing process
	Environmental footprint	2	Here full analysis is still in progress, but there is room for it
	Energy	1	This depends on a range of factors
	Strategy	3	Addictive Manufacturing reduces material inputs per product volume
Regional Impact			
	Safety, Health and Environment	1	Health and environment can be positively impacted
	Material flow	2	New suppliers are emerging in this context
	Direct jobs	3	It is expected to create additional jobs closer to the customer
	Business opportunities	2	It does create local business opportunities
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	1	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	1	
	Steel	3	
	Water	1	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	1	

	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.2.2Sensors, monitoring and control

Relevance: High

TRL: market present

- There are two main sensor categories in modern industries: process sensors and product sensors. Smart sensors enable automation, variety, diversity and flexibility at the same time: intelligent sensing technology can detect and measure any object, and this refers to almost all industrial automation applications.
- Process sensors enable smart manufacturing and their rule is to check and monitor the overall production process in different steps and timing; product sensors are instead put inside the products in order to check performances, trend, malfunctions and anything else that can be verified and, finally, can improve the customer experience.
- This leads to a better and faster communication. Improving and accelerating communications can also achieve rapid, automated product changeovers on a production line to allow intelligent analysis and finally small batch manufacture necessary to handle customized production.[27]
- Many products can be sensed to collect information that are used at multiple levels providing a service to different stakeholders (the producer, the user,). Different sectors are already using them: the most active are chemical, transportation and automotive sector (defect detector, vehicle speed sensor, parking sensors).

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	IoT automation solutions for industries are already in the market (e.g. NEC, Siemens, Emerson and Honeywell…)
Flexibility			
	Capacity	3	smart sensor technology, coupled with adaptive automation systems can enable plants flexible to adapt to individual customer requirements
	Product	3	enabling high product variance in smaller quantity
	Innovation	3	effective collaboration between different industrial processes enables high efficiency
	Location	1	less relevant for this aspect
	Feedstock (or Input)	2	traceability of supply of parts and row materials (e.g. by RFID) is enabled
	Energy	3	costs and energy consumption of industrial production can be reduced
Business Model Impact			
	Supply	2	technology suppliers
	Demand	2	better quality and responsiveness
	Chain	1	not so relevant
	Ecosystem	2	Depends on the specific process and sector

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[27] http://smartmachinesandfactories.com/news/fullstory.php/aid/17/Sensors_look_smart_for_Industry_4.0.html

	Cost	2	Cost intensive but the average cost of IoT sensors is falling
	Revenue	1	less relevant for this aspect
	Overall	Definitely	goods are produced in a more efficient way saving resources and achieving better quality
Sustainability			
	Material use	1	Depends on the specific process and sector
	Environmental footprint	2	costs and energy consumption of industrial production can be reduced
	Energy	2	same as above
	Strategy	3	small batch production is enabled, efficient monitoring and control during production and product use (product maintenance)
Regional Impact			
	Safety, Health and Environment	1	Depends on the specific process and sector
	Material flow	2	Coordination is usually improved
	Direct jobs	1	Depends on the specific process and sector
	Business opportunities	2	It can create local business opportunities by exploiting local strength
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	0	
	Chemicals	1	
	Engineering	3	
	Non-ferrous metals	1	
	Minerals	1	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.2.3Adaptable and reconfigurable systems

Relevance: High

TRL: market present

- The concept of “adaptable and reconfigurable systems” refers to the development of strong and independent models that can be easily adapted, integrated, reconfigured, and provided with advanced diagnostics.[28]
- The support of software instruments implementing design and evaluation methods is required for improving the correctness and managing variety and complexity of decisions.

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[28] http://www.fabbricaintelligente.it/wp-content/uploads/Booklet-Fabbrica-Intelligente-2015-PAGINE-SINGOLE.pdf

- Industrial systems suitable for rapid change in their configuration to satisfy custom requirements are essential for the efficient production of custom products with high added value.[28] Electrical design, mechanical design, software design and technical assistance are the areas affected by and involved in this technology.
- Combining mechanical, electrical and software parts forming the technological modules requires five main characteristics: modularity, standardization: scalability, compactness and “advanced diagnostics to be integrated with innovative remote tools (e.g. augmented reality)”.[28] These characteristics help companies to follow the economic trends and to catch new market niche with evolving interests and needs.
- Some current production planning software can provide much of the required functionality. Engineering, automotive and electronic machinery sectors have interesting industrial applications.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	Some current production planning software can provide much of the required functionality
Flexibility			
	Capacity	3	Reduces costs
	Product	3	Reduces lead time and production effort
	Innovation	2	Reduces lead time for the introduction of emerging innovations
	Location	3	Reduces lead time
	Feedstock (or Input)	2	It depends on the feedstock availability
	Energy	1	Depends on the specific process and sector
Business Model Impact			
	Supply	1	Possibly technology suppliers; generally, it depends on the specific process and sector
	Demand	1	Of course, the technology enables better responsiveness to customer demand, but it depends on the specific process and sector
	Chain	2	Coordination is usually improved
	Ecosystem	2	Certain behaviors might be pushed and even modify the company's inclination
	Cost	3	The software might be proprietary and there will be costs for staff training, maintenance, etc.
	Revenue	3	Customers are willing to pay more
	Overall		Not substantial, but can be important in the medium-long period
Sustainability			
	Material use	2	Coordination is usually improved
	Environmental footprint	1	Depends on the specific process and sector
	Energy	2	Potentially less energy is used for material production and transport
	Strategy	3	Innovation is facilitated, and small batch production is enabled
Regional Impact			
	Safety, Health and Environment	1	Depends on the specific process and sector
	Material flow	2	Coordination is usually improved
	Direct jobs	1	Depends on the specific process and sector
	Business opportunities	3	Better information on available materials might trigger innovation and potentially enable to satisfy new market niches
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	0	
	Chemicals	1	
	Engineering	3	

	Non-ferrous metals	1	
	Minerals	0	
	Steel	1	
	Water	0	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	1	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.2.4Multipurpose and hybrid processes

Relevance: Medium

TRL: market ready

- Hybrid manufacturing can be considered as “the combination of two or more manufacturing processes” [29] with the purpose of enhancing their advantages whilst at the same time minimizing their disadvantages.
- Hybrid manufacturing processes are in fact based on the simultaneous and controlled interaction of process mechanisms and/or energy sources/tools having a significant effect on the process performance.[30]
- “These processes have a large influence on the processing/manufacturing characteristics resulting in higher machinability, reductions of process forces, etc.” [31] The hybridization of traditional technologies, or rather the integration into a single machine of different transformation processes, is a step towards a potentially extensive diversification of alternative technologies.[32]
- The hybrid/additive technologies supported by innovative approaches to the production process and its control will allow the development of dedicated machines for both customization in B2B and B2C for the manufacturing of personalized components and products.
- The adoption of innovative technologies for the customized production of consumer goods represents a challenge that extends its potential to products for client’s well-being and health and to products in advanced mechanics, sensorial products, microelectronics and optoelectronics.[32]
- Some current application is available but there are not extensive test and use (e.g. laser cutting and engraving machines for leather in the footwear industry).

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[29] Zhu, Z., Dhokia, V. G., Nassehi, A., & Newman, S. T. (2013). A review of hybrid manufacturing processes–state of the art and future perspectives. *International Journal of Computer Integrated Manufacturing*, *26*(7), 596-615.

[30] https://www.linknovate.com/

[31] Lauwers, B., Klocke, F., Klink, A., Tekkaya, A. E., Neugebauer, R., & Mcintosh, D. (2014). Hybrid processes in manufacturing. *CIRP Annals-Manufacturing Technology*, *63*(2), 561-583.

[32] http://www.fabbricaintelligente.it/wp-content/uploads/Booklet-Fabbrica-Intelligente-2015-PAGINE-SINGOLE.pdf

Indicator	Category	Score	Explanation
Technology Readiness Level			
	Overall	3	Some current application is available but there are not extensive test and use
Flexibility			
	Capacity	3	It facilitates producing small volumes
	Product	3	Usually major changes to the plant are not required
	Innovation	2	Reduces lead time for the introduction of emerging innovations
	Location	3	It enables flexibility
	Feedstock (or Input)	1	It depends on the feedstock availability
	Energy	3	It eases to scale up and scale down the energy use of the production process
Business Model Impact			
	Supply	3	You have to rely on new suppliers
	Demand	3	The technology enables better responsiveness to customer demand
	Chain	3	MC is positively affected
	Ecosystem	2	Certain behaviors might be pushed and even modify the company's inclination
	Cost	3	There will be costs for new machinery and even staff training, maintenance, etc.
	Revenue	3	Customers are willing to pay more
	Overall		The impact on the BM can be substantial
Sustainability			
	Material use	3	The total amount of waste is reduced
	Environmental footprint	1	Depends on the specific process and sector
	Energy	2	Potentially less energy is used for material production and transport
	Strategy	3	Innovation is facilitated, and small batch production is enabled
Regional Impact			
	Safety, Health and Environment	1	Depends on the specific process and sector
	Material flow	3	Coordination is usually improved; the impact on the sourcing process can be high
	Direct jobs	1	Depends on the specific process and sector
	Business opportunities	3	Better information on available materials might trigger innovation and potentially enable to satisfy new market niches
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	1	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	1	
	Minerals	1	
	Steel	1	
	Water	1	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	1	
	Electrical & electronic machinery	3	

	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.2.5Robotics

Relevance: Medium/high
TRL: Market ready/market present

- With robotics we mean the "interdisciplinary branch of engineering and science that includes mechanical engineering, electrical engineering, computer science, and others. Robotics deals with the design, construction, operation, and use of robots, as well as computer systems for their control, sensory feedback, and information processing." [33]
- As personalization is getting more and more complex, robotic automation allows companies to easily change materials without having much downtime.[34]
- Robots can be outfitted "with vision systems that can easily adjust to different colors or sizes of products, and interact with them accordingly. These vision systems can also help to sort items that are batch made in several colors or shapes and get them to their right containers or areas of the shop." [34]
- Robots can be also implemented in realization of artisanal products for what concerns standard operations that not require handcraft ability of experienced operators. Machines will be able to evolve and learn complex tasks thanks to teaching through example and tasks, and working in adjacent contact with humans.[35]
- The introduction of robotics can lead to increased speed, efficiency and productivity[36]. Companies are becoming more and more inclined to take advantage of robotics as a way to increase sales by making smarter, more personalized product recommendations in a wide range of sectors.
- Interesting applications can be found in the footwear and construction industries[37]. When a close cooperation between the operator and the machine is needed, the working environment must be equipped with sensors (laser scanners, vision systems, photocells, etc.) that allow visualization of the workplace.[38]

Indicator	**Category**	**Score**	**Explanation**

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[33] https://en.wikipedia.org/wiki/Robotics
[34] https://www.robots.com/
[35] http://www.fabbricaintelligente.it/wp-content/uploads/Booklet-Fabbrica-Intelligente-2015-PAGINE-SINGOLE.pdf
[36] https://www.pwc.com/us/en/industries/industrial-products/library/next-manufacturing/robotic-trends-changing-manufacturing.html
[37] Paoletti I., Naboni R.S. (2013) Robotics in the Construction Industry: Mass Customization or Digital Crafting?. In: Emmanouilidis C., Taisch M., Kiritsis D. (eds) Advances in Production Management Systems. Competitive Manufacturing for Innovative Products and Services. APMS 2012. *IFIP Advances in Information and Communication Technology, vol 397. Springer, Berlin, Heidelberg*
[38] http://www.fabbricaintelligente.it/wp-content/uploads/Booklet-Fabbrica-Intelligente-2015-PAGINE-SINGOLE.pdf

Technology Readiness Level	Overall	4	Some applications are present in the market in different sectors
Flexibility			
	Capacity	3	increase production flexibility
	Product	3	robots can be easily reconfigured to different operations
	Innovation	1	it depends on how the process changes
	Location	1	it depends on how the process changes
	Feedstock (or Input)	1	handling flexibility
	Energy	2	the energy per unit of output is optimized by the consistency of robot and reduction in scrap or rework
Business Model Impact			
	Supply	2	tech provider for equipment and maintenance
	Demand	2	increase product manufacturing flexibility enabling better response to customer demand
	Chain	0	less relevant in this case
	Ecosystem	1	it depends on how the process changes
	Cost	3	Initial investment costs and maintenance, reduction of operating costs
	Revenue	1	possible revenue increases due to product quality increase
	Overall	yes	
Sustainability			
	Material use	2	reduce material waste and increase yield
	Environmental footprint	1	it depends on how the process changes
	Energy	2	robots do not need the same heating, cooling or lighting necessary for manual labor
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	1	robots can increase workplace health and safety, complying with safety rules and executing some dangerous operations
	Material flow	0	not relevant for this
	Direct jobs	1	it depends on how the implementation affect the process. Generally, robots reduce labor turnover and difficulty of recruiting workers
	Business opportunities	1	it depends on how the process changes
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement		
	Ceramics		
	Chemicals	1	
	Engineering	3	
	Non-ferrous metals		
	Minerals		
	Steel	3	
	Water		
	Food processing & beverages	3	
	Textiles including clothing	1	
	Paper and furniture	1	

	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.3 ICT

A1.3.3.1Internet of Things

Relevance: Medium

TRL: market present

- The Internet of things (IoT) has several important applications, mainly for equipment manufacturing and ICT: by IoT, we mean the network of physical devices, vehicles, and other items enabling objects to collect and exchange data through sensors or control systems.
- Considering IoT, sensors and actuators together, it emerges a wider class of cyber-physical systems, which also include technologies such as smart homes, intelligent transportation and smart cities that can refer to a large variety of devices and field of applications.[39]
- The interconnection and data exchange are the main factors enabling Mass Customization because each object can be personalized not only by itself, but also in relation to the world around itself. The main items are related to electronics, software, actuators, and network connectivity.
- The existing internet infrastructure allow things to interoperate. The main sectors involved are infrastructure management, manufacturing, agriculture and energy management; specific examples of consumer applications are entertainment, connected car, connected health, radios, air conditioning systems and containers for transporting good.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	The data collected into computer-based systems is creating opportunities for more direct integration of the physical world, and this is reducing the human action and, at the same time, improve efficiency, accuracy and economic benefit (+ SENSORS!)
Flexibility			
	Capacity	3	these systems allow to optimize the use of capacity
	Product	3	Modularity, postponement etc. ease the adaptation and preparation of the production process to product flexibility
	Innovation	3	Better management of the innovation, help to the definition and analysis of the effects of product and process innovation
	Location	3	help to infrastructure management and to the definition and analysis of the effects of location
	Feedstock (or Input)	2	help to the definition and analysis of the effects of using different kind of feedstock
	Energy	3	these systems allow to optimize the definition and analysis of the effects of using different kind of energy

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[39] http://idioknowledge.blogspot.it/

Business Model Impact	Supply	1	Depends on the specific sector. Potentially, the current suppliers can also deliver the required feedstock
	Demand	1	The technology enables better response to customer demand (time and location), but can also be employed in the current BM
	Chain	2	The technology enables better coordination and contents definition
	Ecosystem	3	the performance of the network is strongly improved
	Cost	2	the cost of the technology is limited but it allows to avoid other costs of inefficiency, supporting the optimization of the processes
	Revenue	2	revenues can increase because of the focus of BM on the specific needs of customer, who are willing to pay more
	Overall	Definitely	IoT allows to optimize the use of other technologies and to define in the proper way the level of customization
Sustainability			
	Material use	2	IoT allows to improve the use of materials and to analyze their impact on sustainability
	Environmental footprint	2	It can print new scenarios for environmental footprint
	Energy	1	Depends on the specific process and sector
	Strategy	3	IoT is a good support to analyze the weakness, strength and futurity of the company
Regional Impact			
	Safety, Health and Environment	1	Probably yes, but it depends on the specific process and sector
	Material flow	2	Probably yes, but it depends on the specific process and sector
	Direct jobs	2	The human action is globally reduced, but it created opportunities for new jobs with different capabilities and skills required
	Business opportunities	2	IoT can create new business opportunities for SMEs that are facing the new digitalization and automation trend
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.3.2Modelling and simulation

