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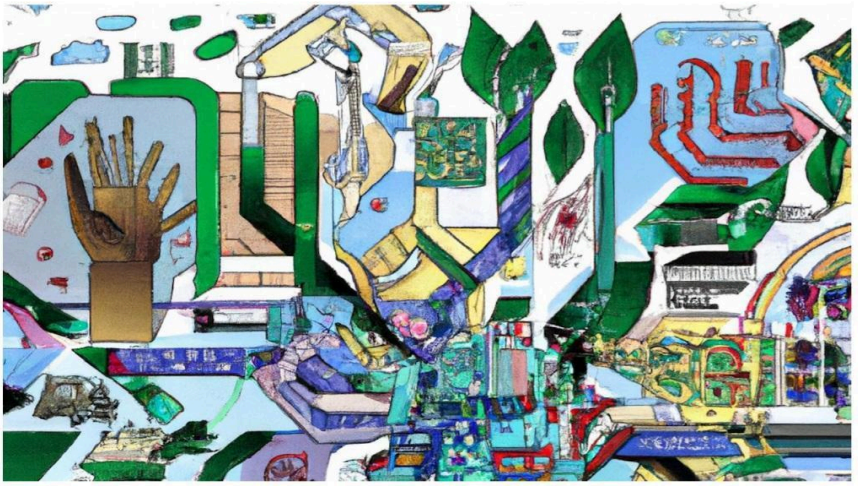

AI-powered image generator DALL-E 2 created this image when asked to visualize “how AI tools will enable the circular economy."

Τίτλος διπλωματικής

Τεχνητή Νοημοσύνη και Κυκλική Οικονομία: Μετάβαση και νέες επιχειρηματικές ευκαιρίες

Φοιτήτρια: Δοϊτσίνη Γεωργία
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Η Διπλωματική Εργασία παρουσιάστηκε ενώπιον

του Διδακτικού Προσωπικού του Πανεπιστημίου Αιγαίου & του Εθνικού Μετσόβιου Πολυτεχνείου

Σε Μερική Εκπλήρωση των απαιτήσεων για την απόκτηση του μεταπτυχιακού διπλώματος ειδίκευσης «Ψηφιακή Καινοτομία και Νεοφυής Επιχειρηματικότητα»

Η ΤΡΙΜΕΛΗΣ ΕΠΙΤΡΟΠΗ ΔΙΔΑΣΚΟΝΤΩΝ
ΕΠΙΚΥΡΩΝΕΙ ΤΗ ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ
Χ. Αλεξόπουλος, Β. Διαμαντοπούλου, Ε. Λουκής

της Δοϊτσίνη Γεωργίας

κος Αλεξόπουλος Χαράλαμπος, Επιβλέπων

Τμήμα Μηχανικών Πληροφοριακών
και Επικοινωνιακών Συστημάτων

Contents

Thesis title: How artificial intelligence can accelerate the transition to a circular economy through new business opportunities?

1. Abstract

This thesis examines the role of artificial intelligence (AI) in enhancing circular economy practices. It discusses how AI can accelerate the transition to a circular economy. It finds that AI can enhance and enable circular economy innovation. AI can help unlock circular economy opportunities by improving design, operating business models, and optimising infrastructure. The discussion includes real-world examples, potential challenges, and the broader implications of adopting AI in the pursuit of a circular and sustainable economy.

The adoption of circular business models can accelerate the transition to a circular economy, as they serve to reduce resource consumption and waste generation. Policymakers and regulators have a role to play in facilitating the adoption of circular business models. In turn, businesses and industries that adopt circular business models can support the transition by achieving efficiency gains through higher resource and economic productivity, reductions in CO2 emissions and new opportunities for jobs and prosperity.

It presents a SWOT analysis highlighting recent advancements in AI and its role in promoting sustainability. Key findings include the importance of data availability and quality as critical enablers for AI's effectiveness in sustainable applications, and the necessity of AI explainability to mitigate risks, particularly for smaller companies facing financial constraints in adopting AI. Secondly, the study identifies future research areas, emphasizing the need for appropriate regulations and the evaluation of general-purpose models, such as the latest large language models, in sustainability initiatives. This research contributes to the growing body of knowledge on AI's role in the circular economy by providing insights and

recommendations for researchers, practitioners, and policymakers, thus paving the way for further exploration at the intersection of AI and circular economy.

Περίληψη

Η παρούσα διπλωματική εξετάζει τον ρόλο της τεχνητής νοημοσύνης (AI) στην ενίσχυση των πρακτικών κυκλικής οικονομίας. Συζητά πώς η τεχνητή νοημοσύνη μπορεί να επιταχύνει τη μετάβαση σε μια κυκλική οικονομία. Διαπιστώνει ότι η τεχνητή νοημοσύνη μπορεί να ενισχύσει και να επιτρέψει την καινοτομία στην κυκλική οικονομία. Η τεχνητή νοημοσύνη μπορεί να βοηθήσει να αναδειχτούν ευκαιρίες κυκλικής οικονομίας βελτιώνοντας τον σχεδιασμό νέων κυκλικών προϊόντων, τη λειτουργία καινοτόμων επιχειρηματικών μοντέλων και τη βελτιστοποίηση της κυκλικής υποδομής. Η συζήτηση περιλαμβάνει παραδείγματα απο startups στην κυκλική οικονομία και πιθανές προκλήσεις της υιοθέτησης της τεχνητής νοημοσύνης στην επιδίωξη μιας κυκλικής και βιώσιμης οικονομίας. Παρουσιάζει τα εμπόδια στην εφαρμογή της τεχνητής νοημοσύνης στην κυκλική οικονομία και προτείνει στρατηγικές για την ενίσχυση της συμβολής της τεχνητής νοημοσύνης στο CE..

Η υιοθέτηση κυκλικών επιχειρηματικών μοντέλων μπορεί να επιταχύνει τη μετάβαση σε μια κυκλική οικονομία, καθώς χρησιμεύουν στη μείωση της κατανάλωσης πόρων και της παραγωγής αποβλήτων. Οι υπεύθυνοι χάραξης πολιτικής και οι ρυθμιστικές αρχές πρέπει να διαδραματίσουν ρόλο στη διευκόλυνση της υιοθέτησης κυκλικών επιχειρηματικών μοντέλων. Με τη σειρά τους, οι επιχειρήσεις και οι βιομηχανίες που υιοθετούν κυκλικά επιχειρηματικά μοντέλα μπορούν να υποστηρίξουν τη μετάβαση επιτυγχάνοντας περισσότερα κέρδη και μεγιστοποίηση της αποδοτικότητας.

Παρουσιάζει μια ανάλυση SWOT που υπογραμμίζει τις πρόσφατες εξελίξεις στην τεχνητή νοημοσύνη και τον ρόλο της στην προώθηση της βιωσιμότητας και μια γεννήτρια καινοτομίας στην κυκλική οικονομία που είναι ενδιαφέρουσα για ιδέες για startups.

