Circular TwAIn

AI Platform for Integrated Sustainable and Circular Manufacturing

Deliverable

D7.4 SMART standards and Exploitation Plan - 1st version

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1.0	30/06/2023	ENG	Final Coordinator review before submission

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Definitions and acronyms

AAS	*Asset Administration Shell*
AI	*Artificial Intelligence*
AIA	*Artificial Intelligence Act*
CAGR	*Compound Annual Growth Rate*
CE	*Circular Economy*
CEFIC	*European Chemical Industry Council*
DEG	*Diethylene Glycol*
DIH	*Digital Innovation Hub*
DT	*Digital Twins*
EC	*European Commission*
EDPIA	*Ethics and Data Protection Impact Assessments*
EDSCA	*European Data Space for Smart Circular Applications*
EEE	*Electrical and Electronic Equipment*
EG	*Ethylene Glycol*
EO	*Ethylene Oxide*
EU	*European Union*
EV	*Electric Vehicle*
GA	*Grant Agreement*
GDP	*Gross Domestic Product*
HRIA	*Human Rights Impact Assessment*
IIoT	*Industrial Internet of Things*
ICT	*Information Communication Technology*
IP	*Intellectual Property*
IPR	*Intellectual Property Right*
IT	*Information Technology*
KER	*Key Exploitable Results*
KPI	*Key Performance Indicator*
LCO	*Lithium Cobalt Oxide*
LIB	*Lithium-ion Battery*
MEG	*Monoethylene Glycol*
NCA	*Nickel Cobalt Aluminium*
NDA	*Non-Disclosure Agreement*
NMC	*Nickel Manganese Cobalt*
PESTLE	*Political, Economic, Social, Technological, Legal, and Environmental*
PET	*Polyethylene Terephthalate*
RA	*Reference Architecture*
ROI	*Return on Investment*
R&D	*Research and Development*
R&I	*Research and Innovation*
SME	*Small Medium Enterprise*
SWOT	*Strengthen, Weaknesses, Opportunities, Threats*
TEG	*Triethylene Glycol*
ToC	*Table of Contents*
TRL	*Technology Readiness Level*
UI	*User Interface*
UK	*United Kingdom*
US	*United States*
WEEE	*Waste Electrical and Electronic Equipment recycling*
WIPO	*World Intellectual Property Organization*
WP	*Work Package*
XAI	*eXplainable Artificial Intelligence*

Disclaimer

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Executive Summary

Circular TwAIn is aimed to support, within a unique AI platform, manufacturing and process industry towards a sustainable, eco-friendly and circular production, i.e., increasing the reconditioning, remanufacturing and recycling capabilities while reducing the waste. The key factor is a full integration among systems (holistic approach), reached through the usage of AI Digital Twins for each level (product/process/value chain) leading to the 'Circularity by-design'. The Project will showcase how Digital Twins and AI algorithms help in optimizing sustainability aspects for products and production processes and will create new circular Business Models through digitalization. The technological solutions are domain agnostic, mainly based on open-source components.

Deliverable D7.4 SMART Standards and Exploitation Plan, reports on the preliminary activities carried out for the definition of the Circular Exploitation plan to ensure that Project's results become sustainable well after the conclusion of the research Project period so as to create impact: set up a clear methodology and timeline from the early beginning of the Project is crucial to align also development activities.

The activities that have been resumed in the deliverable include:

1. Market analysis, critical investigation to understand the potential of the business in which Circular TwAIn results are going to operate.
2. Exploitation strategy, detailed workplan to be followed during and beyond the Project.
3. Key Exploitable Results, preliminary list of the foreseen results that have a value in terms of direct or indirect (e.g., know how that can serve for further developments) commercialization.
4. Individual and Joint Exploitation Strategy, to highlight the intent of each partner of the Consortium as well as to start discussing about possible joint exploitation.
5. Standardization activities, relevant standards for the Project are handled.

Finally, the deliverable reports on the ethical and legal approach to be followed by Pilots and Technical partners dealing with AI and experimentations, in particular the applicable legislations are listed, the process to elicit the legal and ethical requirements is defined, and the consultation with stakeholders (including regional authorities and policy makers) and the ALTAI - driven human rights impact assessment (HRIA) is presented.

1 Introduction

1.1 Scope of the document

The Circular TwAIn exploitation plan is based on individual and joint exploitation plans. The Project partners form the value chain for exploitation and are providing their first approach to the exploitation. This includes research from the academic partners and technology transfer from the industry partners into their respective lines of business. Whilst the exploitation of the Circular TwAIn results will be encouraged outside the Consortium, there are internal approaches to ensure the longevity of the Circular TwAIn outcomes. This involves the development of a plan that defines a roadmap for future development and support of the Circular TwAIn market exploitation. This document defines the preliminary plans in terms of key exploitable results, as well as individual and joint exploitation opportunities. To define the perimeter in which the Consortium is dealing, an accurate market analysis in the three businesses of the Pilots and in the application of AI technologies and tools in Manufacturing has been conducted.

Furthermore, a picture of the legal and ethical framework in which Project results are playing is provided, as well as relevant standardization activities that are involving some Project partners.

1.2 Document Structure

Apart from the Introduction and the Conclusions and Future Outlook, the document is structured as follows:

- Section 2 reports the market and environmental analysis.
- Section 3 describes the exploitation strategy, defining its objectives and the roadmap to achieve them.
- Section 4 details the Key Exploitable Results identified at M12, the options in term of joint exploitation strategy and the individual plans of each Project partner.
- Section 5 outlines preliminary considerations on the Trustworthy Framework for Circular TwAIn that will be further discussed in D7.2 Liaison with AI4MAN Ecosystem, Didactic Factories Network, Legal and Ethical Issues - 1st (M18).
- Section 6 reports on standards and initiatives with aimed impact on operational SMART standards (Standards that are Machine Applicable, Readable, and Transferable).

2 Market analysis

2.1 Market analysis

The section on market analysis holds important significance in any business plan or strategic goal. It entails a detailed examination of the industry landscape, target markets, and potentially competitors. By conducting a comprehensive market analysis, valuable insights are gained to guide the decision-making processes and formulate effective commercialization strategies. The primary objective of the market analysis is to assess the potential of a product or service within a specific market segment. This involves evaluating factors like market size, growth patterns, customer demographics, buying behaviour, and competitive influences. By gathering and analysing data, organizations can identify favourable opportunities, evaluate risks, and position themselves strategically to maximize their chances of success. Market analysis is also important for understanding customer needs, preferences, and pain points. By recognizing these key insights, the offering can be customized to better meet market demands, create competitive value propositions, and differentiate from existing solutions.

2.1.1 AI-driven Circularity in Manufacturing

The concept of a Circular Economy requires manufacturers to reconsider how they design, produce, and distribute their products, moving away from linear processes and embracing circular practices that contribute to sustainability. In response to the climate crisis, unsustainable consumption patterns, and resource depletion, companies and policymakers worldwide are increasingly prioritizing environmental sustainability and striving to build competitive Circular Economies. Circular manufacturing entails a significant departure from the traditional linear production model, where materials are extracted, used to make products, and ultimately discarded, resulting in waste accumulation and resource depletion. In contrast, circular manufacturing aims to minimize waste, promote material reuse and recycling, and create a closed-loop system. According to McKinsey, the adoption of a technology-enabled Circular Economy could provide a primary-resource benefit of up to 0.6 trillion € per year to Europe's economies by 2030. Furthermore, it could generate 1.2 trillion € in non-resource benefits and externalities, leading to a total annual benefit of around 1.8 trillion € compared to the present situation. The limitations of the linear economy, which include issues like product waste, raw material scarcity, and carbon emissions, have necessitated the exploration of an alternative model that aligns with the cyclical processes observed in nature and mitigates the negative impacts of industrial waste. The Circular Economy model shows promise in addressing these challenges by adopting principles similar to those found in the Earth's natural cycles. At its core, the Circular Economy is built upon the principles of the 4Rs: Reduce, Reuse, Recycle and Recover. These principles emphasize waste reduction, optimal utilization of resources, and the reuse of existing products, ultimately fostering resource circularity.

Digitalization plays a crucial role in enabling companies to transition towards a more circular and sustainable model by providing precise information on product location and availability, facilitating the closure of material loops. By utilizing digital technologies, organizations can reduce waste, extend the lifespan of products, and minimize transaction costs, leading to more efficient processes. This, in turn, enhances Circular Business Models by promoting resource efficiency and closing, slowing, and narrowing material loops. The integration of the Circular Economy with Industry 4.0 opens new possibilities for sustainability, motivating businesses to adopt sustainable supply chains and transforming production and consumption practices. The adoption of a Circular Economy approach maximizes resource utilization in manufacturing and contributes to sustainability objectives. According to reports, manufacturers and distributors consider cloud applications (74%), data analytics (68%), and automation (67%) as the most important technologies for sustainable business operations.

- Cloud applications and infrastructure have already had a significant impact on modern manufacturing. They enable more effective product development and support sustainable practices like 3D printing.
- Data analytics, particularly for predictive intelligence, help businesses refine product development, optimize supply chains, and monitor equipment to increase resource efficiency.
- Automation plays a vital role in boosting productivity by streamlining workflows and reducing human error. It also provides valuable data-driven insights that can be analysed to improve production performance and sustainability.

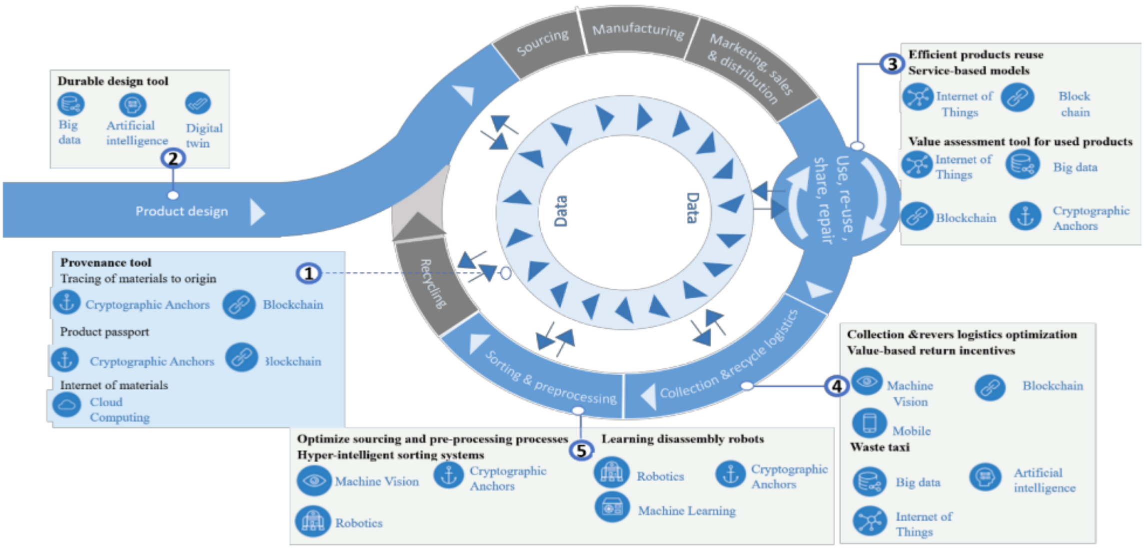

Figure 1: Industry 4.0 solutions for circularity (adapted from [1])

Overall, the adoption of digital technologies and the integration of Circular Economy principles into business operations offer opportunities to maximize resource usage, meet sustainability goals, and drive positive environmental impact.

Industry 4.0 technologies offer significant advantages in circular manufacturing, primarily through their real-time data and insights capabilities. These technologies provide manufacturers with the ability to optimize production processes, reduce waste, and enhance overall efficiency. By employing sensors and other digital tools, manufacturers can monitor material flow, product movement, and waste generation, enabling them to identify and address inefficiencies in real-time. Leveraging data and insights from production processes, manufacturers can design products that are easily disassembled and recycled, leading to waste reduction and supporting sustainability efforts. Furthermore, Industry 4.0 technologies facilitate the development of energy-efficient and long-lasting products. By integrating these technologies, manufacturers can create products that require fewer replacements, extending their lifespan and contributing to a more circular manufacturing approach.

Another vital aspect of Industry 4.0 technologies in circular manufacturing is their role in driving innovation. Data analytics and artificial intelligence (AI) algorithms can analyse vast datasets, enabling the identification of new materials with desired properties and predicting their behaviour in different environments and applications. This fosters the development of new, more sustainable materials and technologies, further promoting circular manufacturing practices. Overall, Industry 4.0 technologies play a crucial role in advancing circular manufacturing by minimizing waste, maximizing the reuse, and recycling of materials, and fostering innovation in material development. Their real-time data capabilities and potential for optimizing production processes make them powerful tools in driving sustainability and circularity within manufacturing industries.

Artificial Intelligence (AI) plays a vital role in driving circularity by enabling more efficient processes for managing materials, products, and waste. Through AI algorithms, manufacturers can predict product and material lifecycles, allowing for optimized planning and resource utilization. This helps reduce waste and minimize the consumption of new resources, contributing to a sustainable future. Additionally, AI can optimize production processes by analysing large amounts of manufacturing data, identifying inefficiencies and bottlenecks in real-time. In product design, AI can have a significant impact by facilitating the incorporation of circular principles. AI algorithms can analyse existing products to identify those suitable for reuse and recycling, assisting manufacturers in making informed decisions about materials and design. Moreover, AI can aid in designing products that are easily disassembled and recycled, further reducing waste, and promoting sustainability. AI also plays a crucial role in monitoring and tracking the performance of circular manufacturing systems. By analysing data from sensors and cameras, AI algorithms can identify areas of waste and inefficiency, enabling manufacturers to make necessary adjustments and improvements. Furthermore, AI can monitor the environmental impact of circular manufacturing systems, helping manufacturers track their progress towards more sustainable production methods. The adoption of AI in manufacturing is growing rapidly, driven by increased automation, the demand for big data management, and the exploration of data solutions. The Industrial Internet of Things (IIoT) provides the framework for leveraging real-time data and enhancing productivity and efficiency in industrial operations. Asia Pacific is expected to be the largest market for AI in manufacturing, followed by Europe, where countries like the UK are investing heavily in advanced technologies. The manufacturing industry generates a significant amount of data annually, and AI is being adopted to process and utilize this data more efficiently. With its ability to identify patterns and optimize complex problems, AI is considered a pivotal technology that can revolutionize manufacturing, driving growth and innovation in the industry.

The Global Artificial Intelligence in Manufacturing Market is expected to reach 21.3 billion € by 2028, rising at a market growth of 42.2% CAGR during the forecast period [1]. As data has become the new must, the manufacturing industry has become an important sector for the adoption for artificial intelligence. The adoption of AI in manufacturing sector in growing due to increased automation and demand for big data management and data exploration solutions. The Industrial Internet of Things (IIoT) offers the architecture to leverage real-time data about products, operational processes, and business systems, providing the means for increased productivity and efficiency in industrial operations. Asia Pacific is estimated to be the largest shareholder for the Global AI in Manufacturing Market with 37.2% due to the presence of large number of manufacturing companies in China, India, Japan, and South

Korea along with their rising focus on digitization and technological advancement. Europe is estimated to be the next biggest shareholder after Asia Pacific, because of countries like UK which are making huge investments in R&D of advanced technologies like AI. Also, the latest guidelines of government of Italy about the National Strategy in Artificial Intelligence are likely to boost the use of AI in the region. Based on a Deloitte's study, manufacturing is estimated to generate about 1,812 petabytes (PB) of data every year, more than, finance, retail, and several other industries. Manufacturers are shifting their attention to Artificial Intelligence to process and utilize information more efficiently, leveraging smart technologies, AI based technologies will support manufactures to identify data patterns and optimize problems that could not previously be tackled or discovered with traditional tools. AI will be a pivotal technology to revolutionize manufacturing and drive growth and innovation in the industry.

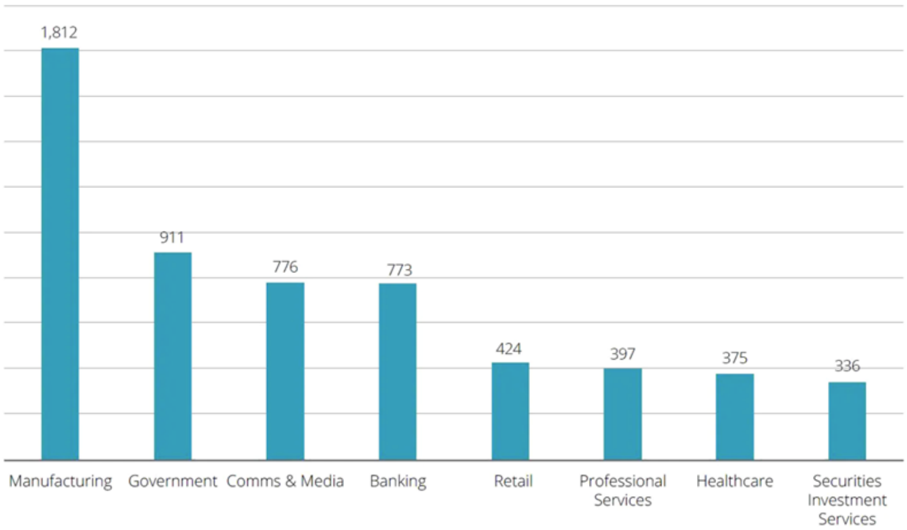

Figure 2: Annual data creation by industry (Petabytes)

The adoption of AI in manufacturing can effectively support the principles of the Circular Economy, which aim to limit resource consumption, minimize waste and pollution, and promote the continuous use of products. McKinsey estimates that implementing a Circular Economy in Europe could generate a net benefit of 1.8 trillion € by 2030 [3], addressing environmental concerns, fostering innovation, and creating new job opportunities. AI technology enables the automatic and remote monitoring of manufacturing processes and the lifecycle of products within a Circular Economy framework. Through AI, large volumes of data generated throughout the manufacturing process, product disposal, and use can be analysed efficiently. AI's ability to handle complexity and analyse vast amounts of data makes it a valuable complement to human capabilities, facilitating more effective learning from feedback. AI can accelerate the transition to a Circular Economy by enabling faster prototyping, iterative design cycles, and feedback collection. This supports the redesign of key product features towards a more sustainable and economically viable model. In line with the vision of the Circular Economy, AI can contribute to increasing material efficiency, extending product life, and improving recycling efficiency, as defined by Vanegas et al. [4]. In summary, the adoption of AI in manufacturing aligns with the principles of the Circular Economy, and it can play a significant role in enabling the systematic shift towards more sustainable and efficient product design and resource utilization.

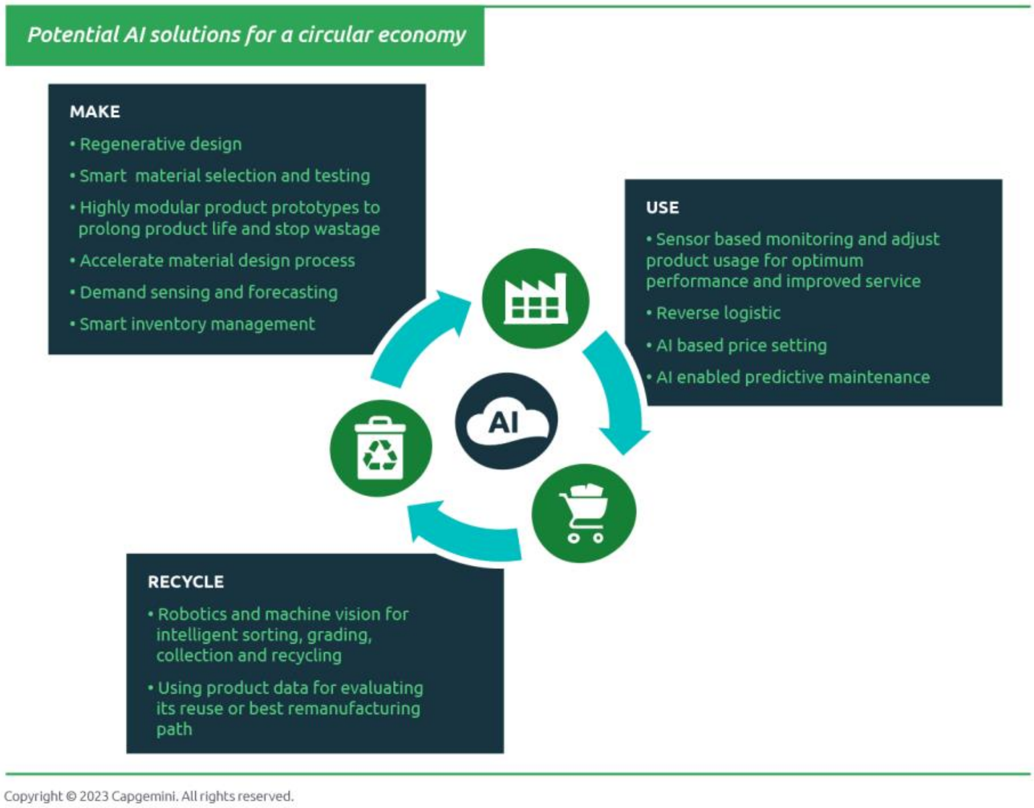

Figure 3: Potential AI solutions for circular economy [5]

AI's capabilities in reasoning, acting, and learning make it a valuable component in the development of future manufacturing systems. By complementing human skills and effectively managing complexity, AI reduces human involvement in industrial manufacturing systems. AI applications in the product lifecycle encompass intelligent cloud-based technologies for design, innovation, production equipment, operation and management, simulation and experimentation, and service guarantee. As defined by Vanegas et. al. [6], there are three product designs in the vision of CE, increasing material efficiency, product life extension and improving recycling efficiency:

- Incorporate circularity into product design by leveraging iterative machine learning and AI suggestions to extend the product's lifespan and address resource scarcity. AI can be used to predict product and carbon costs during the design phase, enabling optimized scenarios. For instance, AI algorithms can identify local sourcing options to reduce the carbon footprint associated with transportation or suggest product substitutions during manufacturing. Amazon has utilized AI algorithms to develop sustainable packaging designs, allowing certain products to be shipped in padded mailers instead of boxes, reducing packaging waste and carbon emissions per item while lowering delivery costs.
- Utilize data-driven AI algorithms to develop innovative circular business strategies and frameworks for sustainable growth. By leveraging data from various stakeholders such as producers, manufacturers, suppliers, and consumers, AI can optimize processes and enable automated decision-making. H&M, for example, uses AI to assess the environmental impact of its raw materials and optimize its value chain. AI helps understand consumer needs, produce the right products in the right

quantities, and allocate them effectively. This approach has reduced time-to-market for use case development by 50%, from 12 to six months.

- Implement circular production practices to optimize infrastructure and create material flows for acquiring used products, waste assessment, and reprocessing. AI plays a role in enhancing the selection of materials and products by utilizing visual recognition techniques to sort mixed material streams from post-consumer waste. Unilever and the Alibaba Group have developed an AI-enabled recycling system that automatically identifies and sorts of plastic packaging, aiming to accelerate the return of high-grade plastic into the circular economy and promote waste reduction. Through AI technology, it identifies the type of plastic, sorts, and stores it, facilitates collection and return to recycling centres, and expedites its reuse.

When considering the impact of AI in the role of an enabler and innovations enhancer of CE, according to Ellen MacArthur Foundation (2019), AI's role can be divided into three categories:

- By improving the sorting and disassembling product processes, remanufacturing the components and recycling materials: AI can help in closing the loops by building and improving the reverse logistics infrastructure.
- To expand innovative circular business models: AI can help to combine real-time and historical data from users and products to increase product circulation and asset utilization through pricing and demand prediction, predictive maintenance and smart inventory management.
- Design and develop circular products, components and materials: by rapid prototyping and testing through machine-learning-assisted design processes, AI can help in design out the waste for food in CE and generate the potential value of 127 million € by 2030 [6].

2.1.2 Waste Electric and Electronic Equipment Market (RECYCLIA & REVERTIA)

E-waste, or electronic scrap, refers to discarded electrical and electronic equipment (WEEE) that owners no longer intend to reuse. This term encompasses a wide range of products, including household items, commercial devices with circuits, and electrical components with power or battery supply. Electronic waste is categorized into six [7] plus one groups [8]:

1. Temperature exchange equipment: Includes refrigeration, freezing, air conditioning, and heat pump equipment.
2. Screens, monitors, and equipment with screens larger than 100 cm2: Includes televisions, monitors, and laptops.
3. Lamps: Encompasses fluorescent, high-intensity discharge, and LED lamps.
4. Large equipment: This category includes various items such as household appliances, IT and telecommunication equipment, consumer equipment, luminaires, sound or image reproducing equipment, musical equipment, electrical and electronic tools, toys, leisure and sports equipment, medical devices, monitoring and control instruments, automatic dispensers, and equipment for generating electric currents. It does not include items in categories 1 to 3.

5. Small equipment: Includes items like vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric razors, scales, calculators, radio equipment, video cameras, electric and electronic toys, small electric and electronic tools, small medical devices, and small monitoring and control instruments.
6. Small computer and telecommunications equipment: Encompasses mobile phones, GPS devices, pocket calculators, personal computers, and printers.
7. Large photovoltaic panels (with an external dimension greater than 50 cm).