Relevance: Medium

TRL: market ready/market present

- Companies has been perceiving the need to develop analytical and simulation models to analyze the integrated behavior of “processes, resources, systems and factories of collaborative companies throughout all phases of their life cycle in order to make the best choices in the design phase and in all phases of use and reconfiguration until the end of life”.[40]
- The optimization and simulation of design processes and production - throughout the life cycle of products processes-systems for customized solutions - is the basis for developing production network organization models.[40]
- Models are required to support companies in defining customization scenarios in which strategies for postponement, product modularization and management of the decoupling point of the order will be confronted dynamically for better managing the supply chain.[40]
- It is challenging and necessary to find a way to overcome the “trade-off between sustainability, management of the warehouses, stock and transport for the products personalization”.[40]
- Application is considered for designing an integrated management system of products, processes and systems; for forecasting manufacturing systems performance.[40]
- Some tools are already used for product and process optimization and simulation, i.e. analysis of the performance of the product features, factory plant simulation, decision support systems for production optimization, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	some tools already used for product and process optimization and simulation (i.e. analysis of the performance of the product features, factory plant simulation, decision support systems for production optimization, etc.).
Flexibility			
	Capacity	2	these systems allow to optimize the use of capacity
	Product	3	ease the adaptation and preparation of the production process to product flexibility (optimization of the modularity , postponement strategies, etc.)
	Innovation	2	ease management of the innovation, help to the definition and analysis of the effects of product and process innovation
	Location	2	help to the definition and analysis of the effects of location
	Feedstock (or Input)	2	help to the definition and analysis of the effects of using different kind of feedstock
	Energy	2	help to the definition and analysis of the effects of using different kind of energy
Business Model Impact			
	Supply	1	Potentially, the current suppliers can also deliver the required feedstock
	Demand	1	The technology enables better response to customer demand (time and location), but can also be employed in the current BM
	Chain	2	The technology enables better coordination and contents definition
	Ecosystem	3	coordination of parties would be useful to exchange information and data to feed modeling and simulation tools and to optimize the performance of the network
	Cost	2	the cost of the technology is limited but it allows to avoid other costs of inefficiency, supporting the optimization of the processes
	Revenue	1	revenues can increase because of cost reduction
	Overall	Definitely	modeling and simulation allows to optimize the use of other technologies and to define in the proper way the level of customization

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[40] http://www.fabbricaintelligente.it/wp-content/uploads/Booklet-Fabbrica-Intelligente-2015-PAGINE-SINGOLE.pdf

Sustainability			
	Material use	2	modeling and simulation allows to optimize the use of materials and to analyze their impact on sustainability
	Environmental footprint	2	integrating simulation with LCA it is possible to create scenarios for environmental footprint
	Energy	1	modeling and simulation allows to optimize the use of energy and to analyze their impact on sustainability
	Strategy	3	modeling and simulation is a good support to analyze the level of circularity of the company
Regional Impact			
	Safety, Health and Environment	2	modeling and simulation is a good support to analyze the impact of customization on safety, health, etc.
	Material flow	2	modeling and simulation is a good support to analyze the impact of customization on material flows.
	Direct jobs	2	it is necessary to have dedicated people to use this kind of tools, or it can be good to train staff in case these tools have user friendly interface and are easily integrated with existing platforms.
	Business opportunities	2	local IT providers or consulting companies can find new business opportunities to support industrial companies in the implementation of these tools
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.3.3Big data

Relevance: High

TRL: market present

- The explosion of data collected, accumulated and analyzed is affecting the value-added-chain at all levels from manufacturers to customers in the current economic[41]. Big data refers to complex data sets with large information so that it emerged the need to create new processing application software because the traditional ones were not adequate to deal with them.

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[41] Chehbi-Gamoura, Samia, and Ridha Derrouiche. "Big Valuable Data in Supply Chain: Deep Analysis of Current Trends and Coming Potential." *Working Conference on Virtual Enterprises*. Springer, Cham, 2017.

- Currently, big data refers to "the use of predictive analytics, user behavior analytics, or certain other advanced data analytics methods that extract value from data" [42] through an appropriate use of informatics tools for search, "capturing data, data storage, data analysis, information privacy, sharing, transfer, visualization, querying and updating. They are increasingly gathered by cheap and numerous information-sensing Internet of things devices such as mobile devices", cameras, RFID and so on.[43]
- Large data sets are growing rapidly. This is why big data management is so important to respond to each market, in particular when dealing with customized solutions. In particular, solutions "to implement service oriented distributed and collaborative platforms".[44]
- Big data management is positively influencing mass customization in terms of personalized marketing, assistance, features of the products and, in the last years, even distribution channels.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Big data management is positively impacting Mass Customization in terms of personalized marketing, assistance, features of the products and, in the last years, even distribution channels
Flexibility			
	Capacity	3	It gives new instruments to optimize the use of capacity
	Product	1	Generally, yes, but it depends on the specific process and sector
	Innovation	3	Better management of the innovation: it helps the definition and analysis of the effects of product and process innovation
	Location	3	It serves new instruments to the management for the definition and analysis of the effects of location
	Feedstock (or Input)	2	More and detailed info on feedstock are provided
	Energy	0	Not relevant for this
Business Model Impact			
	Supply	1	Depends on the specific process and sector
	Demand	2	The technology enables more data to better response to customer demand
	Chain	2	Big data can lead to new scenarios
	Ecosystem	1	Depends on the specific field of application
	Cost	3	Manufacturing costs are driven down
	Revenue	3	Customer needs are collected and analyzed in detail and they are willing to pay more for a customized product
	Overall	Definitely	Big data allows to define in the proper way the level of customization
Sustainability			
	Material use	1	It depends on the specific sector and process
	Environmental footprint	1	It depends on the specific sector and process
	Energy	1	It depends on the specific sector and process
	Strategy	1	It depends on the specific sector and process
Regional Impact			
	Safety, Health and Environment	1	It depends on the specific sector and process
	Material flow	1	It depends on the specific sector and process
	Direct jobs	1	It depends on the specific sector and process
	Business opportunities	2	Big data can create new business opportunities for SMEs that select and properly serve one or more market niche

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[42] http://winegourd.blogspot.it/

[43] https://en.wikipedia.org/wiki/Big_data

[44] http://www.fabbricaintelligente.it/wp-content/uploads/Booklet-Fabbrica-Intelligente-2015-PAGINE-SINGOLE.pdf

Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	1	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	1	
	Steel	3	
	Water	1	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.3.4Business intelligence

Relevance: Medium

TRL: market present

- Business Intelligence refers to the strategies and technologies used by enterprises for the data analysis of business information and provide historical, present and future trends of business operations.
- A business intelligence dashboard is a data visualization tool that displays the evolution of key performance indicators for an enterprise by showing customizable interface and pulling real-time data from multiple sources.
- The most frequent functions are business performance management, benchmarking, complex event processing, reporting, online analytical processing and process mining.
- What is most interesting to Mass Customization is the easy interpretation of structured big data, sometimes unstructured, for creating new strategic business opportunities and satisfy the pressing and evolving specific customer needs.
- In particular, application for customization is related to data warehouse and dashboards for trends evaluation and profile identification.
- The best example probably is the marketing customization in the fashion industry, where Nike and Converse have built popular “Mass Customization” services, which allow customers to participate in the design of their products, and all the data are then collected, analyzed and exploited for further uses.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	some complex tools already used for product and process optimization and simulation (i.e. evolution of key performance indicators, real-time data from multiple sources).
Flexibility			
	Capacity	3	these systems allow to optimize the use of capacity
	Product	2	it depends on the product and sector
	Innovation	2	it can help to analysis and evaluate the effects of product and process innovation
	Location	2	help to the definition and analysis of the effects of location

	Feedstock (or Input)	2	it depends on the product and sector
	Energy	2	it can help to the definition and analysis of the effects of using different kind of energy
Business Model Impact			
	Supply	2	Potentially, information can be shared bidirectionally with suppliers
	Demand	1	The technology enables better response to customer demand (time and location)
	Chain	3	The technology enables better coordination and contents definition
	Ecosystem	2	it depends on the product and sector
	Cost	3	it allows to avoid other costs of inefficiency and it supports the optimization of the processes
	Revenue	1	revenues can increase because of the overall optimization
	Overall	Definitely	Business intelligence allows to optimize the use of other technologies and to define in the proper way the level of customization
Sustainability			
	Material use	1	it depends on the product and sector
	Environmental footprint	1	it depends on the product and sector
	Energy	1	it depends on the product and sector
	Strategy	1	it depends on the product and sector
Regional Impact			
	Safety, Health and Environment	1	it depends on the product and sector
	Material flow	2	business intelligence can be a good support to analyze the impact of customization on material flows.
	Direct jobs	1	it depends on the product and sector
	Business opportunities	1	it depends on the product and sector
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.4 Sustainability

A1.3.4.1 Life cycle assessment

Relevance: Medium/high

TRL: market ready/market present

- It refers to factual analysis of a product's entire life cycle in order to evaluate the environmental impacts of a product or service from cradle to grave. Nowadays LCA is a “transdisciplinary integration framework of models rather than a model in itself”.[45] It can provide to the companies a comprehensive approach to assess the environmental burden of manufacturing activities with an overall perspective.

- Companies obtain effectiveness in environmental impact reduction since the design phase, and LCA allows companies not only to evaluate the environmental impact of their processes and products, but also to use this information for the customer.
- In a globalized world where transparency and information occupy a predominant place and where consumers and companies are continuously evolving and transforming themselves and the world around them, LCA brings strong social value; companies are pushed to communicate about the social impacts of their products and to inform their efforts to the customers.[46]
- Many companies are testing a life cycle assessment to measure the impact of the whole chain, starting from the raw materials. LCAs involving several actors of the supply chain, both upstream and downstream, can strongly help companies that are facing an evolution to Mass Customization strategy.
- Some applications are already used in industry with good results, mainly in the leather and footwear sector.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Some applications are already used in industry with very good results
Flexibility			
	Capacity	2	A good evaluation can bring benefits for MC application
	Product	3	It is possible to manufacture a different product
	Innovation	3	High analysis frequency leads to a higher level of innovation
	Location	1	Depends on the specific process and sector
	Feedstock (or Input)	2	To a certain extent, depending on the specific technology
	Energy	1	Depends on the specific process and sector
Business Model Impact			
	Supply	3	Potentially, the current suppliers can also deliver the required feedstock
	Demand	1	Depends on the specific process and sector
	Chain	1	Depends on the specific process and sector
	Ecosystem	1	Depending on how it is employed
	Cost	3	The cost structure of the production operations can significantly increase. In the short term, the cost structure is expected to increase, then it decreases as the technology matures.
	Revenue	3	Sustainable companies that are able to communicate it can get a market segment which is expecting to increase in the following years
	Overall	yes	Not substantial, but can be important in the medium-long term
Sustainability			
	Material use	3	Yes, life cycle assessment involves less waste production, mainly during and after the manufacturing process
	Environmental footprint	3	Certainly, leading to material savings
	Energy	3	Yes, it facilitates the integration of renewable energy
	Strategy	2	Depends on the specific process and sector
Regional Impact			
	Safety, Health and Environment	3	Very useful to all the companies’ areas

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[45] Guinee, Jeroen B., et al. "Life cycle assessment: past, present, and future." (2010): 90-96.

[46] Benoît, C., Norris, G.A., Valdivia, S. et al. Int J Life Cycle Assess (2010) 15: 156. https://doi.org/10.1007/s11367-009-0147-8

	Material flow	3	New suppliers are emerging in this context
	Direct jobs	1	Depends on the specific process and sector
	Business opportunities	2	It can create local business opportunities by exploiting local strength
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	1	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	1	
	Steel	3	
	Water	1	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	1	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.4.2Materials end-of-life

Relevance: Medium

TRL: market ready/market presence

- The research on materials EOL mainly comes from the need to design high-performance components, machines and robots that optimize the consumption of materials and energy. These technologies could also relate to other sectors and other applications.
- In order to develop adaptive control systems that optimize the energy and material consumption aspects, process-monitoring solutions are necessary, particularly complex and innovative processes linked to the re- or de-manufacturing of components and products[47].
- Materials EOL is a technology enabling sustainability, without negatively affecting Mass Customization. Considering that customized products are uniquely produced for a specific client, new challenges arise when dealing with EOL strategies for reuse and recycle.
- Dismissal, recycling and separation of materials has been studied and applied in some sectors with good implications on sustainability.
- The concept of Materials EOL has been successfully applied in the computing field, where it has significance in the production, supportability and purchase of software and

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[47] http://www.fabbricaintelligente.it/wp-content/uploads/Booklet-Fabbrica-Intelligente-2015-PAGINE-SINGOLE.pdf

hardware products. The technology is now ready to be implemented in almost every sector.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Dismissal, recycling and separation of materials has been studied and applied in some sectors with good implications on sustainability
Flexibility			
	Capacity	0	Not relevant for this
	Product	0	Not relevant for this
	Innovation	0	Not relevant for this
	Location	0	Not relevant for this
	Feedstock (or Input)	0	Not relevant for this
	Energy	0	Not relevant for this
Business Model Impact			
	Supply	2	It depends on the specific process
	Demand	1	It depends on the specific process and sector
	Chain	2	MC is not negatively affected by sustainability
	Ecosystem	1	It depends on the specific process and sector
	Cost	3	The cost structure of the product EOL can increase. While in the short term it is expected to increase, then it settles as the technology matures.
	Revenue	2	Depending on how the technology is employed
	Overall		Not substantial, but can be important in the medium-long term
Sustainability			
	Material use	3	Yes, life cycle assessment involves less waste production, mainly during and after the manufacturing process
	Environmental footprint	3	Certainly leading to material savings
	Energy	3	Yes, it facilitates the integration of renewable energy
	Strategy	2	Depends on the specific process and sector
Regional Impact			
	Safety, Health and Environment	0	Not relevant for this
	Material flow	1	Depends on the specific process and sector
	Direct jobs	1	Depends on the specific process and sector
	Business opportunities	2	It can create local business opportunities by exploiting new and high-performance materials
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	1	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	1	
	Textiles including clothing	3	

	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.5 Supply Chain Management

A1.3.5.1 Cloud based platforms

Relevance: High

TRL: Market present

- Cloud computing is an information technology paradigm, a model for enabling easy access to shared pools of configurable resources (such as computer networks, servers, storage, applications and services), which can be rapidly provisioned with minimal management effort.
- It allows users to store and process data either in a private-space cloud, or on a third-party server located in a data center enabling thus companies to minimize up-front IT infrastructure costs, to focus on their core business, to more rapidly adjust resources and to meet fluctuating and unpredictable demand.
- This technology is used in the customization context to support process monitoring with suppliers, loading and sharing orders, price negotiation.
- There are many examples mainly coming from the consulting business, where this mechanism makes data-accessing mechanisms more efficient and reliable. Cloud computing growth has been expanding for ten years after the increasing availability of high-capacity networks, low-cost computers and storage devices.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Most of the informatic tools and software are cloud based and improves the company's performances
Flexibility			
	Capacity	2	Reduces lead time
	Product	3	Reduces lead time and production effort
	Innovation	2	Enables coordination and reduces lead time for the introduction of emerging innovations
	Location	3	Reduces lead time
	Feedstock (or Input)	2	It depends on the feedstock availability
	Energy	1	Depends on the specific process and sector
Business Model Impact			
	Supply	2	Coordination is usually improved
	Demand	2	The technology enables better responsiveness to customer demand
	Chain	2	Coordination is usually improved
	Ecosystem	2	Coordination is usually improved
	Cost	0	Cloud based platforms often are low price and does not increase the costs
	Revenue	3	Revenues can increase thanks to the better performances of many business areas
	Overall	Definitely	Substantial, it is already important in the short-medium term
Sustainability			
	Material use	0	Not relevant for this
	Environmental footprint	0	Not relevant for this
	Energy	0	Not relevant for this

	Strategy	0	Not relevant for this
Regional Impact			
	Safety, Health and Environment	1	Depends on the specific process and sector
	Material flow	2	Coordination is usually improved
	Direct jobs	1	Depends on the specific process and sector
	Business opportunities	2	More available information and better coordination can ease the creation of business networks where SME find a comfortable environment
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.5.2Dynamic supply chain

Relevance: High

TRL: market ready

- It refers to a new way of looking at and managing Supply Chains, even considering the evolving trends: the relationships between different actors of the supply chain is not static anymore, at any level and sector.
- Dynamic supply chain refers to the modelling and simulation at individual business and networks levels, capable of catching the collaborative and dynamic dimension.
- The evolving supply chain tends to be proactively ready to respond to the evolving customer needs. To face customization companies in fact must reorganize their internal processes as well as those in relation to the other companies with which they collaborate.
- Therefore, production network organization models must be developed on the basis of the optimization and simulation of design processes and production throughout the life cycle of product-processes- systems for customized solutions.
- Models are also required to support companies in defining customization scenarios in which strategies for postponement, product modularization and management of the decoupling point of the order will be confronted dynamically in order to optimize the management of the supply chain.
- At the same time, it is necessary to optimize the trade-off between sustainability, management of the warehouses, stock and transport for the products personalization.
- Many sectors are testing or solutions and technologies for the management of collaborative, agile, sustainable networks, mainly in the context of SMEs.