Περιγράφει πιθανή εφαρμογή του XAI στη βελτιστοποίηση προϊόντων, φέρνοντας επανάσταση στον τρόπο που αλληλεπιδρούν με συστήματα τεχνητής νοημοσύνης και βελτιώνοντας τις ικανότητες λήψης αποφάσεων. Επίσης, αναλύοντας τα αποτελέσματα από την εστιασμένη έρευνα σε ελληνικές εταιρείες για τη χρήση της AI στην κυκλική οικονομία, η μελέτη προσδιορίζει μελλοντικούς τομείς έρευνας, τονίζοντας την ανάγκη για κατάλληλους κανονισμούς, επενδύσεις στην AI και συνεργασία όλων των μερών, δηλαδή ακαδημαϊκών και επιχειρήσεων.

Keywords: circular economy, artificial intelligence, explainable AI

Thank you letter

I would like to thank my prof Mr Alexopoulo Charalampo for his patience, guidance and support for my thesis and all my professors for their unique initiation to the world of business and innovation. Also, I would like to thank the companies that replied to my questions and filled my google paper and last but not least my newborn baby for the time i left her alone.

Context

This master's thesis is conducted within the framework of the Inter-institutional program, "Digital Innovation and New Entrepreneurship", of the University of the Aegean, Samos department and the National Technical University of Athens. This thesis is important as there is little research that has presented a structured discussion on the association of AI with the circular economy.

It responds to an initiative for extensive research into AI and its opportunities for CE and highlights the importance of emerging AI-embedded applications and equipment. It also outlines avenues for future research and suggestions for the development of AI in the circular economy.

Motivation

Being an entrepreneur for more than 20 years with a lot of experience in commerce and studies in French literature,, I wanted to expand my knowledge about start-up entrepreneurship.
I believe that the circular economy gives golden business opportunities and that artificial intelligence can contribute to the acceleration of circularity and best utilization of resources. My research and study started looking for an opportunity to create a startup in the field of circular economy using artificial intelligence.

Objectives

Thesis title: How artificial intelligence can accelerate the transition to a circular economy through new business opportunities?

This master's thesis explores artificial intelligence in the context of circular economy..It examines key functions of CE and describes the business problems they solve through AI applications.

I examine the theory about the circular economy and climate change, the sustainable development Goals, the circular economy action plan, the relevant regulation and legislation for the CE and the principles of CE.
I realise that the adoption of circular business models can accelerate the transition to a circular economy.
I study use cases worldwide in CE using AI.
I form a roadmap for data driven circular value creation by AI.
I realise that XAI helps create effective, more human understandable AI systems.
I describe potential application of XAI in product optimization revolutionising the way they interact with AI systems and improving the decision-making capacities.
I analyse the barriers to the use of AI in the transition to a CE.
I propose strategies to enhance AI's contribution to CE.
I form a swot analysis of AI in CE and a generator of innovation in the circular economy which is interesting for start up ideas.
I evaluate the results of a questionnaire regarding CE and AI.
I call to action for further research and implementation the researchers, policymakers and businesses.
Scientists, politicians and entrepreneurs could collaborate in order to create new circular business models that could offer great value for the economy and environment.

Research questions:

What is AI and why is it important for a circular economy?

How can AI solve the challenges in a circular economy?

What is the future of the circular economy?

Is there any regulation or legislation for circular economy?

Which are the principles of a circular economy?

Can we propose good practices for the integration of the circular economy?

How can we accelerate the transition to a circular economy through circular business models ?

Which strategies to enhance AI's contribution to CE?

Can we make a SWOT analysis for AI in CE?

Can we propose actions for further research and implementation?

Are there case studies in CE using AI?

How to make better decisions via AI processes ?

How can AI help unlock circular economy opportunities?

Does XAI offer new opportunities and solve challenges for CE ?

The research methodology

My research follows a qualitative method because I analyse articles in depth and some case studies and my questionnaire was addressed to a focused group.
My results are analysed in depth and interpreted in order to understand more about the opportunities in CE using AI.

The research methodology used consists mainly of four parts. First, a deductive analysis was performed, sourcing relevant literature from the field of applied AI to improve circularity, including, for example, case studies or secondary analyses. The notable characteristics and results were extracted from the compiled literature, with an emphasis on recurrent terms. The subsequent SWOT analysis of these key attributes allowed categorization of the insights.

The study culminated with the generation of recommendations to increase the use of AI in the context of circular economy.

The thesis has two types of analysis, the theoretical analysis and the practical analysis.
On the one hand, the theory is examined, i.e. concepts such as the circular economy and climate change, the principles of circularity, the relevant legislation or regulations, the sustainable development goals, the artificial intelligence and the explainable artificial intelligence in the circular economy.
The theory focuses on the importance of the circular economy for society, environment and economy and highlights new business opportunities leveraging artificial intelligence's new trends.

On the other hand, we have the practical analysis that consists of a survey to Greek companies and entrepreneurs where a questionnaire is given to them to answer questions about the applications of artificial intelligence in circular business models, an analysis of startups using artificial intelligence, the strategies that could be followed, the barriers to implementation and the proposals for the circular economy, a swot analysis for AI in CE and the creation of innovation generator for CE.

On the one hand, I studied the relevant literature regarding AI in CE and on the other hand I tried to form a strategy and suggestions to better leveraging AI in CE via swot analysis and a questionnaire regarding AI in CE. The questionnaire was delivered via google form to 5 entrepreneurs and 10 companies, some of them strong in their field without any prior relevant discussion. The purpose of my questionnaire was to raise awareness of the use of AI in CE by tracing the rate of integration of AI in business models in Greek companies, tracing if and where AI needs to be used in CE and tracing the investment intent in AI in CE.