The Waste Electrical and Electronic Equipment Directive (WEEE Directive) is a regulation from the European Community, known as Directive 2012/19/EU. Its focus is on waste electrical and electronic equipment (WEEE). Along with the RoHS Directive 2011/65/EU, it became European Law in February 2003. The WEEE Directive establishes targets for the collection, recycling, and recovery of all types of electrical goods, with a minimum recovery rate of 4 kilograms (9 lb) per person per year for recycling by 2009. The RoHS Directive imposes restrictions on the material content of new electronic equipment sold in Europe. In March 2020, the European Commission introduced a new Circular Economy action plan to address electronic and electrical waste reduction. The plan includes goals such as the right to repair, improved reusability, a common charger, and a rewards system to incentivize electronics recycling. Electrical and electronic waste continues to be one of the EU's fastest-growing waste streams, with an annual growth rate of 2%. Less than 40% of electronic waste is estimated to be recycled in the EU. To tackle these challenges, the Commission will launch a 'Circular Electronics Initiative' and implement measures to promote longer product lifetimes, including eco-design regulations for electronics and ICT devices. In line with the new sustainable products policy framework, this initiative will promote longer product lifetimes and include, among others, the following actions [9]:

- Regulatory measures for electronics and ICT including mobile phones, tablets and laptops under the Eco-design Directive so that devices are designed for energy efficiency and durability, reparability, upgradability, maintenance, reuse and recycling. The upcoming Eco-design Working Plan will set out further details on this. Printers and consumables such as cartridges will also be covered unless the sector reaches an ambitious voluntary agreement within the next six months.
- Focus on electronics and ICT as a priority sector for implementing the ‘right to repair’, including a right to update obsolete software.
- Regulatory measures on chargers for mobile phones and similar devices, including the introduction of a common charger, improving the durability of charging cables, and incentives to decouple the purchase of chargers from the purchase of new devices.
- Improving the collection and treatment of waste electrical and electronic equipment [9] including by exploring options for an EU-wide take back scheme to return or sell back old mobile phones, tablets and chargers.

Recycling practices for e-waste vary among EU countries. In 2017, Croatia had an 81% recycling rate, while Malta's rate was 21%. In 2020, the EU collected an average of 10.3 kilos of electrical and electronic waste per person [10]. Asia is the largest e-waste producer, accounting for the generation of 24.9 Mt, followed by North and South America (13.1 Mt), Europe (12 Mt), Africa (2.9 Mt) and Oceania (0.7 Mt). However, Europe has the highest e-waste generation rate at 16.2 kg per capita, and Oceania rates second at 16.1 kg per capita, then North and South America at 13.3 kg per capita, and Asia and Africa with 5.6 and 2.5 kg per capita, respectively [11]. The increase in e-waste is driven by factors such as higher disposable income, urbanization, and industrialization, leading to increased consumption of Electrical and Electronic Equipment (EEE). Recycling rates also differ globally, with higher rates in high-income countries and lower rates in low-income nations. Every year, EEE consumption increases by about 2.5 million Mt. For instance, 42.5% of total e-waste is collected and recycled in Europe whereas this rate is much lower for Asia (11.7%), America and Oceania (9.4%) and lowest in Africa (0.9%). Many high-income countries have introduced e-waste management policies which are missing in most low-income nations.

Table 1: E-waste generation

Continent	E-waste (Mt)	E-waste (kg per capita)	E-waste documented properly as collected and recycled (Mt)	E-waste documented properly as collected and recycled (%)
Europe	12	16.2	5.1	42.5
Asia	24.9	5.6	2.9	11.7
Americas	13.1	13.3	1.2	9.4
Africa	2.9	2.5	0.03	0.9
Oceania	0.7	16.1	0.06	8.8

The collection of e-waste is predominantly comprised of large household appliances, accounting for 57.2% of all collected e-waste. This is followed by IT and telecommunications equipment at 14.1%, consumer equipment and photovoltaic panels at 14.2%, and small household appliances at 10.1%. Other categories, such as electrical tools and medical devices, make up only 8.4% of collected e-waste [10][9].

The consumption of Electrical and Electronic Equipment (EEE) is closely linked to global economic development. While EEE enhances living standards, its production and usage are resource-intensive, presenting a counter to the improvement in living standards. Factors such as higher disposable incomes, urbanization, and industrialization contribute to the growing amounts of EEE. In high-income countries with developed waste recycling infrastructure:

- Around 8% of e-waste is disposed of in waste bins and ultimately ends up in landfills or incinerators, primarily consisting of small equipment and small IT.
- Discarded products sometimes undergo refurbishment and are shipped as second-hand goods from high-income to low- or middle-income countries. However, a significant amount of e-waste is illegally exported or misrepresented as scrap metal or for reuse. Transboundary movements of used EEE or e-waste are estimated to range from 7% to 20% of generated e-waste.
- Undocumented domestic and commercial e-waste often gets mixed with other waste streams, such as plastic and metal waste. This leads to recycling of easily recyclable fractions under inferior conditions without depollution and complete material recovery, making such recycling less desirable.

In middle- and low-income countries, where e-waste management infrastructure is underdeveloped or absent, e-waste is predominantly managed by the informal sector. Handling e-waste under inferior conditions poses severe health risks to workers and nearby children. According to a report by Grand View Research, the global WEEE market was valued at 41.1 billion € in 2020 and is projected to grow at a compound annual growth rate (CAGR) of 8.1% from 2021 to 2028 [12]. The Asia Pacific region is expected to dominate the market due to high electronic device production and consumption in countries like China, Japan, and India. Market drivers for the WEEE market include increasing production and consumption of electronic devices worldwide, environmental concerns, government regulations, consumer awareness, technological advancements, urbanization, rising income levels, and economic factors. These drivers contribute to the demand for proper e-waste disposal and recycling. However, the WEEE market also faces barriers to its growth and development, including lack of awareness, high costs, limited recycling facilities and technologies in certain regions, complexity of electronic devices, fragmented value chain, and difficulty in recycling certain types of electronic waste. Current market trends include the adoption of circular economy principles, innovative recycling technologies, research and development investments, collaboration between stakeholders, new business models, adoption of blockchain technology, and the development of new markets for recycled electronic components and materials.

WEEE market is driven by a combination of environmental, regulatory, economic, and societal factors. The primary drivers of the WEEE market include:

- Increasing production and consumption of electronic devices globally.
- Growing concerns over environmental sustainability and the need for proper disposal and recycling of electronic waste.
- Implementation of stringent government regulations and policies for the disposal and recycling of electronic waste.
- Growing awareness among consumers regarding the benefits of recycling and reusing electronic devices.
- As technology continues to advance, newer and more sophisticated electronic devices are being introduced into the market. This has led to a shorter lifespan for electronic devices, resulting in an increased amount of electronic waste being generated.
- The trend of urbanization has led to an increase in the amount of electronic waste generated in cities, leading to a corresponding increase in the demand for WEEE services.
- Economic factors such as rising income levels, increasing consumer spending, and the growth of the consumer electronics industry have contributed to the growth of the WEEE market.

The WEEE market faces several barriers that can limit its growth and development:

- Lack of awareness and knowledge about electronic waste disposal and recycling among consumers and small businesses.
- High costs associated with electronic waste disposal and recycling.
- Limited availability of recycling facilities and technologies in certain regions.
- The complexity of electronic devices and the difficulty in dismantling and recycling them.

- The value chain for electronic waste recycling is often fragmented, with multiple stakeholders involved in the process. This can lead to inefficiencies and higher costs.
- The recycling of certain types of electronic waste can be challenging due to the complexity of the materials used in their production. This can limit the ability to recycle certain types of electronic waste.

Market Trends:

- Adoption of circular economy principles and the development of closed-loop recycling systems for electronic devices.
- The emergence of innovative recycling technologies such as plasma gasification and pyrolysis.
- Growing investments in research and development of sustainable electronic waste management solutions.
- Increased collaboration between manufacturers, governments, and non-profit organizations to promote electronic waste recycling and reuse.
- Introduction of new business models for electronic device recycling and refurbishment.
- Adoption of blockchain technology for transparent and efficient tracking of electronic waste disposal and recycling.
- Development of new markets for recycled electronic components and materials.

2.1.3 Battery Market (COBAT & RAEEMAN)

Lithium-ion batteries come in a variety of shapes and sizes, and not all of them are made equal. Below are six different lithium-ion battery types, as well as their positive and negative characteristics [13].

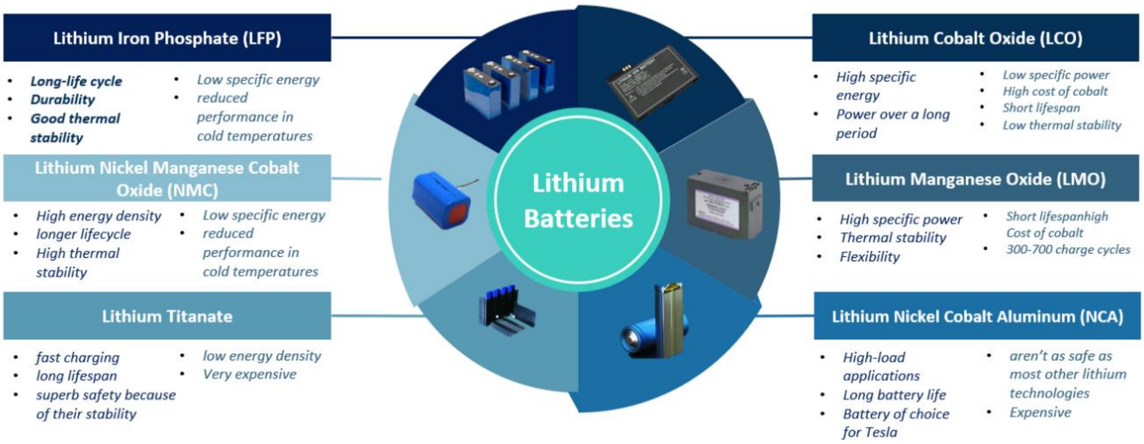

Figure 4 : Lithium-ion battery types

Lithium Cobalt Oxide: Also known as lithium coba-ltate or lithium-ion cobalt batteries reused in cell phones, laptops, and electronic cameras because of their high specific energy.

Lithium Manganese Oxide: Known as lithium manganate or lithium-ion manganese batteries, or li-manganese or manganese spinel batteries. They are frequently found in medical equipment and devices, but they can also be used in power tools, electric motorcycles, and other applications.

Lithium iron phosphate: Phosphate is used as a cathode in lithium iron phosphate batteries, often known as li-phosphate batteries. These batteries are frequently used in electric bikes and other applications requiring a long lifecycle and high levels of safety.

Lithium Nickel Manganese Cobalt Oxide: Constructed of a variety of materials that are universal in lithium-ion batteries. Most seen in power tools and automobile powertrains.

Lithium Nickel Cobalt Aluminium Oxide: These systems, like Li-manganese, can be modified to serve as Energy Cells or Power Cells. These batteries are used for power tools, e-bikes, and other electric powertrains.

Lithium Titanate: Known as li-titanate. These batteries could be used for military and aerospace applications, as storing wind and solar energy, and constructing smart grids [14].

The lithium-ion battery market is projected to reach a revenue of 165,847.8 million € by 2030, with a high compound annual growth rate (CAGR) of 15.3% [12]. NMC (Nickel Manganese Cobalt) remains the most popular battery chemistry due to its excellent thermal stability, long lifespan, and high energy storage capacity. This makes Li-NMC batteries ideal for consumer electronics and electric vehicles (EVs), both of which are experiencing a growing demand. In terms of revenue distribution, the LCO (Lithium Cobalt Oxide) segment accounted for the largest share at around 30% in 2021, driven by the high demand for mobile phones and laptops. However, an increasing demand for NCA (Nickel Cobalt Aluminium) batteries is expected due to their usage in EVs and industrial applications. The Asia-Pacific region leads the market with a revenue share of approximately 40%, fuelled by the growing electric vehicle market in countries like India and China. In Europe, Germany is anticipated to experience significant growth due to the rising adoption of batteries in energy storage systems and EVs. Germany is a world leader in energy storage systems and renewable energy solutions. The market's growth is primarily driven by the increasing adoption of electric vehicles and high consumer demand for electronics. Additionally, the growing renewable energy sector plays a significant role in boosting the market. Investments in energy and infrastructure development projects further contribute to the growth and development of the lithium-ion battery market [15].

Between 2020 and 2029, the electric vehicle (EV) market is expected to grow to 95 million €, driven by the increasing demand to reduce carbon emissions in the transportation sector. The Asian segment currently dominates the market, but manufacturers in the US and EU are making efforts to ramp up domestic production. CATL, the leading battery supplier, has expanded its market share from 32% in 2021 to 34% in 2022. One-third of the world's EV batteries are supplied by the Chinese company. CATL provides lithium-ion batteries to several major automakers, including Tesla, Peugeot, Hyundai, Honda, BMW, Toyota, Volkswagen, and Volvo [16]. In 2019, the EV market in Europe was valued at 25,489 million €, and it is projected to reach 143,084 million € by 2027, with a compound annual growth rate (CAGR) of 25.4% from 2020 to 2027. Electric cars rely on a continuous energy supply from batteries, such as lithium-ion batteries, offering benefits such as higher fuel economy, low carbon emissions, reduced maintenance, and quieter engines. In the European market, major manufacturers like Renault, Tesla, Mitsubishi, Nissan, BMW, Volvo, Peugeot, Audi, and Hyundai contribute to the EV landscape [17]. To enhance the sustainability of the emerging battery value chain and promote circularity in all batteries, the European Commission plans to propose a new regulatory framework for batteries. This proposal will consider rules on recycled content, measures to improve collection and recycling rates, recovery of valuable materials, and consumer guidance. It will also address non-rechargeable batteries with the aim of gradually phasing them out where alternatives are available. Additionally, sustainability and transparency requirements will be introduced, considering factors such as the carbon footprint of battery manufacturing, ethical sourcing of raw materials, security of supply, and facilitating reuse, repurposing, and recycling. The Commission will also propose revisions to the rules on end-of-life vehicles to encourage circular business models, including linking design issues to end-of-life treatment, mandatory recycled content for certain components, and improving recycling efficiency. Effective measures for the collection and environmentally sound treatment of waste oils will also be considered. The primary focus of remanufacturing is to rebuild a product using a combination of reused, repaired, and new parts, thereby extending its useful lifetime. This process not only recovers a whole product but also has a limited environmental impact compared to traditional manufacturing methods. Remanufactured products predominantly utilize components from the original product, requiring minimal energy for inspection, preparation, and reuse.

The adoption of electric vehicles (EVs) has gained momentum due to their potential environmental benefits and reduced reliance on fossil fuels. China has witnessed significant EV adoption, with approximately 4.40% of all 28.08 million automobiles sold in 2018 being EVs, surpassing the rates in the United States and Europe. Lithium-ion batteries (LIBs) are favoured power sources for EVs due to their desirable characteristics such as high energy density, low self-discharge rate, and extended lifespan. However, as many LIBs reach their end-of-life, proper disposal is essential to prevent adverse environmental impacts. The composition of lithium-ion batteries used in EVs, and plug-in electric hybrid vehicles prohibits simple disposal at the end of their vehicle application. Additionally, the high cost per kWh of new lithium-ion batteries remains a significant economic barrier to widespread commercialization of plug-in electric vehicles, as estimated by the US Department of Energy [18]. The annual availability of lithium-ion batteries for remanufacturing, recycling, and repurposing is projected to exceed 3,000,000 between 2029 and 2032 and may even meet 50% of new vehicle demand between 2020 and 2033. This indicates a sufficient supply of batteries for such purposes. Cost-benefit analyses demonstrate that remanufacturing is economically viable, providing savings of approximately 40% compared to using new batteries. Repurposing also proves economically feasible if research and development costs for new applications are below certain thresholds. Recycling, however, becomes economically feasible only under specific conditions, such as a shortage of new lithium leading to an increase in the price of lithium salts. Overall, the remanufacturing, recycling, and repurposing of lithium-ion batteries present viable options for addressing their end-of-life management while considering economic factors, environmental sustainability, and the growing demand for EVs [19].

2.1.4 Petrochemical, Market (SOCAR & TEKNOPAR)

Petrochemicals play a crucial role in the chemical industry, as there is a consistent rise in demand for synthetic materials. The global petrochemicals market was valued at 556 billion € in 2021 and is projected to grow at a compound annual growth rate (CAGR) of 6.2% from 2022 to 2030 [20]. To address the challenges posed by geopolitical tensions and promote sustainability, petrochemical companies are advised to invest in measures such as decarbonization and the development of low-carbon products and processes. These sustainability efforts create opportunities for value creation and drive growth in the industry.

Petrochemicals Europe, a sector of CEFIC (the European Chemical Industry Council), represents approximately 29,000 chemical companies of various sizes, employing around 1.2 million people [21]. This sector accounts for nearly 17% of global chemical production, contributing to innovation, manufacturing, and employment. The increasing demand for petrochemicals can be attributed to the growing need for downstream products in industries like construction, pharmaceuticals, and automotive. Petrochemicals are vital components in various industrial processes, making them a cornerstone of the industrial economy. Petrochemical feedstocks account for 12% of global oil demand, a share that is expected to rise due to the increasing demand for plastics, fertilizers, and other products. The market for petrochemicals is primarily driven by the growing demand for downstream specialty chemicals and plastics. Although the petrochemical industry contributes to greenhouse gas emissions, it remains a fundamental pillar to produce non-durable and durable consumer goods, including plastics, industrial oil, medical devices, fertilizers, and components for modern energy systems like solar panels, wind turbine blades, batteries, thermal insulation, and electric vehicles.

Major players in the market include DOW, BASF, Total, LyondellBasell Industries, DuPont de Nemours, Phillips 66, Marathon Petroleum, China National Petroleum Corp, JXTG Holdings Inc, Saudi Basic Industries Corporation, Sinopec Limited, and Royal Dutch Shell. These companies have significant manufacturing facilities and a global presence across different regions. The petrochemicals industry is vital for meeting the demand for synthetic materials across various sectors. While environmental concerns exist, efforts towards sustainability and the development of low-carbon solutions present opportunities for growth and value creation in the industry. DOW is one of the major players in the market with 109 manufacturing facilities in 31 countries from across the United States, Canada, Latin America, Asia-Pacific, Europe, Middle East, Africa, and India. BASF is a Germany based company with 385 manufacturing sites and more than 117,000 employees across six segments. Total is French-based company with more than 107,000 employees and aside from manufacturing petrochemicals, the company engages in the exploration and production of oil and gas and distributes energy in various forms to end consumers. Other non-EU based major corporations are LyondellBasell Industries with 18 manufacturing sites in North America, Australia, New Zealand, Africa, Middle East, and South and Central America, DuPont de Nemours (US), Phillips 66 (US) with 13 refineries in the United States and Europe where they process crude oil and other feedstocks. Marathon Petroleum (US) is engaged in the refining, marketing, and transport of petroleum products in the United States. China National Petroleum Corp owns the largest refining and chemical production bases in China, while China National Petroleum Corp partners venture refineries in UK and France among others. Other key industry corporations are JXTG Holdings Inc, Saudi Basic Industries Corporation, Sinopec Limited, Royal Dutch Shell [22].In April 2022, Adnoc made an announcement regarding its plan to purchase a 25 percent stake in Borealis, an Austria-based chemicals producer, from Mubadala Investment Company. This strategic move by the state-owned oil and gas producer is aimed at expanding its presence in the chemical and petrochemical sector. The majority control of Borealis, accounting for 75 percent, would be held by OMV, an integrated oil, gas, and petrochemical company listed in Vienna. Furthermore, in September 2022, Israel Petrochemical Enterprises received approval from, the Prime Minister of Israel, to acquire full ownership of Bazan, the largest oil refinery in Israel located in the Haifa Bay. Israel Petrochemicals exercised its right of refusal to veto a previous bid for Bazan made by the Hagag Group, a group of property developers. With a

15 percent stake in the Bazan oil refineries stock, Israel Petrochemicals had the opportunity to become a joint owner. Additionally, in September 2021, the Saudi Industrial Investment Group completed the acquisition of the National Petrochemical Co., forming one of the largest chemical manufacturers in the Middle East. This all-share transaction brought together two companies with a combined market capitalization of 11.2 billion €. The consolidation of these firms reflects a broader trend among Saudi Arabia's industrial companies, aiming to achieve scale and enhance profitability in the face of rising prices.

More specifically, Circular TwAIn's petrochemical pilots represents an EO/EG plant. Which refers to facilities involved in the production of ethylene oxide (EO) and ethylene glycol (EG). Ethylene oxide (EO) is one of the major products from ethylene. EO can be made from petroleum-based or bio-based ethylene and is used as an intermediate in the manufacture of plastics, fibres, detergents, automotive coolants, resins, papers and other downstream chemicals. Ethylene oxide (EO) is a flammable and colourless gas used primarily as a sterilizing agent for medical equipment and supplies. It is also used in the production of ethylene glycol. EO is highly reactive and can be hazardous to human health and the environment. Ethylene glycol (EG) is a collarless, odourless liquid with a sweet taste. It is widely used as an antifreeze and coolant in automobiles, as well as a raw material in the production of polyester fibres, films, and polyethylene terephthalate (PET) bottles [23]. PET is then converted into plastic bottles which are used globally. It is estimated that 70-80% of all the Monoethylene glycol (MEG) consumed is used as a chemical intermediate in these polyester production processes. MEG is a clear, colourless, odourless liquid with a sweet taste. It is an important chemical compound derived from the reaction of ethylene oxide (EO) with water. MEG has numerous industrial applications and can be found in many consumer products such as antifreeze, ani-icer, de-icers, brake fluids, adhesives, automotive care products, cosmetics, toners, fabrics, inks, pens, paints, plastics and coatings [24].

EO/EG plants typically consist of several units and processes, including:

- The first step in the EO/EG manufacturing process involves the production of ethylene oxide (EO) through a catalysed, direct partial oxidation of ethylene. During this reaction, a portion of the ethylene is fully oxidized, resulting in the formation of carbon dioxide (CO2) and water. This reaction occurs in an isothermal reactor, typically a tubular reactor, at temperatures ranging from 230 to 270°C. The reaction conditions are controlled and optimized using an organic chloride. After the reaction, the EO is extracted from the reactor product gas by absorbing it in water. The co-produced CO2 and water are then removed from the gas mixture. To continue the process, fresh ethylene and oxygen are added to the gas mixture, and it is returned to the EO reactor as feed. The EO-water mixture obtained from the absorption process can be directed to a purification section to recover high-purity EO. Alternatively, it can be routed to a reaction section where EO and water are converted into glycols, which are useful chemical compounds in various applications Ethylene Glycol Production: Ethylene oxide is further reacted with water to produce ethylene glycol through a process called hydrolysis. The reaction is typically catalysed by either an alkali or an acidic catalyst [25].
- In the conventional thermal glycol reaction process, ethylene oxide (EO) and water are reacted at high temperature (around 200°C) and pressure without the use of a catalyst. This process typically results in the production of approximately 90-92%

monoethylene glycol (MEG) and 8-10% heavier glycol products, primarily diethylene glycol (DEG) and triethylene glycol (TEG). To limit the formation of higher glycols, excess water is employed to minimize the reaction between EO and the glycols. The mixture of water and glycols obtained from the reactor is then directed to multiple evaporators, where the excess water is separated and mostly recycled. Subsequently, the water-free glycol mixture undergoes distillation to separate the MEG from the higher glycols. Storage and Distribution: The purified ethylene glycol is stored in tanks and then transported to various industries for further processing or used as an end product in applications like antifreeze.

- A more advanced approach in EO/EG technology involves the reaction of ethylene oxide (EO) with carbon dioxide (CO2) to produce ethylene carbonate (EC). Subsequently, EC is catalytically reacted with water to produce monoethylene glycol (MEG). This two-step process utilizes catalysts for both reactions. One significant advantage of this modern technology is that the majority of MEG is formed in an EO-free environment. This minimizes the co-production of heavier glycols and allows for a MEG yield of over 99%. The process ensures high purity and efficiency in MEG production.

The markets for EO and EG continue to see growth, and there is a continuous drive to improve EO/EG manufacturing economics. Even in 2020, when businesses faced unprecedented challenges, global ethylene demand increased. In 2021, ethylene glycols, including monoethylene glycol (MEG), diethylene glycol (DEG), and triethylene glycol (TEG), were the largest consumers of ethylene oxide (EO), representing over 70% of the EO market. About 65% of global output is converted to monoethylene glycol (MEG) for polyester fibres, resins, and antifreeze formulations, while more than 5% is used in diethylene glycol (DEG) and triethylene glycol (TEG). Ethylene glycols have a wide range of applications and are used in various industries.

The annual production of monoethylene glycol (MEG) is approximately 30 million metric tons [26]. The European MEG market experienced challenges in the first half of 2020, resulting in reduced demand and oversupply. Automotive manufacturers temporarily closed, leading to a significant decrease in anti-freeze demand. In the second half of 2020, European MEG supply was constrained due to reduced imports and localized production issues. Hurricane-related outages in the US limited MEG spot supply for imports to Europe. Additionally, an anti-dumping investigation launched by the EU on material from Saudi Arabia and the US created hesitancy in importing from these regions. Shortages in co-product diethylene glycol (DEG) in December led to significant price increases. As spot prices rose and supply tightened, European MEG contractual demand increased. Container shortages hindering imports contributed to increased downstream demand for PET. MEG availability improved slightly in February 2021 as production issues were resolved, and imports from Asia arrived in Europe [27]. The global MEG market has shown remarkable growth from 2015 to 2022, with a demand of around 28 million tonnes in 2022. It is expected to grow steadily at a CAGR of 3.2% until 2030. Saudi Basic Industries Corporation commenced operations at its plant in Jubail, with an annual capacity of 700 thousand tonnes. Key players in the global MEG production include Saudi Basic Industries Corporation, ExxonMobil Corporation, Mitsubishi Chemical, Formosa, Chemtex Speciality Limited, The Dow Chemicals, LyondellBasell Industries, Royal Dutch Shell, AkzoNobel, MEGlobal, Reliance Industries, Lotte Chemical

Corporation, Nan Ya Plastics Corporation, China Petroleum and Chemical Corporation, India Glycols, and Sinopec Zhenhai Refining & Chemical Co.

Europe MEG capacity
'000 tonnes/year

Company	Location	Capacity
BASF	Antwerp, Belgium	325
INEOS Oxide	Antwerp, Belgium	290
INEOS Oxide	Dormagen, Germany	160
Shell Chemicals	Moerdijk, Netherlands	155
Clariant	Gendorf, Germany	140
Industrias Quimicas Del Oxido De Etileno	Tarragona, Spain	106
Petkim Petrokimya	Aliaga, Turkey	90
PKN Orlen	Plock, Poland	85
Nouryon	Stenungsund, Sweden	20

Figure 5: EU MEG Capacity per facility (2021)

The global Ethylene Oxide and Ethylene Glycol market size was estimated around 44 billion € in 2022 and is forecasted to reach 59 billion € by 2028 with a CAGR of 4.9% [28]. The global Ethylene Glycol market size was estimated in 33 billion € in 2022 and is forecast to reach 39 € billion by 2028 with a CAGR of 2.7% [29].