Indicator	**Category**	**Score**	**Explanation**

Technology Readiness Level			
	Overall	3	Modelling and simulation at individual business and networks levels, capable of catching the collaborative and dynamic dimension
Flexibility			
	Capacity	2	these systems allow to optimize the use of capacity for small volumes with algorithms that allow to consider features specific for customization (postponement, modularization, decoupling point, etc.)
	Product	3	ease the adaptation and preparation of the production process to product flexibility (optimization of the modularity , postponement strategies, etc.)
	Innovation	2	ease management of the innovation, help to the definition and analysis of the effects of product and process innovation
	Location	2	help definition and analysis of the effects of location
	Feedstock (or Input)	0	not relevant
	Energy	0	not relevant
Business Model Impact			
	Supply	1	Potentially, the current suppliers can also deliver the required feedstock
	Demand	1	dynamic tools for SCM enables better response to customer demand (time and location), but can also be employed in the current BM
	Chain	2	The technology enables better coordination and contents definition among the partners . Partners should be ready to share information
	Ecosystem	3	coordination of parties would be useful to exchange information and data to feed modeling and simulation tools and to optimize the performance of the network
	Cost	2	the cost of the technology is limited but it allows to avoid other costs of inefficiency, supporting the optimization of the processes
	Revenue	1	revenues can increase because of cost reduction
	Overall	Definitely	modeling and simulation allows to optimize the use of other technologies and to define in the proper way the level of customization
Sustainability			
	Material use	2	Dynamic tools for SCM allow to optimize the use of materials and to analyze their impact on sustainability
	Environmental footprint	2	integrating SCM with LCA it is possible to create scenarios for environmental footprint
	Energy	1	Dynamic tools for SCM allows to optimize the use of energy and to analyze their impact on sustainability
	Strategy	0	
Regional Impact			
	Safety, Health and Environment	1	modeling and simulation is a good support to analyze the impact of customization on safety, health, etc.
	Material flow	2	this kind of tools make it easy to adapt and to change the network configuration and management according to the needs and the specific product to be produced.
	Direct jobs	1	it is necessary to have dedicated people to use this kind of tools, or it can be good to train staff in case these tools have user friendly interface and are easily integrated with existing platforms.
	Business opportunities	1	local IT providers or consulting companies can find new business opportunities to support industrial companies in the implementation of these tools
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	

	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.5.3Data mining

Relevance: High

TRL: market ready/market present

- DM is the computing process of discovering patterns in large data sets involving methods at the intersection of machine learning, statistics, and database systems. The overall goal of the data mining (DM) process is to extract information and transform it into an understandable structure for further use.
- With regards to customization, as consumer preferences change and vary from country to country, the service is capable to be flexibly adapted by integrating new market information through consumers, retailers, designers and suppliers' interactions.
- In the last years, the concept of data mining mainly refers to data warehouse, dashboards and OLAP (on-line analytical processing) for clustering and association rules for trends evaluation and profile identification.
- These data serve as an input for many innovative tools, for example the implementation of online services that offers customized products for a specific target of people.
- Interesting applications has been proved in computer science, such as neural networks, cluster analysis, genetic algorithms, decision trees and decision rules, and support vector machines. Both supply chain management and design and configuration benefits from this technology.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	In the last years, the concept of data mining mainly has evolved to data warehouse, dashboards and OLAP (on-line analytical processing) for trends evaluation and profile identification
Flexibility			
	Capacity	3	It gives new instruments to optimize the use of capacity
	Product	1	Generally yes, but it depends on the specific process and sector
	Innovation	3	Better management of the innovation, help to the definition and analysis of the effects of product and process innovation
	Location	3	It serves new instruments to the management for the definition and analysis of the effects of location
	Feedstock (or Input)	1	It can help the definition and analysis of the effects of using different kind of feedstock

	Energy	0	Not relevant for this
Business Model Impact			
	Supply	1	Depends on the specific process and sector
	Demand	3	The technology enables more data to better response to customer demand
	Chain	3	The technology enables better coordination and contents definition
	Ecosystem	2	the performance of the network can be improved
	Cost	2	In the medium term, it eases the reduction of inefficiency
	Revenue	3	Customer needs are collected and analyzed in detail and they are willing to pay more for a customized product
	Overall	Definitely	Data mining allows to define in the proper way the level of customization
Sustainability			
	Material use	1	It depends on the specific sector and process
	Environmental footprint	1	It depends on the specific sector and process
	Energy	1	It depends on the specific sector and process
	Strategy	1	It depends on the specific sector and process
Regional Impact			
	Safety, Health and Environment	1	It depends on the specific sector and process
	Material flow	1	It depends on the specific sector and process
	Direct jobs	1	It depends on the specific sector and process
	Business opportunities	2	Data mining can create new business opportunities for SMEs that are facing the new digitalization and automation trend
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	1	
	Minerals	1	
	Steel	3	
	Water	0	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	1	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.6 Design and configuration

A1.3.6.1 Product configuration

Relevance: High

TRL: market present

- A configurator is a piece of software that assists the person in charge of the configuration task. It is composed of a knowledge base that stores the generic model of the product and a set of assistance tools that help the user to find a solution or to select components.
- The requirement is to understand accurately the customer's needs and to create a complete description of a product variant that meets those needs. Input is the catalogue of products with configuration options (type, model, shape, size, color, material type and design, components, add-ons, etc.).
- For the configuration and design of personalized solutions, it is necessary to develop technologies and applications that involve clients in the manufacturing chain, incorporating their needs and expectations starting from the design of the product to the innovative services associated with its production.
- Product configurators shall give customers the chance to define their needs objectively so that they are easy to manage at the production level. Clients become consumer-actors with an active role in defining their product. In particular, the use of Augmented Reality (AR) can support the configuration and testing of customized products.
- Online ordering and buying configurable catalogue product, as garments and footwear with special features, shall include full visualization of products characteristics, made-to-measure functionalities and payment.
- Product configurators shall guarantee the possibility of full visualization (even 3D) of products characteristics, both online and in the retail shop. In the latter case the consumer can be guided by a shop assistant through the technical, functional and aesthetical configuration process.
- The data of the products to be configured are provided by the manufacturer, each with a dedicated configuration space. Alternatively, a retailer itself can configure and order a set of products suitable to his/her strategies.
- It is already on the market in many sectors (clothing, automotive, etc.).

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	already on the market in many sectors (clothing, automotive, ...)
Flexibility			
	Capacity	0	not relevant for this
	Product	0	not relevant for this
	Innovation	0	not relevant for this
	Location	0	not relevant for this
	Feedstock (or Input)	0	not relevant for this
	Energy	0	not relevant for this
Business Model Impact			
	Supply	1	tech provider for equipment and maintenance
	Demand	2	easier to handle options for customers
	Chain	3	in the sales phase
	Ecosystem	1	it depends on how the process change
	Cost	1	it depends on how the process change
	Revenue	1	it depends on how this affect product offer
	Overall	Definitely	
Sustainability			
	Material use	0	not relevant for this

	Environmental footprint	0	not relevant for this
	Energy	0	not relevant for this
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	0	not relevant for this
	Material flow	0	not relevant for this
	Direct jobs	2	it is necessary to have dedicated people to use this kind of tools, or it can be good to train staff in case these tools have user friendly interface (e.g. sales assistants)
	Business opportunities	1	local IT providers or consulting companies can find new business opportunities to support industrial companies in the implementation of these tools
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement		
	Ceramics		
	Chemicals		
	Engineering	2	
	Non-ferrous metals		
	Minerals		
	Steel	2	
	Water		
	Food processing & beverages	1	
	Textiles including clothing	3	
	Paper and furniture		
	Electrical & electronic machinery		
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.6.2Smart materials

Relevance: High

TRL: Market ready/market present

- The name of “smart materials” is commonly applied to materials or components that exhibit some kind of useful reactions to an external input or change.
- Compared to other materials, they have one or more properties that significantly changes by reacting to the environment all by itself in terms of volume, color or viscosity; this may occur in response to a change in temperature, stress, magnetic field, pH changes, water content, corrosion, electrical current and mechanical forces.
- The development of technologies and processes for the production of innovative materials with advanced mechanical and functional characteristics (e.g. sensor-based fabrics, display materials, micro- and nano-materials, multifunctional textile materials, medical materials, high-performance renewable materials, etc.), which may have different characteristics based on the specific needs of the consumer, plays an important role within the sphere of custom production. In particular bio-based and eco-compatible materials; multi-functional materials; micro-nano materials
- Some applications are present in the market, increasing number of end user applications. Among the others, their application in textile, construction, medical, aerospace and electronics industries are bringing valuable benefits and it is increasing the customization trend to respond to group and even individual requests.

Indicator	**Category**	**Score**	**Explanation**

Technology Readiness Level			
	Overall	4	Some applications are present in the market Increasing number of end user applications
Flexibility			
	Capacity	2	Depends on kind of application
	Product	3	according to treatments and materials, characteristics of products can vary on the basis of specific requirements
	Innovation	3	smart materials enable to realize innovative products implementing specific features answering to customer demand
	Location	0	not relevant for this
	Feedstock (or Input)	1	Depends on kind of application
	Energy	0	Less relevant for this
Business Model Impact			
	Supply	2	suppliers for raw materials and treatments
	Demand	3	innovative materials with advanced mechanical and functional characteristics enable to realize product based on specific customer needs
	Chain	1	Depends on kind of application
	Ecosystem	1	Depends on kind of application
	Cost	2	high costs associated with the high level of R&D involved
	Revenue	3	new market niche and market needs can be addressed
	Overall	Definitely	increased value proposition and market opportunities
Sustainability			
	Material use	1	in case of use of homogeneous materials, more easily recyclable
	Environmental footprint	1	in case of new advanced composite materials based on natural polymers of plant origin or biodegradable polymers
	Energy	2	Applications of nano and smart materials in renewable energy production and storage devices (e.g. Hybrid Piezoelectric Photovoltaic (HPP) Films and Fibres, carbon nanotubes (CNTs) and graphene nanosheets (GNS)
	Strategy	3	the technology enables to customize product features and functionalize materials according to specific needs
Regional Impact			
	Safety, Health and Environment	1	Depends on kind of application (e.g. they have been widely used for water treatment, remediation, and pollution prevention)
	Material flow	2	New suppliers will potentially emerge
	Direct jobs	1	Depends on kind of application
	Business opportunities	1	Potentially through new products
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement		
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals		
	Minerals		
	Steel		
	Water		
	Food processing & beverages	3	

	Textiles including clothing	3	
	Paper and furniture	1	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.6.33D scanning

Relevance: High

TRL: market ready/market present

- 3D scanning, like 3D printing, is a broad term that describes many different processes and applications: it is the act of capturing data from objects in the real world and bringing them into the digital pipeline.
- The 3D scanner is the device that analyses a real-world object or environment in order to collect data on its shape and possibly its appearance.
- The collected data can then be used to construct digital three-dimensional models for a wide variety of applications.
- Potentially this is one of the best technologies suiting the increasing customization through common applications in construction industry and civil engineering, industrial design, orthotics and prosthetics, quality control/inspection, reverse engineering and prototyping.
- 3D scanning is used in customized manufacturing to enable nearly infinite variations of existing consumer products, including toys, accessories and apparel.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	3D scanning is used in customized manufacturing to enable nearly infinite variations of existing consumer products, including toys, accessories and apparel.
Flexibility			
	Capacity	2	The scanning process makes it easy and cost efficient to quickly generate basic data for implementing customer requirements enabling customization and small lots
	Product	3	the technology is an enabler for product customization, in particular if combined with addictive manufacturing
	Innovation	3	huge potential of this technology to support innovation in practice
	Location	0	Less relevant for this
	Feedstock (or Input)	1	Depends on kind of application
	Energy	0	Less relevant for this
Business Model Impact			
	Supply		tech provider for equipment and maintenance

	Demand	3	enables designing a custom product based on client requirements
	Chain	1	Depends on the specific sector
	Ecosystem	1	Depends on the specific process and sector
	Cost	2	Lower costs are now broadening the market. Moreover reduced costs in the design and prototyping phase and also reduced warehousing costs
	Revenue	3	Greater accuracy, speed and reliability in answering to customer and market requirements
	Overall	Definitely	yes, and impact will grow in the future
Sustainability			
	Material use	1	Less relevant for this
	Environmental footprint	1	Less relevant for this
	Energy	0	Less relevant for this
	Strategy	3	the technology deeply impacts the way products are designed, engineered, manufactured, inspected and archived
Regional Impact			
	Safety, Health and Environment	0	Less relevant for this
	Material flow	1	Depends on kind of application
	Direct jobs	2	Depends on the specific sector
	Business opportunities	1	Potentially through new products
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	3	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	1	
	Steel	3	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	3	
	Paper and furniture	0	
	Electrical & electronic machinery	1	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.3.6.4Virtual and augmented reality

Relevance: Medium

TRL: Market ready

- Virtual reality (VR) is an artificial, computer-generated simulation or recreation of a real-life environment or situation. It immerses the users by making them feel like they are experiencing the simulated reality firsthand, primarily by stimulating their vision and hearing.
- Augmented reality (AR) is a technology that layers computer-generated enhancements atop an existing reality in order to make it more meaningful through the ability to interact with it. AR can be useful for supplying information on product, process and progress in production both to the operator and to the line managers in a more natural and effective way.
- Applications have already become widely used in many products. It can also be the technological base for the development of digital environments or serious games for a variety of ends: factory layout design, monitoring/control, and training.
- For what concerns customization, VR can be applied in shortening the time of building a prototype of a product and its verification. Virtual reality systems are increasingly used in engineering design because VR is a basis of smart design. Moreover it offers innovative ways for customer experience such as dress test etc.
- Some applications are present in the market but there is big application potential, mainly considering engineering, textiles, vehicles, and leather and footwear sectors.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Some applications are present in the market but there is big application potential
Flexibility			
	Capacity	0	not relevant for this
	Product	2	ease the adaptation and preparation of the production process to product flexibility
	Innovation	3	impact on product and system design: ease management of the innovation through the analysis of the effects of product and process innovation
	Location	0	not relevant for this
	Feedstock (or Input)	0	not relevant for this
	Energy	0	not relevant for this
Business Model Impact			
	Supply	1	tech provider for equipment and maintenance
	Demand	3	impact on product configuration and design
	Chain	3	Product configuration in the sales phase
	Ecosystem	1	it depends from how the process changes
	Cost	2	Initial investment costs and maintenance
	Revenue	1	Product configuration in the sales phase
	Overall	yes	
Sustainability			
	Material use	0	not relevant for this
	Environmental footprint	0	not relevant for this
	Energy	0	not relevant for this
	Strategy	3	smarter manufacture in the design phase
Regional Impact			
	Safety, Health and Environment	0	no direct impact
	Material flow	0	no direct impact

	Direct jobs	1	it depends from the application
	Business opportunities	1	it depends from the application
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement		
	Ceramics		
	Chemicals		
	Engineering	3	
	Non-ferrous metals	1	
	Minerals		
	Steel	1	
	Water		
	Food processing & beverages		
	Textiles including clothing	3	
	Paper and furniture	1	
	Electrical & electronic machinery	1	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.4 Servitization of the process industry (PSS)

A1.4.1 Overview

A1.4.2 Equipment manufacturing

A1.4.2.1 Cold Welding

Is a technology defined as "*a solid-state welding process in which joining takes place without fusion/heating at the interface of the two parts to be welded*" (Ferguson, Chaudhury, Sigal, & Whitesides, 1991); the main difference of this process versus typical welding is that there is no liquid or molten phase in the joint.