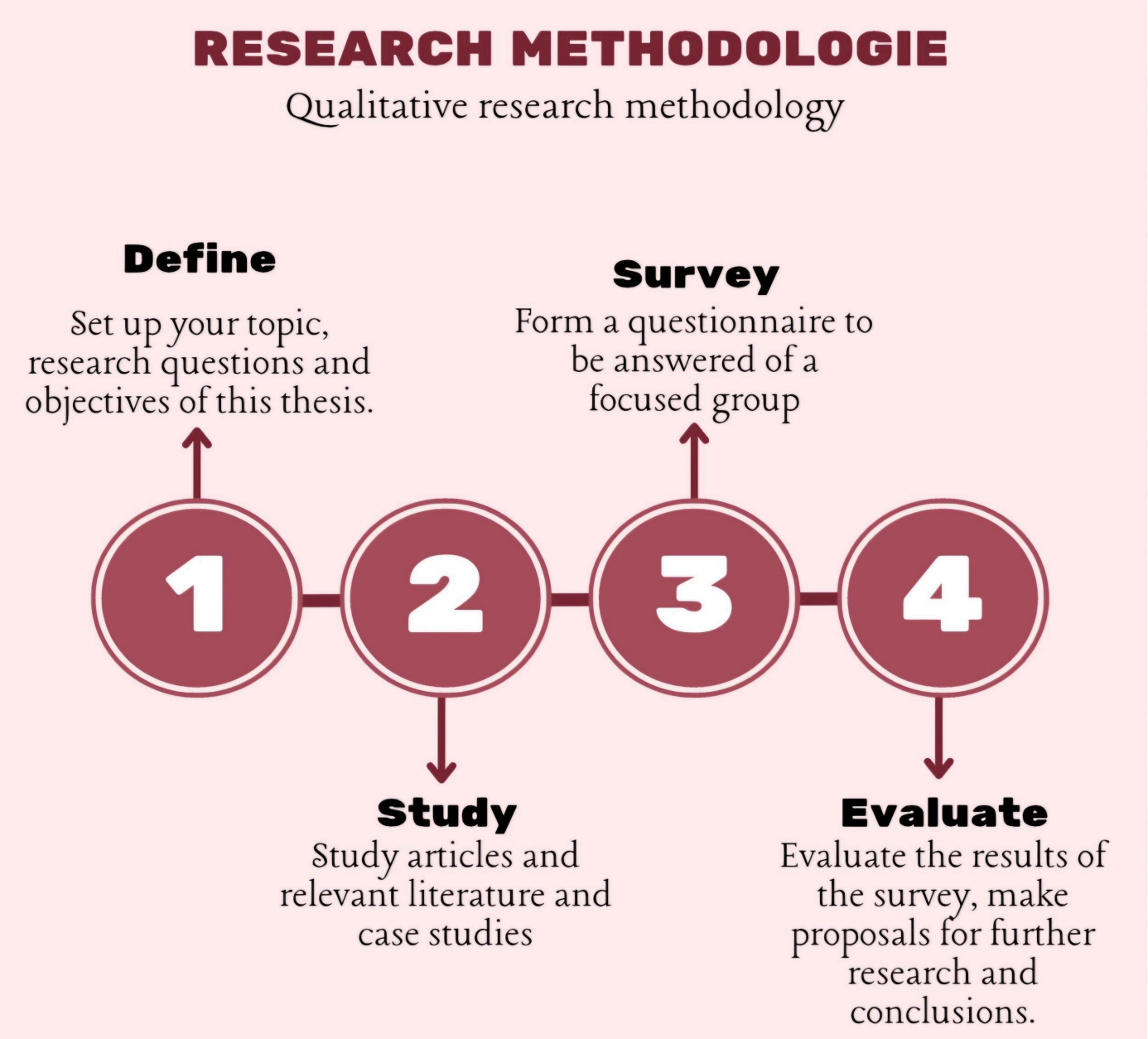


Figure 1 : research methodology

2. Circular economy - Definition (by wikipedia)

A circular economy (also referred to as circularity or CE) is a model of resource production and consumption in any economy that involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible.The concept aims to tackle global challenges such as climate change, biodiversity loss, waste, and pollution by emphasising the design-based implementation of the three base principles of the model. The three principles required for the transformation to a circular economy are: designing out waste and pollution; keeping products and materials in use, and regenerating natural systems. CE is defined in contradistinction to the traditional linear economy. It has been gaining popularity because it can help to minimise carbon emissions and the consumption of raw materials, open up new market prospects, and, principally, increase the sustainability of consumption.

An illustration showing the difference between the take, make linear economy approach and the circular economy approach.

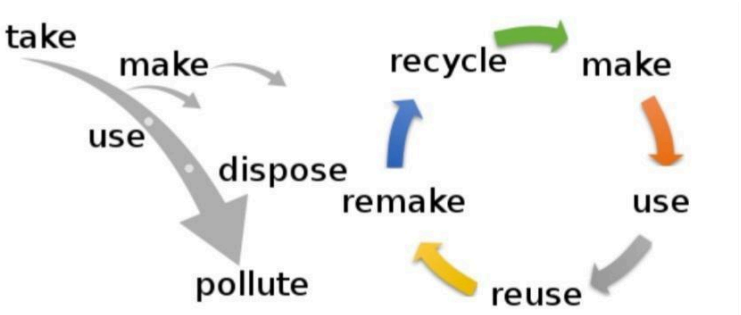


Figure 2 : linear economy vs CE

Circular economy and climate change

Our current economic system can be considered a “linear economy”, built on a model of extracting raw materials from nature, turning them into products, and then discarding them as waste. Currently, only 7,2 % of used materials are cycled back into our economies after use. This has a significant impact on the environment and contributes to the climate, biodiversity, and pollution crises.

Circular economy, on the other hand, aims to minimise waste and promote a sustainable use of natural resources, through smarter product design, longer use, recycling and more, as well as regenerate nature.

Besides helping tackle the problem of pollution, the circular economy can play a critical role in solving other complex challenges such as climate change and biodiversity loss.

A circular economy is essential for fighting climate change. That means that if we want to significantly reduce emissions, we have to look at “hot spots” of unsustainable consumption and production in high-impact sectors such as industry, buildings and construction, and agriculture.

Of course, these changes won’t happen overnight. Governments need to develop credible long-term pathway scenarios and provide policy frameworks to reach these goals. Once business, consumers and investors commit to those goals, behaviours can align, risks can be taken, and coalitions can be formed.

COVID-19 has provided an unexpected push for circularity as people realise it is possible to embrace a lifestyle for which they have never dreamed possible, one that includes remote work, more decentralised living options and appreciation for a shortened value chain. Changes brought by the pandemic helped spark a genuine interest in pursuing more localised production and consumption systems.

At this crossroad of human history, I firmly believe pursuit of circularity provides a powerful solution to the challenge at hand. Transformation of entire systems will be required, involving every quarter of the world, from industry leaders, policy makers, consumers and investors. If we join hands, we can make this journey together.

Sustainable Development Goals

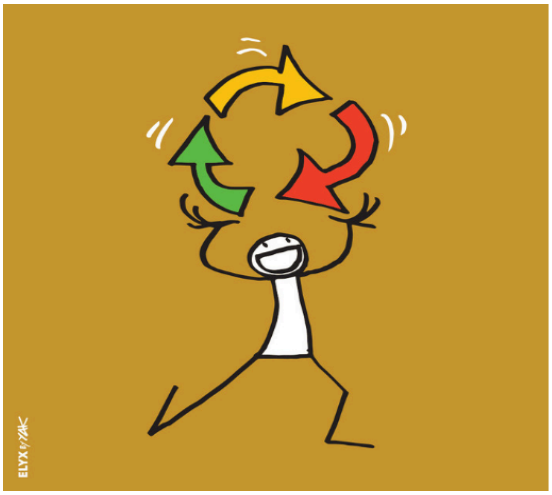
The Sustainable Development Goals (SDGs) was introduced in 2015 as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030. They recognise ending poverty must go together with strategies that build economic growth and address a range of social needs including, education, health, social protection, and job opportunities while tackling climate change and environmental protection. The 17 SDGs have 169 specific targets which help to catalyse actions over the 15 years.