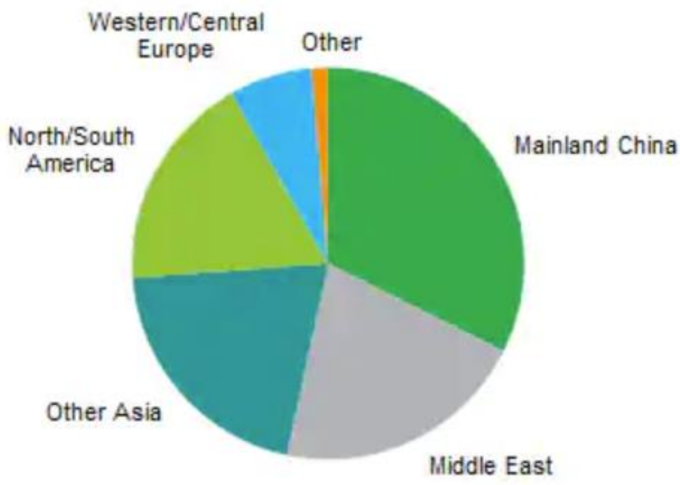

Figure 6: World consumption of EO by 2021 (spglobal.com)

While the United States aims to leverage its lower feedstock costs to enhance its competitive edge, the European market is grappling with ongoing energy cost challenges within the increasingly demanding global market that emerged in the latter half of 2022. Petrochemical companies in Europe must compete against Middle Eastern producers benefiting from favourable oil and gas feedstock, as well as shale gas-based petrochemicals from the United States. Energy prices in Europe rank among the highest worldwide, and since oil and gas constitute 80% of production costs, it is imperative to establish a stable and competitive energy market within the European Union to maintain industry competitiveness. A survey conducted by Deloitte in North America reveals that industry leaders anticipate significant changes in the next decade regarding operational practices, posing a test for the preparedness of the petrochemical industry. Emphasis will be placed on asset reliability through the utilization of advanced technologies such as real-time monitoring through the Internet of Things (IoT), asset optimization using artificial intelligence (AI) across the value chain, and the implementation of Digital Twins to connect, simulate, and predict various scenarios. The topics of sustainability and the Circular Economy have gained significant momentum and attention from world leaders who are driving their green agendas through legislation and incentives. This shift is compelling companies to embrace a greener future. Furthermore, by leveraging advanced technologies, petrochemical firms can integrate diverse information sources, simulate scenarios, and predict outcomes, ultimately aiming to enhance utilization rates and address capacity challenges. The global socio-political landscape, as depicted in this report, is altering the availability of feedstock for petrochemicals. Therefore, any technological solutions that enable manufacturers to streamline their daily operations and optimize the entire product value chain can alleviate the financial burden resulting from global disruptions. Additionally, the petrochemical sector is the leading investor in research and innovation within the European Union's chemical industry, accounting for a third of the total investment [30].

2.2 Environmental analysis

The process of environmental analysis holds significant importance for organizations as it allows them to evaluate external factors affecting their business and their future plans. Through the analysis, organizations or individuals gain insights into the political, economic, social, technological, legal, and environmental aspects, commonly known as PESTLE analysis. SWOT analysis is another tool utilized to assess internal strengths and weaknesses, as well as external opportunities and threats. By conducting a thorough environmental analysis, knowledge about the external environment, both present and future can be acquired. This analysis aids in identifying opportunities, anticipating challenges, and making informed strategic decisions.

The PESTLE analysis provides a structured framework to examine macro-environmental factors influencing the Project. It covers political factors such as government policies and stability, economic factors including growth and consumer behaviours, social factors such as demographics, technological factors encompassing innovations, legal factors and environmental factors related to sustainability. More specifically PESTLE is an acronym that stands for Political, Economic, Social, Technological, Legal, and Environmental factors:

- **Political factors** encompass the impact of government policies, regulations, and political stability. This includes areas such as tax policies, trade regulations, labor laws, government stability, and political ideologies. In the context of Circular TwAIn government policies and regulations concerning resource management, waste reduction, and sustainable manufacturing practices are under the radar.
- **Economic factors** focus on the economic conditions and trends that may impact a project or an organization. This includes factors such as economic growth, inflation rates, interest rates, exchange rates and employment levels. Economic factors within

the Circular Economy encompass market demand for sustainable products, resource availability, and the costs associated with transitioning to circular manufacturing models. This involves assessing the economic viability of implementing circular practices, such as recycling or remanufacturing, and evaluating potential cost savings through reduced resource consumption and waste generation.

- **Social Factors**: Social factors refer to the cultural, demographic, and societal influences that affect end-user preferences. This includes aspects such as demographics, cultural attitudes and consumer attitudes towards sustainability. Understanding social factors can assist in aligning their products and services, with target customers preferences. End-users are increasingly seeking environmentally-friendly and socially-conscious products, which significantly impacts manufacturing practices. Understanding social factors allows manufacturers to adapt their product offerings and strategies to align with consumer demands for sustainable and circular products.
- **Technological Factors**: Technological factors are related to technology innovations, and technological trends impacting industries and organizations. This includes factors such as technological disruptions, research and development activities, digitalization, and the adoption of new technologies. Technological factors relevant to the Circular Economy involve innovations and advancements that facilitate resource efficiency, waste reduction, and the development of circular manufacturing processes. Assessing technological factors helps the identification of opportunities for integrating sustainable technologies and optimizing production processes according to circular principles.
- **Legal Factors**: Legal factors encompass laws, regulations, and legal frameworks that must be adhered. This includes areas such as employment laws, intellectual property rights, data protection laws and industry-specific regulations. Legal factors in manufacturing and the Circular Economy encompass regulations related to waste management, product lifecycle assessments, and environmental standards. Understanding legal factors enables us to navigate complex regulatory landscapes and ensure compliance while circular practices.
- **Environmental Factors:** Environmental factors address sustainability, environmental regulations, and ecological considerations. This includes factors such as climate change, energy consumption, waste management, and increasing environmental awareness. Environmental factors lie at the core of the Circular Economy. By analysing environmental factors, opportunities to adopt sustainable materials, optimize production processes, and minimize their ecological footprint can be identified.

By conducting a comprehensive PESTLE analysis, a holistic understanding of the external factors influencing Circular TwAIn is gained. This analysis helps identify opportunities, anticipate threats, and make informed decisions that align with market dynamics. It is important to regularly update and reassess the PESTLE analysis as external factors can evolve over the period of time. To this end the PESTLE analysis for Circular TwAIn will be updated till the end of the Project, to portray the realistic situation at any given time.

SWOT analysis, on the other hand, focuses on evaluating internal strengths and weaknesses, as well as external opportunities and threats. It offers a comprehensive understanding of the organization's competitive position, highlighting areas for improvement and potential risks. This comprehensive will provide insights into the competitive position of Circular TwAIn and make better informed strategic decisions. The SWOT analysis comprises the following components:

- **Strengths** encompass the internal capabilities and resources providing a competitive edge. These may include factors like a strong innovative products or services, efficient processes, or a sound financial analysis. Recognize and leverage the strengths, serves to differentiate Circular TwAIn's results from other market competitors.
- **Weaknesses** refer to internal limitations or areas in need of improvement. These could include technology shortcomings, infrastructure, insufficient expertise in certain areas, or inefficient processes. By Identifying weaknesses, a strategy to address these areas and enhance the offering can be settled.
- **Opportunities** represent external factors that have the potential to positively influence the project's growth and success. These can arise from emerging market trends, technological advancements or new regulations. Opportunities identifications is crucial to align the Circular TwAIn strategies accordingly and gain a competitive advantage.
- **Threats** are external factors that pose challenges or risks to a project's success. They may include existing competition threats (e.g., other innovative products with stronger market presence), technological threats (e.g., fail to adapt with technological advancements), economic threats (e.g., Downturns, limited purchasing power of buyer's), regulatory changes (e.g., policies or legal requirements), environmental threats (e.g., Environmental regulations), supply chain threats (e.g., Raw material shortages) or cultural threats (e.g., Societal preferences) Recognizing threats enables the development of mitigations measures towards risks.

Conducting a SWOT analysis provides a comprehensive understanding of the current position and the external factors influencing the Project. It serves as a foundation for developing effective strategies by leveraging strengths, addressing weaknesses, capitalizing on opportunities, and mitigating threats. Moreover, SWOT analysis is a recognized tool used to guide decision-making. It is essential to regularly review and update the SWOT analysis as the landscape evolves.

In this section, an in-depth environmental analysis is conducted using the PESTLE and SWOT analysis tools. By employing these frameworks, the external factors impacting Circular TwAIn are explored as well as Project's internal capabilities. The analysis will serve as enabler to comprehend the opportunities and challenges present in the environment, and to align Project strategies accordingly. It's important to note that the environmental analysis is based on available data up to the current date.

2.2.1 PESTLE Analysis

For the PESTLE analysis of Circular TwAIn and to streamline the research process, the focus is on the main technological pillars of Circular TwAIn, namely the Data Spaces, AI applications in manufacturing and circular manufacturing. As mentioned in previous section the PESTLE analysis will be updated throughout the Project lifecycle to depict the current state of the economy and the external environment. Also, the impact of the recognized factors will be assessed as proceeding with the technical developments.

Table 2: Circular TwAIn PESTLE Analysis

Category	Factors
Political *Political factors are basically how the government intervenes in the economy:* • *Labour Laws* • *Privacy, data, rights* • *Public policies* • *Trade restrictions* • *Sustainability issues*	✓ *Government policies and regulations related to data privacy and security.* ✓ *International trade policies and agreements that impact data sharing and transfer between countries.* ✓ *The Commission supports the development of common European Data Spaces with European data Governance Act (February 2022). The Data Governance Act will also support the set-up and development of common European Data Spaces in strategic domains, involving both private and public players including energy and manufacturing sectors.* ✓ *European Data Space for Smart Circular Applications (EDSCA), which is going to be a registry that will make available the relevant data for enabling circular value creation along supply chains.* ✓ *The European AI Alliance is an initiative of the European Commission to establish an open policy dialogue on Artificial Intelligence. Since its launch in 2018, the AI Alliance has engaged around 6000 stakeholders through regular events, public consultations, and online forum exchanges.* ✓ *In 2021, the European Commission announced a budget of €8 billion for the Digital Europe Program, which includes funding for AI and advanced manufacturing initiatives (European Commission) [31].* ✓ *United States, and China have developed national AI strategies to drive technological advancements, economic growth, and job creation in the manufacturing sector (World Intellectual Property Organization.*
Economic *The broader economic climate a business is operating in, both from the country's economy and the consumer's side:* • *GPD, taxes* • *Employment rates* • *Market growth* • *Economic barriers* • *Access to capital*	✓ *The new rules are expected to create 270 billion € of additional GDP for EU Member States by 2028 [32].* ✓ *530% increase of global data volume, from 33 zettabytes in 2018 to 175 zettabytes in 2025 [33].* ✓ *EU data strategy from 301 billion € (2.4% of EU GDP) in 2018 to 829 billion € in 2025 [32].* ✓ *4 to 6 billion € in common European Data Spaces and a European federation of cloud infrastructure and services.* ✓ *Global GDP may increase by up to 14% (the equivalent of 15.7 trillion €) by 2030 as a result of the accelerating development and take-up of AI.* ✓ *Leading countries could capture an additional 20 to 25 percent in net economic benefits compared with today, while developing countries may capture only about 5 to 15 percent.* ✓ *Technology revolution can create a net benefit of 1.8 billion € per year by 2030 when implementing Circular*

• *Target markets*	*Economy models, which is 0.9 trillion € more per year [34].* ✓ *In 2020, the average cost of a data breach was estimated to be $3.86 million, with potential long-term reputational damage (IBM Cost of Data Breach Report).*
Social *High trends in social factors affect the demand for a company's products and how that company operates:* • *AI impact on society* • *Culture impact* • *Human behaviours* • *Quality of work* • *Public opinions*	✓ *Attitudes and perceptions of workers towards the use of data in manufacturing* ✓ *Lower-paid jobs that typically require routine manual and cognitive skills stand the highest risk of being replaced by AI.* ✓ *The current world population of 7,3 billion people is expected to reach 8,5 billion in 2030 and 9,7 billion in 2050. To face the demand of this growing population with limited resources, new consumptions patterns must be found [35].* ✓ *Up to 20 million manufacturing jobs could be automated by 2030 (International Federation of Robotics).* ✓ *The ethical implications of AI in manufacturing, have initiated public debates and discussions on responsible AI deployment (The Hastings Centre).* ✓ *AI-enabled robots have helped reduce injury rates by 72% in some industries (National Institute for Occupational Safety and Health).* ✓ *In 2020, data centres consumed about 1% of the global electricity supply, with projections estimating this to increase to 3-13% by 2030 (International Energy Agency).*
Technological *Technological factors include technological aspects like R&D activity, automation, technology incentives and the rate of technological change:* • *Process efficiency* • *Entry barriers* • *Technical specs* • *Research and innovation* • *Technology changes*	✓ *AI in the manufacturing industry offers cost savings on labour, reduced unplanned downtime, fewer product defects, and increased production speed and accuracy.* ✓ *By 2030 about 70 percent of companies will have adopted some sort of AI technology [36]* ✓ *Common European Data Spaces will be central to enable AI techniques and supporting the marketplace for cloud and edge-based services.* ✓ *Availability and cost of data analytics tools, platforms, and software.* ✓ *A report on AI by the World Intellectual Property Organization (WIPO) shows that there has been a boom in the number of scientific papers in the field since the start.* ✓ *The availability of large datasets and the development of industrial Data Spaces provide opportunities for AI-driven data analytics of the century.* ✓ *The adoption of AI in manufacturing is expected to increase by 25% by 2025 [37].* ✓ *By 2025, it is projected that 75% of enterprise data will be processed at the edge rather than in centralized data centres [38].*

	✓ As of 2021, there are over 30 industrial Data Spaces established in various industries, with the number expected to grow rapidly in the coming years (Fraunhofer).
Legal *While similar to the political aspects, the legal elements in Circular TwAIn's PESTLE analysis examine the practical application of those political factors into rules and regulations that impact the Project:* • *Labour Laws* • *Privacy, data, rights* • *Public policies* • *Trade restrictions* • *Sustainability issues* • *Copyright and intellectual property law*	✓ *AI Act Proposal (AIA-E): Proposed in April 2021, legislative procedure ongoing. It is the EU framework for regulating AI; it applies to both providers and users of AI.* ✓ *Data Act Proposal (DA-E): Proposed in February 2022, legislative procedure ongoing. It includes obligations for developers and manufacturers of products to facilitate the user's access to data generated during the use. It will serve facilitating switching of data processing services, introducing safeguards, and interoperability standards.* ✓ *Data Act Proposal (DA-E): Proposed in February 2022, legislative procedure ongoing. It depicts obligations of developers and manufacturers of products to facilitate the user's access to data generated during the use. It will facilitate switching of data processing services, introducing safeguards, and interoperability standards.* ✓ *Open-source AI regulation is mentioned in the Artificial Intelligence Act (AIA), which is now under discussion in the EU. However, severely restricting the use, sharing, and distribution of general-purpose, open-source AI (GPAI) can be seen as a step backward.* ✓ *Compliance with data protection and privacy laws such as GDPR, CCPA, and HIPAA. The GDPR is believed to be one of the most rigid privacy and security regulations in the world.* ✓ *Intellectual property rights and ownership of data generated within Data Spaces.* ✓ *ISO/IEC 38507 will help organizations to adapt their existing governance and organizational policies for the use of AI. It offers guidance on defining responsibilities and assigning accountability.*

2.2.2 SWOT Analysis

Considering Circular TwAIn as a potential business a preliminary SWOT analysis has been performed. The analysis has been conducted based on a literature review to act as the basis for the next phases of the process. The SWOT analysis framework utilized for the project categorizes the four components into external and internal factor, which can have either positive or negative implications for future adoption.

Figure 7 : SWOT Analysis framework

Below the results of the preliminary analysis are presented:

- **Strengths:**
    - Novelty of the Circular TwAIn solutions in terms of advanced AI features and functionalities.
    - Coverage of the compete AI value chain and offering of a wide array of novel services.
    - AI can help reduce labor costs and improve production efficiency.
    - Data Spaces enhance collaboration and data sharing across the value chain.
    - Reduced resource consumption and waste generation though circular manufacturing practices.
    - Trustworthy AI Techniques
    - Improved decision-making through real-time insights.
    - Integration of sustainable and circular manufacturing principles
    - Strong technical expertise in scientific pillars addressed by Circular TwAIn
- **Weaknesses:**
    - New Cybersecurity risks.
    - Product or service may still be in the early stages of development.
    - Lack of strong commercial presence exclusively in the emerging AI market.
    - Lack of needed skills from the workforce and expertise in AI technologies.
    - Limited availability of recycling and remanufacturing infrastructure
    - Higher resources needed for implementing circular practices compared to linear manufacturing.
    - Compliance with regulations related to materials and safety standards can pose a challenge for remanufacturing.
- **Opportunities:**
    - Need for a safe and human-centric AI.
    - Need for collaboration with partners and stakeholders to create interconnected ecosystems.
    - Increasing regulations and incentives to reduce carbon emissions and promote Circular Economy practices.

- Leverage Data Spaces for compliance with regulations and standards.
- Fill the gap of existing marketplaces for one EU-wide one-stop-shop platform for AI solutions.
- AI is currently the most disruptive digital enabler in smart manufacturing.
- Increased demand for AI-based sustainability solutions.
- Industry 5.0 Transition
- Potential for new products development and market expansion based on AI-solutions.
- Remanufacturing allows for the extraction of valuable components and materials, leading to value recovery and new revenue streams.

- **Threats:**
  - Resistance and low acceptance of AI solutions by manufacturers.
  - Emergence of competing solutions in the AI ecosystem.
  - Lack of standardization on Circular Twain's related themes
  - Limited understanding of Data Spaces principles and benefits may hinder adoption.
  - Regulatory gaps regarding data ownership and data sharing.
  - Limited funding sources to carry out further research and development activities
  - Ethical issues related to data privacy and job displacement.

For the purposes of Circular TwAIn, the weighted SWOT Analysis tool developed by CORE will be utilized to have a more in depth understanding on strengths and weaknesses of Circular TwAIn. More specifically a weighted analysis based on criteria and their importance will be conducted by leveraging the knowledge of the market (meaning the end-users) and of the industry (meaning the technology partners). The Weighted SWOT is performed in four steps:

- Preliminary list of strengths and weaknesses related to Circular TwAIn innovations and clustering of the elements.
- Technology Partners to validate and complement the list.
- Technology Partners acting as proxies for Industry and end-users acting as proxies for the market, to rate the statements though a questionnaire that will be circulated to the Consortium.
- CORE to perform the weighted analysis of strengths and weaknesses per cluster and visualize the results.

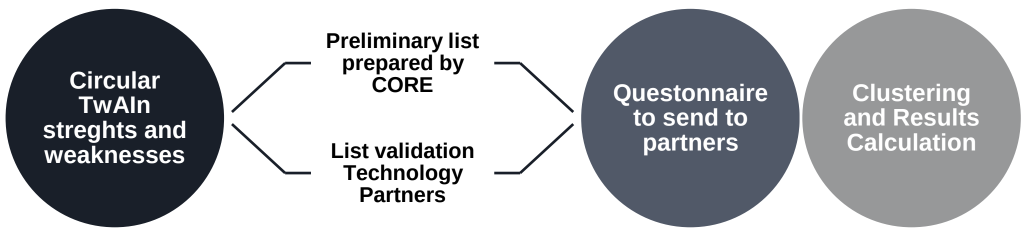

Figure 8: Weighted SWOT Analysis process

The technology partners will be requested to complement the list of strengths and weaknesses regarding their innovation in Circular TwAIn. These elements will be categorized under five categories, to assess Circular TwAIn commercial potential.

- **Technical features**: In this cluster the technical features of Circular TwAIn are rated.
- **Cost competitiveness**: In this cluster the commercial offering of the solutions based on the perception of features costs are assessed.
- **Environmental impact:** In this cluster the impact that Circular TwAIn solution will deliver is assessed.
- **Integration ease**: In this cluster the ease of integrating the solution to the existing infrastructure and systems is assessed.
- **Market replication:** In this cluster the replication capabilities of Circular TwAIn to other use cases and industries are assessed.

CORE will compile the final list with the strengths and weaknesses of all Circular TwAIn innovations, as defined by the technology partners, and will group them accordingly to reflect the complete Circular TwAIn solution. The table below presents the strengths and weaknesses of the Circular TwAIn solution organized in the aforementioned clusters:

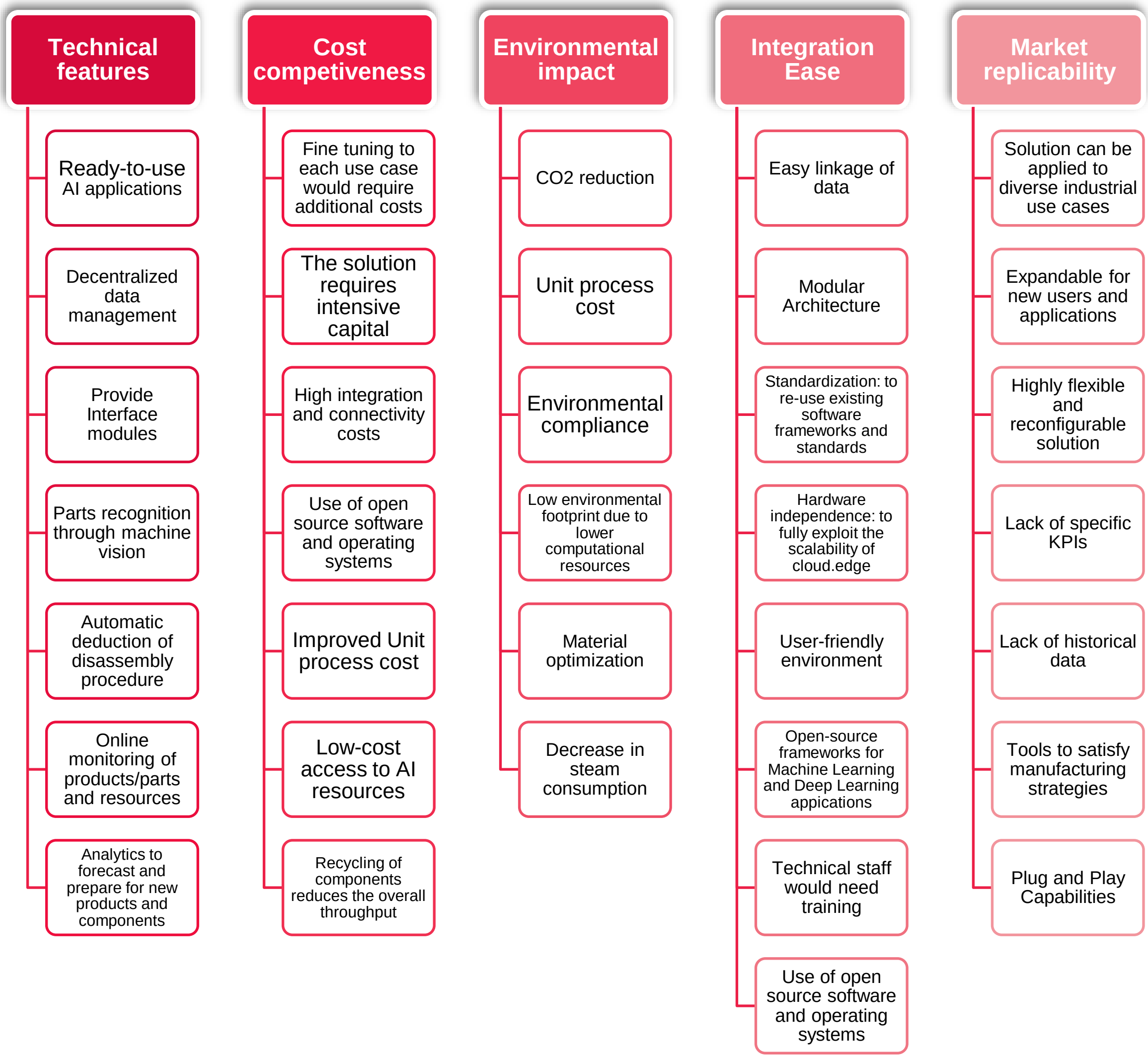

Figure 9: Circular TwAIn clusters and features (preliminary version)

3 Exploitation strategy

Project' Circular TwAIn objective is to deliver an AI-based platform, to enable end-to-end sustainability across the value chain. The Consortium will research, develop, validate and exploit a novel AI platform for circular manufacturing value chains. The exploitation aims to deliver a comprehensive plan to successfully exploit the Circular TwAIn results, lowering the barriers for manufacturing and process industry actors towards trusted AI technologies specifically targeting sustainability and paving the way to Industry 5.0.

3.1 Exploitation objectives

The work concerning the exploitation is included in WP7 and more specifically Task 7.5. The overall objectives of the Work Package are to:

- Roll out Dissemination, Communication and Exploitation Strategies for Circular TwAIn.
- Define and develop Regulatory Sandboxes for experimenting applied AI scenarios with ethical issues and for applying existing standards especially concerning AI and Human-AI interaction.
- Develop a network of Hubs for Circularity and their AI Testing and Experimental facilities.
- Develop and launch an Innovation & Collaboration platform tailored for the Hubs for Circularity.

The Exploitation objective of Circular TwAIn is divided into two main objectives:

- Development of the exploitation strategy and the final Circular TwAIn business model.
- Ensure the exploitation and replication for commercial and non-commercial purposes.