TRL:

- Has potential on industries such as aerospace, robotics and electronics
- There is currently a deep research on applications at nano and micro scale for different industries, mainly focused on the aerospace industry.
- The main principle under the cold welding is to adhere clean, flat surfaces of similar metals (or metallic properties) when they get in contact under vacuum.
- In the nanofabrication processes it has been found that is possible to use this technology "*under relatively low applied pressures to join nanowires (diameters less than 10 nm)*" (Lu, Huang, Wang, Sun, & Lou, 2010)
- This technology is still under development and proving its functionality in specialized industries, such as aerospace. Based on the available information about the technology, is still under Applied Research (TRL INSPIRE 2 / TRL-EU 4)
- Examples of the technology are: application on satellites (aerospace industry)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	Has potential on industries such as aerospace, robotics and electronics
Flexibility			
	Capacity	0	Less relevant for this
	Product	3	new technology that can help generating new products
	Innovation	3	innovation using this technology
	Location	0	Less relevant for this
	Feedstock (or Input)	0	Less relevant for this
	Energy	2	could improve energy consumption over traditional welding
Business Model Impact			
	Supply	1	Depends on how much it differs from current processes
	Demand	1	Depends on how much it differs from current processes
	Chain	1	Depends on how much it differs from current processes
	Ecosystem	0	Less relevant for this
	Cost	4	Costly to implement
	Revenue	1	Depends on how much it differs from current processes
	Overall		
Sustainability			
	Material use	1	Depends on how much it differs from current processes
	Environmental footprint	1	Depends on how much it differs from current processes
	Energy	2	energy intensive on the traditional welding, this could change under cold welding
	Strategy		

Regional Impact			
	Safety, Health and Environment	1	Strongly depends on kind of application
	Material flow	1	Strongly depends on kind of application
	Direct jobs	1	Strongly depends on kind of application
	Business opportunities	1	Strongly depends on kind of application
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	1	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.4.2.2Biodegradable materials

Biodegradable materials are those which “*can be decomposed rapidly by the action of microorganism*” (Song, Murphy, Narayan, & Davies, 2009). Some other extension of the definition, can be interpreted as the part of “*materials composed of waste from living organisms and the actual plant, animal or other organism when its life ends*” (Sprecycling, 2017)

TRL:

- Biodegradable materials are already in the market in different scenarios
- The main objective of biodegradable materials is to reduce the waste generated by incorporating virgin, non-degradable, raw materials, into the manufacturing processes, and changing these for more eco-friendly materials.
- There are many examples of this technology being used nowadays, in different fields and industries, such as construction, painting, polymers, apparel industry, etc.
- The readiness level is on market presence, with improvement and expansion opportunities given by different global trends focused on more sustainable development. Based on the available information about the technology, is still under Market Presence (TRL INSPIRE 4 / TRL-EU 9)

- Examples of the technology are: biodegradables plastic bags, recyclable paper, clothes, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	biodegradable materials are already in the market in different scenarios
Flexibility			
	Capacity	3	large impact based considering the impact of the material
	Product	3	large impact based considering the impact of the material
	Innovation	3	large impact based considering the impact of the material
	Location	2	considering the movement of materials it could be limited to the closer places for production
	Feedstock (or Input)	3	large impact based considering the impact of the material
	Energy	1	biodegradable materials are intensive in energy usage for their production
Business Model Impact			
	Supply	3	supply of materials change
	Demand	3	demand of materials has a large change
	Chain	3	supply chain is shaped around the new materials
	Ecosystem	3	positive impact on the ecosystem by reducing the use of raw materials
	Cost	2	production with biodegradable materials could be costly
	Revenue	3	high impact from reducing product cost
	Overall		positive impact on the business model
Sustainability			
	Material use	3	reduction of raw materials
	Environmental footprint	3	reduction of environmental impact
	Energy	1	biodegradable materials are intensive in energy usage for their production
	Strategy	1, 3	
Regional Impact			
	Safety, Health and Environment	3	an improvement in all of them
	Material flow	2	changes the supply chain
	Direct jobs	1	not necessarily a consequence
	Business opportunities	3	different business could result from development of this material
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	1	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	1	
	Minerals	3	
	Steel	0	
	Water	3	
	Food processing & beverages	3	

	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	1	
	Vehicles & auto components	1	
	Leather & footwear	3	

A1.4.2.3Micro and nano-manufacturing

The micro and nanomanufacturing technologies considers the production of materials and parts at nanoscale level, for high precision industries, with objects dimensions between one and one hundred nanometers (Wang, 2009).

TRL:

- New manufacturing process that represents a new field of science and also a new marketplace (Wang, 2009)
- Nanomanufacturing can be made “bottom up” from nanoscale materials to produce largest parts or components, or “top down” by reducing the size of the equipment and adding higher precision to the industries where is required (Dimov, Brousseau, Minev, & Bigot, 2011).
- It enables manufacturing and creation of “*new materials and products that have applications such as material removal processes, device assembly, medical devices, electrostatic coating and fibers, and lithography*” (Wang, 2009).
- The technology is currently under research and development, and it requires collaboration between different research fields, “*such as engineers, biologist, material scientist, chemist, physicists*” (Wang, 2009). Based on the available information about the technology, is still under Applied Research (TRL INSPIRE 2 / TRL-EU 5)
  Examples of the technology are: molecular biology, aerospace engineering, material removal from medical devices, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	New manufacturing process that represents a new field of science and also a new marketplace
Flexibility			
	Capacity	1	changes at microlevel of materials, possibility to scale down products
	Product	2	different products can take advantage of the technology
	Innovation	2	adaptable to create new products
	Location	0	Less relevant for this
	Feedstock (or Input)	0	Less relevant for this
	Energy	1	Strongly depends on kind of application
Business Model Impact			
	Supply	1	suppliers for different materials
	Demand	2	portfolio expanded

	Chain	2	SC changes based on demand
	Ecosystem	0	Less relevant for this
	Cost	4	costly technology development
	Revenue	2	revenue depends on investment and use of equipment
	Overall		
Sustainability			
	Material use	0	Less relevant for this
	Environmental footprint	0	Less relevant for this
	Energy	1	Strongly depends on kind of application
	Strategy	1, 3	
Regional Impact			
	Safety, Health and Environment	1	Strongly depends on kind of application
	Material flow	1	Strongly depends on kind of application
	Direct jobs	1	Strongly depends on kind of application
	Business opportunities	1	Strongly depends on kind of application
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	1	
	Chemicals	1	
	Engineering	1	
	Non-ferrous metals	1	
	Minerals	1	
	Steel	1	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.4.2.4Biosensors

Biosensors are devices that integrate biological responses with electrical signals (Grieshaber, MacKenzie, Vörös, & Erik, 2008); these devices are "*used in order to determine the concentration of substances and other parameters of biological interest even where they do not utilize a biological system directly*". (Thevenot, Toth, Durst, & Wilson, 2001)

TRL:

- Combines a biological component with a physicochemical detector
- It integrates the signal generated by a biological element (tissue, microorganism, etc.) when in interaction with the material under study.
- The biosensor reader device is "*responsible for the display of the results in a user-friendly way*" (Cavalcanti, Shirinzadeh, Zhang, & Kretly, 2008).
- The technology is currently under research and development, and it requires multidisciplinary collaboration, spanning but not limited to "*biochemistry, bioreactor*

science, physical chemistry, electrochemistry, electronics and software engineering" (Chaplin, 2014). Based on the available information about the technology, is still under Applied Research (TRL INSPIRE 2 / TRL-EU 4)

- Examples of the technology: blood glucose biosensor, interferometric reflectance imaging sensor, DNA biosensors, microbial biosensors, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	combines a biological component with a physicochemical detector
Flexibility			
	Capacity	1	small batches are possible at high cost
	Product	2	different versions of the products with different purposes
	Innovation	2	adaptable to create new products
	Location	0	Less relevant for this
	Feedstock (or Input)	0	Less relevant for this
	Energy	1	Strongly depends on kind of application
Business Model Impact			
	Supply	1	suppliers for materials related to biological sensors
	Demand	2	portfolio expanded based on biological sensor
	Chain	2	SC changes based on demand and biological sensor
	Ecosystem	0	Less relevant for this
	Cost	4	costly technology development
	Revenue	2	revenue depends on use of the equipment
	Overall		
Sustainability			
	Material use	0	Less relevant for this
	Environmental footprint	0	Less relevant for this
	Energy	1	Strongly depends on kind of application
	Strategy	1, 3	
Regional Impact			
	Safety, Health and Environment	1	Strongly depends on kind of application
	Material flow	1	Strongly depends on kind of application
	Direct jobs	1	Strongly depends on kind of application
	Business opportunities	1	Strongly depends on kind of application
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	1	
	Minerals	3	
	Steel	3	
	Water	0	
	Food processing & beverages	0	

	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	3	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.4.2.5Microelectromechanical systems (MEMS)

This technology refers to the “microscopic devices, particularly those with moving parts. It merges at the nanoscale into nanoelectromechanical systems (NEMS) and nanotechnology” (Waldner, 2008).

TRL:

- Microscopic devices with moving parts
- It combines what can be done at nano-level with mechanical parts (engineering) and how these moving parts can be used in different industries and products.
- The technology consists of central unit that processes the data and different components interacting with microsensors (Waldner, 2008), where very small machines are used in the device fabrication technologies to make electronics.
- “*MEMS are made up of components between 1 and 100 micrometers in size (i.e., 0.001 to 0.1 mm), and MEMS devices generally range in size from 20 micrometers to a millimeter (i.e., 0.02 to 1.0 mm), although components arranged in arrays (e.g., digital micromirror devices) can be more than 1000 mm2*” (Waldner, 2008).
- Based on the available information about the technology, it is currently under research and development, however there are some applications ready to be tested in certain industries with prototypes. As it is not a fully developed technology, it is defined mostly under Applied Research (TRL INSPIRE 2 / TRL-EU 6), with some specific (small in number) cases at Market Ready (TRL INSPIRE 3 / TRL-EU 7)
- Examples of the technology: Piezoelectric sensors, capacitive sensors, photodiodes, thermocouples, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	Microscopic devices with moving parts
Flexibility			
	Capacity	1	customized products at high cost
	Product	2	portfolio expanded with different products
	Innovation	2	adaptable for new product manufacturing
	Location	0	Less relevant for this
	Feedstock (or Input)	0	Less relevant for this
	Energy	1	Strongly depends on kind of application
Business Model Impact			
	Supply	1	suppliers for different materials, parts and elements
	Demand	2	customer demand driven

	Chain	2	SC changes based on demand
	Ecosystem	0	Less relevant for this
	Cost	4	costly technology development
	Revenue	3	high revenue based on product use
	Overall		
Sustainability			
	Material use	0	Less relevant for this
	Environmental footprint	0	Less relevant for this
	Energy	1	Strongly depends on kind of application
	Strategy	1, 3	
Regional Impact			
	Safety, Health and Environment	1	Strongly depends on kind of application
	Material flow	1	Strongly depends on kind of application
	Direct jobs	1	Strongly depends on kind of application
	Business opportunities	1	Strongly depends on kind of application
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	1	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	1	
	Minerals	1	
	Steel	1	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	1	
	Paper and furniture	0	
	Electrical & electronic machinery	3	
	Vehicles & auto components	1	
	Leather & footwear	0	

A1.4.2.6Industry 4.0

Industry 4.0 is a type of industry in which “*computers and automation come together in an entirely new way, with robotics connect to computed systems equipped with machine learning algorithms that can learn and control the robotics with very little input from human operators*” (Marr, 2016)

TRL:

- Mix of automation and data exchange in manufacturing technologies
- The technology operates in a way that generates an autonomous “*smart factory, where the modular structured connected entities, cyber-physical systems monitor physical*

processes, create a virtual copy of the physical world and make decentralized decisions" (Hermann, Pentek, & Otto, 2016).

- The technology is currently under research and development, however there are some applications already available.
- The technology is currently under research and development, however there are some applications already available. However, given that there are many things that need to be implemented to have a successful deployment of the technology, we consider that is on Applied Research (TRL INSPIRE 2 / TRL-EU 5) level.
- Examples of the technology: energy-efficient process optimization (signal acquisition and conversion into real movement).

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	Mix of automation and data exchange in manufacturing technologies
Flexibility			
	Capacity	3	Capacity will be shifted under "smart factory" concepts
	Product	3	quick product innovation under "smart factory" concept
	Innovation	3	easiness of product innovation under "smart factory" concept
	Location	1	"smart factory" could be moved within a range
	Feedstock (or Input)	0	Less relevant for this
	Energy	1	Strongly depends on kind of application
Business Model Impact			
	Supply	2	managing different suppliers to create different products
	Demand	2	demand driven meets different needs from customer
	Chain	2	SC changes based on demand and supply
	Ecosystem	0	Less relevant for this
	Cost	2	design of "smart factory" could be costly
	Revenue	3	high revenue on taking advantage of "smart factory"
	Overall		
Sustainability			
	Material use	1	Strongly depends on kind of application
	Environmental footprint	0	Less relevant for this
	Energy	1	Strongly depends on kind of application
	Strategy	1, 3	
Regional Impact			
	Safety, Health and Environment	1	Strongly depends on kind of application
	Material flow	2	Material input based on the "smart factory"
	Direct jobs	1	Strongly depends on kind of application
	Business opportunities	1	Strongly depends on kind of application
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	1	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	

	Steel	3	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	1	
	Paper and furniture	1	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	1	

A1.4.3 ICT

A1.4.3.1Big data

Is a trend that is currently used to describe "*the large volume of data, structured and unstructured, that refers to the use of analytics that extract value from any given set of data and what organizations do with that data*" (SAS Institute Inc, 2017).

TRL:

- Big data is essential on ICT and has large potential for impact
- The technology uses predictive data analytics to extract value from data.
- "*There is little doubt that the quantities of data now available are indeed large, but that's not the most relevant characteristic of this new data ecosystem*" (Boyd & Crawford, 2011).
- "*Big data can be analyzed for insights that lead to better decisions and strategic business moves*" (SAS Institute Inc, 2017).
- Technology is currently under development; however it has some applications already available. The readiness is in between applied research and market ready level. Given that it is not a mature technology on the market ready level, but is moving rapidly into this level, we consider that is on Applied Research (TRL INSPIRE 3 / TRL-EU 7) level.
- Examples of the technology: transportation services, banking sectors and fraud detection, insurance services, learning services, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	Big data is essential on ICT and has large potential for impact
Flexibility			
	Capacity	0	No change
	Product	3	Product innovation based on customer needs and shared information
	Innovation	3	Innovative products based on information
	Location	0	No change
	Feedstock (or Input)	0	No change
	Energy	0	No change
Business Model Impact			
	Supply	1	Depends on the specific process

	Demand	3	information will change the demand
	Chain	3	information-based SC
	Ecosystem	0	No change
	Cost	0	No change
	Revenue	2	Low investment, high revenue
	Overall		
Sustainability			
	Material use	0	Less relevant for this
	Environmental footprint	0	Less relevant for this
	Energy	0	Less relevant for this
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	3	for each of them, analysis of the information through BD is meaningful
	Material flow	0	Less relevant for this
	Direct jobs	1	jobs related to data analytics
	Business opportunities	3	business creation based on BD
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	1	
	Chemicals	1	
	Engineering	1	
	Non-ferrous metals	1	
	Minerals	1	
	Steel	1	
	Water	1	
	Food processing & beverages	1	
	Textiles including clothing	1	
	Paper and furniture	1	
	Electrical & electronic machinery	1	
	Vehicles & auto components	1	
	Leather & footwear	1	

A1.4.3.2Internet of things

Is defined as a concept of "*basically connecting any device with an on and off switch to the Internet (and/or to each other). This includes everything from cellphones, coffee makers, washing machines, headphones, lamps, wearable devices and almost anything else you can think of*" (Morgan, 2014).