According to the Scaling Up Climate Action to Achieve Sustainable Development Goals report, The United Nations Development Programme ("UNDP") pinpointed that these goals are interlinked, particularly between climate action and the other SDGs. Climate change is a cross-cutting development issue that affects every aspect of the sustainable development agenda. Thus, every party must step up to escalate climate action to achieve the SDGs by 2030.

Take Action for the Sustainable Development Goals

The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace and justice. The 17 Goals are all interconnected, and in order to leave no one behind, it is important that we achieve them all by 2030.


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS




12 RESPONSIBLE CONSUMPTION AND PRODUCTION
To ensure sustainable consumption and production patterns
SUSTAINABLE DEVELOPMENT GOALS

[13] **Photo 1**

The Circular Economy Action Plan

The EU's Circular Economy Action Plan (CEAP) was a comprehensive body of legislative and non-legislative actions adopted in 2015, which aimed to transition the European economy from a linear to a circular model. The Action Plan mapped out 54 actions, as well as four legislative proposals on waste. These legislative proposals were put forward by the European Commission along with the Action Plan and included targets for landfill, reuse and recycling, to be met by 2030 and 2035, along with new obligations for separate collection of textile and biowaste. The Action Plan covered several policy areas, material flows, and sectors alongside cross-cutting measures to support this systemic change through innovation and investments. It also announced a sectoral strategy for plastics. More than EUR 10 billion of public funding was allocated to the transition between 2016 and 2020.

The outcomes

All 54 actions were adopted or implemented by 2019. The EU is now recognised as a leader in circular economy policy making globally. The waste legislation was adopted in 2018, following negotiations with the European Parliament and Member States in the European Council. According to Eurostat, jobs related to circular economy activities have increased by 6% between 2012 and 2016 within the EU. The action plan has also encouraged at least 14 Member States, eight regions, and 11 cities to put forward circular economy strategies. **[12]**

Regulation (EU) 2020/852

On The Establishment of a Framework To Facilitate Sustainable Investment (Taxonomy Regulation)

In December 2019, the European Council and the European Parliament reached political agreement on the text of the Taxonomy Regulation. On 15 April 2020, the European Council adopted, at first reading, the proposed Taxonomy Regulation and published the adopted text. On 22 June 2020, the Regulation (EU) 2020/852 on the establishment of a framework to facilitate sustainable investment (Taxonomy Regulation), and amending Regulation (EU) 2019/2088 was published in the Official Journal. Regulation 2020/852 also amends Regulation 2019/2088 on sustainability-related disclosures in the financial services sector.

The proposed Taxonomy Regulation establishes an EU-wide classification system or 'framework' intended to provide businesses and investors with a common language to identify to what degree economic activities can be considered environmentally sustainable.

The Taxonomy Regulation imposes three key obligations:

- on member states and at EU level to apply the Taxonomy when regulating how environmentally financial products or corporate bonds are made available
- on "financial market participants" to make statements about alignment of investments with the Taxonomy when making available financial products
- on large public-interest entities to include information about how their activities align with the Taxonomy in the non-financial disclosure part of their financial statements.
-

The Taxonomy Regulation brings new disclosure requirements for large listed companies that are already required to provide a non-financial statement under Non-Financial Reporting

Directive (NFRD). They will have to start disclosing how their business activities align with the climate objectives (adaptation and mitigation) under the EU Taxonomy Regulation in the course of 2022 and all six environmental objectives in the course of 2023. This requirement aims to address the data gap for investors who in turn will be required to disclose the degree of alignment of their financial products with the Taxonomy objectives. Indeed, the EU Taxonomy is a classification system to identify economic activities that achieve performance levels making a 'substantial contribution' to at least one of six environmental objectives, while ensuring that the activity will 'do no significant harm' to any of the other five objectives and also meet minimum safeguards .

The objectives are:

- Climate change mitigation and adaptation
- Sustainable use and protection of water and marine resources
- Transition to a circular economy, including waste prevention and increasing the uptake of secondary raw materials
- Pollution prevention and control
- Protection and restoration of biodiversity and ecosystems
- Boosting green investments.

[14]

New Legislative for the Circular Economy

In the context of the European Green Agreement 2 (European Green Deal), in March 2020 the European Commission adopted the new Action Plan for the Circular Economy, which is the extension of the first European Plan Action issued in 2015.

On 27 May 2024, the Council adopted new ecodesign requirements for sustainable products. The new rules aim to:

- set environmental sustainability requirements for almost all kinds of goods placed on the EU market
- establish a digital product passport that will provide information about a product's environmental sustainability and prohibit the destruction of certain unsold consumer goods.

On 30 May 2024, the Council adopted the right-to-repair (or R2R) directive. The main elements of which are:

- a right for consumers to request that manufacturers repair products that are technically repairable under EU law (for instance, washing machines, vacuum cleaners or mobile phones)
- a free-of-charge European repair information for an online repair platform to connect consumers with repairers the extension by 12 months of the seller's liability period after the repair of a product.

By creating incentives for producers and consumers to prolong life cycles of products, the new legislation will also reduce waste and promote more sustainable business models.

At the national level, the Ministry of Environment and Energy proceeded in December 2018 to publish the National Strategy and the operational action plan 2018-2019 for the Circular Economy, around the pillars of sustainable resource management and the strengthening of Circular entrepreneurship and consumption.

In May 2022, the Ministry of Environment and Energy published a new National Action Plan - Circular Economy Roadmap, which aims to implement even more ambitious actions to accelerate the country's transition to a Circular Economy. Its main actions of the new plan concern the basic aspects of the Circular Economy such as production, consumption, waste management and other horizontal issues, while actions concerning the sectors where the European action plan is focused are also analysed.

3. The principles of circular economy

The circular economy is based on three principles:
First, waste and pollution are designed out. This means that the products of today can become the resources of tomorrow and the negative impacts of economic activity that cause damage to human health and natural systems are eliminated. This includes factors such as the release of greenhouse gases, the use of toxic and hazardous substances, the pollution of air, land, and water, and the landfilling and incineration of waste.
Second, products and materials are kept in use. This includes favouring activities that increase product utilisation, and reuse to preserve the embedded energy, labour, and materials.
Third, natural systems are regenerated. This entails, for instance, deploying agricultural practices that not only avoid degrading soil, but actually rebuild soil health over time.

The circular economy model distinguishes between technical and biological cycles. In biological cycles food and biological materials (e.g. cotton or wood) feed back into the system through processes such as composting and anaerobic digestion. These cycles regenerate living systems such as soil, which provide renewable resources for the economy. Technical cycles recover and restore products, components, and materials through strategies including reuse, repair, remanufacturing, or recycling.