To achieve these objectives CORE will leverage recognized methodologies and tools that fit the profile of Circular TwAIn and support the involvement of the Consortium towards a strategic exploitation plan with strong partnerships and a clear path paving the way to the market penetration. As described in Task 7.5: Market analysis and Exploitation of Results, to achieve these objectives an overview of the activities planned by CORE are listed below:

- Market Analysis
- Environmental Analysis
- Exploitable Results Identification and target stakeholders
- Design the Exploitation Roadmap
- Market Replication Analysis
- Development of Business Model

Also, through the exploitation of the Project results CORE will support the Consortium to materialize the expected outcomes, meaning to:

- Boost sustainability of European manufacturing and process industry through the development and exploitation of trustworthy AI technologies.

- Exploit the potential of circular manufacturing and re-manufacturing solutions based on state-of-the-art AI technologies, across the entire value chain and product lifecycle.

Overall, the objective of the exploitation is to deliver a clear exploitation strategy, showcasing the potential of the Circular TwAIn solutions and a robust business model bringing the Project developments closer to the market and the adoption from industrial end-users.

3.2 Exploitation methodology

For the purpose of Circular TwAIn, CORE prepared a tailor-made plan in sync with Project timelines. In this section the exploitation work plan and the roadmap designed to achieve the expected results are presented.

3.2.1 Exploitation Work Plan

A work plan to fulfil the exploitation strategy of Circular TwAIn and follow the Project developments is presented in Figure 10. The work plan considers:

- The commercial exploitation of the relevant results,
- The non-commercial exploitation of the relevant results,
- The replication of the Circular TwAIn individual and joint exploitable results.

The activities towards the exploitation objectives, listed in the previous section are segregated in three distinct phases (Figure 10).

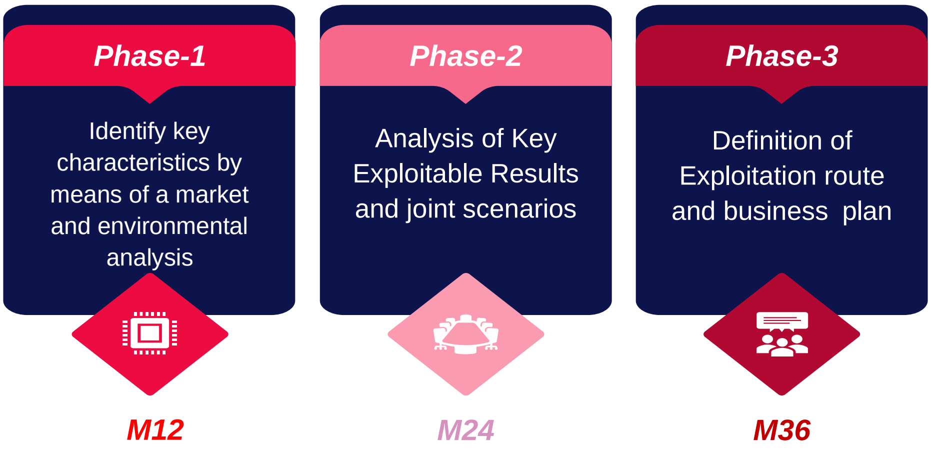

Figure 10: Exploitation work plan

During the first iteration the goal was to have the initial analysis of the market characteristics and a clear picture of the Individual Exploitable results. By the end of the Project in M36 the goal is to build on the work done in Phase-1 and Phase-2 and deliver the final business model, while making the necessary updates to existing work since the environment is rapidly changing and several unforeseen external or internal events may occur with great impact to Project outcomes.

- **Phase 1** was focused to the analysis of the end users' market and specifically to re-manufacturing and de-manufacturing aspects of the industries. In addition, recognized strategic tools has been leveraged to assess the external environment around Circular TwAIn scientific domains and the general socio-economic environment and its potential impact to the Project.

- **Phase 2** will be focused to finalize the list of the Individual Exploitable results and their definition (several iterations with the partners will take place to evaluate the need of including new potential results according to technical developments), proceed to in a depth analysis of each exploitable result, expand the analysis on the barriers to innovation related to Circular TwAIn and finally formulate the joint exploitation scenarios.
- **Phase 3** will focus mainly on the financial aspects of Circular TwAIn preparing the way to commercialization, while working also with the partners to provide a concrete replication methodology in terms of technology and market replication. Near the end of phase 3 the business plan compiled in cooperation with the Consortium will be delivered.

3.2.2 The Exploitation Roadmap

The exploitation roadmap is a tool designed to help the Consortium to identify and plan activities to pave the path towards the market and the activities to be performed after the end of the Project to ensure the continuity of Circular TwAIn and impact delivery. The roadmap towards commercialization is presented through 5 distinct steps (see Figure 11).

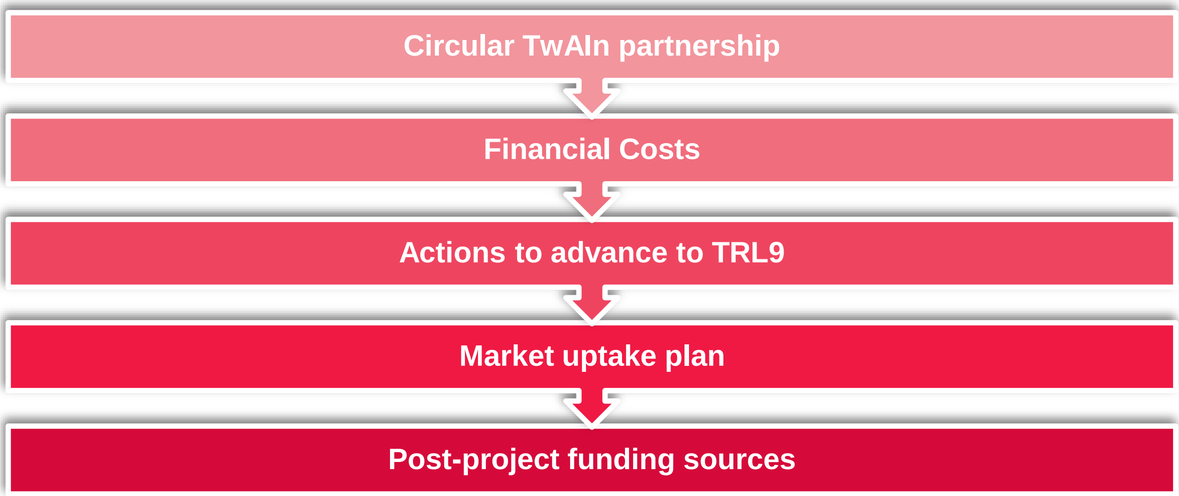

Figure 11: Exploitation Roadmap

Further elaborating on the roadmap activities:

- ✓ **Circular TwAIn partnership**: In this step the roles and the participation of the partners towards the joint exploitation of the Project will be defined, and the individual actions needed to both advance technologically the innovation produced through Circular TwAIn and the relations between the partners for carrying on the business will be analysed.
- ✓ **Financial costs:** In collaboration with the technology partners, the costs needed to develop and pilot the technologies post Project along with the key resources will be defined.
- ✓ **Actions to advance to TRL9:** Define the actions to be taken after the Project ends and advance innovations to TRL9.

- ✓ **Market uptake plan:** Use recognized methodologies to research the market and the external environment and suggest actions to maximize the commercial impact of Circular TwAIn.
- ✓ **Post-project funding:** Potential funding sources will be examined to help bring the Project innovation in higher TRL, cover the financial costs and ensure the continuity of Circular TwAIn after the Project ends.

4 Exploitation of results

4.1 Exploitable results

The first step towards the exploitation is to identify and clearly define the Individual Exploitable Results provided by each partner. On the basis of the individual exploitable results and the refinement by CORE, the Key Exploitable Results (KERs) of Circular TwAIn will be compiled. According to Horizon Results Platform, a KER is a main interesting result, which has been selected due to its high potential to be “exploited” – meaning to make use and derive benefits - downstream the value chain of a product, process or solution, or act as an important input to policy, further research or education. Any tangible or intangible result such as data or knowledge acquired or developed during a project can be considered as a Key Exploitable Result. These results can satisfy stakeholders with different goals and expectations, including scientific, societal or economic purposes.

In order to collect the information related to Circular TwAIn’s KERs, a Word file or the so called “Exploitation Table” has been circulated to the Consortium, where except the provision of the desired result a set of important information has been required to the Consortium, to better define the exploitable results. The Exploitation Table is presented below (Table 3).

Table 3: Exploitation table

Criteria	Description
Circular TwAIn Individual Exploitable result	What results or innovations do you expect to exploit through the Circular TwAIn Project?
Utility	What is the benefit your solution offers?
Characterize the type of your innovation	Will you develop a Product, service, process, framework etc.?
Target market	To which market segment the potential deployed solution will/could be applied?
Barriers to innovation	***Deployment barriers***: barriers that may hamper the solution from fully being deployed and penetrating the market. ***Adoption barriers***: barriers that may hamper the end-users from adopting the solution.
Market trends	Relevant trends and drivers in the end user sector that will act in favour of Circular TwAIn creating significant opportunities.
Intellectual Property rights (IPR) method	How do you expect/foresee to protect your Exploitable Result (Trademark, Copyrights, patent etc...)?
Background Intellectual Property (IP)	What expertise do you bring to the Project in relation to your exploitable results?

Circular TwAIn Work Package	Work Package in which the exploitable will be developed?

Further explaining the table of the elements requested to the partners is described:

- **Circular TwAIn Individual Exploitable result:** What is the expected result each partner expects to develop through Circular TwAIn and exploit post Project.
- **Utility:** Description of the exploitable result and the benefits that will bring to the target stakeholders.
- **Characterize the type of your innovation:** Define if the related exploitable refers to an innovation for commercialization (e. g., Software-As-a-Service) or other type of non-commercial purpose (e. g., Reference framework, policy making).
- **Target market:** The main target groups and end-user markets considered by the owner of the exploitable result.
- **Barriers to innovation:** A set of high-level barriers provided by the partners, to be used as the basis for further analysis of Circular TwAIn barriers to market uptake. An extensive analysis of the barriers is presented in Section 4.1.1.
- **Market trends:** Short, intermediate, or long-term market trends perceived by the exploitable owner as opportunities that will act in favour of each result exploitation and thus Circular TwAIn market uptake.
- **Intellectual Property rights (IPR) method:** in what way the owner of the exploitable result is considering taking advantage of the benefits from their developments. Foreground knowledge/IP is all the knowledge produced during the Project lifecycle. In Figure 12 the most common ways of Intellectual Property protection are displayed. Other protections ways that may apply to an innovation could be:
    - Database rights, consisting of collections of ordered data that may be protected by database rights.
    - Tradename law, to protect the name under which an enterprise does business.
    - Semiconductor topography rights, to protect the design of electronic circuits on computer chips.
    - Design files for manufacturing companies: An industrial design right protects only the appearance or aesthetic features of a product, whereas a patent protects an invention that offers a new technical solution to a problem. In principle, an industrial design right does not protect the technical or functional features of a product.
    - Non-Disclosure Agreement (NDA): legally enforceable agreements between parties that are used to ensure that certain information will remain confidential [39].
    - Utility model: A utility model is a patent-like intellectual property right to protect inventions. A utility model is a registered right that gives the holder exclusive use of a technical invention.

Figure 12: IPR protection methods

- **Background Intellectual Property (IP):** The existing Intellectual Property rights the partner is bringing to the Project.
- **Circular Twain Work Package:** The related Work Package which is directly linked with individual exploitable result.

4.1.1 Barriers to innovation

In this section, the barriers that may delay the Project outcomes towards innovation impact and creation. As a first step towards this action, literature research to identify common barriers that are usually the case for projects such as Circular TwAIn has been conducted, introducing to the Industry novel and advanced technologies that are going to disrupt the business model and open new paths to the industrial operations. Understanding and addressing these barriers is essential for organizations to unlock the true potential of their innovations and remain competitive in the rapidly evolving world. This section aims to examine the obstacles to innovation within the context of Circular TwAIn, shedding light on the challenges faced by organizations and presenting mitigation strategies to overcome these hurdles. The barriers to innovation are diverse, encompassing technological, organizational, and societal aspects. The barriers span from the complexities associated with implementing and integrating new technologies (deployment barriers) to cultural resistance and regulatory challenges (adoption barriers). By acknowledging and addressing these barriers, organizations can realize its complete potential to foster innovation, growth, and competitive advantage [40].

The barriers can either derive from the technology providers side or from the end-user side. While generating and orchestrating innovative ideas is crucial, effectively implementing and deploying these technological innovations may be proven very complex and in some instances may lead to failure. Some key challenges that industrial companies face in technology deployment are (deployment barriers):

- Complexity of Technology: Integrating novel and advanced technologies such as the Artificial intelligence (AI), Big data infrastructure, and Data Spaces could lead to technical complexities, including compatibility and interoperability with existing infrastructure issues, connectivity problems between system domains and more. Overcoming these challenges requires expertise, collaboration among stakeholders and carefully execution.

- Limited Resources: Deploying technological innovations, requires significant resources in terms of finances, skilled personnel, infrastructure and time, elements critical for every industrial organization. Resource constraints such as inadequate funding or insufficient infrastructure can lead to unsuccessful implementations. The stakeholders involved must assess and provision for the necessary resources to support an effective deployment.
- Culture and Resistance: On of the barriers in the wider Industry 4.0 era, there is the culture and readiness of the people to embrace radical changes with massive impact in their daily operations. Uncertainty about job stability and a lack of a culture building can hinder the deployment of new technologies. To this end, effective change management strategies should be adopted to address resistance and ensure a collaborative transition [41].
- Regulatory and Compliance Issues: Innovations in several topics of Industry 4.0, such as Industrial Sustainability, Circular Manufacturing, Data Spaces often challenge existing regulations and frameworks, leading to compliance issues. It is important for the stakeholders involved to navigate the legal and regulatory landscape to ensure adherence to data protection and security, industry regulations and especially for AI-based innovations assess the ethical aspects. Staying updated with existing regulations and contributing towards regulatory bodies can support organizations to tackle these deployment challenges [42].
- Skills and Training: Successful deployment of innovations requires a skilled workforce, to understand and utilize the new technologies. Training workforce with the necessary digital skills and competencies can be a challenge, thus investing in training and development, leveraging partnerships with institutions shall be proven helpful [43].

In addition to the challenges associated with deploying innovation, organizations often encounter obstacles when it comes to end-user involvement. The process of integrating and deploying new technologies, practices, or ideas within the existing operations can pose as a threat to fully deploying an innovation (adoption barriers):

- Awareness and Understanding: A lack of awareness and understanding regarding the benefits of the related technologies and topics is a primary barrier to adoption. Organizations may lack familiarity with the capabilities and possible applications of AI in manufacturing, the utilization of data and circular manufacturing concepts [44].
- Cost and Return on Investment (ROI): The costs associated with adopting new technologies are one of the most common barriers, especially for small and medium-sized enterprises (SMEs) in the manufacturing Industry. Investing in technologies and especially novel components requires significant financial resources and most organizations may hesitate to commit to such investments without a clear understanding of the expected return on investment. Thus, demonstrating the potential return on investment and other benefits is crucial to penetrate the market and the concerned stakeholders [45].
- Interoperability and Integration: Technology adoption requires the integration of diverse systems, which can pose as a challenge. Developing an innovation with

seamless interoperability and integration capabilities can overcome this barrier and facilitate the adoption of innovation without critical issues [46].

- Security and Privacy Concerns: The increased connectivity and data exploitation in manufacturing organizations has serious security and privacy risks. Concerns about data breaches, cyber-attacks can impede the adoption of innovation. Implementing security techniques, ensuring compliance with data privacy, can help to address these concerns [47].

To overcome these challenges, a systematic approach to innovation deployment should be adopted, meaning conducting technological assessments, securing resources, promoting a collaborative culture and establishing strategic partnerships. In addition, clearly displaying an approach that includes education and awareness, Return on Investment and a robust integration planning with security measures could ease the adoption challenges expected by the end-users. By addressing these barriers, the stakeholders can effectively deploy innovations, unlocking the full potential of their developments to drive growth. As preliminary analysis of the barriers a set of barriers from the Technology Partners and owners of the exploitable results as been gathered, requiring feedback for both deployment and market adoption barriers that will be analysed further at the next phase of the Project. These barriers will become more targeted while progressing with the technical developments of Circular TwAIn. Figure 13 depicts the process that will be followed to collect and analyse the barriers of Circular TwAIn.

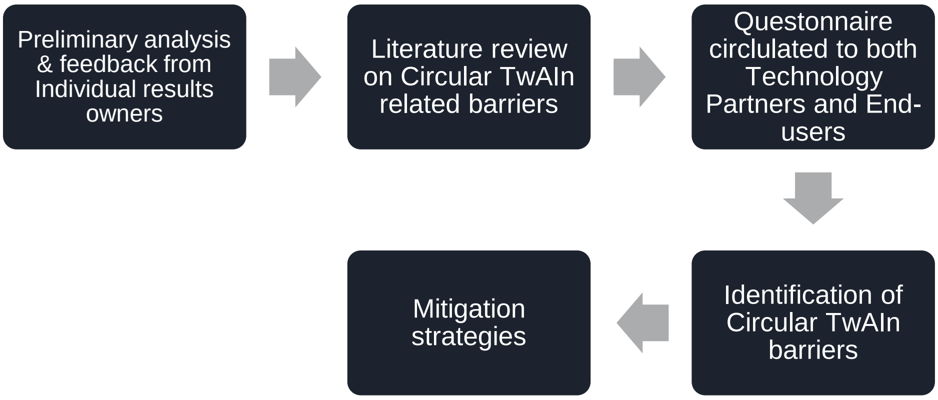

Figure 13: Process steps to identify Circular TwAIn barriers

The preliminary analysis of the barriers based on partners feedback is summarized in Table 4. Each individual result owner provided though the exploitation table a set of deployment and adoption barriers. These barriers will be further complemented following the aforementioned process to include feedback from the Consortium and define the Circular TwAIn barriers to innovation as whole.

Table 4: Circular TwAIn barriers preliminary analysis

Circular TwAIn Deployment barriers	Circular TwAIn Adoption barriers
The success of the marketplace depends on the poll of users accounted and on the number of products/services available	The user-friendly interface should incentivize the users, other feedback from stakeholders will be evaluated and implemented to break down the barriers

Actual deployment of the Reference Architecture should be evaluated considering possible use case limitations	The full development of the solution may be not feasible in most cases, but can consist a solid state of the art for future applications
Easy maintenance and upgrades should lower the barriers for adoption.	The solution has been developed to assist also not technical people and its openness nature should be a further incentive in the adoption
Technical challenges could be relevant for Hybrid Digital Twin to fully being deployed and penetrate the market	Hybrid Digital Twins are a frontier technology, yet to be fully exploited and adopted
Poor growth of AI standards for smart manufacturing and low adoption of I4.0 standards	Reluctance (doubtfulness) from manufacturers to adopt AI technologies to enhance their business operations
Emergence of competing solutions, offering similar services from key industry players	Lack or unavailability of adequate data volume to train and create the XAI models/algorithms
Privacy and security concerns over sharing shopfloor data	Privacy and security concerns over sharing shopfloor data
Poor engagement in AI-based sustainable manufacturing processes and to implement and integrate intelligent asset management solutions	Lack of Data Analysts and expertise within the organisation and conservativeness in business practices for consuming AI services
Each user might have the need of data format customization	The battery remanufacturing service can be used only if the reuse and remanufacturing technological routes for batteries are unlocked
Problems in the application of robots, sensors and AI to the WEEE treatment plants and processes	Lack of trust of end-users in new business models and waste recovered (2nd hand markets or reused devices)
Lack of collaboration environment for WEEE recovery systems	Prices no competitive enough to promote second hand markets or reuse businesses
Conservativeness of manufacturing companies in experimenting new technologies and approaches	New skills requirements to shift from an OT to an IT managed industrial system
Lack of awareness about Asset Administration Shell and its potential	Lack of awareness about Asset Administration Shell and its potential
Lack of awareness of AI-based intelligent process/energy optimization tools	Lack of trust to the AI tools for optimization of the energy consumption

4.1.2 Exploitation routes

The exploitation of the results and utilization of downstream actors can follow multiple routes, either direct or indirect. These direct routes consist of straightforward ways of taking advantage of the Project results:

- **Commercialization of a new product or service:** Introduce new products or services to market,
- **Contract research to other clients:** provides support to others in the form of research services outsourced on a contract basis,
- **New research project:** contribute to other research projects,
- **New course:** Provide new knowledge responding to specific stakeholders and societal needs.

The indirect routes consist of ways indirectly taking advantage of the project results:

- **License agreement** [48]: One or more companies enter into a licensing agreement that allows them to use each other's IP in return for payment.
    - Benefits by making the license reward for the use of the owned IP.
    - Benefits the license by giving them a product or technology better than the competitor.
    - Allow the licensee (depending on the terms of the licence) to take legal action against others who copy the idea.
- **Spin-off**: formulation of a company as a result of the innovations developed by individuals or teams.
- **Contribution to standards/policy:** produce new standards or contribute to ongoing procedures.
- **Joint venture activities**: A joint venture with a company - or an individual, or a university - whose expertise are needed.

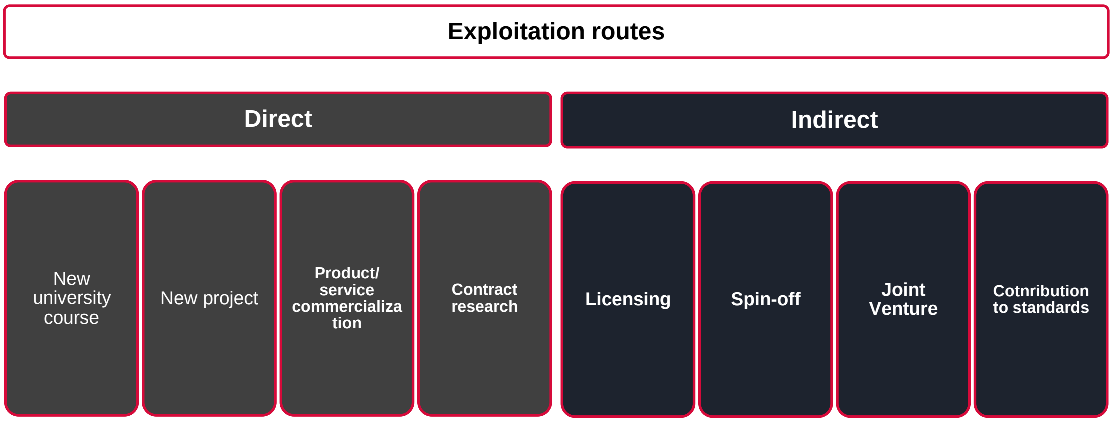

Figure 14: Potential Exploitation routes

For the purposes of Circular TwAIn, following the identification in the analysis of the Key Exploitable Results the best exploitation route for each case will be defined. Based on the information gathered so far for the exploitation, both direct and indirect routes are in scope. For example, a direct route for the commercialization of the AI services and indirect routes such as the contribution to standards.

4.1.3 Joint Exploitation

The joint exploitation refers to the joint use of results to deliver benefits downstream the manufacturing value chain leveraging the collaborative work performed throughout the Project lifecycle and boosting the innovation capability and market offering of the Individual exploitable results. The joint exploitation plan can either be formulated around the holistic and integrated Circular TwAIn novel platform or formulated leveraging joint teams of exploitation, thus segregating the platform to modules according to the technical specifications and components of the Project. To this end, two scenarios have been presented by CORE as the basis for further ideation and exploration with the Consortium.

Although exploiting the whole Consortium as one joint effort, seems the most value return method to the European Commission and the overall goal of boosting collaborative innovation there are some important criteria that should be considered when planning and formulating a joint exploitation plan, namely:

- **The complexity of the partnership**: I.e., how feasible is for all organizations involved to jointly exploit their innovation given the fact that there are organisations with different orientations and goals (e.g., universities, research centres, private companies).
- **The technical feasibility**: proceeding with the Project development, the feasibility, and the complexity of implementing the platform as whole and the potential technical challenges that may occur given the diverse nature and operations of the potential end-users must be considered.
- **The market needs**: In what way the offering will be more appealing to the market/end-users, in terms of investment, value proposition, digital maturity level, infrastructure and in general to find the best fit between the current market needs and the Circular TwAIn offering.

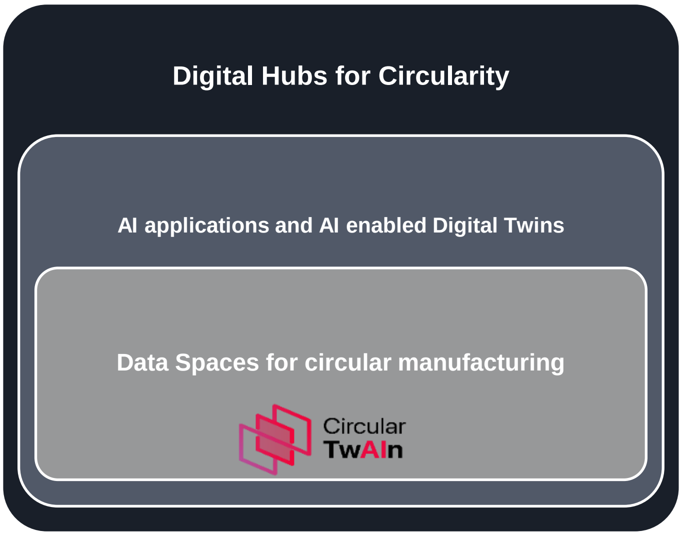

Figure 15: Joint Scenario 1 - Circular TwAIn Novel AI Platform

The first scenario refers to the idea to exploit the Circular TwAIn platform as whole service, considering all the developments of the Project in an integrative way. This scenario follows the goal of Circular TwAIn Project to develop and exploit a Novel AI Platform for circular manufacturing, providing a set of technologies and tools to boost the adoption of AI-based intelligence and sustainability of the industry.