TRL:

- IoT will change how products and services are offered today
- "*This also applies to components of machines, for example a jet engine of an airplane or the drill of an oil rig*" (Morgan, 2014)
- It collects data through the use of various existing technologies and devices, from diverse locations, and then flows the data between different devices in an autonomous way.
- "*The quick expansion of Internet-connected objects is also expected to generate large amounts of data from diverse locations, with the consequent necessity for quick aggregation of the data, and an increase in the need to index, store, and process such data more effectively*" (Hendricks, 2015).

- The technology has some applications already available and different industries are adding more devices that can be online, thus the readiness is almost at market ready (TRL INSPIRE 3 / TRL-EU 7) level.
- Examples of the technology: smart home, wearable, connected cars, smart cities, smart retail, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	IoT will change how products and services are offered today
Flexibility			
	Capacity	1	Depends on the specific process
	Product	3	Products developed around IoT
	Innovation	3	IoT forces innovation on design and development
	Location	0	Less relevant for this
	Feedstock (or Input)	0	Less relevant for this
	Energy	0	Less relevant for this
Business Model Impact			
	Supply	2	sourcing using IoT
	Demand	2	demand made by things, approved by humans
	Chain	3	IoT changes the way the SC moves nowadays
	Ecosystem	0	Less relevant for this
	Cost	4	IoT requires large investment
	Revenue	2	Revenue relies on the price
	Overall		
Sustainability			
	Material use	0	Less relevant for this
	Environmental footprint	4	IoT will require large amounts of virgin raw materials, mainly electronics
	Energy	4	IoT is intensive in energy consumption
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	1	Depends on the specific process
	Material flow	1	Depends on the specific process
	Direct jobs	3	new jobs around the IoT
	Business opportunities	3	opportunities for business innovation
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	1	
	Chemicals	1	
	Engineering	3	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	1	
	Water	0	
	Food processing & beverages	1	
	Textiles including clothing	1	
	Paper and furniture	1	
	Electrical & electronic machinery	3	

	Vehicles & auto components	3	
	Leather & footwear	1	

A1.4.3.3Automation

Defined as the use of technologies that allows creating repeated processes that replace manual work from different professionals, allowing them to focus in different tasks that require more attention and avoiding non-value-added activities (Mikell, 2014).

- Automation mixed with ICT changes the industrial processes
- Integrates tools that control for "*operating equipment such as machinery, processes in factories, boilers and heat-treating ovens, switching on telephone networks, steering and stabilization of ships, aircraft and other applications and vehicles with minimal or reduced human intervention, with some processes have been completely automated*" (Rifkin, 1996).
- This can be done via remote control or using 100% automated systems that take care of all the decisions involved in the process.
- The technology that has been around for some years in different industries, however new industries are joining the discussion. The readiness level is Market Ready (TRL INSPIRE 3 / TRL-EU 8) and Market Presence with improvement opportunities (TRL INSPIRE 4 / TRL-EU 9).
- Examples of the technology: automated stirring devices, automated selfie remotes, automated bicycle illumination, garage opener apps, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Automation mixed with ICT changes the industrial processes
Flexibility			
	Capacity	3	changes in production capacity
	Product	3	automated manufacturing
	Innovation	3	innovation bring through automation
	Location	0	additional equipment is required
	Feedstock (or Input)	0	additional equipment is required
	Energy	2	could be a source of higher energy consumption
Business Model Impact			
	Supply	3	automated sourcing processing
	Demand	3	automated demand processing
	Chain	3	changes in the SC
	Ecosystem	0	No changes
	Cost	3	Automation is costly
	Revenue	2	will depend largely on initial cost
	Overall		
Sustainability			
	Material use	1	Depends on the specific process
	Environmental footprint	1	Depends on the specific process
	Energy	4	could be a source of higher energy consumption
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	1	Depends on the specific process

	Material flow	0	No changes
	Direct jobs	3	running, maintenance, implementation
	Business opportunities	2	business industries around the automation
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	1	
	Steel	1	
	Water	0	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	1	

A1.4.3.4Robotics

Is a mix of different disciplines (mechanics, electronics, computer science, etc.) that allows the "*design, construction, operation and use of robots, as well as computer systems for their control, sensory feedback and information processing*" (Nocks, 2007)
TRL:

- Robotics have been around for a while, and applications are vast
- Robots can be used in different situations, mostly to avoid losing human lives under dangerous environments (such as bomb de-activation) or where humans cannot survive due to the environmental conditions.
- The technology takes advantage of the mechanics parts and electronic integration, to generate movements similar to anything a human can do, but being under control of a human being to make sure that the task is completed satisfactorily (Nocks, 2007).
- The technology that has been around for some years in different industries. The readiness level is Market Presence with innovation opportunities (TRL INSPIRE 4 / TRL-EU 9).
- Examples of the technology: space and military robots, bomb de-activation systems, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Robotics have been around for a while, and applications are vast
Flexibility			
	Capacity	3	Broad range of potential applications
	Product	3	Potential for product development
	Innovation	3	Potential for innovation on products
	Location	3	
	Feedstock (or Input)	0	No visible change in the short term

	Energy	4	Is likely that will increase the energy consumption, no being efficient
Business Model Impact			
	Supply	3	Potential for big change in supply
	Demand	3	Robotics can make orders on their own and help to automate the demand of parts and components
	Chain	3	Robotics can add a new layer of automation to the SC
	Ecosystem	0	No changes on the ecosystem
	Cost	4	Robotics implementation are costly
	Revenue	2	Revenue will depend on the cost
	Overall		
Sustainability			
	Material use	3	Efficient use of materials
	Environmental footprint	2	Impact of efficient use of materials
	Energy	1	Likely to increase energy consumption
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	2	research and applications are under development
	Material flow	2	probably will change how SC is shaped
	Direct jobs	3	maintenance, design and implementation
	Business opportunities	3	maintenance, design and implementation
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	1	
	Minerals	3	
	Steel	3	
	Water	1	
	Food processing & beverages	1	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	1	

A1.4.3.5Artificial Intelligence

Has been defined as “*the science and engineering of making intelligent machines, especially intelligent computer programs*” (McCarthy, 2007); although, the term is applied “*when a machine mimics cognitive functions that humans associate with other human minds, such as learning and problem solving*” (Russell & Norvig, 1995).

TRL:

- There's a large potential for the technology, but further research is needed
- Artificial Intelligence (AI) takes the learning opportunity provided by the coders and programmers and makes sure to mimic human cognitive functions to learn quickly how to perform different activities in an automated manner, “making decisions” on its own.

- The technology is currently under research and development, and requires collaboration between different fields. However there are some applications already available at market presence, therefore the readiness level is currently under Market-ready with research and improvement opportunities (TRL INSPIRE 3 / TRL-EU 7).
  Examples of high-profile AI are seen in a daily base life, such as "*autonomous vehicles (such as drones and self-driving cars), medical diagnosis, creating art (such as poetry), proving mathematical theorems, playing games (such as Chess or Go), search engines (such as Google search), online assistants (such as Siri), image recognition in photographs, spam filtering, prediction of judicial decisions and targeting online advertisements*" (Aletras, Tsarapatsanis, Preoţiuc-Pietro, & Lampos, 2016)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	There's a large potential for the technology, but further research is needed
Flexibility			
	Capacity	0	No direct influence in capacity
	Product	2	Products geared using AI
	Innovation	2	Adaptation to different processes processed using AI
	Location	0	Additional equipment required
	Feedstock (or Input)	0	Additional equipment required
	Energy	0	Additional equipment required
Business Model Impact			
	Supply	2	changes on how supply is made
	Demand	2	demand updated automatically via AI instruments
	Chain	2	meaningful changes on the SC
	Ecosystem	0	no change
	Cost	4	AI will be costly
	Revenue	2	revenue could be achieved, but initial investment is large
	Overall		
Sustainability			
	Material use	1	Depends on the specific process
	Environmental footprint	1	Depends on the specific process
	Energy	4	is likely that AI will increase the energy consumption
	Strategy		
Regional Impact			
	Safety, Health and Environment	1	Depends on the specific process, but could create new processes on Health
	Material flow	0	Additional equipment required
	Direct jobs	1	likely to have new jobs based on AI maintenance
	Business opportunities	2	some opportunity, definitively
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	0	

	Food processing & beverages	1	
	Textiles including clothing	1	
	Paper and furniture	0	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	0	

A1.4.3.6Body Scanners

The Computed tomography (CT) of the body uses special x-ray equipment to help detect a variety of diseases and conditions (RSNA, 2017). CT is recognized as an invaluable medical tool for the diagnosis of disease, trauma, or abnormality in patients with signs or symptoms of disease (FDA, 2015).

TRL:

- Body scanners allow medical workers to detect and treat abnormal conditions in the human body
- With CT scanning, "*numerous x-ray beams and a set of electronic x-ray detectors rotate around the person, measuring different portions of the body*” (RSNA, 2017) and checking the effects of radiation absorption along the body.
- Then, large amount of data is processed and creates two-dimensional cross-sectional images of the body and display them on a monitor, resulting in a very detailed multidimensional view of the body’s interior (FDA, 2015).
- The technology has applications already available at medical industry, thus the readiness is at market presence (TRL INSPIRE 4 / TRL-EU 9).
- Examples of the technology: Millimeter wave scanners, backscatter X-Ray, through-body X-Ray, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Body scanners allow medical workers to detect and treat abnormal conditions in the human body
Flexibility			
	Capacity	0	Less relevant for this
	Product	2	adaptation for many products
	Innovation	2	different types of scanner for many health problems
	Location	0	Less relevant for this
	Feedstock (or Input)	0	Less relevant for this
	Energy	0	Less relevant for this
Business Model Impact			
	Supply	1	Depends on the specific process
	Demand	1	Depends on the specific process
	Chain	1	Depends on the specific process
	Ecosystem	0	Less relevant for this
	Cost	4	costly for development and implementation
	Revenue	1	relies on the initial cost and use of the equipment
	Overall		

Sustainability			
	Material use	0	Less relevant for this
	Environmental footprint	0	Less relevant for this
	Energy	4	highly intensive in energy use
	Strategy		
Regional Impact			
	Safety, Health and Environment	3	health is the key
	Material flow	0	Less relevant for this
	Direct jobs	1	Depends on the equipment and its usage
	Business opportunities	1	Depends on the equipment and its usage
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	0	
	Paper and furniture	0	
	Electrical & electronic machinery	3	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.4.3.7Elderly support

It is a multidisciplinary research engineered towards to provide services to the rapidly growing aging population.

TRL:

- Research on elderly and their current (and future) needs has developed some applications at market ready level, as well as others to come.
- It considers the fact that "*aging is a disruptive force in many countries and economies*" (Coughlin, 2017) and that elderly people require more services, especially those focused on caretaking.
- According to the words of Coughlin this is related to "*providing unpaid support to a family member or friend who has physical, psychological or development needs*" (Coughlin, 2017).
- The technologies around the elderly are related to provide a better life style, by offering customized services in different fields (nursing, transportation, food, apparel industry, etc.).

- The technology is currently under research but has successfully deployed different services and technologies. Thus, the readiness level is currently Market Ready with innovation and improvement opportunities (TRL INSPIRE 4 / TRL-EU 9).
- Examples of the technology: hospice care, residential care, adult day care, nursing home, palliative care, transportation support, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Research on elderly and their current (and future) needs has developed some applications at market ready level, as well as others to come
Flexibility			
	Capacity	1	maybe by providing different capacities for different products
	Product	3	products for elderly people are different and require new developments
	Innovation	3	new features on products targeting elderly
	Location	0	no changes expected
	Feedstock (or Input)	0	no changes expected
	Energy	1	possible changes in the energy amount required on manufacturing
Business Model Impact			
	Supply	3	new services targeted for elderly population
	Demand	3	growing elderly population demand for new services
	Chain	3	SC shaped to meet new needs
	Ecosystem	0	not visible change on ecosystem
	Cost	2	product prices are likely to increase
	Revenue	3	revenue will increase from larger elderly population
	Overall		
Sustainability			
	Material use	2	special products could be manufactured using different materials
	Environmental footprint	1	not pretty likely to reduce footprint
	Energy	1	is likely that products for elderly will consume more energy
	Strategy	3	development of different products targeted for elderly
Regional Impact			
	Safety, Health and Environment	3	new requirements from elderly
	Material flow	1	different products require different materials, but it won't reshape the current material flow
	Direct jobs	2	creation of jobs related to elderly caring
	Business opportunities	2	development of different products targeting elderly
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	1	
	Chemicals	0	
	Engineering	0	
	Non-ferrous metals	0	
	Minerals	0	

	Steel	0	
	Water	1	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	1	
	Electrical & electronic machinery	1	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.4.4 Health-care related technologies

The Medical technology has different definitions, ranging a wide type of products and services, with the solely intention "*to improve the quality of healthcare delivered through earlier diagnosis, less invasive treatment options and reductions in hospital stays and rehabilitation times*" (ADVAMED, 2009).

- The specific case of Health Information Technology (HIT) aims to support the information management across several automated and computerized systems, ensuring the secure exchange among consumers, health providers, monitors and service payers.
- According to the Agency for Healthcare Research and Quality, the objectives of the HIT are:
    - "*Improve health care quality or effectiveness*
    - *Increase health care productivity or efficiency*
    - *Prevent medical errors and increase health care accuracy and procedural correctness*
    - *Reduce health care costs*
    - *Increase administrative efficiencies and healthcare work processes*
    - *Decrease paperwork and unproductive or idle work time*
    - *Extend real-time communications of health informatics among health care professionals*
    - *Expand access to affordable care*" (Shekelle, Morton, & Keeler, 2006)
- The technology has different levels of readiness, however those related to HIT are already available at applied research and market ready level.

Below are defined some examples of Health care related technologies that can help to understand how these technologies are reshaping the health-care industry and what are the perspectives in the near future.

A1.4.4.1E-health

Relatively "*recent healthcare practice supported by electronic processes and communication that intend to communicate the electronic processes in health through data exchange about the patient records*" (Mea, 2001)

TRL:

- eHealth has several applications in many different health related services

- "*It is used in small projects where images are transmitted from a primary care setting to a medical specialist, who comments on the case and suggests which intervention might benefit the patient*" (Allday, 2007).
- "*A field that lends itself to this approach is dermatology, where images of an eruption are communicated to a hospital specialist who determines if referral is necessary*" (Allday, 2007).
- The technology has some applications already available at market level. The readiness is in between applied research and market ready level (TRL INSPIRE 3 / TRL-EU 7).
- Examples of the technology: SaaS in e-health market, telecommunication among companies, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	eHealth has several applications in many different health related services
Flexibility			
	Capacity	0	Less relevant for this
	Product	3	services around many products
	Innovation	3	a wide range of service innovation
	Location	0	Less relevant for this
	Feedstock (or Input)	0	Less relevant for this
	Energy	0	Less relevant for this
Business Model Impact			
	Supply	2	Supply based on customer needs
	Demand	2	Demand driven by customer
	Chain	2	Changes based on supply and demand
	Ecosystem	0	Less relevant for this
	Cost	3	not costly and provides answers to different request
	Revenue	2	high revenue based on services with low cost
	Overall		
Sustainability			
	Material use	0	Less relevant for this
	Environmental footprint	0	Less relevant for this
	Energy	0	Less relevant for this
	Strategy		
Regional Impact			
	Safety, Health and Environment	3	main point is here!
	Material flow	0	Less relevant for this
	Direct jobs	1	possible to have new jobs
	Business opportunities	1	new business is possibility
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	1	

	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	0	
	Electrical & electronic machinery	3	
	Vehicles & auto components	0	
	Leather & footwear	1	

A1.4.4.2Electronic Medical Records and Electronic Health Records

Electronic Medical Records (EMR) and Electronic Health Records (EHR) are clinical data gathered with the patient medical history, designed to contain and share information about all providers that take part of a patient's care (Hillestad, et al., 2005).