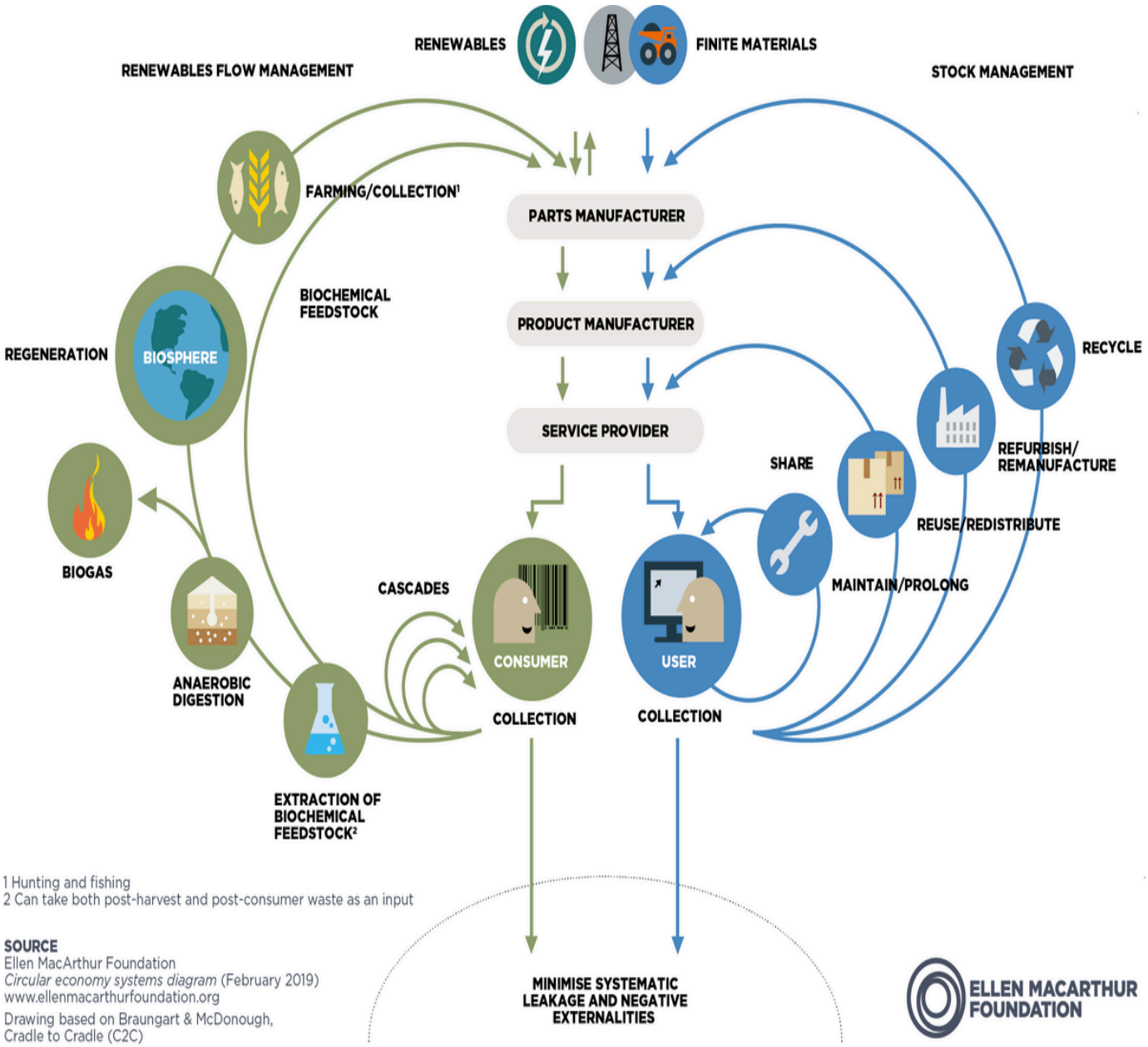


Figure 3 : *The circular economy system diagram* ***(12)***

The circular economy system diagram, known as the butterfly diagram, illustrates the continuous flow of materials in a circular economy

. There are two main cycles – the technical cycle and the biological cycle

. In the technical cycle, products and materials are kept in circulation through processes such as reuse, repair, remanufacture and recycling
. In the biological cycle, the nutrients from biodegradable materials are returned to the Earth to regenerate nature.

The 5 R : Reduce, Repair, Reuse, Remake, Recycle

The impact of circularity is the sustainability and positive results for society, environment and economy.

In Greece, there are high potentials and favourable factors so to apply the productive and economic model of circularity :
Available natural sources and unused secondary resources and waste.
Scientist and know-how as well as productive and technical tradition in technical professions.
Primary sector with growth potential and needs to modernise and reduce production costs.
Available strategic framework from the EU and accessible financial tools.

10 Proposals for the integration of the Circular Economy

1. Systematic information of businesses and presentation of good practices.

2. Educating and informing consumers to recognize and choose products/services with circular characteristics.

3. Funding research and innovation to solve difficult problems with high potential for profit.

4. Formation of a special governance structure and participation of business entities.

5. Completion of waste collection, storage, transport and treatment infrastructure to meet national targets at optimal cost.

6. Setting up an incentive/disincentive framework so that recycling is the most expensive option.

7. Establishment of standards/specifications for secondary materials and fuels & redesign of products with criteria of circularity.

8. Implementation of the national plan for Green Public Procurement and expansion to more materials.

9. Priority in the preparation of the national plans provided for the Circular Economy Road Map.

10. Implementation of a framework of indicators and its use in decision-making.

4. Accelerating the transition through circular business models

The widespread adoption of circular business models can accelerate the transition to a circular economy, as they serve to reduce resource consumption and waste generation. Policymakers and regulators have a role to play in facilitating the adoption of circular business models. In turn, businesses and industries that adopt circular business models can support the transition by achieving efficiency gains through higher resource and economic productivity, reductions in CO2 emissions, and new opportunities for jobs and prosperity.

Five examples of circular business models are described below:

Product life extension and reuse: maximising utilisation rates, achieving optimal value out of the energy and resources used to produce a given product with durable and easily repaired products.

Recycling of waste: ensuring that when the lifetime of products can no longer be prolonged, materials of the product can be kept in circulation and used in the production of new products through recycling.

Product-as-a-service: enabling access to – rather than owning – a product or asset through leasing, renting or pay-per-use plans. Repair and maintenance schemes are often included, without immediate costs for the consumer.

Sharing business models: the same products are made available to more than one user. It facilitates the sharing of products that are otherwise underutilised between consumers or companies.

Circular bio-based business models – materials extracted from virgin resources are replaced with bio-based, renewable, or recovered materials. By-products from production processes

can be upgraded to obtain high-value products and energy as well as optimising resource efficiency throughout the production process.

Circularity from use of data, digital tools, and design

The realisation of circular business models often depend on and can be scaled by the use of design, data and digital tools.

In many cases, realising these circular business models will require the use of data collection, digital tools, and design.

Strengthening reporting practices and data collection is particularly significant, as information about product design and material content, quality and origin are necessary inputs to evaluate whether a product can be better designed, repaired, reused, recycled, or needs to be maintained.