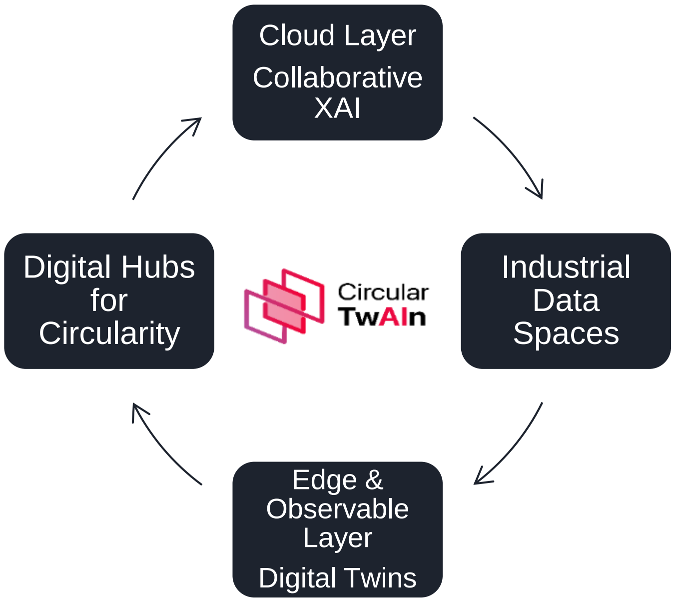

Figure 16: Joint Scenario 2 - Circular TwAIn modules

The joint scenario 2 refers to the exploitation of Circular TwAIn in modules. This approach follows the reference architecture developed in WP3 (see Figure 16). This modular approach will streamline the expectations of end-users, will potentially overcome technical challenges, driving decision making and shall be used as an upselling method for the integrated solution developed by the Consortium.

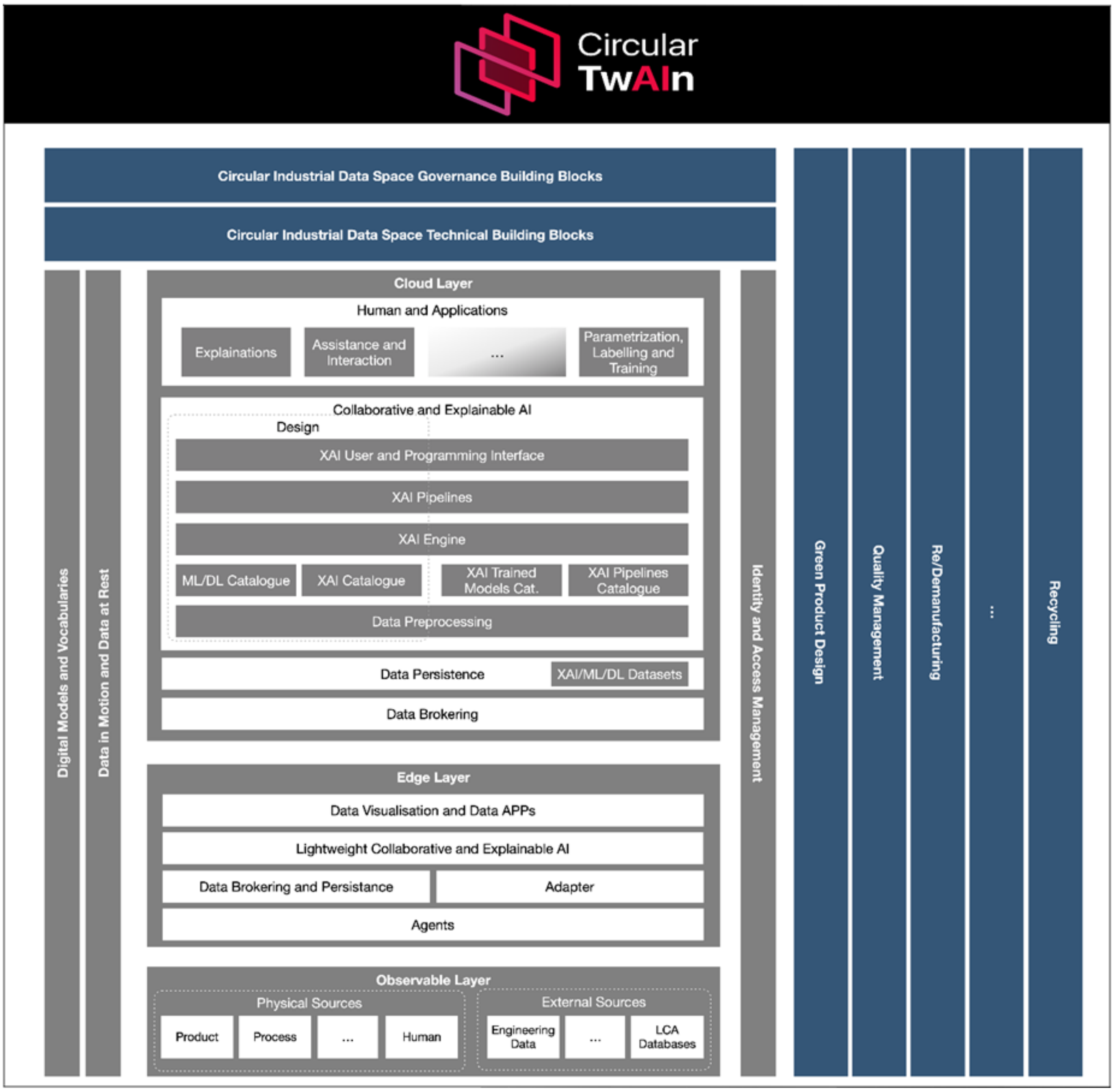

Figure 17: Circular TwAIn Reference Architecture

At this stage of the Project the conceptualization of the joint exploitation has been performed, however the discussion around the joint scenario will be initiated at later stages of the Project moving towards the formulation of the finalized exploitation plan.

4.2 Individual exploitation plan

In this section a description of each partner and their involvement in the Project activities is presented to understand the link between the work of each task and the contribution to exploitation of the Project results. The individual exploitable results that have already been included from several partners will be further analysed in the following phases of the Project, while the provision of additional exploitable results will be discussed and evaluated with the rest partners in a recurring manner throughout the Project lifecycle. Also, any potential modification to the currently considered individual exploitable results will be assessed following the technical developments of Circular TwAIn.

Up until this phase of the Project 18 individual exploitable results have been provided by the partners towards the exploitation of Circular TwAIn results. The table below summarizes the Individual Exploitable results along with some key elements to clearly define them.

Table 5: Circular TwAIn Individual Exploitable Results

ER #	Individual Exploitable Result	Type of innovation	Expoitable Result Utility
		ENG	
1	Circular TwAIn Marketplace	Marketplace Service	One-stop-shop providing access to technical expertise and experimentation.
2	Reference Architecture	Framework	Elaboration of the Circular TwAIn Reference Architecture.
3	AI implementation module	Digital Service	Edge Processing Service module to enable the deployment and operation of AI services on-the-edge or on the cloud.
		SUITE 5	
4	AI applications toolkit	Software-As-a-Service	Provide end users with an intuitive and user-friendly manner XAI Engine (UI) execute AI/XAI analytics workflows utilizing different ML/DL models and visualize/export the results.
		GFT	
5	Human Digital Twin	Product / Service	Enhance the AI-based Collaboration between Human and Machine.
		TEKNOPAR	
6	Hybrid Circular twin	Framework	Reduction of the formation and emissions of CO_2 and Process optimization.
7	AutoML tool	Framework/tool	Reduction of the formation and emissions of CO_2 and Process optimization.
		COBAT	

8	Decision support system	Digital Service	Identify the most convenient circular economy option applied to a specific battery.
	RECYCLIA		
9	Assessment and new Business models	Guidelines and best practices	Better efficiency of the processes and new uses for the waste recovered are projected, including raw materials dependency.
	TECNALIA		
10	Data Space Lab	Digital Service	Provide a Data Spaces testing environment to allow manufacturing companies to test Data Spaces implementation.
	SUPSI		
11	Clawdite IIoT Platform	Platform/Service	Provide a modular infrastructure to ease Digital Twins installation.
	SOCAR		
12	New business models	Knowledge and assessment of AI tools for process industry	Evaluation of waste CO2 for DME process, to optimize energy consumption and reduce CO2 emissions.
	REVERTIA		
13	Knowledge on IT equipment recovery	New procedures and best practices	Strengthen reuse procedures or to open up new lines of research in the manufacture of computer equipment.
	NOVA		
14	Asset Administration Shell (AAS)	Framework/service	Middleware for digitalizing physical assets, harmonize the way data is represented and exchanged.
15	Process Digital Twin	Software/service	Orchestrate a system for exploring live data by executing of AI-models for the envisioned applications.

	POLIMI		
16	Process Digital Twin	Software	Machine learning program to optimize the disassembly parameters according to the battery.
17	Process Digital Twin	Software	Mutual data and model driven AI supported program to certify the state-of-health and remaining useful lifespan of LIB cells.
18	Process Digital Twin	Software	AI driven optimization program for mechanical recycling, in function of the LIB cells materials and economic value.

Based on the above information, Circular TwAIn envisions several services, that can be characterized as intangible assets, to provide end-users with tools and software's to operate AI systems with the goal to bridge the gap between Artificial Intelligence and people without advanced skills in the related technologies. The exploitation plan will provide the optimal way to exploit and commercialize these services, considering the end-user needs and partners requirements and realistic goals, while the Marketplace of Circular TwAIn can serve as an exploitation tool. Furthermore, the development of frameworks is a key component of exploitation with the Reference Architecture being an important result contributing to further research and Projects.

4.2.1 Engineering Ingegneria Informatica SpA

Engineering Ingegneria Informatica SpA (ENG) is Italy's largest systems integration company. With approximately 12,000 professionals in 40+ locations (in Italy, Belgium, Germany, Norway, Serbia, Spain, Switzerland, Sweden, Argentina, Brazil, Mexico and the USA), the Engineering Group designs, develops, and manages innovative solutions for the areas of business where digitalisation generates major change, such as digital finance, smart government & e-health, augmented cities, digital industry, smart energy & utilities, and digital media & communication.

The R&D lab, founded in 1987, with 250 researchers has participated in more than 100 EU funded projects and gained international research awards.

Engineering has also a long-standing expertise in Industry and a strong focus on R&I projects, where it has shown the capacity of exploiting research results. In fact, ENG is also very active in many key international initiatives and activities including NESSI (Networked European Software and Service Initiative), founding partner of the Future Internet PPP initiative, FIWARE and active contributor to IDSA (International Data Space Association) and DFA (Digital Factory Alliance) initiatives. Furthermore, ENG is a corporate member of OW2 Consortium and Eclipse Foundation.

Engineering is Circular TwAIn's Project Coordinator, leader of WP4, Data Space for Circular and Resilient manufacturing, responsible of the Circular TwAIn Reference Architecture and Innovation and Collaboration Marketplace. ENG will contribute to exploitation by leading tasks/WPs with critical outcomes towards the technical specifications of Circular TwAIn platform and develop interesting results that shall be used and derive benefits downstream the value chain of a Circular TwAIn solution and act as an important input to further research or education. At this stage of the Project, Engineering Ingegneria Informatica SpA has contributed with three exploitable results with commercial and non-commercial purpose.

The first Exploitable result is the Circular TwAIn marketplace: its definition and design are still ongoing, but it will not need any on-premises technologies/deployment. Its success will mostly depend on the poll of users accounted, in parallel with the number of products or services available in the Marketplace. The service is intended to provide an user-friendly interface to incentivise the users and consider further developments based on users and stakeholders feedback. The marketplace will provide access to technical expertise as one-stop shop that helps manufacturing companies to become more competitive leveraging digital technologies to transform their processes. Any technology providers or manufacturers that are interested in boosting their innovation capability though technologies that target circularity and sustainability are considered as potential customers.

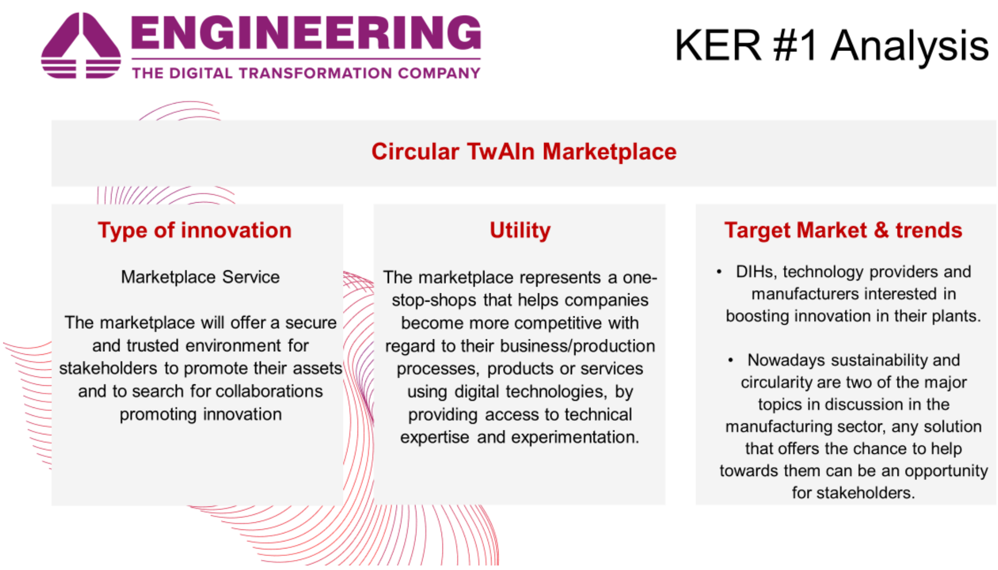

Figure 18: ENG Individual Exploitable result #1

The next individual exploitable result provided by ENG refers to the Reference Architecture (RA) of Circular TwAIn. Actual deployment of the RA should be evaluated case by case considering possible use case limitations. The full development of the solution wild provide a solid state of the art for future applications based on existing references in the manufacturing domain. Manufacturing companies and technology providers active in the domain of AI and circularity are target stakeholder groups to utilize the exploitable result.

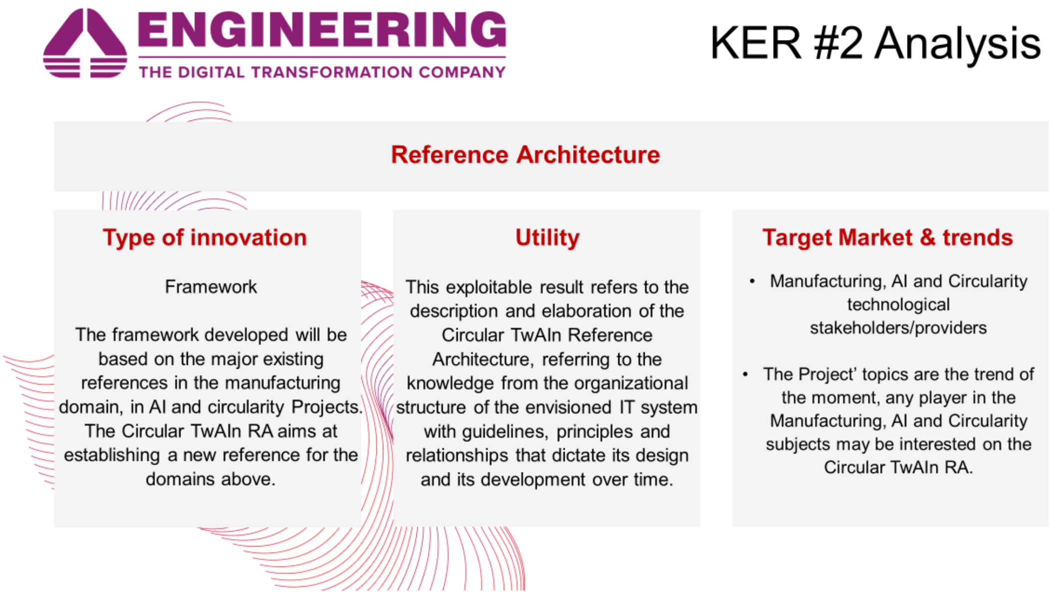

Figure 19: ENG Individual Exploitable result #2

The third individual exploitable result provided by ENG refers to the AI implementation module. The deployment of the solution includes an AI Edge Processing module enabling the deployment and operation of AI services on-the-edge or on the cloud. It will be based on sensor data acquisition and real-time analytics modules. More importantly the solution will support the end-users, without the necessary expertise, to run and customize AI services.

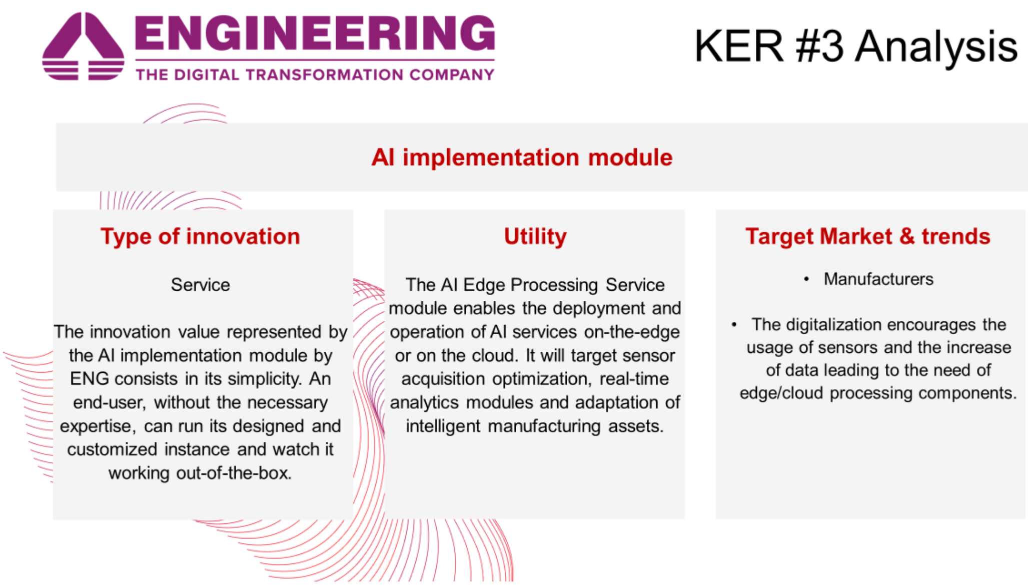

Figure 20: ENG Individual Exploitable result #3

Overall, ENG will use the Project outcomes to identify and address the new and emerging key clients' needs and to strengthen its presence in the industry sector. In addition to that, ENG is also interested in the potential re-use and adaptation of some innovative technologies being researched and developed in the Project.

4.2.2 Politecnico di Milano

Politecnico di Milano or POLIMI is an important technical university in Italy and one of best in Europe, according to related rankings. The Manufacturing research group of the university will be involved in Circular TwAIn with its competences in the fields of Manufacturing Strategy, ICT for Manufacturing, Factory Digital Transformation, Product and Service Development, Manufacturing Systems Design, Production and Maintenance Management, Human-Centric Manufacturing and Education in Manufacturing.

POLIMI has expertise in several Scientific Technological Domains addressed by Circular TwAIn such as AI Manufacturing, Data spaces for Manufacturing, Circular Value Chains and Hubs for circularity. POLIMI with expertise and knowledge of how product and process related data influence the process scenario of the battery pilot use cases, will contribute to individual exploitation plan with three exploitable results, aiming to develop machine learning algorithms and AI-driven methodologies to significantly improve battery treatment processes.

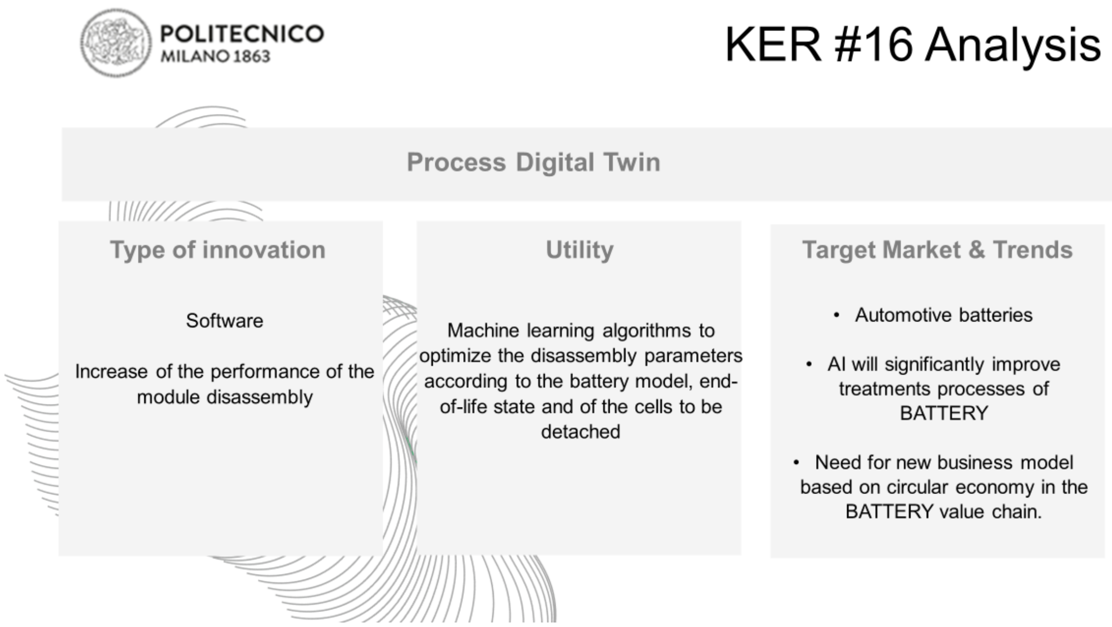

Figure 21: POLIMI Individual Exploitable Result #1

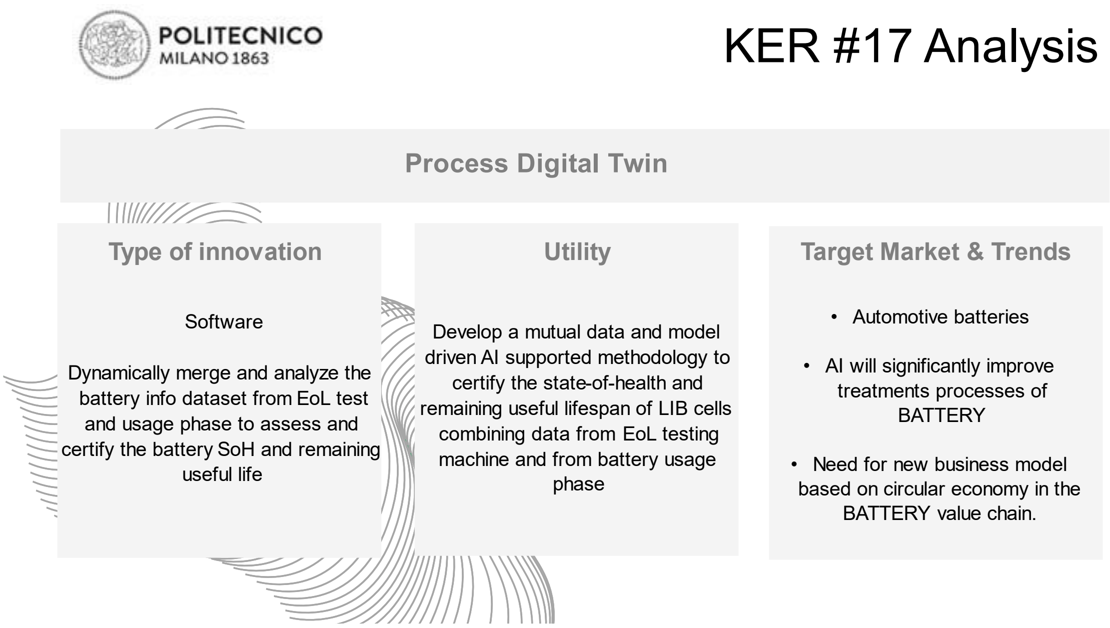

Figure 22: POLIMI Individual Exploitable Result #2

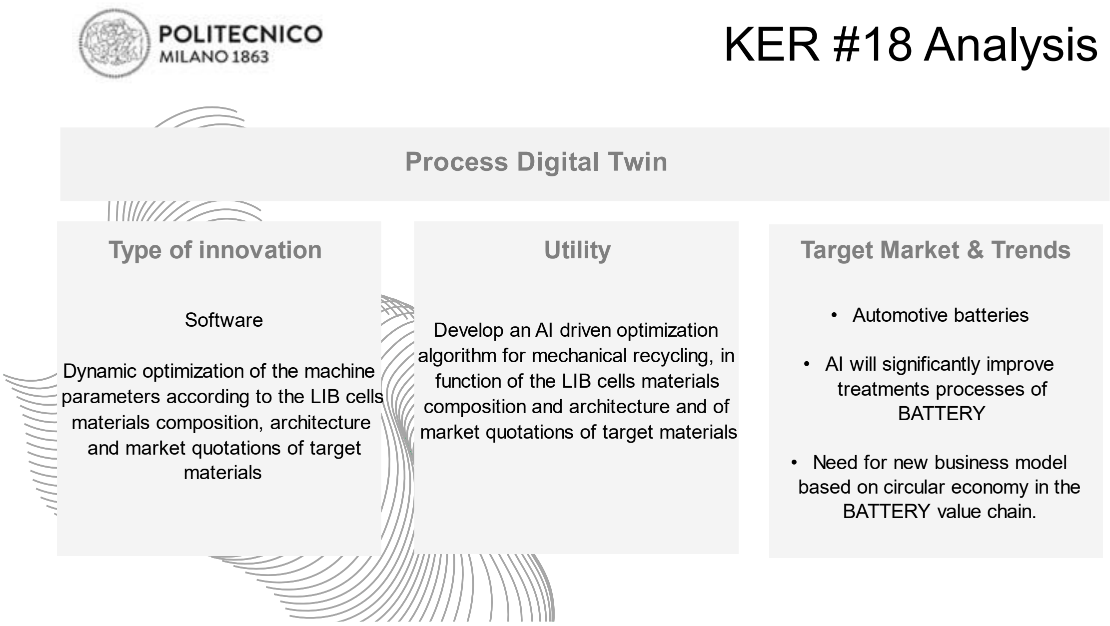

Figure 23: POLIMI Individual Exploitable Result #3

4.2.3 Fundacion TECNALIA Research & Innovation

TECNALIA is a non-for-profit private research institute and its role in Circular TwAIn is basically the definition and implementation of a Circular Data Space which means, on the one hand, the analysis of trustworthy solutions for the data transaction amongst services and SMEs and, on the other hand, the validation of an AI model-based optimization tool on an SME.