TRL:

- Easiness access to medical information, having the potential to eliminate clinician's workflow
- These records "*can be created, managed, and consulted by authorized providers and staff from across more than one health care organization*" (HealthIT, 2016)
- "*In short, is a digital version of a paper chart that contains all of a patient's medical history, and is mostly used by providers for diagnosis and treatment*" (HealthIT, 2016).
- The idea behind the EMR and EHR is to "*facilitate workflow and improve the quality of patient care and patient safety*" (DesRoches, et al., 2008)
- The technology has been around for some years, but its implementation has been really low, especially in countries like the US; therefore, there exist a large room for improvement and development. The readiness level is Market Ready (TRL INSPIRE 3 / TRL-EU 8).
- Examples of the technology: eClinical Works, McKesson, Cerner, Allscripts, Athena Health, Care360, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	Easiness access to medical information, having the potential to eliminate clinician's workflow
Flexibility			
	Capacity	0	Less relevant for this
	Product	2	products geared by medical history
	Innovation	2	innovation based on medical information
	Location	0	Less relevant for this
	Feedstock (or Input)	0	Less relevant for this
	Energy	0	Less relevant for this
Business Model Impact			
	Supply	1	information sharing
	Demand	3	demand will increase as long as clinicians see an opportunity
	Chain	2	depends on the demand and supply
	Ecosystem	0	Less relevant for this
	Cost	4	could be costly to access to private information
	Revenue	2	relies on the implementation cost
	Overall		

Sustainability			
	Material use	1	depends on the specific process
	Environmental footprint	1	depends on the specific process
	Energy	0	Less relevant for this
	Strategy		
Regional Impact			
	Safety, Health and Environment	3	health is the key here
	Material flow	0	Less relevant for this
	Direct jobs	1	jobs related to information analytics
	Business opportunities	1	business related to development and implementation
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	1	
	Minerals	1	
	Steel	1	
	Water	1	
	Food processing & beverages	1	
	Textiles including clothing	1	
	Paper and furniture	0	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.4.4.3 Telemedicine

It has been defined as the integration of telecommunications and information technologies with the medical area, aiming to "*provide clinical health care from a distance*" (Conde, et al., 2010).
TRL:

- Providing virtual health care from the distance
- The main advantage of the telemedicine is that overcomes distance barriers, providing access to medical services that are not available in the short distance, or under critical care and emergency situations.
- It uses ICT means to communicate with the patient, "*may involve the use of live interactive video or the use of store and forward transmission of diagnostic images, vital signs and/or video clips along with patient data for later review*" (World Health Organization, 2010).
- In summary, "*allows healthcare providers to evaluate, diagnose and treat patients without the need for an in-person visit*" (Rouse, 2017).
- The technology has been around for some years, but its implementation has been really low as it requires large investment from governments. The readiness level is Market Ready with improvement opportunities (TRL INSPIRE 3 / TRL-EU 7).
- Examples of the technology: Teleradiology, telepsychiatry, tele nephrology, telepathology, tele rehabilitation, etc.

Indicator	**Category**	**Score**	**Explanation**

Technology Readiness Level	Overall	3	Providing virtual health care from the distance
Flexibility			
	Capacity	0	Less relevant for this
	Product	3	different products can be created for different medical purposes
	Innovation	3	new products are required
	Location	0	Less relevant for this
	Feedstock (or Input)	0	Less relevant for this
	Energy	0	Less relevant for this
Business Model Impact			
	Supply	3	growing supply of medical products
	Demand	3	growing demand for health services
	Chain	3	balance of supply and demand
	Ecosystem	0	Less relevant for this
	Cost	2	depend on each product, but in the overall they can be less costly than expected
	Revenue	3	overcoming the cost will imply a high revenue based on intensive use of products and services
	Overall		
Sustainability			
	Material use	4	investment on materials for the product production
	Environmental footprint	0	Less relevant for this
	Energy	2	services could be energy intensive
	Strategy	3	
Regional Impact			
	Safety, Health and Environment	3	this is the main focus
	Material flow	1	depends on the specific process
	Direct jobs	2	linked to job generation
	Business opportunities	2	likely to generate new business around the products and services
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	1	
	Minerals	1	
	Steel	1	
	Water	1	
	Food processing & beverages	3	
	Textiles including clothing	1	
	Paper and furniture	0	
	Electrical & electronic machinery	3	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.4.4.4360-degree view of medical data

Is the use of technology to make sure that there exists a holistic patient profile, "*to ensure that care decisions are based upon the most pertinent, complete, and timely data*" (Sullivan, 2017)

TRL:

- Sharing information among medical entities and being able to share family history data
- Integrates different platforms to allow different medical groups to analyze structured and unstructured data about a patient, within a continuity of care document.
- "*This further improves the efficiency and completeness of the analytically driven patient profile upon which the clinical teams rely*" (Sullivan, 2017).
- Moreover, it allows different companies (care service providers) to integrate and communicate with each other.
- The technology that allows the integration has been around for some years, but has not been used for this purpose. However, its implementation can be made easily. The readiness level is Market Ready with improvement opportunities (TRL INSPIRE 3 / TRL-EU 8).
- Examples of the technology: SaaS in e-health market, telecommunication among companies, etc.

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	Sharing information among medical entities and being able to share family history data
Flexibility			
	Capacity	1	Depends on the specific process
	Product	2	customized products based on medical history
	Innovation	2	innovative products based on medical history
	Location	0	No change
	Feedstock (or Input)	0	No change
	Energy	0	No change
Business Model Impact			
	Supply	3	supply driven by customer needs
	Demand	3	demand changes how manufacturer reacts
	Chain	3	changes the whole SC based on medical history
	Ecosystem	0	No change
	Cost	2	costly for implementation
	Revenue	3	benefits outfit the cost
	Overall		
Sustainability			
	Material use	1	Depends on the specific process
	Environmental footprint	1	Depends on the specific process
	Energy	1	Depends on the specific process
	Strategy	1, 3	
Regional Impact			
	Safety, Health and Environment	3	main focus of the research
	Material flow	0	No change
	Direct jobs	1	Depends on the specific process
	Business opportunities	2	services around the medical industry
Industrial Applicability (SPIRE and			
	Cement	0	
	Ceramics	0	

Manufacturing clusters)	Chemicals	0	
	Engineering	0	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	0	
	Water	1	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	1	
	Electrical & electronic machinery	0	
	Vehicles & auto components	0	
	Leather & footwear	0	

A1.5 Reuse - Sustainability

A1.5.1 Overview

Recycling describes technologies that aim to recover materials from end-of-life products (cores). From a sustainability performance point of view, recycling is often less advantageous than longer use, reuse, remanufacturing, refurbishing, and repair. Depending on different circumstances like the energy consumption of the product's technology or the condition of the core, it might be the best solution for a specific situation or it is preferred for economic reasons or the availability of infrastructure.

Remanufacturing, refurbishing, and repair technologies that aim to restore or recover parts from end-of-life products (cores). From a sustainability performance point of view these technologies are often more advantageous than recycling but not as effective as longer use or reuse. Depending on different circumstances like the reliability or visual requirements, it might be the best solution for a specific situation.

Reuse, longer lifetimes technologies are the third group of Circular Economy or Re-X technologies aimed at minimizing resource input into and waste and emission leakage out of the economic system. The technologies aim to prolong the use life of a product to reduce the waste associated with disposing and the resource input necessary to replace the product with a new one. This is often the most effective solution in regard to sustainability, but there are exceptions, e.g. if the impact of higher energy efficiency of a new product surpasses the impact of replacement.

Information and Communication Technology (ICT) comprises information and telecommunication technologies that allow access, storage, transmission, and manipulation of data. In the context of Circular Economy business models, it describes IT and communication technologies that support the planning and coordination of the Re-X production principles outlined above.

Information and simulation based decision and design describes technologies that enable the simulation of the key elements of an organization and its environment as well as the interaction between these elements using simulation software. These technologies support decision making in the development and design of Circular Economy operations and organizations by calculating and visualizing the outcomes of different scenarios based on assumptions and empiric data.

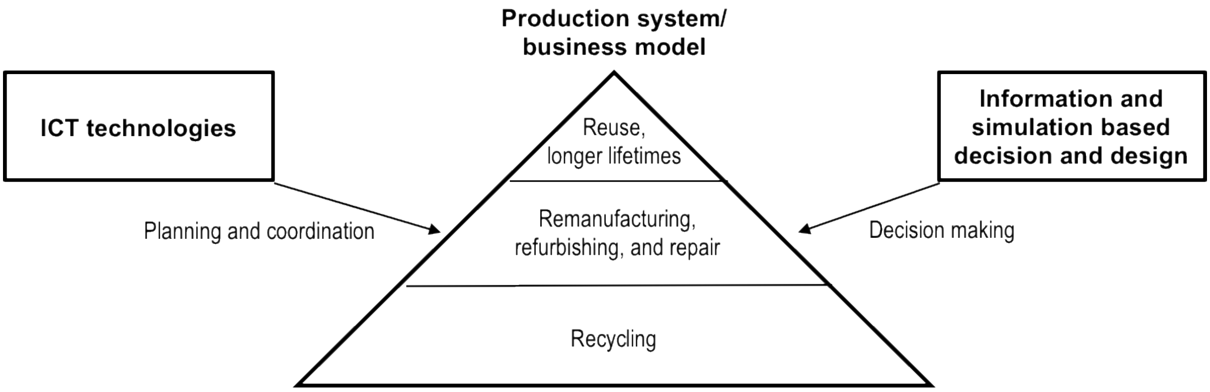

Figure 57: Graphical representation of the technology clusters that facilitate and support deployment of circular strategies

A1.5.2 Remanufacturing, refurbishing, repair

A1.5.2.13D printing

TRL: Market presence

- 3D printing or additive manufacturing describes a production process in which the product is printed in layers
- This can be done with a range of materials, resulting in a broad range of process characteristics and output quality
- Compared to conventional subtractive manufacturing, additive manufacturing has a potentially lower material input
- Additional sustainability improvements can be achieved through better product design enabled by the more complex geometries and more rapid prototyping that this technology allows
- Additive manufacturing also facilitates more localized production, known as re-distributed manufacturing (RdM) with comprehensive implications for manufacturing operations and supply chains
- Some applications are already used in industry with a comprehensive introduction of additive manufacturing to be expected in additional sectors
- This technology facilitates narrowing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Some applications are already used in industry with a comprehensive introduction of additive manufacturing to be expected in additional sectors
Flexibility			
	Capacity	3	Design to production times are short and one printer can produce a broad range of different product designs
	Product	3	Design to production times are short and one printer can produce a broad range of different product designs
	Innovation	3	Design to production times are short and one printer can produce a broad range of different product designs, for different process however, in most cases new devices have to be acquired
	Location	3	Small-batch production close to the customer is one of the key advantages of additive manufacturing
	Feedstock (or Input)	2	To a certain extent, depending on the specific printer technology
	Energy	3	Yes, most devices can be switched on and off quite quickly
Business Model Impact			
	Supply	1	Potentially, the current suppliers can also deliver the required feedstock
	Demand	2	The technology enables better response to customer demand (time and location), but can also be employed tin the current BM
	Chain	2	Yes, additive manufacturing (AM) is a key enable for redistributed manufacturing (RdM)
	Ecosystem	1	Depending on how it is employed it potentially does, see RdM
	Cost	2	The cost structure of the production operations changes significantly with both advantages and disadvantages involved. The cost structure is expected to improve as the technology matures.
	Revenue	1	Depending on how the technology is employed
	Overall		Depending on how the technology is employed it can be
Sustainability			
	Material use	3	Yes, additive manufacturing involves less waste production during the manufacturing process
	Environmental footprint	2	Probably through to material savings, but comprehensive system analyses are still nascent
	Energy	1	This depends on a range of factors

	Strategy	1, 3	AM reduces material inputs per product volume and might facilitate intelligent energy management through short warm-up times
Regional Impact			
	Safety, Health and Environment	1	Potentially less dangerous and noisy than other production processes
	Material flow	1	Potentially new suppliers emerge in the context of AM
	Direct jobs	2	In the context of RdM it is expected to create additional jobs closer to the customer
	Business opportunities	2	Yes it does in the context of RdM
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	1	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	1	
	Steel	3	
	Water	1	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	1	
	Electrical & electronic machinery	1	
	Vehicles & auto components	1	
	Leather & footwear	3	

A1.5.2.2Automated disassembly

TRL: Market presence

- Automated disassembly describes the process and the underlying technologies of retrieving parts and materials from a core without human assistance
- Disassembly is one of the key manufacturing steps for circular operations based on re-X processes (recycling, remanufacturing, etc.)
- While the process is often performed with a considerable amount of manual labor, there are attempts at automatization
- Automatization can reduce variable costs and therefore the efficiency of circular production systems
- It often does require a certain volume of not too diverse cores to operate effectively and efficiently
- More efficient circular production systems can potentially improve the organizations sustainability performance
- Several studies to provide the technology with some industry applications
- This technology facilitates closing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Several studies to provide the technology with some industry applications
Flexibility			
	Capacity	1	Maybe through providing parts but probably not
	Product	1	Depends on the specific process
	Innovation	1	Depends on the specific process
	Location	0	Additional equipment
	Feedstock (or Input)	0	Additional equipment
	Energy	0	Additional equipment
Business Model Impact			
	Supply	1	Depends on how much it differs from current processes
	Demand	1	Depends on how much it differs from current processes
	Chain	1	Depends on how much it differs from current processes
	Ecosystem	1	Depends on how much it differs from current processes
	Cost	1	Depends on how much it differs from current processes
	Revenue	1	Depends on how much it differs from current processes
	Overall		Depends on how much it differs from current processes
Sustainability			
	Material use	3	Material input through recycling probably decreases
	Environmental footprint	3	Material input through recycling probably decreases
	Energy	1	Not necessarily
	Strategy	1	Reuse of parts and materials facilitated through potentially quicker and cheaper process
Regional Impact			
	Safety, Health and Environment	2	Material input through recycling probably decreases
	Material flow	3	Material input through recycling probably decreases
	Direct jobs	0	It might jeopardize current disassembly jobs
	Business opportunities	1	Potentially through higher supply of recycling materials and parts
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	0	
	Ceramics	0	
	Chemicals	0	
	Engineering	3	
	Non-ferrous metals	0	
	Minerals	0	
	Steel	3	
	Water	0	
	Food processing & beverages	0	
	Textiles including clothing	1	
	Paper and furniture	1	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	1	

A1.5.2.3IoT Smart Industry

TRL: Market presence

- The Internet of things (IoT) describes a network of physical devices, and their computing system, sensors and actuators, that are connected with the internet and over it with electronic end devices like PCs or tablets.
- IoT is gradually introduced in some industries, the potential for deeper and broader introduction is considerable
- Digitalization of production processes by integrating physical devices, sensors, and software into networks can improve a broad range of production processes
- This comprises the production processes of circular business models
- Especially the reverse supply chain and re-X (recycling, remanufacturing, etc.) processes
- This can improve material and energy efficiency
- IoT is gradually introduced in some industries, the potential for deeper and broader introduction is considerable
- This technology especially facilitates narrowing and slowing resource loops, which are two of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	IoT is gradually introduced in some industries, the potential for deeper and broader introduction is considerable
Flexibility			
	Capacity	3	these systems allow to optimize the use of capacity
	Product	3	Modularity, postponement etc. facilitate the adaptation and preparation of the production process to product flexibility
	Innovation	3	Better management of the innovation, help to the definition and analysis of the effects of product and process innovation
	Location	3	help to infrastructure management and to the definition and analysis of the effects of location
	Feedstock (or Input)	2	help to the definition and analysis of the effects of using different kind of feedstock
	Energy	3	these systems allow to optimize the definition and analysis of the effects of using different kind of energy
Business Model Impact			
	Supply	1	Depends on the specific sector. Potentially, the current suppliers can also deliver the required feedstock
	Demand	1	The technology enables better response to customer demand (time and location), but can also be employed in the current BM
	Chain	2	The technology enables better coordination and contents definition
	Ecosystem	3	The performance of the network is strongly improved
	Cost	2	The cost of the technology is limited but it allows to avoid other costs of inefficiency, supporting the optimization of the processes
	Revenue	2	Revenues can increase because of the focus of BM on the specific needs of customer, who are willing to pay more
	Overall	Definitely	IoT allows to optimize the use of other technologies and to define in the proper way the level of customization
Sustainability			
	Material use	2	IoT allows to improve the use of materials and to monitor their impact on sustainability
	Environmental footprint	2	IoT allows to improve the use of materials and to monitor their impact on sustainability
	Energy	1	IoT allows to improve the use of energy and to monitor its impact on sustainability
	Strategy	3	IoT is a good support to analyze the weakness, strength and futurity of the company