Circularity from use of data, digital tools, and design

Use of data, digital tools and design of products and materials are important enablers in the development of various circular business models. Data about product design and material content, quality and origin are valuable inputs to evaluate whether a product can be better designed, reused, recycled or needs to be repaired and maintained. Therefore, data is also crucial information, when delivering the product as a service.

Denmark is a highly digitised country. Most transactions are cashless, and almost all interaction with the Danish authorities takes place online. Data on materials, product lifecycle and production currently exist, however these data are to a large extent, not yet digitalised at the level of transparency and streamlined so that they can be readily shared across value chains.

Data, digital tools, and traceability

Data on the use, location and condition of the product are important to continuously maintain and optimise the performance of the product, e.g., a rental platform can register data on the use and wear at the end of a rental period, which the producers can then use to design more

durable products in the future. Another example is outdoor facilities such as bridges and buildings, where sensor data can be combined with weather and traffic data, and the use of AI to optimise the facility's use, enable predictive maintenance and reduce operational costs. Information on circular products and buildings are also important for sustainability documentation and reporting, which increasingly are considered a competitive advantage for businesses. Large companies and investors are demanding documentation from suppliers regarding whether their activities are sustainable. For companies and businesses to collect, use and share data for business development and documentation, they need supportive digital tools. There is a growing market for enablers delivering software and blockchain solutions for data sharing about materials and traceability as well as on product performance.

Designing for the circular economy

Design refers to the way products, services and systems are created. The circular design of products is crucial in the development of circular business models, products, and buildings. According to the European Commission, more than 80 per cent of a product's environmental impact is determined in the design phase. New value can be unlocked for both producers, constructors, and consumers by designing products and buildings to be easily reused, repaired, refurbished, remanufactured, or shared.

Design is also central for delivering a product-as-a-service giving access to the use of a product, rather than selling the product, through rental, subscription, sharing or leasing schemes. Design – or redesign – is central, when giving used clothes a second life. Design can also be used strategically to connect customers more closely to the product, the store, and/ or the manufacturer, to enable a stronger commitment to the product, which can increase the use period.

A few additional examples of the role of design include:

• Plastic packaging can be designed to be recycled at high value when it is produced with only one type of plastic rather than a mix, impairing recycling.

• A building can be designed for circularity if it is designed to be easily decommissioned, e.g., using principles of modularity and design-for-disassembly to enable higher reuse of the building materials.
• Design has an important role to play to enable sustainability in the fashion industry where production has doubled worldwide from 2000 to 2015 and the average customer buys 60 per cent more clothing than they would 15 years ago and only uses it for about half as long. This dramatic development is not sustainable and can be reversed by using design to change customer consumption patterns, e.g., by designing for better use of clothes, using sharing and rental platforms.
• Strategic use of design could for instance be a restaurant or food delivery business that supplement their offer with opportunities for the customer to meet and eat together with the food producers to provide the customer a deeper understanding of the process of producing food and the importance of doing so sustainably. Another example is inviting clients to be investors and co-responsible for supporting sustainable local production.

The use of data, digital tools, and strategic design can be found at the core of the business models for circular economy; product life extension and reuse, recycling of waste, product-as-a-service and sharing business models.
Incorporating circular economy principles in the design of products is central, as this optimises products or services ability for enhanced use. Data on the product enables evaluation and improvement. Digital tools enable the use and shareability of the data for traceability and assure quality for reuse, recycling and management of products based as product-as-a-service or in a sharing business model.

Transitioning to a circular economy requires collaboration, education, and knowledge sharing amongst policymakers, business leaders and universities. Doing so creates innovative solutions which are then refined, and implemented for mutual benefit, and without job losses or lowered efficiency or living standards. Addressing essential value chains is often a matter of great complexity. Dialogue between authorities and the commercial sector in order to overcome barriers is of great value for both parties. At times, current regulations may pose obstacles to value chain development.

Therefore, appropriate regulatory framework conditions for circular economic development are important to drive dynamic development and ensure a reliable supply chain. **(10)**

Circular economy and AI

The term industrial revolution (IR) refers to the technological advancements introducing novel ways of living that drastically transform society. This revolution process began by the first industrial revolution (Industry 1.0) and was characterised by steam engines. This was the base of the technological revolution (Industry 2.0) that allowed more outstanding production with the help of mechanical machines. The application of IT processes in production led to the third industrial revolution (Industry 3.0), enabling the automation of the entire production process. The concept of mass production was introduced during Industry 3.0. The production systems already benefiting from computer technology fueled the digital evolution (Industry 4.0) of the past decade by incorporating new technologies: robotics, artificial intelligence, deep learning, augmented reality, cloud technologies, 3D printing, for mass production. A major milestone was the improvement in network connectivity of manufacturing and production systems, taking the production automation to another level. This digital evolution of the past decade has laid the foundation for the human-machine coworking era (Industry 5.0), pertaining to increased collaboration between humans and smart systems to address mass personalization while improving the work efficiency. The European Economic and Social Committee (EESC) describes Industry 5.0 as a combination of human beings' creativity with robots' speed, productivity, and consistency. The vision is to strive for a human-centered society by an enhanced partnership between humans and smart systems. With this partnership, machines take over the monotonous, tedious, and repetitive tasks, while machines' increased supervision and creative jobs rests with humans. Industrial revolutions are already being performed by robotic process automation (RPA) tools, 3D printing is already prevalent, and chatbots are increasingly being deployed to serve the customers. In IR 5.0, there will be increased collaboration between humans and smart systems like robots.

To future proof the success, innovation is the key. The Artificial Intelligence (AI) and RPA tools assist in decision-making processes across numerous industries. The black-box nature of these systems allows accurate prediction mechanisms. However, in life-threatening scenarios (health care, national defence, autonomous vehicles), an insight of the internal mechanism is required. This insight is achieved via Explainable Artificial Intelligence, which aims to create more explainable AI algorithms while maintaining high-performance levels. There has been some effort to employ explainable AI techniques in context-aware computing paradigms to construct a smart society consisting of smart homes and cities. However, it is a challenging task to keep a balance between accuracy and explanation of an AI model. (5)

Circular Economy Circular Economy (CE) promotes an enhanced socio-economic paradigm for sustainable development. It aims to fulfil current needs without jeopardising the needs of future generations under three dimensions: economic, social, and environmental. The European Green Deal, Europe's new agenda for sustainable growth, is an ambitious action plan to move to a clean circular economy, to restore biodiversity, to reduce emissions by at least 55% by 2030, and to become the world's first climate neutral continent by 2050. The EC strategy is well aligned with the United Nations (UN) 2030 Agenda for Sustainable Development. The 17 Sustainable Development Goals (SDGs) are at the heart of the EU policy making across all sectors. CE reforms current linear "take-make-dispose" economic models based on unsustainable mass production and consumption and proposes a new model that is restorative by design (materials, components, platforms, resources, and products add as much value as possible throughout their life cycle). Such a model also aligns the needs of the different stakeholders through business models, government policies, and consumer preferences. At the end of their lifetime, much of these products and components are regenerated and/or recycled. The European Commission adopted a new Circular Economy Action Plan (CEAP) in March 2020, as one of the main key elements of the European Green Deal. Such an action plan promotes initiatives along the entire life cycle of products, from design to the end of their lifetime, encouraging sustainable consumption and waste reduction. According to the World Economic Forum, achieving a CE transition will require unprecedented collaboration, given that, in 2019, only 8.6% of the world was circular, although CE can yield up to USD 4.5 trillion in economic benefits in 2030. Digital Circular