TECNALIA is part of the BDIH (Basque Digital Innovation Hub) and so our strategy of exploration is through the BDIH.

Tecnalia is planning to develop in Circular TwAIn a Data Space testbed to introduce manufacturing SMEs into the data space methodology so they can understand the requirements and expectations.

In the short term, we will include our services in the list of services of the BDIH so SMEs can access to it. BDIH has already established links and agreements with several other European DIH so access for funding is also available within certain regions.

In the mid-term, considering TECNALIA is a non-profit company focused on research and not on profit, TECNALIA. will license or transfer the knowledge to a service provider.

The main risk we see is related with the implementation of IDS RA in the circular manufacturing domain. The provision of services through an IDS RA requires the implementation of connectors on every node of the net, which is an important effort for both service providers and manufacturing companies.

TECNALIA is open to discuss any possible exploitation strategy. On the first hand, we consider licensing or start up creation. but we are open to other type of possibilities.

TECNALIA does not plan to carry out any joint exploitation activities with other Circular TwAIn partners.

Knowledge gained within Circular TwAIn will allow TECNALIA to participate in other activities/initiatives/research On the one hand on the implementation of AI tools in manufacturing SMEs and on the other on the analysis of IDS RA on DIH ecosystem. Also, on the circularity domain.

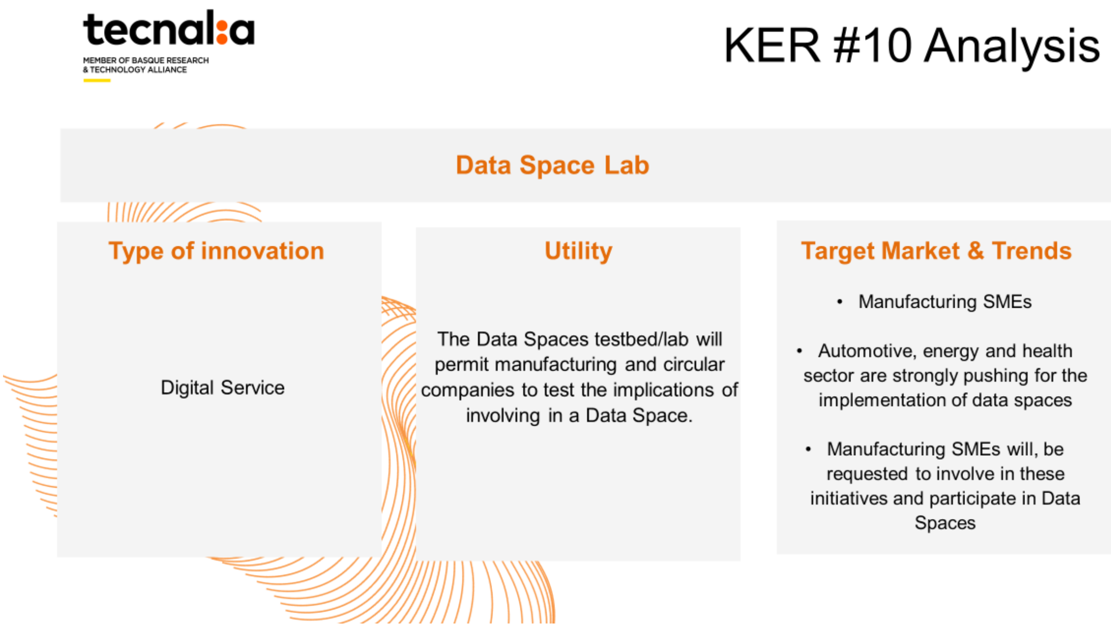

Figure 24: TECNALIA Individual Exploitable Result

4.2.4 SINTEF AS

SINTEF is a multidisciplinary independent research organisation with international top-level expertise in the fields of technology, located in Scandinavia with around 2300 employees. SINTEF Digital Smart Data group has strong expertise in knowledge representation and

Data4AI with semantic models enabling machine learning/AI and analytics and Cognitive Digital Twins.

SINTEF has strong proficiency in the main Scientific Technological Domains such as AI Manufacturing, Data spaces for Manufacturing, Circular Value Chains and significant knowledge towards Hubs for circularity. Individual exploitable results linked with the work of the partner will be re-evaluated at a later stage.

4.2.5 FRAUNHOFER Gesellschft zur Foerderung der Angewandten Forschung

The Fraunhofer-Gesellschaft is a leading organization of institutes of applied research in Germany, undertaking contract research on behalf of industry, the service sector and the government. At present, the organization maintains 76 research institutes with more than 30,000 employees at locations throughout Germany.

Fraunhofer IOSB is one of the larger Fraunhofer Institutes. The core expertise of Fraunhofer IOSB comprises information and knowledge management, software architectures and object-oriented systems, signal, and image processing, optronics and image exploitation, system technologies, modelling and optimization. The field of system technology at Fraunhofer IOSB covers everything required for analysis, understanding, modelling, development, and control of complex systems to finding holistic solutions to challenging, complex problems.

Fraunhofer IOSB will contribute with its competencies in the domains of control technology, and information and communication management, especially in the field of modelling and management of digital twins for cross-company use cases. Fraunhofer IOSB is an active member and contributor to IDS, IDTA, etc. Fraunhofer IOSB also leads the IDS-I community, whose goal is to bridge the gap between the Industrie 4.0 and IDS. As we proceed with the development of the Circular TwAIn platform, the results of FhG IOSB's participation in the Project will be evaluated as potentially exploitable individual results.

4.2.6 Asociacion de Investigacion Metalurgica del Noroeste

Asociacion de Investigacion Metalurgica del Noroeste or AIMEN is a Non-Profit Innovation and Technology Centre, that was set up in 1967. It provides technological support to companies dedicated to industrial or commercial activity in multiple fields. AIMEN promotes and undertakes research, as well as improves design, simulation and manufacturing technologies by participating in R&D&I initiatives and disseminating the results with Open Source software, datasets and publications

AIMEN offers expertise in the Scientific Technological Domains of AI Manufacturing and Data spaces for Manufacturing, while can provide experience related to Circular Value Chains and Hubs for circularity. At this stage, there are no individual results derived directly from the activities that show exploitation potential.

4.2.7 Privredno Drustvo za Pruzanje Usluga Istrazivanje I Razvoj NISSATECH Innovation Centre DOO

Privredno Drustvo za Pruzanje Usluga Istrazivanje I Razvoj NISSATECH Innovation Centre DOO or NISSATECH is an Innovation Centre providing cutting edge research and development of novel technologies, application and advanced IT solutions. The main relevant commercial product is D2Lab (Data Diagnostic Laboratory, the Framework for Big

Data Analytics) which has been used in various application domains for the development of big data analytics applications.

NISSATECH offers strong capabilities in digital technologies such as Industrial IoT, Data technologies and AI technologies, while the results of its work will be examined further on the topic of exploitation of Circular TwAIn.

4.2.8 SUITE5 Data Intelligence Solutions Limited

SUITE5 Data Intelligence Solutions Limited or SUITE5 is a technology provider for data-driven intelligence solutions that specializes on Artificial Intelligence & Explainable Artificial Intelligence, Big Data Analytics, Trusted Data Management, Semantics & Data Interoperability, Data Sharing & Distributed Ledger Technologies.

SUITE5 posses strong competencies in digital technologies such as Industrial IoT, Data Technologies, AI Technologies and edge-cloud technologies.

SUITE5 has contributed to exploitation plan with one exploitable result, namely the AI for circularity and resilience applications toolkit. The toolkit will provide the end-users and potential customers with and explainable AI engine and pre-trained explainable AI models to fulfil their business needs in the context of circular and resilient manufacturing. The intention is to provide the AI for Circularity and Resilience applications Toolkit as software as a service, targeting all the stakeholders with high interest in circular manufacturing and AI applications, within the manufacturing and process industry. To this end, the company will work on creating links with interested stakeholders to showcase the usage of the toolkit and also discuss its applicability to other domains as well, as an asset that can be used by any company that would like to design and eventually execute analytics at the edge.

Moreover, internal exploitation is also expected to be conducted by SUITE5, by using the outputs of the research that will lead to the development of the toolkit as knowledge to be transported to the different products and services already developed by the company, in an effort to make them also component for operating in edge execution scenarios.

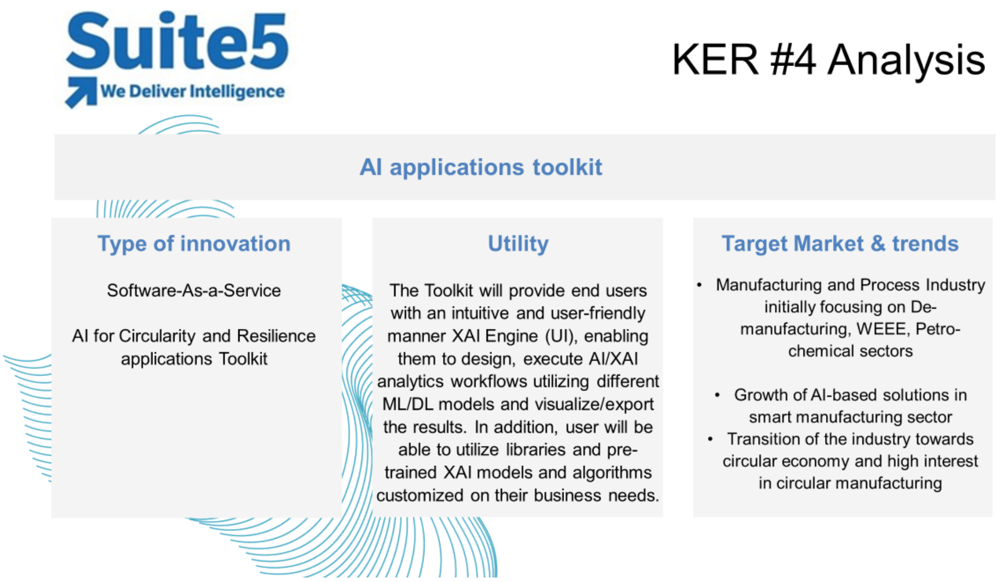

Figure 25: Suite5 Individual Exploitable result

4.2.9 UNINOVA-Instituto de desenvolvimento de Novas Tecnologias Associaciao

UNINOVA-Instituto de desenvolvimento de Novas Tecnologias Associaciaoor or NOVA is a multidisciplinary, independent, and non-profit research institute located in Lisbon, formed by the Faculty of Sciences and Technology of the Nova University of Lisbon, a group of industrial associations, a financial holding, and up to 30 companies.

NOVA offers strong competencies in the scientific domains of Industrial Digital Twin (aka Asset Administration Shell), AI in manufacturing, Data Spaces for manufacturing and Hubs for Circularity. For the purpose of exploitation, NOVA will contribute with the design, development and deployment of AI-enabled Process Digital Twin. The intention is to deeply explore how AI can be integrated within the AAS at process. The AI-enabled AAS will operate within a system where the physical assets are digitalized using the AAS approach and will orchestrate such a system to fulfil the business needs. To do that, NOVA provided NOVAAS an open source implementation of the AAS concept, that will be used as technological background and framework for building AI-enabled AAS. The usage of NOVAAS will enable – from one side – the easy customization of the AI-enabled AAS for each one of the considered application scenarios, and – from the other side – the possibility to further develop, improve and spread the adoption of the AAS and NOVAAS component. Finally, project NOVA's contribution to the exploitation will be further evaluated as we proceed with the technical developments of the Circular TwAIn Project.

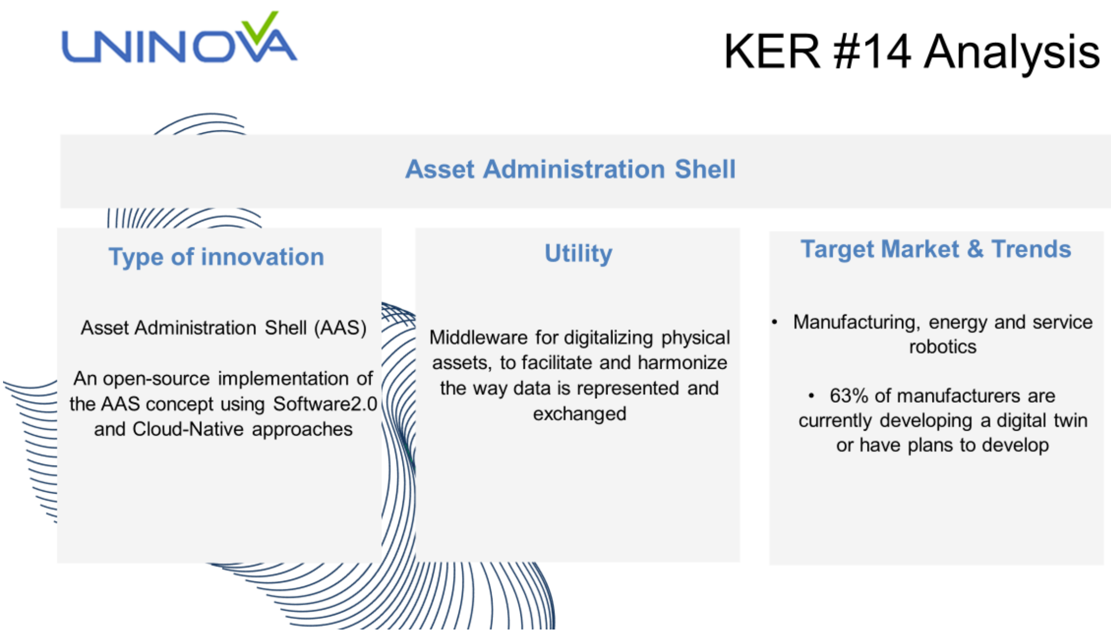

Figure 26: NOVA Individual Exploitable Result #1

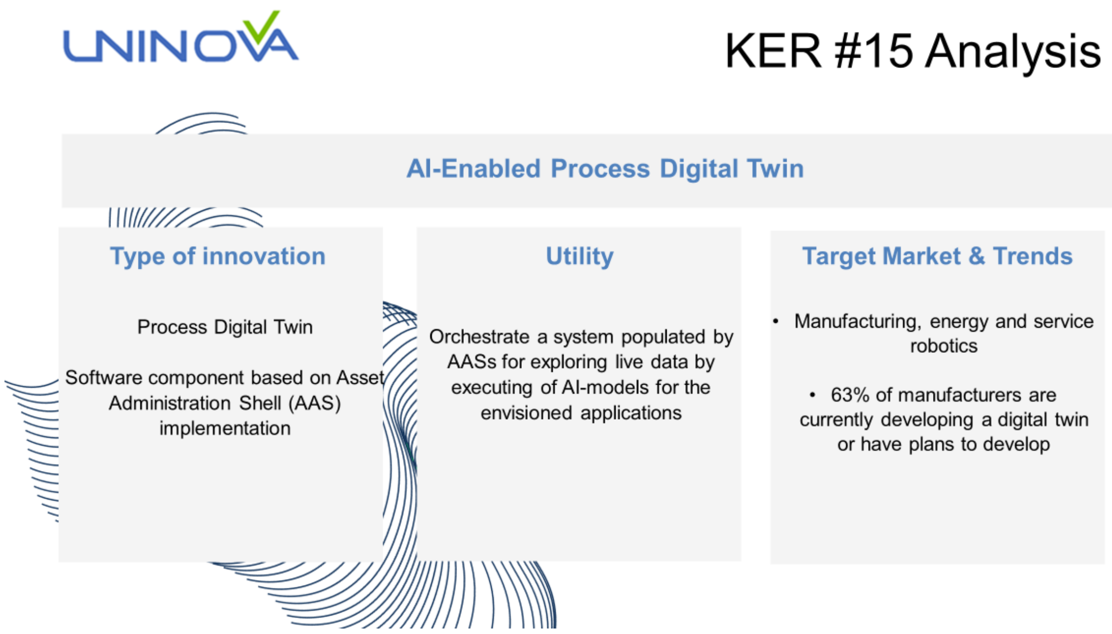

Figure 27: NOVA Individual Exploitable Result #2

4.2.10 Intrasoft International S.A

Intrasoft International S.A or INTRA is a leading European IT Solutions and Services Group with strong international presence and expertise, offering innovative and added-value solutions of the highest quality to a wide range of international and national public and private organizations and a strong R&I record in the manufacturing sector including Data Spaces, AI and Digital Twins.

INTRASOFT has strong expertise in Industrial IoT technologies, AI technologies, Edge-Cloud technologies, and Data & Security technologies. For the purposes of exploitation, the contribution of INTRA will be evaluated as we proceed with technical developments of Circular TwAIn.

4.2.11 CORE Innovation Center NPO

Core Kentro Kainotomias AMKE or CORE Innovation Centre is a subsidiary of Core Innovation & Technology OE working on Research and Innovation for Industry 4.0 technologies with the aim to bring them to the market and bridge the real market needs of the industry with innovative applied research. CORE also works with IoT, big data, machine and deep learning, edge, and cloud computing, while uses its strong expertise in dissemination, communication, and exploitation.

CORE is responsible for developing a clear exploitation plan, to convey the impact of Circular TwAIn and manage project results and knowledge to develop a business model that meets both partners and market needs. The exploitation strategy will be further developed and enhanced in sync with the project's technical developments.

4.2.12 GFT ITALIA SRL

GFT ITALIA SRL or GFT is a global IT services and software engineering provider driving the digital transformation of leading companies in financial services, insurance, and manufacturing. GFT provides manufacturing AI-based solutions for analysing big data for machines, production, and planning.

GFT has core competencies in several digital technologies such as Industrial IoT, Data Technologies, AI Technologies, and Security Technologies. Regarding the exploitation plan, GFT provided one exploitable result namely the Human Digital Twins knowledge and technology. Partner's intention is to exploit the project results and expand the scope of their services, leveraging their existing accounts and sales channels in manufacturing and automotive industries. While the main target market is Manufacturing, GFT will build on top of CT solutions and background in order to improve also the services for the Finance market, e.g., with the introduction of digital twins modelling customers.

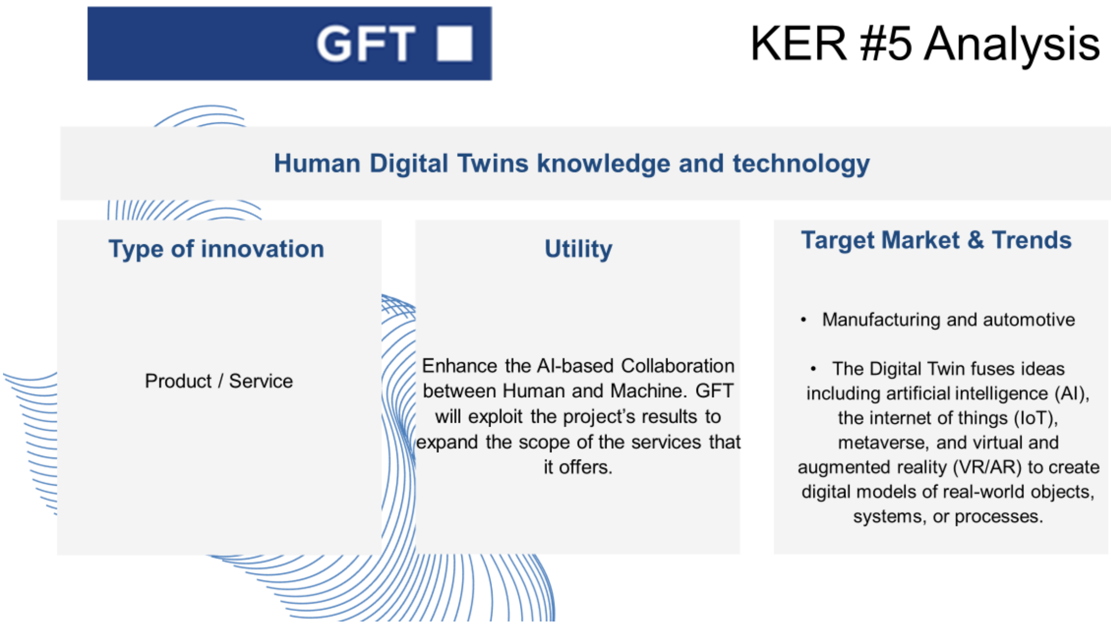

Figure 28: GFT Individual Exploitable result

4.2.13 Sig de RAEE y Pilas Sociedad Limitada

Sig de RAEE y Pilas Sociedad Limitada (RECYCLIA) has large experience in designing WEEE collection networks, adapting containers and operations to different waste streams, operating the most extensive waste collection network for WEEE and Batteries in Spain. RECYCLIA will contribute to Circular TwAIn supporting the WEEE Industrial Pilot.

RECYCLIA will contribute to the competitiveness and circularity of EU industry by following the deployment of the technologies in the WEEE pilot. They will improve the sustainability and profitability of the industry by using life-cycle data analytics along the value chain and also will get advantage on industrial processes automation that could potentially lead to better achievement of the collection and recycling targets set by the legislation. The application of these developments in the WEEE industry may also result in a better acceptance by the end-users in regards to new business models.

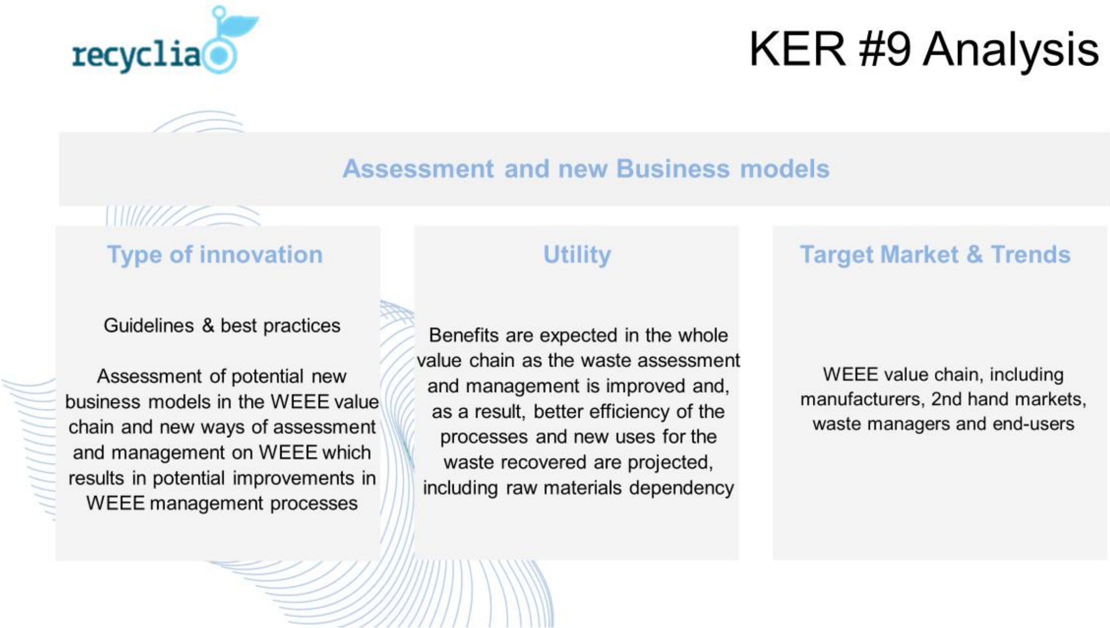

Figure 29: RECYCLIA Individual Exploitable Result

4.2.14 Revertia reusing and recycling

Revertia reusing and recycling or REVERTIA is a private company authorised as Waste Electric and Electronic Equipment (WEEE) manager that combines e-waste management services with a circular value proposal consisting in the preparation of IT equipment for reuse. In Circular TwAIn it will participate as the WEEE use case working with the partners towards the optimization of the re-manufacturing cycle of WEEE and the component identification and automated disassembly of consumer WEEE. Revertia brings current knowledge to lay the foundations for the reconditioning and recycling processes of computer equipment and components. Being the treatment plant that has provided the current procedures and work instructions in the recovery processes.

The Industrial use case will participate in the exploitation plan as a proxy for future customers, providing insights and feedback from market perspective and also though Circular TwAIn involvement will have the opportunity to assess new ways of assessment and management, assess new potential business models in WEEE and become more efficient in waste management.