Regional Impact	Safety, Health and Environment	1	Probably yes, but it depends on the specific process and sector
	Material flow	2	Probably yes, but it depends on the specific process and sector
	Direct jobs	2	The human action is globally reduced, but it created opportunities for new jobs with different capabilities and skills required
	Business opportunities	2	IoT can create new business opportunities for SMEs that are facing the new digitalization and automation trend
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.5.3 Recycling

A1.5.3.1Biodegradable materials

TRL: Market presence

- Biodegradable materials are materials that decompose into their natural ingredients over a short time under normal environmental conditions, e.g. on a landfill
- Biodegradable materials can replace materials that have a higher footprint when discarded
- There is only a limited range of biodegradable materials available, constraining their application in product design
- Widespread application of biodegradable materials could mitigate waste problems caused by material disposal
- Also, they enable a more sustainable utilization of landfills
- There are already biodegradable materials on the market that could be potentially used in the case companies
- This technology facilitates closing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**

Technology Readiness Level	Overall	4	There are already biodegradable materials on the market that could be potentially used in our case companies
Flexibility			
	Capacity	1	This is limited by the processes rather than the material itself
	Product	1	This is limited by the processes rather than the material itself
	Innovation	1	This is rather lower than with more established materials
	Location	2	Within reasonable limits from the place of material production
	Feedstock (or Input)	2	It works with a broader set of feedstocks, although often undesirable because of lower efficiencies
	Energy	0	Probably not
Business Model Impact			
	Supply	1	Potentially some of the current supplier might be able to offer these materials
	Demand	1	Potentially environmentally aware customer segments can be won
	Chain	0	Probably not
	Ecosystem	1	Potentially certification might be desirable
	Cost	2	The technology is assumed to be more expensive than more established solutions
	Revenue	2	If cost up --> revenues down, potentially offset by higher price and/or more volume
	Overall		Not necessarily
Sustainability			
	Material use	2	Desirable, but downstream/ unintended issues have to be monitored
	Environmental footprint	2	Desirable, but downstream/ unintended issues have to be monitored
	Energy	1	Depends on energy consumptions in early supply chain stages
	Strategy	3	Reduce/ substitute with renewables (This seems not to be a useful classification)
Regional Impact			
	Safety, Health and Environment	1	Potentially less health effects than conventional plastics
	Material flow	1	Depends on the specific supply chain
	Direct jobs	1	There might be downstream jobs created
	Business opportunities	1	Potentially if new suppliers emerge
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	1	
	Ceramics	1	
	Chemicals	3	
	Engineering	1	
	Non-ferrous metals	1	
	Minerals	1	
	Steel	1	
	Water	1	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	1	

	Leather & footwear	1	

A1.5.3.2Chemical markers

TRL: Market presence

- Chemical markers are chemicals that are durable and easy to identify, which facilitates the identification of materials on which they are applied
- Chemical markers enable the unambiguous identification of materials
- This facilitates re-X processes and appropriate disposal
- There are already some chemical markers available but the potential for further applications is considerable
- Clearer identification of materials increases the efficiency and effectiveness of circular production systems and therefore potentially their sustainability performance
- Already on the market in some areas but big technological and application potential
- This technology facilitates closing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Already on the market in some areas but big technological and application potential
Flexibility			
	Capacity	0	Role is rather in later stages of the value chain, less relevant for this
	Product	0	Role is rather in later stages of the value chain, less relevant for this
	Innovation	0	Role is rather in later stages of the value chain, less relevant for this
	Location	0	Less relevant for this
	Feedstock (or Input)	3	Identifiers facilitate sorting of feedstock and adaption of processes
	Energy	0	Less relevant for this
Business Model Impact			
	Supply	2	If suppliers are not able or willing to use markers
	Demand	0	Less relevant for this
	Chain	2	Reverse logistics partners also potentially have to introduce systems to utilize markers
	Ecosystem	1	Potentially standard definition and certification is required
	Cost	2	There will be initial extra costs
	Revenue	1	While initial costs will reduce revenues, higher efficiency might have the opposite effect in the longer run
	Overall		No
Sustainability			
	Material use	3	Facilitates recycling
	Environmental footprint	2	Facilitates recycling
	Energy	2	Facilitates recycling
	Strategy	1	Facilitates recycling
Regional Impact			
	Safety, Health and Environment	2	Facilitates reuse and recycling, might avoid problems caused by misinterpreted materials
	Material flow	2	Some suppliers will have to introduce the technology
	Direct jobs	0	The link will probably be weak
	Business opportunities	1	It might facilitate some operations, which might allow market entry for new players

Industrial Applicability (SPIRE and Manufacturing clusters)	Cement		
	Ceramics		
	Chemicals		
	Engineering		
	Non-ferrous metals		
	Minerals		
	Steel		
	Water		
	Food processing & beverages		
	Textiles including clothing		
	Paper and furniture		
	Electrical & electronic machinery		
	Vehicles & auto components		
	Leather & footwear		

A1.5.4 Reuse, longer lifetimes

A1.5.4.1Biomimicry

TRL: Applied research

- Biomimicry is the imitation of characteristics of natural systems like plants and animals to achieve the same functionality in artificial systems.
- Only few applications are currently on the market, no systematic way to utilize biomimicry in industrial applications
- Production and use efficiency is expected to increase by learning from nature
- This could result in decreasing material flows and more eco-effective products
- This in turn could facilitate circular operations and improve sustainability performance
- Only few applications are currently on the market, no systematic way to utilize biomimicry in industrial applications
- This technology facilitates narrowing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	Only few applications are currently on the market, no systematic way to utilize biomimicry in industrial applications
Flexibility			
	Capacity	1	Strongly depends on kind of application
	Product	1	Strongly depends on kind of application
	Innovation	1	Strongly depends on kind of application
	Location	1	Strongly depends on kind of application
	Feedstock (or Input)	1	Strongly depends on kind of application
	Energy	1	Strongly depends on kind of application
Business Model Impact			
	Supply	1	Strongly depends on kind of application
	Demand	1	Strongly depends on kind of application

	Chain	1	Strongly depends on kind of application
	Ecosystem	1	Strongly depends on kind of application
	Cost	1	Strongly depends on kind of application
	Revenue	1	Strongly depends on kind of application
	Overall		Strongly depends on kind of application
Sustainability			
	Material use	2	Is expected to decrease by learning from nature
	Environmental footprint	2	Is expected to decrease by learning from nature
	Energy	1	Is expected to decrease by learning from nature
	Strategy	3	Production and use efficiency is expected to increase by learning from nature
Regional Impact			
	Safety, Health and Environment	1	Strongly depends on kind of application
	Material flow	2	Material flows are expected to decrease by learning from nature
	Direct jobs	1	Strongly depends on kind of application
	Business opportunities	1	Potentially through new products
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	There is a broad range of potential applications
	Ceramics	3	There is a broad range of potential applications
	Chemicals	3	There is a broad range of potential applications
	Engineering	3	There is a broad range of potential applications
	Non-ferrous metals	3	There is a broad range of potential applications
	Minerals	3	There is a broad range of potential applications
	Steel	3	There is a broad range of potential applications
	Water	3	There is a broad range of potential applications
	Food processing & beverages	3	There is a broad range of potential applications
	Textiles including clothing	3	There is a broad range of potential applications
	Paper and furniture	3	There is a broad range of potential applications
	Electrical & electronic machinery	3	There is a broad range of potential applications
	Vehicles & auto components	3	There is a broad range of potential applications
	Leather & footwear	3	There is a broad range of potential applications

A1.5.4.2Identifiers

TRL: Applied research

- Identifier are active or passive signals that can be processed by production equipment
- Already on the market in some areas but considerable technological and application potential
- Identifiers facilitate sorting of feedstock and optimization of Re-X processes
- This increases material and energy efficiency and potentially improves sustainability performance
- Already on the market in some areas but big technological and application potential
- This technology facilitates closing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Already on the market in some areas but big technological and application potential
Flexibility			
	Capacity	0	Role is rather in later stages of the value chain, less relevant for this
	Product	0	Role is rather in later stages of the value chain, less relevant for this
	Innovation	0	Role is rather in later stages of the value chain, less relevant for this

	Location	0	Less relevant for this
	Feedstock (or Input)	3	Identifiers facilitate sorting of feedstock and adaption of processes
	Energy	0	Less relevant for this
Business Model Impact			
	Supply	2	If suppliers are not able or willing to use identifiers
	Demand	0	Less relevant for this
	Chain	2	Reverse logistics partners also potentially have to introduce systems to utilize identifiers
	Ecosystem	2	Potentially if actors outside the value chain are involved or certain behaviors (e.g. not removing identifiers) is required
	Cost	2	There will be initial extra costs
	Revenue	1	While initial costs will reduce revenues, higher efficiency might have the opposite effect in the longer run
	Overall		No
Sustainability			
	Material use	3	Facilitates reuse and recycling
	Environmental footprint	2	Facilitates reuse and recycling
	Energy	2	Facilitates reuse and recycling
	Strategy	1	
Regional Impact			
	Safety, Health and Environment	2	Facilitates reuse and recycling, might avoid problems caused by misinterpreted materials
	Material flow	2	Some suppliers will have to introduce the technology
	Direct jobs	0	The link will probably be weak
	Business opportunities	1	It might facilitate some operations, which might allow market entry for new players
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement		
	Ceramics		
	Chemicals		
	Engineering		
	Non-ferrous metals		
	Minerals		
	Steel		
	Water		
	Food processing & beverages		
	Textiles including clothing		
	Paper and furniture		
	Electrical & electronic machinery		
	Vehicles & auto components		
	Leather & footwear		

A1.5.4.3Materials mapping

TRL: Applied research

- Materials mapping describes the identification and communication of available materials, their location, and key parameters like composition, purity, volume over time, etc.
- Materials mapping would facilitate Industrial Symbiosis
- One of the major barriers to Industrial Symbiosis is a lack of information among stakeholders, which output materials are available and which input materials are required
- Providing the characteristics, the geographical location and the volume of input and output materials would facilitate transactions and the development of Industrial Symbiosis clusters and parks

- With its potential to substitute energy and material inputs through waste outputs, Industrial Symbiosis could improve cost structure and sustainability performance
- There are different projects working on this, but maturity levels are hard to estimate
- This technology facilitates closing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	There are different projects working on this, but maturity levels are hard to estimate
Flexibility			
	Capacity	1	It might be easier to identify small batch suppliers for certain materials
	Product	1	It might be easier to identify small batch suppliers for certain materials
	Innovation	1	It might be easier to identify small batch suppliers for certain materials
	Location	2	It facilitates identification of local suppliers
	Feedstock (or Input)	2	It facilitates identification of suppliers of different feedstock
	Energy	0	The link is probably weak
Business Model Impact			
	Supply (chain?)	2	It facilitates switching suppliers, the software supplier might also be a new stakeholder
	Demand (Value proposition?)	1	Product quality might vary more, additional products might become feasible
	Chain (Delivery, Customer channels?)	0	The link is probably weak
	Ecosystem	0	It both facilitates coordination and requires uptake by a range of stakeholders and additional stakeholders might join, but they are also part of the supply chain
	Cost	2	The software might be proprietary and there will be costs for staff training, maintenance, etc.
	Revenue	1	Potentially, if the product portfolio is expanded
	Overall		The supply chain is potentially considerably transformed
Sustainability			
	Material use	2	It facilitates industrial symbiosis
	Environmental footprint	2	It facilitates industrial symbiosis
	Energy	1	Potentially less energy is used for material production, currently wasted energy might be utilized
	Strategy	1	It facilitates industrial symbiosis
Regional Impact			
	Safety, Health and Environment	1	It facilitates industrial symbiosis
	Material flow	2	It facilitates identifying new suppliers
	Direct jobs	2	It facilitates industrial symbiosis
	Business opportunities	2	Better information on available materials might trigger innovation and enable small batch production
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	It facilitates industrial symbiosis
	Ceramics	3	It facilitates industrial symbiosis
	Chemicals	3	It facilitates industrial symbiosis
	Engineering	3	It facilitates industrial symbiosis
	Non-ferrous metals	3	It facilitates industrial symbiosis
	Minerals	3	It facilitates industrial symbiosis
	Steel	3	It facilitates industrial symbiosis
	Water	3	It facilitates industrial symbiosis
	Food processing & beverages	3	It facilitates industrial symbiosis
	Textiles including clothing	3	It facilitates industrial symbiosis
	Paper and furniture	3	It facilitates industrial symbiosis

	Electrical & electronic machinery	3	It facilitates industrial symbiosis
	Vehicles & auto components	3	It facilitates industrial symbiosis
	Leather & footwear	3	It facilitates industrial symbiosis

A1.5.4.4Well-aging materials

TRL: Market presence

- Well-aging materials are materials that have certain characteristics that allow them to stay visually and haptically attractive and maintain their function in a product over a long use phase
- Well-aging materials are required for long life products
- There is a range of time tested materials already available
- However, the choice is limited and there are gaps in the material range that impede innovation towards longer product life times
- New well-aging materials would enable more application possibilities, leading to longer product use phases
- This would decrease material and energy input and waste and energy leakage and therefore pose potential sustainability advantages
- Some materials are well established, but there is a research need concerning the development of additional materials and the systematic employment of existing ones
- This technology facilitates slowing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Some materials are well established, but there is a research need concerning the development of additional materials and the systematic employment of existing ones
Flexibility			
	Capacity	0	No big influence
	Product	0	No big influence
	Innovation	0	No big influence
	Location	0	No big influence
	Feedstock (or Input)	0	No big influence
	Energy	0	No big influence
Business Model Impact			
	Supply	1	Depends on how much it differs from current processes
	Demand	1	Depends on how much it differs from current product
	Chain	1	Depends on how much it differs from current processes
	Ecosystem	1	Depends on how much it differs from current processes
	Cost	2	Materials might be more expensive
	Revenue	1	If material cost goes up, prices might follow
	Overall		From an exchange of materials to a completely different product life cycle with adapted revenue model
Sustainability			
	Material use	3	Longer use phase with similar amount of material
	Environmental footprint	3	Longer use phase with similar amount of material
	Energy	3	Longer use phase with similar amount of energy
	Strategy	2	Longer use phase
Regional Impact			
	Safety, Health and Environment	2	Longer use phase with similar amount of material

	Material flow	3	Longer use phase with similar amount of material
	Direct jobs	0	No big influence
	Business opportunities	0	No big influence
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.5.5 Simulation

A1.5.5.1 Business model simulation

TRL: Applied research

- Business model simulation is the simulation of the key elements of an organization and its environment as well as the interaction between these elements using simulation software.
- Business model simulation would facilitate data-driven decision makers for top management teams
- It allows both experimentation with different business models as well as the simulation of different alternatives as scenarios
- This could improve business model innovation decision-making and facilitate the creation of circular business models
- Circular business models that create sustainable value for a broad range of stakeholders improve the sustainability performance of the organization
- There are projects working on this, but maturity levels are varying
- This technology facilitates designing business models with along the five central characteristics of circular business models, slowing, closing, narrowing, dematerializing and intensifying material and energy loops

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	There are projects working on this, but maturity levels are varying
Flexibility			
	Capacity	1	Only very indirectly
	Product	0	The link is probably weak
	Innovation	3	Different product-market scenarios as well as the consequences of other changes in the BM can be tested
	Location	1	Only indirectly