Economy (DCE) Data Centers and digital infrastructures require substantial levels of energy. ICT accounts for 5 to 9% of the total electricity demand with a potential increase to 20% by 2030. In addition, materials (e.g., physical resources, raw materials) linked to the digital transformation are also a problem: the world produces over 50 million tons of electronic and electrical waste (e-waste) annually and just 20% is formally recycled. Such an amount of waste will reach 120 million tons annually by 2050. The challenge posed by the increase in digital technologies requires the application of circular economy principles to the digital infrastructure. While currently, the focus of the sector is mainly on meeting the needs in a sustainable way (e.g., energy efficiency and cybersecurity), the supply of critical raw materials will be an issue in the coming years. Moreover, the opportunities provided by the DCE to the digital transition should be also explored (e.g., new business models, new markets, and reduced information asymmetry). (7)

A circular economy, in which growth is gradually decoupled from the consumption of finite resources, offers a response. Its principles are to design out waste and pollution, keep products and materials in use, and regenerate natural systems. The advantages of such an approach are substantial. For example, research has shown that a circular economy in Europe can create a net benefit of EUR 1.8 trillion and 18 millions new jobs globally by 2030, while addressing mounting resource-related challenges, creating jobs, spurring innovation, and generating substantial environmental benefits.

The 21st century is posing serious challenges to both advanced and developing economies, especially regarding the environmental impact of the current unsustainable production systems and consumption habits. The current linear economic model, which has global economic expansion over the last few decades, is proving to be an increasingly unsustainable system, with evident environmental and social repercussions, such as deforestation, soil erosion, overflowing landfills, polluted ecosystems e.t.c.
In this context, the circular economy emerges not only as an alternative to the traditional system, but as an essential paradigm shift, representing a holistic approach to address the

numerous challenges of our time, and a blueprint towards a more sustainable, prosperous, and equitable future. Generally, the circular economy is focused on providing a viable strategy to counteract the environmental challenges by minimising waste and pollution and fostering healthier and more resilient communities, as well as offering a roadmap to a future marked by prosperity, equity, and ecological balance.

The principles underlying the circular economy, such as reuse, recycling, and regeneration, are postulated as the starting point for the development of innovative solutions to develop a socioeconomic model that decouples growth from resource consumption, guaranteeing supply, stabilising markets, and reducing dependence on exhaustible raw materials. Furthermore, the alignment of circular economy principles with several of the sustainable development goals designed by the United Nations, such as responsible consumption and production, clean water supply and climate action, underscores the relevance of adopting and integrating circular economy practices for the fulfilment of the commitments set for 2030.

Central to this discourse is the role of emerging technologies in shaping, facilitating, and enhancing the principles of circularity, which has important implications that warrant scholarly exploration. The transition towards a circular paradigm and, especially, an environmentally sustainable production, requires the development of innovations, especially new technologies, that facilitate the circular flow of materials, and generate new employment opportunities in emerging sectors such as recycling, sustainable product design and resource management.

The world is witnessing unprecedented technological advances, with profound implications for the implementation of circular practices across various strata of society, that can reshape economies, industries, and social structures.

The artificial intelligence can favour the optimization in the allocation of resources, improve product life cycle management, transform processes, and predict behavioural patterns, in order to boost the efficiency and effectiveness of recycling and reuse processes of materials

that today are discarded as waste, acting as a tool in favour of achieving the objectives pursued by the circular economy.

The role of artificial intelligence goes beyond the allocation of resources, since it allows the analysis of consumption patterns and calibrate production processes in real time, serving as a bulwark against overproduction and the uncontrolled generation of waste, which would make it possible to adapt production to real demand and move towards a circular production model while the predictive capabilities of machine learning algorithms may allow industries to anticipate resource needs more accurately and ensure the efficient use of materials. Therefore, they can be instrumental in changing production processes, reducing the destructive environmental effects of industry and optimising the production of goods through machine learning and neural networks.

Case studies world wide in CE using Artificial Intelligence

Separating or sorting garbage is as important as effective waste collection to ensure that the right materials are sent for recycling. Unfortunately, this process is still a bottleneck for many waste management facilities as the majority of them follow a single-sort system in which all the recyclables end up in the same box. But the recyclables like plastic and cardboard need to be separated.

AI-powered sensors differentiate among items made from different materials as well as nuances among the ones of the same materials. It also detects chemical contamination in the items. This is why the use of AI in waste management is one of the emerging circular economy trends. Moreover, AI-driven machines sort recyclables much faster than humans using computer vision and deep learning algorithms. AI enables waste management companies to reduce the need for manual labour, thus, cutting costs and maximising efficiency.

Unilever has successfully integrated artificial intelligence (AI) into its circular economy initiatives. Leveraging AI algorithms, Unilever optimized packaging design, enhancing

recyclability and reducing environmental impact. AI-driven analytics analyzed consumer behavior and waste patterns, allowing Unilever to tailor product life cycles, minimize packaging waste, and enhance resource efficiency. Additionally, robotic sorting systems guided by AI were implemented in recycling facilities, significantly improving the accuracy and speed of material segregation. This holistic AI integration has not only streamlined Unilever's circular practices but also demonstrated the potential of AI in revolutionizing the consumer goods industry's commitment to sustainable and circular solutions

RECYCLEYE designs AI-Powered Waste Management Solutions

British startup RECYCLEYE offers automated waste management solutions that utilise AI and robotics. The solution's algorithms replicate the power of human vision to identify items in waste streams. Recycleye engages in waste sorting with its AI vision system that identifies and classifies all items on waste streams – by material, object, and even brand.

WasteNet, the startup's visual database of labelled waste items, identifies waste at the brand level. Leveraging AI to power Recycleye's robotic picker, it adapts to changing waste compositions without any need for retrofit.

Lixo provides an AI Tool for Waste Characterization

Lixo is a French startup that offers hardware and software tools for waste management companies. The startup's digital twin connects to the waste management infrastructure. The software solution consists of an AI tool that provides a precise view of waste flows, analyses their composition, and characterises the waste in real time. A dashboard allows the stakeholders to view key indicators like purity, flow, and downtime.

Case studies in Greece start ups in circular economy using AI

CYCLEFI

Photo 2

For “Cyclefi IKE” to be a pole of research excellence for our country. Regarding the strong research interest and action of Cyclefi IKE, this results from the fact that Cyclefi has invented appropriate technology that allows the recording of waste produced, the identification of users, as well as the additional groups of data collected for comprehensive monitoring of user recycling performance, parameterization and quantification, data monitoring model and methodology, specification of the proposed approach and data requirements from partnering systems. For the above solution, Cyclefi has registered a Patent entitled "Method for recycling materials and system for its application".