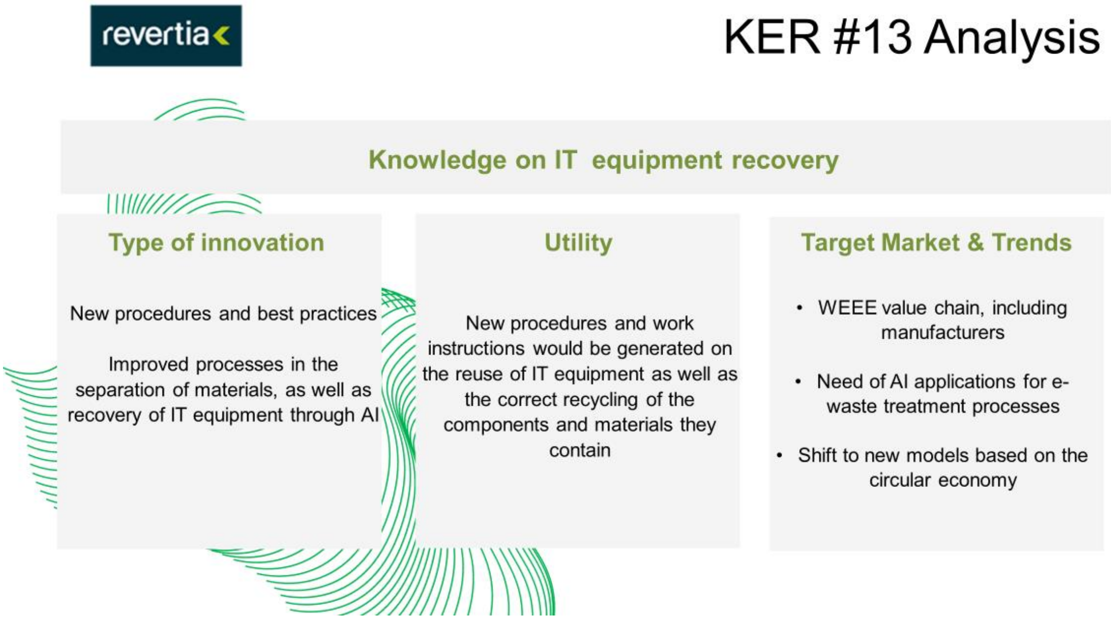

Figure 30: REVERTIA Individual Exploitable result

4.2.15 ExpertAI LUX SARL

ExpertAI LUX SARL (EAI) is a SME based in Luxembourg specialized in combining leading-edge expertise across a full range of ELSA (Ethical, Legal and Societal Aspects) services for AI systems and tools, including advice on intellectual property, IT law and research ethics, privacy, data protection, data ownership and data sovereignty, moral rights, human rights and informed consent, technology transfer and, in general, ELSA of R&I projects, especially in the AI domain. Whitin the project EAI is bringing its expertise and guidance about such topics in the Circular TwAIn project, both as regards the piloting activities and as regards the design and development of the technological artefacts of the project, as well as its overall AI-empowered and data-driven system.

Thanks to the participation to Circular TwAIn, EAI is going to extend and improve its consulting offering, making it more attractive and will reuse the project results to investigate further models, solutions and services in Responsible Research & Innovation, particularly in relation to the human centric AI aspects, such as solutions that facilitate the adaption of AI solutions to the human context, human machine interaction solutions for AI systems and more, the legal and ethical implications of the AI-related Simulation and Digital Twins services as well as the data management solutions AI in manufacturing nurturing the data sovereignty paradigm. EAI is also exploring to enhance its training offering on these topics.

4.2.16 TEKNOPAR Endustriyel Otomasyon Sanayi ve Ticaret Anonim Sirketi

Teknopar Industrial Automation Inc. or TEKNOPAR has large experience in the design and implementation of advanced automation systems in developing industrial sectors and industrial facilities. TEKNOPAR will lead the implementation in the Petrochemical industrial pilot and contribute towards the digitization and automated process automation of the petrochemicals pilot.

TEKNOPAR has contributed to the exploitation plan by providing two exploitable results, namely the Hybrid Circular twin for the process industry and the AutoML tool for process industry. The AutoML tool will support the easy deployment of human-centred AI tools and ensure a ready-to-use framework to support end -users (e.g., Managers, operators) without the requirement of AI and Machine Learning skills. The Hybrid Circular twin will be developed to support process improvements as a combination of a data-driven Digital Twins and a first-order physical model. It will rely on data from various sources and apply AI analytics techniques to achieve higher predictive capabilities.

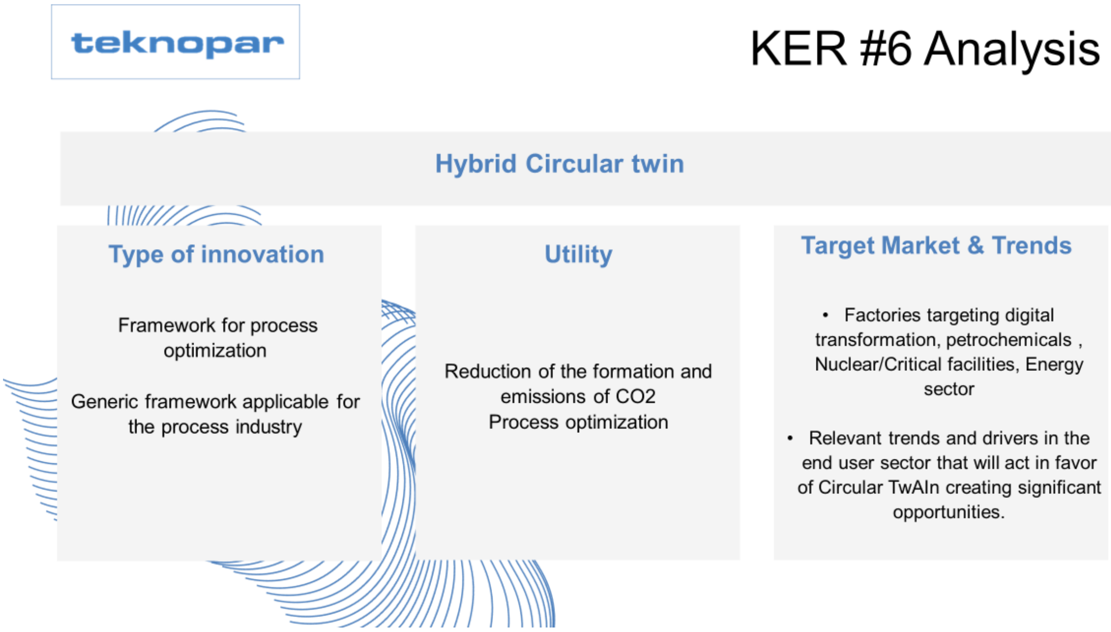

Figure 31: TEKNOPAR Individual Exploitable result #1

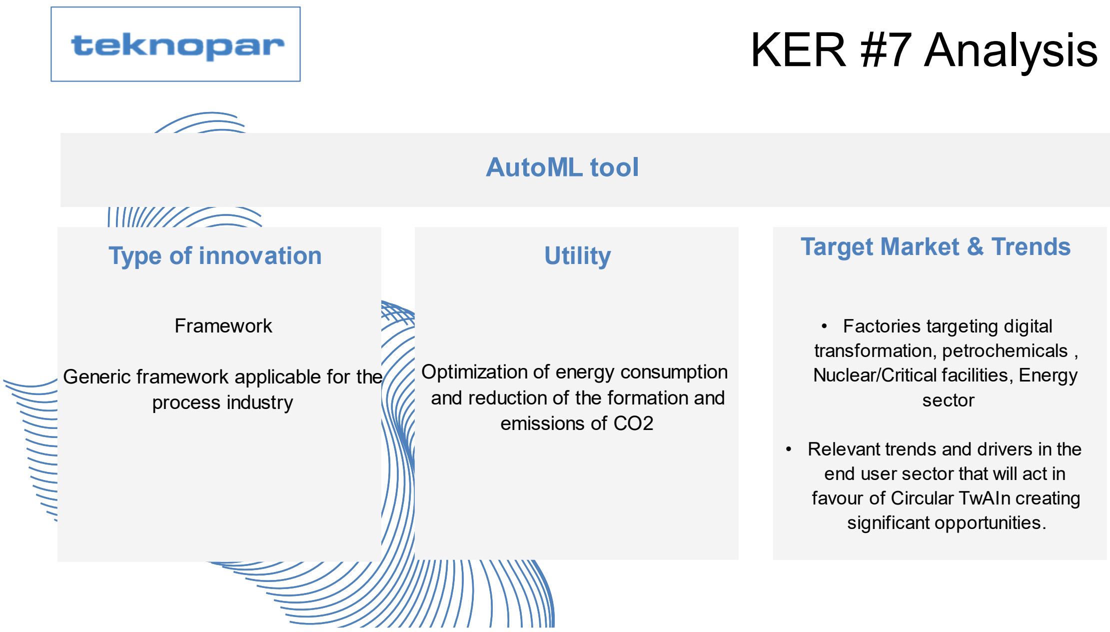

Figure 32: TEKNOPAR Individual Exploitable result #2

4.2.17 COBAT Servizi

COBAT Servizi or COBAT is a non-profit organization that was established as a Consortium for Spent Lead Batteries and Lead Waste and assigned the function of ensuring the collection and recycling of spent lead batteries throughout Italy. COBAT will be mainly involved in the Battery Pilot (WP6). COBAT will provide the end-of-life batteries needed for the use case development (different chemistries, cells type, designs and conditions - i.e., new, aged, defected, damaged and used - will be specifically identified) and also in collaboration with the Battery Pilot partners will support the provision of essential data for the digital twin of the product. More specifically will contribute to the market-oriented decision support system and the collaborative robotics solutions for the disassembly if batteries.

COBAT has contributed to exploitation plan with one exploitable result for the battery industry. Cobat aims to exploit the Decision support system as a digital service. The proposed solution is very product specific, therefore, it can be applied to automotive batteries or might embrace also in-use batteries tracking and not only end-of-life units.

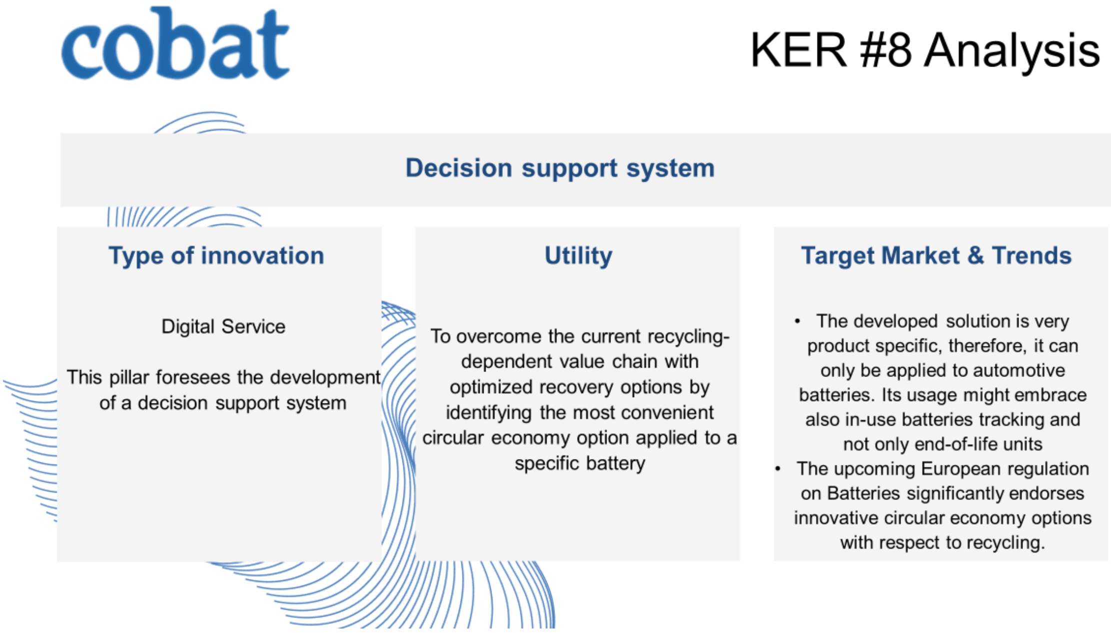

Figure 33: COBAT Individual Exploitable result

4.2.18 SOCAR Turkey Arastirma Gelistirme ve Inovasyon Anonim Sirketi

SOCAR Turkey Arastirma Gelistirme ve Inovasyon Anonim Sirketiprovides R&D or SOCAR provide services to SOCAR Turkey group companies and various legal entities providing service in the fields of petrochemicals, refinery, storage and gas distribution. It develops innovative, sustainable, environmentally friendly and market-driven products, new fields of application, catalyst and digital technologies. In Circular TwAIn, SOCAR's Ethylene Oxide/ Ethylene Glycol (EO/EG) plant will be the pilot.

In the Circular TwAIn Project, SOCAR will participate as a petrochemical use case for the implementation/validation of AutoML to be developed for energy consumption reduction as well as the development of a digital twin for the evaluation of waste CO2 for DME production.

The petrochemical use case will participate in the exploitation plan by giving feedback on the performance of AutoML and the opportunity to implement the AI tool at SOCAR's other facilities. The digital twin of the DME process will allow the evaluation of waste CO2 for low-carbon fuel production and will contribute to the exploitation plan by being applicable in other companies with intense CO2 emissions.

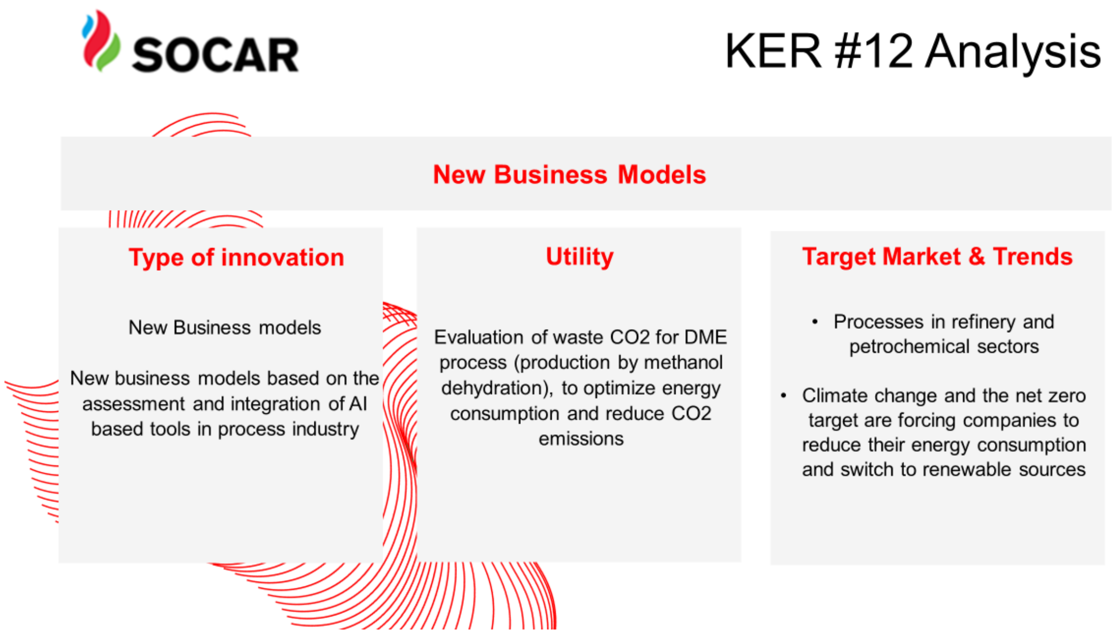

Figure 34: SOCAR Individual Exploitable Result

4.2.19 RAEEMAN

RAEEMAN is an SME specialized in the management of hazardous and non-hazardous waste including WEEE, batteries and accumulators. It also provides related services and operates mainly in northern Italy. RAEEMAN will be mainly involved in the Battery Pilot (WP6) in collaboration with COBAT, will also provide the facility for the battery experimental campaign and final demonstration. The Industrial use case will participate in the exploitation plan as a proxy for future customers, providing insights and feedback from market perspective.

4.2.20 Scuola Universitaria Professionale della Svizzera Italiana

Scuola Universitaria Professionale della Svizzera Italiana (SUPSI) is one of the Universities of Applied Sciences of the Swiss Confederation, located in Switzerland. Its Sustainable Production Processes Lab (SPS) leads top-level university programs and continuing education courses, national and international applied research and provides services related to the innovation of manufacturing systems, production processes, products, and business models, sustainable and circular manufacturing and Human-Centred Smart Production.

SUPSI posses strong expertise in the field of AI for Manufacturing, Circular Value Chains and Hubs for Circularity. In terms of exploitation results, SUPSI provided Clawdite, an extensible and flexible IIoT - industrial internet of things - based platform supporting the creation of customised data representations of production systems and their entities, including humans. The project results will be exploited to further improve the Clawdite platform, making it ready to cope with humans involved in Circular Economy scenarios, so that to spread the platform adoption by SUPSI's partners (e.g., Swiss projects with local SMEs). A specific instance of the Clawdite platform will be made available for each Circular Economy scenario foreseen in the project, until the project end. Before the project end, licensing agreements will be established to manage future platform use.

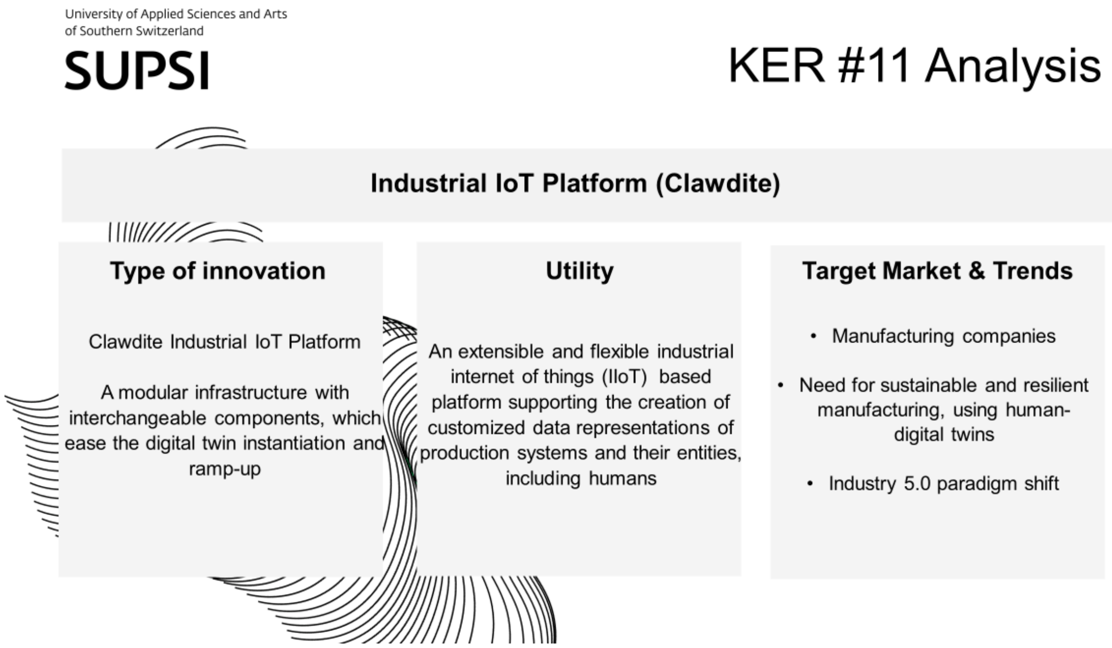

Figure 35: SUPSI Individual Exploitable Result

4.2.21 Switzerland Innovation Park BIEL/BIENNE AG

Switzerland Innovation Park BIEL/BIENNE AG or SSF is Switzerland's first Digital Innovation Hub and a private Swiss non-profit organisation that performs and supports industry-focused applied research and development. SSF sets focus on supporting manufacturing SMEs with training and the uptake and introduction of Circular TwAIn technologies. SSF has experience in training and coaching in the area of innovative ICT concepts. SSF is practising an open science and co-creation approach being the neutral coordinator of an open partner network of more than 60 partners from research and industry that openly share ideas, concepts and resources in the area of Industry 4.0. At this stage of the Project there are no individual exploitable results as an outcome of SSF's activities.

5 Preliminary considerations on the Trustworthy Framework for Circular TwAIn

This chapter provides preliminary considerations and the description of the methodological approach to be followed regarding:

- the legal and ethical review and analysis of applicable European, national and sector-specific regulatory framework and relevant ethics sources;
- the elicitation of the legal and ethical requirements for Circular TwAIn technological assets and pilots;
- the two-cycle consultation with regional authorities and policy makers, civil society organisations, representatives from the workers;
- the ALTAI - driven human rights impact assessment (HRIA).

These aspects will be fully elaborated in D7.2 Liaison with AI4MAN Ecosystem, Didactic Factories Network, Legal and Ethical Issues - 1st (M18), where also the outcomes of the first iteration of the consultation and the first release of the HRIA will be included. The second release of such document, namely D7.8 Liaison with AI4MAN Ecosystem, Didactic Factories Network, Legal and Ethical Issues - 2nd (M36), will include the Circular TwAIn workbook, to be elaborated in the second phase of the Project, taking into account the Ethics and Data Protection Impact Assessments (EDPIAs) conducted for each of the pilot under WP1, in conjunction with WP6, the HRIA conducted in WP7, as well as the lessons learnt from the piloting operations themselves performed in WP6.

5.1 Initial considerations for the Legal and Ethical Review and Analysis and related requirements for Circular TwAIn

As indicated in D1.2 “Ethics Analysis, Governance and Guidelines – 1st version”, the Consortium and its Ethical Policy adhere to the Ethics and Privacy by design approach. Such an approach consists in the continuous reference and implementation of the ethical principles and legal mandates during the Project lifetime, from the initial phases of the design process throughout the whole design, development and/or adaptation of Circular TwAIn tools and components. This approach is strictly interconnected both with the value-sensitive design and with the fairness principle, besides being consistent with the strong Consortium’s commitment to prioritize the well-being. Efforts will be directed to promote human flourishing, safety and empowerment of the operator and, more in general, the human being, in line with the human-centric approach fostered by the EC and by important initiatives, like the European Factories of the Future Research Association (EFFRA).

In line with this holistic approach and in order to address the key ethical challenging and pressing concerns surrounding the Circular TwAIn technologies and the piloting operations, as well as in order to adhere to the applicable legal framework, an in-depth legal survey, both at European and at national and domain specific level, is underway and two categories of Ethical and Legal requirements will be elicited, as already mentioned in D2.2 “User Scenarios, Requirements and Performance Indicators - 1st version”. This elicitation, together with the mapping of the regulatory and ethical reference landscape, will be reported in the D7.3 “Liaison with AI4MAN Ecosystem, Didactic Factories Network, Legal and Ethical Issues - 1st version” (at month 18). Such survey and the resulting requirements will be functional to guide the Consortium, especially the technological development team, both to maximize the human comfort and well-being and to identify and implement appropriate actions when necessary to eliminate or minimize any risks for humans. From a wider perspective, the legal and ethical review and related requirements are expected to contribute to promote the trustworthiness of the Circular TwAIn system and its services and components, respecting human rights and European values (and, therefore, to build trust).

I. European-level Regulatory Framework and Ethical and Legal Requirements for Circular TwAIn Technology

The legal and ethical sources identified as relevant, or potentially relevant, for Circular TwAIn during the Project development phase (including research, demonstration activities and results), and after the end of the Project, in the exploitation phase, are under investigation and will be reported and analysed in the next months. The main pieces of legislation and ethical instruments will cover different fields and will be studied in a systematic way for eliciting the legal and ethical requirements towards delivering a value-driven and legal-respectful technology. The initial selection of the European legal and ethical reference framework mainly comprises the following areas of law and instruments: Privacy & DataProtection Law ("General Regulation on data protection" and Directive 2002/58/EC "ePrivacy Directive"); Regulatory landscape relevant to data sharing (Regulation on the free flow of non-personal data, e-Commerce Directive, Platform-to-Business Regulation - P2BR, eIDAS, Directive on certain aspects concerning contracts for the supply of digital content and digital services); Security Law (Nis Directive and Cybersecurity Act); Human rights Law (European Convention of Human Rights and the Charter of Fundamental Rights of the European Union); Regulatory reforms under development (Data Governance Act, Data Act, Artificial Intelligence Act and AI Liability Directive); Ethics and soft law (White Paper on Artificial Intelligence – A European Approach to Excellence and Trust, EC Communications "AI for Europe", "Building Trust in Human-Centric AI" and "2030 Digital Compass: the European way for the Digital Decade"). By analysing these and other pieces of legislation and by analysing the technologies under development, legal and ethical requirements will be defined to support the design, development and validation of mutualistic human-AI symbiosis for a human-centric sustainable manufacturing environment in Circular TwAIn. They will be also relevant in the post-Project phase, for the future adoption and operation of Circular TwAIn, thanks to their nature of first guideline for legal compliance and ethically-sound activities and results. In this perspective, the attention will be mainly focused on the Artificial Intelligent System and tools, in particular considering T3.2 "Trustworthy AI and Collaborative Intelligence", T5.2. "AI for Circularity and Resilience applications Toolkit" and WPX "AI-enabled Digital Twins for distributed manufacturing" in general, besides the Data Space for Manufacturing System, where the innovations and breakthroughs of WP4 "Data Space for Circular and Resilient Manufacturing" will be analysed to provide a first guideline for legal compliance and ethically-sound results. Alignment activities and exchanges are already underway between the technical teams and the ethics-related figures of the Project, and a roadmap of joint activities has been agreed. In relation to WP4, attention will be also given to the Data Sovereignty Agreements and the underlying topics of confidentiality and Trust models Specifications of common Data Spaces for Circular value chains. More in general, the EL Requirements for Circular TwAIn Technology will refer especially to the Circular TwAIn Data Space for Manufacturing System and to the Circular TwAIn Artificial Intelligence System. Furthermore, the requirement elicitation will also rely on an in-dept legal and ethical review and analysis of the applicable European and national legislation and relevant ethics sources applicable to the envisaged technological artefacts and systems. Furthermore, such elicitation will also be based on both the outcomes and findings of the consultation with key stakeholders and the ALTAI - driven human rights impact assessment (HRIA), which are described in the next paragraph. The Ethics and Legal requirements will be accompanied, when opportune, by related guidelines in order to be easily used by the technological team for adequately addressing the challenges posed by the technology under development, in line with the ethics-by-design approach.

II. Pilot-level Regulatory Framework and Ethical and Regulatory Requirements for the Circular TwAIn Pilots

The legal and ethical instruments relevant to the technology involved in the Pilots, such as legislations, standards, sector-specific policies and company practices/policies, have been identified and will be integrated, refined and analysed by each of the Circular TwAIn Pilots, with the support of the Ethics Mentor and of the Ethics Advisory Board of the Project where opportune. These sources also comprise non-binding sources. By referring to such sources, the corresponding group of requirements will be set, pertaining to the Pilots of the Project, as well as related use cases and corresponding technological artefacts specifically used by them. As outlined in D2.1 “Requirements Engineering Methodology - 1st version”, the Trial Handbook will be the key reference source to extract the information on the pilot-level regulatory sources and legal and ethical requirements. In particular, with reference to the Trial Handbook, the legal and ethical framework for the Pilot concerned will be part of Chapter 1, whilst the elicitation of the ethical and legal requirements will be part of Chapter 2, where a description of the requirement will be inserted, together its priority level (critical, preferred or optional), the area of application and the nature (Ethical/Legal), and the Circular TwAIn tool the requirement is linked.