	Feedstock (or Input)	1	Only indirectly
	Energy	0	The link is probably weak
Business Model Impact			
	Supply	3	Different product-market scenarios as well as the consequences of other changes in the BM can be tested and the supply chain can potentially be improved
	Demand	3	Different product-market scenarios as well as the consequences of other changes in the BM can be tested and the value proposition can potentially be improved
	Chain	3	Different product-market scenarios as well as the consequences of other changes in the BM can be tested and the customer channels can potentially be improved
	Ecosystem	3	Different product-market scenarios as well as the consequences of other changes in the BM can be tested and the cooperation with stakeholders can potentially be expanded and intensified
	Cost	2	The software might be proprietary and there will be costs for staff training, maintenance, etc.
	Revenue	3	Different product-market scenarios as well as the consequences of other changes in the BM can be tested and the product mix, prices, and sales volume can be potentially improved
	Overall		If the technology is employed for serious BM innovation the impact is potentially substantial
Sustainability			
	Material use	2	If it is used for sustainable business model innovation
	Environmental footprint	2	If it is used for sustainable business model innovation
	Energy	2	If it is used for sustainable business model innovation
	Strategy	1,2,3	If it is used for sustainable business model innovation
Regional Impact			
	Safety, Health and Environment	2	If it is used for sustainable business model innovation
	Material flow	2	If it leads to substantial changes in the business model
	Direct jobs	3	Additional and improved business models are expected to create jobs
	Business opportunities	3	It helps to identify, test , and refine opportunities
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	It helps to identify, test , and refine new business models
	Ceramics	3	It helps to identify, test , and refine new business models
	Chemicals	3	It helps to identify, test , and refine new business models
	Engineering	3	It helps to identify, test , and refine new business models
	Non-ferrous metals	3	It helps to identify, test , and refine new business models
	Minerals	3	It helps to identify, test , and refine new business models
	Steel	3	It helps to identify, test , and refine new business models
	Water	3	It helps to identify, test , and refine new business models
	Food processing & beverages	3	It helps to identify, test , and refine new business models
	Textiles including clothing	3	It helps to identify, test , and refine new business models
	Paper and furniture	3	It helps to identify, test , and refine new business models
	Electrical & electronic machinery	3	It helps to identify, test , and refine new business models
	Vehicles & auto components	3	It helps to identify, test , and refine new business models

A1.5.5.2Design for X PLM add-ons

TRL: Market presence

- Design for X PLM add-ons are plugins for Product Lifecycle Management software solution that support product developers in optimizing product design in regard to sustainability performance indicators like CO2 equivalent or water consumption.
- For sustainable product design, a range of design parameters has to be optimized
- This includes materials, geometries, and the connection between parts

- To optimize material footprint, ease of disassembly, and ease of repair
- To provide an integrated solution with familiar work processes, integration into existing PLM (Product Lifecycle Management) software is desirable
- This improves the sustainability performance of products designed with the system
- Some initial prototypes, beta-versions, and first add-ons exist already
- This technology facilitates closing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Some initial prototypes, beta-versions, and first add-ons
Flexibility			
	Capacity	0	No big influence
	Product	0	No big influence
	Innovation	0	No big influence
	Location	0	No big influence
	Feedstock (or Input)	0	No big influence
	Energy	0	No big influence
Business Model Impact			
	Supply	1	Depends on how much it differs from current processes
	Demand	1	Depends on how much it differs from current product
	Chain	1	Depends on how much it differs from current processes
	Ecosystem	1	Depends on how much it differs from current processes
	Cost	1	Materials might be more expensive
	Revenue	1	Depends on how much it differs from current product
	Overall		From an exchange of materials to a completely different product life cycle with adapted revenue model
Sustainability			
	Material use	3	Better material selection
	Environmental footprint	3	Better material selection
	Energy	3	Better material selection
	Strategy	1,2,3	Better material selection
Regional Impact			
	Safety, Health and Environment	2	Better material selection
	Material flow	3	Better material selection
	Direct jobs	0	No big influence
	Business opportunities	0	No big influence
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	
	Ceramics	3	
	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	

	Vehicles & auto components	3	
	Leather & footwear	3	

A1.5.5.3Product-aging simulation

TRL: Market presence

- Product-aging simulation is the software-based calculation and visualization of a products aging behavior over its use phase employing different use phase or environmental scenarios
- For the design of long-life product, the aging behavior of the product is central.
- Currently this is done mainly through trial and error with material probes or advanced prototypes.
- This is time and resource intensive.
- Digitalizing this experimentation capability would allow efficient and immediate feedback for the designer.
- Leading to more efficient and more sustainable product design.
- Hard to assess market readiness of software-based product aging
- This technology enables slowing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	4	Hard to assess market readiness of software-based product aging
Flexibility			
	Capacity	0	No big influence
	Product	0	No big influence
	Innovation	0	No big influence
	Location	0	No big influence
	Feedstock (or Input)	0	No big influence
	Energy	0	No big influence
Business Model Impact			
	Supply	1	Depends on how much it differs from current product
	Demand	1	Depends on how much it differs from current product
	Chain	1	Depends on how much it differs from current product
	Ecosystem	1	Depends on how much it differs from current processes
	Cost	1	Depends on how much it differs from current product
	Revenue	1	Depends on how much it differs from current product
	Overall		From an exchange of materials to a completely different product life cycle with adapted revenue model
Sustainability			
	Material use	3	Better product design
	Environmental footprint	3	Better product design
	Energy	3	Better product design
	Strategy	2	Better product design
Regional Impact			
	Safety, Health and Environment	2	Better product design
	Material flow	3	Better product design
	Direct jobs	0	No big influence
	Business opportunities	0	No big influence
Industrial Applicability (SPIRE and			
	Cement	3	
	Ceramics	3	

Manufacturing clusters)	Chemicals	3	
	Engineering	3	
	Non-ferrous metals	3	
	Minerals	3	
	Steel	3	
	Water	3	
	Food processing & beverages	3	
	Textiles including clothing	3	
	Paper and furniture	3	
	Electrical & electronic machinery	3	
	Vehicles & auto components	3	
	Leather & footwear	3	

A1.5.5.4Reverse supply chain simulation

TRL: Market ready

- Reverse supply chain simulation describes the software based simulation of elements, their behavior, and the interactions between the elements of end-of-life supply chains from the user to the Re-X processing facility.
- Reverse supply chain simulation would allow the optimization of existing Re-X operations and facilitate the establishment of new ones
- This could improve the efficiency of process and the dissemination of circular solutions in industry
- This can reduce material and energy input by recycling resource flows and minimizing waste leakage out of the system
- This in turn can improve the environmental footprint of the organization
- Due to its similarity to supply chain simulation, which is already employed in practice, we assume that the technology is mature enough to be potentially used by some organizations. Some current production planning software can provide much of the required functionality.
- This technology facilitates closing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	3	Some current production planning software can provide much of the required functionality
Flexibility			
	Capacity	3	Reduces lead time and pre-production costs
	Product	3	Reduces lead time and pre-production effort
	Innovation	3	Reduces lead time and pre-production costs
	Location	3	Reduces lead time and pre-production costs
	Feedstock (or Input)	3	Reduces lead time and pre-production costs of new processes using different feedstock
	Energy	3	Facilitates process optimization
Business Model Impact			
	Supply	2	A software supplier or external simulation services might be added, changes in the supply chain due to optimization are possible
	Demand	0	This link is probably weak
	Chain	3	Reverse logistics usually involve customer channel actors and B2B customers

	Ecosystem	1	Certain behaviors might be desirable or incentivized to support reverse logistics, e.g. customers or third parties returning cores to collection facility
	Cost	2	The software might be proprietary and there will be costs for staff training, maintenance, etc.
	Revenue	0	This link is probably weak, although there might be increased customer engagement
	Overall		Depends on the results of the simulation, potentially, operations and this (reverse) supply chain are transformed considerably
Sustainability			
	Material use	3	It facilitates circular operations
	Environmental footprint	3	It facilitates a circular business model
	Energy	2	Potentially less energy is used for material production and transport
	Strategy	2	Better information on available materials might trigger innovation and enable small batch production
Regional Impact			
	Safety, Health and Environment	2	Processes might be optimized in these dimensions as well
	Material flow	3	It enables optimization of the reverse supply chain
	Direct jobs	1	Depends on the results of the simulation, potentially, operations and this (reverse) supply chain are transformed considerably leading to more or less jobs
	Business opportunities	0	The link is probably weak although there might be effects on the value network that facilitate integration of a larger number of smaller players
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	It facilitates industrial circular business models
	Ceramics	3	It facilitates industrial circular business models
	Chemicals	3	It facilitates industrial circular business models
	Engineering	3	It facilitates industrial circular business models
	Non-ferrous metals	3	It facilitates industrial circular business models
	Minerals	3	It facilitates industrial circular business models
	Steel	3	It facilitates industrial circular business models
	Water	3	It facilitates industrial circular business models
	Food processing & beverages	3	It facilitates industrial circular business models
	Textiles including clothing	3	It facilitates industrial circular business models
	Paper and furniture	3	It facilitates industrial circular business models
	Electrical & electronic machinery	3	It facilitates industrial circular business models
	Vehicles & auto components	3	It facilitates industrial circular business models
	Leather & footwear	3	It facilitates industrial circular business models

A1.5.6 ICT

A1.5.6.1 Materials-process matching

TRL: Applied research

- Materials-process matching is the software-based identification of manufacturing processes based on a given material and potentially the identification of alternative materials based on a given production process

- Materials-process matching could facilitate Industrial Symbiosis and a range of Re-X processes
- This technology could facilitate the substitution of materials with more sustainable solutions and the design of process that use more advantageous materials
- This can improve resource economics and make manufacturing more sustainable
- There is ongoing research in this direction, but maturity levels are hard to estimate
- This technology facilitates closing resource loops, which is one of the five central characteristics of circular business models (slowing, closing, narrowing, dematerializing and intensifying material and energy loops)

Indicator	**Category**	**Score**	**Explanation**
Technology Readiness Level			
	Overall	2	There are projects working on this, but maturity levels are hard to estimate
Flexibility			
	Capacity	1	It might be easier to identify adequate processes and materials
	Product	1	It might be easier to identify adequate processes and materials
	Innovation	1	It might be easier to identify adequate processes and materials
	Location	1	It might be easier to identify adequate materials at the new location
	Feedstock (or Input)	3	It enables finding additional feedstock for a given process or new processes for a given feedstock
	Energy	1	It might be easier to identify adequate processes
Business Model Impact			
	Supply	2	It facilitates switching suppliers, the software supplier might also be a new stakeholder
	Demand	1	Product quality might vary more, additional products might become feasible
	Chain	0	The link is probably weak
	Ecosystem	0	It both facilitates coordination and requires uptake by a range of stakeholders and additional stakeholders might join, but they are also part of the supply chain
	Cost	2	The software might be proprietary and there will be costs for staff training, maintenance, etc.
	Revenue	1	Potentially, if the product portfolio is expanded
	Overall		Operations and supply chain are potentially considerably transformed
Sustainability			
	Material use	2	It facilitates industrial symbiosis and process efficiency
	Environmental footprint	2	It facilitates industrial symbiosis and process efficiency
	Energy	1	Potentially less energy is used for material production, currently wasted energy might be utilized, more efficient processes might be identified
	Strategy	1, 3	It facilitates industrial symbiosis and the identification of more efficient processes
Regional Impact			
	Safety, Health and Environment	1	It facilitates industrial symbiosis
	Material flow	2	It facilitates identifying new process inputs and suppliers
	Direct jobs	2	It facilitates industrial symbiosis
	Business opportunities	2	Better information on available materials might trigger innovation and enable small batch production
Industrial Applicability (SPIRE and Manufacturing clusters)			
	Cement	3	It facilitates industrial symbiosis
	Ceramics	3	It facilitates industrial symbiosis
	Chemicals	3	It facilitates industrial symbiosis
	Engineering	3	It facilitates industrial symbiosis
	Non-ferrous metals	3	It facilitates industrial symbiosis
	Minerals	3	It facilitates industrial symbiosis
	Steel	3	It facilitates industrial symbiosis
	Water	3	It facilitates industrial symbiosis

	Food processing & beverages	3	It facilitates industrial symbiosis
	Textiles including clothing	3	It facilitates industrial symbiosis
	Paper and furniture	3	It facilitates industrial symbiosis
	Electrical & electronic machinery	3	It facilitates industrial symbiosis
	Vehicles & auto components	3	It facilitates industrial symbiosis
	Leather & footwear	3	It facilitates industrial symbiosis

A2 Assessment template

Indicator	Category	Definition	Score	Explanation	Description
		The level of technology readiness(Tab "TRL Definition")			
Technology Readiness Level	Overall	1-Basic Research, 2-Applied Research, 3- Market ready, 4-Market presence			Score the TRL based on the highest TRL that can be achieved in the specific business case where the technology is mentioned. In the case of Market ready or Market
Flexibility		***The applicability of the technology to different flexibility profiles. (Tab "Scoring Definition")***			
	Capacity	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology facilitate producing small volumes in a cost-efficient way? Is it poss
	Product	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Is it easily possible to produce a (slightly) different product without major technical char
	Innovation	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Is it possible, in an easy way, to try out innovative products and processes?
	Location	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology facilitate easy movement of the process to another location?
	Feedstock (or Input)	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology facilitate handling different kinds of feedstock? Or different suppli
	Energy	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology facilitate easy (and fast) scale up and scale down of the energy use
Business Model Impact		***The business model impact of the technology (Tab "Scoring Definition)***			Score from the perspective of the company that applies the technology under considera
	Supply	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Do you need other supplies, other suppliers of feedstock? Other or additional partners
	Demand	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does your product change? Is your portfolio expanded (or shifted)? Do you expect
	Chain	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does your business model change affect parties further downstream (towards the end
	Ecosystem	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the functioning of the technology require coordination of parties in the
	Cost	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Is the application of the technology cost intensive? Does it incur or avoid other costs?
	Revenue	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Can you expect changes in revenue as a consequence? (Related to demand)
	Overall	#Definitely - #Negatives			Is the overall business model impact substantial?
Sustainability		***The sustainability profile of the technology (Tab "R9 Definition" & "Scoring Definition")***			
	Material use	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology reduce the amount of raw material used or the amount of waste in
	Environmental footprint	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology reduce the environmental footprint of the supply chain?
	Energy	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology facilitate the integration of renewable energy? Or does the technol
	Strategy	1 - Usefull after-life application of materials 2 - Extend lifespan of product and its parts 3 - Smarter manufacture and product use			What is the highest circularity strategy that the technology facilitates?
Regional Impact		***The regional impact of applying the technology (Tab "Scoring Definition")***			Score the technology based on the impact on the region around the location where it is g
	Safety, Health and Environm	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology have impact on local safety, health and environment?
	Material flow	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology have impact on the local sourcing and/or processing of materials?
	Direct jobs	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology create on-site jobs?
	Business opportunities	0-No, 1-Maybe, 2-Limited, 3-Definitely, 4-Undesirable			Does the technology create local business opportunities for SME'S?
Industrial Applicability (SPIRE and Manufacturing clusters)		***The clusters in which the technology is applicable (Tab "Scoring Definition")***			In which Industrial Cluster is the technology applicable?
	Cement	0-No, 1-Maybe, 3-Definitely			
	Ceramics	0-No, 1-Maybe, 3-Definitely			
	Chemicals	0-No, 1-Maybe, 3-Definitely			
	Engineering	0-No, 1-Maybe, 3-Definitely			Equipment suppliers/manufacturers
	Non-ferrous metals	0-No, 1-Maybe, 3-Definitely			Metals that does not contain iron in appreciate amounts
	Minerals	0-No, 1-Maybe, 3-Definitely			
	Steel	0-No, 1-Maybe, 3-Definitely			
	Water	0-No, 1-Maybe, 3-Definitely			
	Food processing & beverag	0-No, 1-Maybe, 3-Definitely			
	Textiles including clothing	0-No, 1-Maybe, 3-Definitely			
	Paper and furniture	0-No, 1-Maybe, 3-Definitely			
	Electrical & electronic mach	0-No, 1-Maybe, 3-Definitely			
	Vehicles & auto componen	0-No, 1-Maybe, 3-Definitely			
	Leather & footwear	0-No, 1-Maybe, 3-Definitely			