The D7.3 “Liaison with AI4MAN Ecosystem, Didactic Factories Network, Legal and Ethical Issues - 1st version” at month 18 will describe, among other topics, the outcomes of the legal and ethical review and analysis of the applicable European and national legislation and relevant ethics sources, both for the Circular TwAIn Pilots and for the Circular TwAIn technologies. The document will also provide the outcomes and insights of the consultation with stakeholders and of the Human Rights Impact Assessment. These elements will be key for deriving the EL requirements for the Circular TwAIn tools and Pilots, which will be reported in the same document. This initial version of the requirements might be enriched or updated taking into account the Project’s progress and its shaping of services, solutions and pilots’ scenarios, as well as the ongoing regulatory developments. If necessary, further requirements will be added in the second release of the deliverable (D7.8 “Liaison with AI MAN Ecosystem, Didactic Factories Network, Legal and Ethical Issues - 2nd, at month 36).

5.2 Methodology and roadmap for the Circular TwAIn two-cycle consultation and the Human Right Impact Assessment

As described in D2.1 “Ethics Analysis, Governance and Guidelines – 1st version”, the Circular TwAIn Consortium is directed by a holistic approach towards trustworthiness and ethically- soundness. Such an approach relies, on the one hand, on the interplay and synergies among the work to be performed under the different tasks of the Project in this regard, due to the transversal nature of the legal and ethics-related activities within Circular TwAIn workplan, and, on the other hand, on the adherence to the “Ethics Guidelines for

Trustworthy Artificial Intelligence" [49] and its "Assessment List for Trustworthy Artificial Intelligence" (ALTAI) for self-assessment [50], both developed by the High-Level Expert Group on Artificial Intelligence (HLEG).

This will ensure to adequately address the legal, regulatory and ethical issues and challenges for the trustworthy AI and human-centric sustainable manufacturing design, development and adoption in relation to the Circular TwAIn system towards a human-enhancement-driven Collaborative Intelligence-inspired mutualistic human-AI symbiosis, capable of upholding EU ethical values and to preserve human rights.

In this direction, among others the following two activities will be performed in the upcoming months.

I. First Consultation with the Stakeholders

The consultation is directed to the relevant stakeholders of the manufacturing value chain, such as Regional Authorities/Agencies, other Public Authorities, Civil Society Organisations, Innovation Agencies, Vanguard Initiatives representatives, representatives from the workers, technology and/or service providers, etc.

It is aimed at capturing their needs and expectations in relation to Circular TwAIn approach and trajectories, focusing on human-centricity and trustworthiness, as well as regulatory and ethical implications.

Its structure has already been elaborated and consists of 5 sections, as follows:

- Section 1 **"About you"**,
- Section 2 "**Artificial Intelligence and Data Spaces for Circular and Resilient Manufacturing",**
- Section 3 "**AI-enabled Human Digital Twins",**
- Section 4 "**Trustworthy Artificial Intelligence**",
- Section 5 "**The evolving regulatory framework**",

The survey is going to be launched online in June 2023 and will remain open till mid July 2023. Its outcomes will be outlined in D7.2 Liaison with AI4MAN Ecosystem, Didactic Factories Network, Legal and Ethical Issues - 1st (M18).

II. An ALTAI-driven Human Rights Impact Assessment (HRIA)

Another important activity relying on the "Ethics Guidelines for Trustworthy AI" is the human rights impact assessment (HRIA), functional to determine the expected impact of Circular TwAIn AI tools on fundamental rights, as well as the potential factors and measures to monitor, in conjunction with the identification of the mitigating measures to ensure citizen-respectful results, in line with the Charter of Fundamental Rights of the European Union. The HRIA in the Project will ensure to avoid that an individual can experience a negative human rights impact as a result of Circular TwAIn technology design, deployment and testing, thereby ensuring that the Project's technology is designed, developed and validated in a human-rights respectful manner, proactively encompassing human rights safeguards and preventive measures, rather than reacting to unexpected incidents.

This approach is related to the implementation of the Circular TwAIn Ethical Policy and its Ethics-and-Privacy-by-Design-and-by-Default approach, as depicted in D1.2 "Ethical Analysis, Governance and Guidelines – 1st version". In addition, thanks to the Collaborative Intelligence paradigm and the AI-empowered Human Digital Twins solution, the efforts will be directed not only to prevent any infringement of human rights and ethics risks, but even to foster human rights and human empowerment and flourishing.

The elaboration of the Circular TwAIn HRIA underway will give rise to actionable results and recommendations for the future work of the technical team and of the piloting operations.

For this purpose, the development and future use of the HRIA for Circular TwAIn AI tools go beyond the traditional approaches and existing methodology for the HRIA, in order to tailor the approach to the specificities of the AI systems and the relationship between such systems and the most salient human rights risks and harms in this framework, aligning the methodology both to the risk-based approach of the AI Act Proposal and to the ALTAI checklist for Trustworthy AI.

Therefore, the Circular TwAIn HRIA enriches the common set of key criteria of the HRIA literature [51] with criteria derived from the Ethics Guidelines for Trustworthy and the Assessment List for Trustworthy Artificial Intelligence (ALTAI), both elaborated by the High Level Expert Group on Artificial Intelligence set up by the European Commission (2020). In fact, the Trustworthy AI is interlinked with the human rights-based approach, since the ethical principles and requirements set by the Ethics Guidelines for Trustworthy AI and fine-tuned in the ALTAI, exactly uphold the fundamental rights and rotate around them.

More details on the HRIA, its function and structure will be provided in D7.2 Liaison with AI4MAN Ecosystem, Didactic Factories Network, Legal and Ethical Issues - 1st (M18).

6 Standardization activities

This section, dedicated to standardization activities within the Circular TwAIn Project, delves into various critical aspects. It encompasses a comprehensive discussion on the Project's defined scope, the employed methodology, best practices, and engagement with standardization bodies. The Circular TwAIn Project actively participates in significant standards initiatives, including ISO SC41 IoT&Digital Twin, AAS with IDTA, and ISO SC42 AI, among others. The primary objective is to drive meaningful impact on the development of operational SMART standards that are machine-applicable, readable, and transferable, aligning with the overarching goals of Circular TwAIn.

6.1 AAS with IDTA

6.1.1 Goal of the standard

There are many standards for digital twins. An overview can be found in [52]. According to the Circular TwAIn project grant agreement, the Asset Administration Shell (AAS) specification will be used as the standard for digital twins developed during the project. The main reason for this is that this is the only standard for digital twins that has a clear reference to industry, as e.g., the typical protocols, such as OPC UA, are explicitly mentioned in the standard.

The AAS is the implementation of the digital twin in Industrie 4.0 [53]. The goal is to bridge the gap between the real and digital worlds via "standardized connectors" by representing an asset of the real world in the information world through the AAS containing structures, properties and services.

As shown in Figure 36, the AAS has been included in the IEC series of standards. Standardization is led by IEC TC65 WG24 in the area of industrial applications and smart manufacturing in particular. The IEC 63278-1 ED1 project "Asset administration shell for industrial applications - Part 1: Administration shell structure" [54] was already published on 31/05/2022.

Figure 36: From specification to standards (Source and © IDTA)

Two parts of this standard are still under development:

- IEC 63278-2 ED1 “Asset Administration Shell for Industrial Applications – Part 2: Information meta model” [55],

- IEC 63278-3 ED1 “Asset Administration Shell for Industrial Applications – Part 3: Security provisions for Asset Administration Shells” [56].

The work on PNW 65-994 ED1 “Asset Administration Shell for Industrial Applications Part 4: Use Cases and Modelling Examples” will start by the end of this year [57].

6.1.2 History of the standard

The AAS specification was initially developed by the Plattform Industrie 4.0, which is a network of companies, associations, trade unions, science and politics in Germany [58]. As shown in Figure 37, the Industrial Digital Twin Association (IDTA) is currently working on refinement of the AAS specifications.

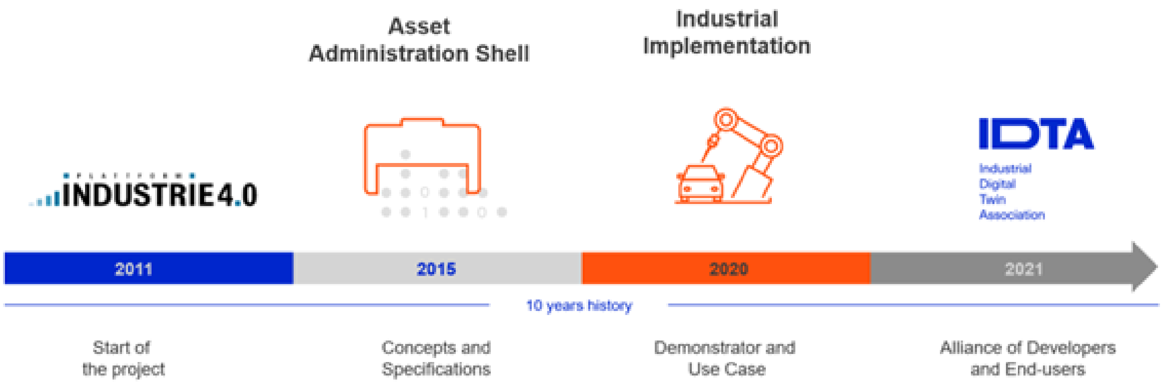

Figure 37: History of AAS (Source and © IDTA)

The latest version of the AAS specification was published in April 2023 and is shown in Figure 38.

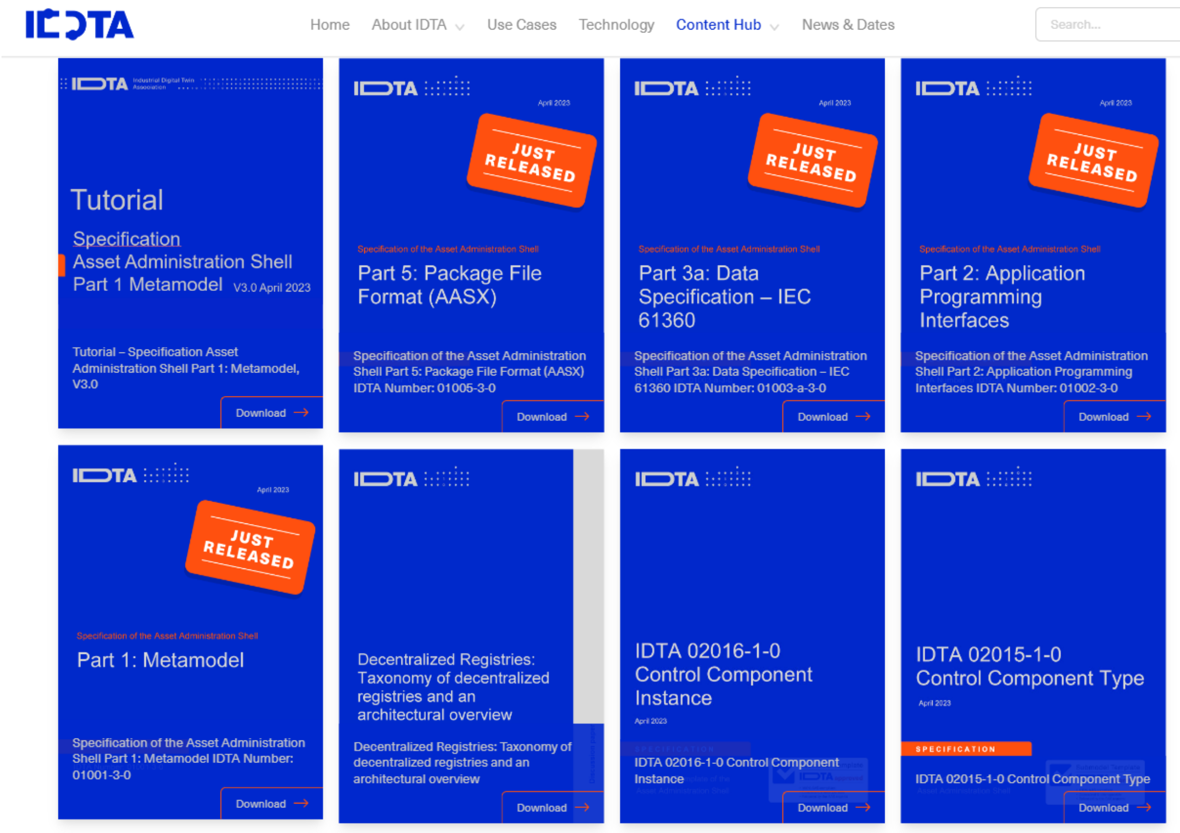

Figure 38: The newest versions of the AAS specification

As it can be seen, the AAS specification is currently structured into five parts:

- Part I is about the AAS metamodel and serialization formats (JSON, XML and RDF)
- Part II specifies the APIs for reactive AASs, which are executable AAS that can be communicated with via APIs
- Part III specifies data specification templates conformant to IEC 61360 which defines the semantics of single properties or values
- Part IV covers the AAS security metamodel
- Part V defines the AASX Package Exchange Format (AASX) to be used as the exchange file format for the transport of information from one partner in the value chain to the next.

All parts of the AAS specification except part IV are already available for download [59].

We note here that the AAS implementations used in the Circular TwAIn Project (as well as the other open source implementations of AAS) focus only on Part I and Part II. A comparison of these AAS implementations can be found in [60].

6.1.3 Project use and impact on the standard

Fraunhofer IOSB is actively involved in the IDTA. This not only ensures that the Circular TwAIn project is informed about all activities related to the AAS specification, but more importantly that feedback on the specification is provided. This is possible because there are two implementations of the AAS specification (namely FA³ST [61] and NOVAAS [62]) that are being used and further developed in the Project.

The following WGs of the IDTA are relevant for the Circular TwAIn Project:

- **Open Technology WG**: The main objective of this WG is to provide the necessary specifications for implementing interoperable digital twins using the AAS. The recently published Part I of the AAS specification specifies the version 3.0 of the metamodel. Although it was published by the IDTA, it is the result of the joint sub working group "Asset Administration Shell" of the working group "Reference Architectures, Standards and Norms" of the Plattform Industrie 4.0 and the IDTA WG "Open Technology". Fraunhofer IOSB is actively involved in this WG and significantly contributed to the refinement of the latest version of the AAS metamodel specification.
- **AAS Repository WG**: The objective of this WG is to provide an enterprise-ready reference implementation of an AAS Cloud Repository, i.e., a scalable webservice that can host up to 50 million Type 2 AASs. Based on the Part I of the AAS specification, the Eclipse AA4J Project [63] was created with the goal to implement it (e.g., metamodels, submodels, serialization and deserialization modules, validators, and transformation libraries based on the AAS specifications). As can be seen from https://projects.eclipse.org/projects/dt.aas4j/who, Fraunhofer is the main contributor and Fraunhofer IOSB made almost 33% of all commits in the last 3 months.
- **IDTA Submodels**: This WG is responsible for the creation and management of the AAS submodels. An AAS submodel template is a predefined structure that defines the format and content of an AAS submodel. It is designed to provide a standardized way of representing a specific aspect of an asset or system, and to make it easier to create and manage AAS submodels. Currently, there are 61 submodel registered [64]. For each of these submodels, there is a WG to develop the submodel. The following submodel WGs are considered relevant for the Circular TwAIn Project:
    - **IDTA Carbon Footprint Submodel Working Group**: The goal of this submodel template is to provide means for exchanging information about a carbon footprint of an asset between value chain partners to document, assess, or optimize the environmental footprint of their assets. This template is strategically important for the Circular TwAIn Project as it could be part of larger initiatives such as the Digital Product Passport (see DPP4.0 – The Digital Product Passport for Industry 4.0 [65]). The template is currently under review.

      We participated in this WG and developed the demonstrator for HMI 2023 based on this submodel template. The next steps are to incorporate community comments into the current version of this submodel template, publish it, and then work on the next version. The next version will go beyond supporting use cases for communicating carbon footprint information (e.g., as a PDF or a link to a website) and sharing carbon footprint information through the value chain, and will support carbon footprint information comparison and verification.
    - **IDTA Time Series Submodel Working Group**: The IDTA Time Series Submodel Template WG is working on the specification of a submodel

template for the AAS to store and reference time series-based values. This WG is relevant for the Circular TwAIn Project, because the time series data is needed for all AI/ML methods.

Fraunhofer IOSB was involved in the specification of the 1st version, which was published in March this year [66] and also implemented it [67]. This WG will continue its work from June 2023 and we will keep following and contributing to it.

6.2 ISO SC41 IoT and Digital Twins

6.2.1 Goal of the standard

The objective of the ISO SC41 Suite of standards is to establish standardization in the area of Internet of Things and related technologies. SC41 acts as the primary driving force within JTC 1's standardization initiative for IoT and Digital Twin, encompassing their corresponding technologies. It also aims to provide guidance to JTC 1, IEC, ISO and other entities developing Internet of Things and Digital Twin related applications.

6.2.2 History of the standard

The ISO SC41, dedicated to IoT and related technologies, was established in 2017. In 2019, it was decided that this committee would also take charge of standardizing Digital Twin within ISO, leading to the name change to ISO/IEC JTC 1/SC 41 Internet of Things and Digital Twin. The committee comprises various working groups, including:

- ISO/IEC JTC 1/SC 41/WG 3 - IoT Architecture
- ISO/IEC JTC 1/SC 41/WG 4 - IoT Interoperability
- ISO/IEC JTC 1/SC 41/WG 5 - IoT Applications
- ISO/IEC JTC 1/SC 41/WG 6 - Digital twin
- ISO/IEC JTC 1/SC 41/WG 7 - Maritime, underwater IoT and digital twin applications

6.2.3 Project use and impact on the standard

Among the ISO SC41 working groups, WG6 Digital Twin hold a prominent position and is the main focus of Circular TwAIn Project. The WG6 is currently developing three key standards related to Digital Twin, including:

- ISO/IEC AWI 30173 – Digital twin — Concepts and terminology
- ISO/IEC AWI 30172 – Digital Twin — Use cases
- ISO/IEC 30186 – Digital Twin - Maturity model and guidance for a maturity assessment
- ISO/IEC 30188 – Digital Twin – Reference Architecture

6.3 ISO SC42 AI and CEN JTC21 AI

6.3.1 Goal of the standards

SC42 operates as a joint committee of ISO and IEC, serving as a central entity for standardization efforts in the field of Artificial Intelligence (AI) and the entirety of the AI ecosystem. Moreover, SC 42 is scoped to provide guidance to ISO and IEC committees involved in the development of AI applications. SC42 will services as the focus and proponent for JTC 1's standardization program on AI.

6.3.2 History of the standards

ISO SC42 AI was established in 2017, involving the previous activities of the Big Data group as an included WG2 Data Working group – which established the first ISO Big Data standards. Additionally, SC42 comprises several other Working Groups, namely:

- ISO/IEC JTC 1/SC 42/WG 1 - Foundational standards Working Group
- ISO/IEC JTC 1/SC 42/WG 2 - Data Working Group
- ISO/IEC JTC 1/SC 42/WG 3 - Trustworthiness Working Group
- ISO/IEC JTC 1/SC 42/WG 4 - Use cases and applications Working Group
- ISO/IEC JTC 1/SC 42/WG 5 - Computational approaches and computational characteristics of AI systems Working Group

6.4 DTC – Digital Twin Consortium

6.4.1 Goal of the standard

The Digital Twin Consortium [68] operates as a program under the Object Management Group (OMG) and comprises members from industry, academia, and government. The DTC's primary objective is to promote the adoption of digital twins across various sectors. This is achieved through the development of shared terminology, related technologies, best practice guidelines, and open-source reference implementations. The working groups within the DTC focus on sectors such as Aerospace & Defense, Agriculture, Food & Beverage, FinTech, Healthcare & Life Sciences, Manufacturing, Mobility & Transportation, and Natural Resources. By addressing these sectors, the DTC aims to facilitate the widespread application of Digital Twins and foster collaboration among stakeholders.

6.4.2 History of the standard

The DTC was established in 2020 and is a program of OMG with the aim to create technology standards. DTC has many working groups including the DTC Manufacturing Working Group which focuses on the applicability of Digital Twins to the manufacturing process in various industries. The group is exploring the use of Digital Twins to:

- Accelerate product development
- Reduce defects
- Troubleshoot equipment
- Increase uptime
- And decrease manufacturing costs.

In 2021, DTC and IIC have established the Joint DTC-IIC Digital Twin Interoperability Working Group to inform on and share concepts relevant to digital twin interoperability, which Fraunhofer IOSB, SINTEF and TEKNOPAR are also members of.

6.5 Ontology Standards

6.5.1 Goal of the standards

The Semantic Web [69] represents an expansion of the World Wide Web facilitated by standards established by the World Wide Web Consortium (W3C). Its primary objective is to enhance the machine-readability of Internet data. The term "Semantic Web" refers to W3C's vision of the Web of linked data. Semantic Web technologies enable people to create data stores on the Web, build vocabularies, and write rules for handling data. Linked data are empowered by standards such as RDF [70], SPARQL [71], OWL [72], and SKOS [73].

Link Data. The Semantic Web is a Web of Data — of dates and titles and part numbers and chemical properties and any other data one might conceive of. The Semantic Web technologies, including RDF, OWL, SKOS, SPARQL, and more, create an environment where applications can effectively query this data, derive meaningful insights, and leverage specialized vocabularies for enhanced understanding and inference capabilities.

Vocabularies. In certain contexts, organizing data can be crucial or advantageous. By utilizing OWL to construct vocabularies, also known as "ontologies," and employing SKOS for designing knowledge organization systems, it becomes feasible to enhance data with additional meaning. This enrichment allows more people (and more machines) to do more with the data.

Query. Query languages and databases are closely intertwined. When considering the Semantic Web as a global database, the necessity for a query language becomes apparent. SPARQL serves as the designated query language for the Semantic Web, allowing users to efficiently retrieve and manipulate data within this expansive information ecosystem.

Inference. Towards the uppermost level of the Semantic Web stack, inference plays a prominent role by enabling logical reasoning over data based on predefined rules. The W3C's efforts in the realm of rules, particularly through RIF (Rule Interchange Format) and OWL, concentrate on tasks such as facilitating translation between rule languages and promoting the exchange of rules across diverse systems.

Vertical Application. W3C is working with different industries — for example in Health Care and Life Sciences, eGovernment, Manufacturing, and Energy — to improve collaboration, research and development, and innovation adoption through Semantic Web technology.

6.5.2 History of the standards

The World Wide Consortium (W3C) [74], founded in 1994 and lead by Tim Berners-Lee, is responsible for the development of several relevant standards (known as "W3C recommendations") for the World Wide Web (or Web). Berners-Lee had envisioned the Semantic Web by at least 1994, only a few years after he began developing the WWW in 1989. He unveiled his idea for the Semantic Web at the First International WWW Conference, held in 1994, which resulted in the formation of the W3C.

As of today, the W3C Semantic Web has published many standards including RDF, OWL, SPARQL, RDFa, JSON-LD, SKOS, RDFS, GRDDL, POWDER, PROV, RIF, SAWSDL, RDB2RDF, SHACL.

6.5.3 Project use and impact on the standards

One of the main activities of Circular TwAIn Project is to build an environment for seamless data sharing within the circular data value following the FAIR principles and employing Data

Space technology. To enable semantic interoperability between the Digital Twins and within the Data Space, information models and vocabularies which are developed based on Semantic Web technologies are considered. Accordingly, we investigate relevant ontologies that have been delivered as industry standards supported by IEC and ISO such as BFO and ISO 15926. Other ontologies recommended by W3C such as SOSA, SKOS, and PROV are also analysed. Furthermore, we also investigated state-of-the-art tools for managing, querying, and making inferences with linked data. Details about the analysis of ontologies and tools are discussed in D4.1 – Circular TwAIn Industrial Data Platform, Standards Ontologies.

SINTEF is also a member of the AIOTI – Alliance for IoT and Edge Computing Innovation [75] and participates in Semantic Interoperability Expert Group of the AIOTI WG Standardization with the goal to support industrial practitioners make the choice of ontologies easier by developing the AIOTI Ontology Landscape Portfolio [76]. The plan is to contribute to this ontology portfolio with the Circular TwAIn Ontology Library which will be developed within the Circular TwAIn Project.

7 Conclusions and Future Outlook

An overview of the exploitation activities has been presented. The exploitation activities will follow a methodical plan to fulfil Circular TwAIn objectives and maximize the multi-dimensional impact post-Project. To this end, in Section 2 a detailed market analysis has been presented, targeting the domains of the Project's industrial use cases and an analysis of the Artificial Intelligence potential for manufacturing has been included as a core scientific pillar of Circular TwAIn. In addition, an extended environmental analysis has been conducted showcasing the rapidly chasing external environment and the potential impact to Project's developments, which will be updated accordingly as the Project proceeds. In Section 3 the exploitation objectives of Circular TwAIn are highlighted, and the plan, which CORE will follow to achieve these objectives, including both the activities and the timeline towards this goal is presented. All the exploitation activities are divided into three phases, starting with the identification and analysis of key outcomes, and reaching to the final business model. Moreover, the exploitation roadmap has been presented aiming to prepare the path towards commercialization and boost Circular TwAIn innovations preparedness for market uptake. Finally in Section 4, the exploitation work to this stage of the Project has been introduced, elaborating on the exploitation process steps and tools, in addition to the exploitation plan of each partner and the general approach towards Circular TwAIn exploitation strategy.

The Ethical and Legal framework is presented, while a full description as well as the results of the consultations with stakeholders will be part of D7.2 Liaison with AI4MAN Ecosystem, Didactic Factories Network, Legal and Ethical Issues - 1st (M18).

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