About

Cyclefi P.C is a specialised private company based in Athens, which acts as an Innovation Lab and builds on the development of cutting-edge technologies to advance its mission to tackle waste, energy and water nexus challenge and fostering partnerships with educational

institutions, and forward-thinking partner companies. Cyclefi as a solution engineering company, is dedicated to craft innovative solutions and develop technology-based products, services, and applications, to bring radical new concepts, from idea exploration to prototyping and eventually full-scale deployment, while promoting the principles of Circular Economy and Green Deal in the European Union.

Innovations within the waste, energy and water sector will reshape the cities of tomorrow. Automation, data analytics, citizen' engagement tools and connected sensors will allow for quieter, cleaner and safer megacities to grow and prosper. For us in Cyclefi, technology means the aspiration to move forward, constantly working together to improve and do better.

Solution & Product

Cyclefi focused on solving cities' greatest waste, energy and water challenges through forward-thinking urban design and cutting-edge technologies. Cyclefi developed applications utilising Big Data Science, Internet of Things (IoT), Artificial intelligence (AI) and machine learning (ML) technologies in the fields of Energy, Water and Waste Management Systems, to enhance human insights and create new opportunities to improve waste, energy and water management. Cyclefi developed and rolled-out the following:

•A first-of-its-kind web and native mobile application that is interconnecting product owners (brands) of Fast-Moving Consumer Goods (FMCGs) and e-shops to reward consumers who actually support environmental causes and respect the principles of circular economy overall

•A first-of-its-kind web and mobile application to measure the actual weight of recyclables and notify waste collectors to automate waste management

•A cloud-based device and data management web app, which can help revealing the value of IoT data collection,

•An in-house designed Smart Scale which -to the best of our knowledge- is the most flexible, yet economically affordable, IoT development system, which can enable a full automation on waste management.

Source:https://www.cyclefi.com/research-development

COFFEECO

Photo 3

Coffeeco's journey started at Patras University where the two Chemical Engineers, Alexis and Marios, shared a common goal. Their own separate research focused on applying scientific knowledge to make products that would contribute to the circular economy and people's wellbeing.

Upcycling Skincare Ingredients

Coffee - Eco finds innovative solutions to reduce waste and promote sustainability.

They develop a unique process to upcycle espresso, beer and wine waste and turn it into ingredients for skincare products.They collect used coffee grounds, beer and wine waste from

cafes, shops and wineries and use the natural antioxidants and caffeine found in them to create effective and eco-friendly skincare products.

They use the following three practices:

Reducing waste by repurposing used coffee grounds, beer and wine waste

Creating eco-friendly skincare products with natural antioxidants that have anti-aging and rejuvenating effects

Lowering the CO2 footprint of skincare products by using repurposed waste as ingredients

https://coffe-eco.gr/

VENDORA

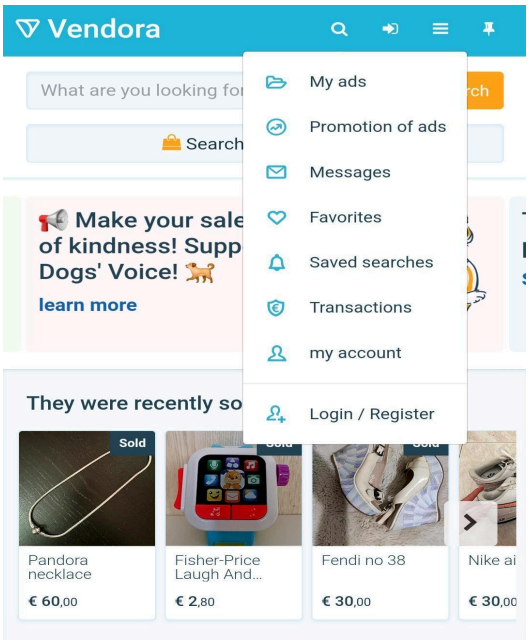


Photo 4

About

Vendora.gr is Greece's #1 C2C marketplace for buying and selling new and used goods, and services.

Solution & Product

A modern responsive web platform and mobile application where consumers can offer the products they no longer need for sale, simply by taking a picture and setting a price. Transactions can take place in-person, or buyers and sellers can transact online through an integrated escrow payment & shipment solution.

Innovation & Scalability

Classified ads marketplaces have proven to be highly scalable in many other markets. Our founder brings two decades hands-on experience with this.
Vendora aims to innovate in making the transaction between buyers and sellers completely safe and frictionless, and to leverage behavioural data to predict and help buyers discover new interests.

source: https://vendora.gr/

We can check more startups who are registered in the list of Elevate Greece which is the official platform and leading resource for in-depth information on the Greek Startup ecosystem.
Check the list of startups specializing in Circular Economy and uses new technologies who are registered in Greek National Startup Registry ***(ANNEX 1)*** and read more at *elevategreece.gov.gr*

It;s really interesting to collect and analyse data in order to create value by the use of AI

DATA -> AI -> VALUE

We collect data regarding waste, we analyse via AI and ML in order to export value for economy, society and environment.

Artificial intelligence importance and solutions for circular economy

Artificial intelligence (AI) can play an important role in enabling this systemic shift. AI is a subset of the technologies enabling the emergent 'Fourth Industrial Revolution' era and deals with models and systems which perform functions generally associated with human intelligence, such as reasoning and learning. AI can complement people's skills and expand their capabilities. It allows humans to learn faster from feedback, deal more effectively with complexity, and make better sense of abundant data. A growing number of initiatives are exploring how AI can create new opportunities to address some of the world's most important challenges.

The adoption of CE practices can bring a range of benefits to businesses, including enhancing their reputation and promoting their commitment to sustainability and environmental responsibility.

How AI can accelerate the transition to a circular economy. It finds that AI can enhance and enable circular economy innovation across industries in three main ways:

1. Design circular products, components, and materials. AI can enhance and accelerate the development of new products, components, and materials fit for a circular economy through iterative machine-learning-assisted design processes that allow for rapid prototyping and testing.

For example, AI algorithms to analyse huge amounts of data on existing materials and their properties to design and test new material formulations.

2. Operate circular business models. AI can magnify the competitive strength of circular economy business models, such as product-as-a-service and leasing. By combining realtime and historical data from products and users, AI can help increase product circulation and asset utilisation through pricing and demand prediction, predictive maintenance, and smart inventory management.

For example, AI algorithms for the pricing of both the products they buy and sell in secondary markets and machine learning to ensure a consistent classification of all resale items.

3. Optimise circular infrastructure. AI can help build and improve the reverse logistics infrastructure required to 'close the loop' on products and materials by improving the processes to sort and disassemble products, remanufacture components, and recycle materials.

For example, AI software analysing the sensor data creates an accurate real-time analysis of the waste stream.

In the transition to a CE, AI can be used in different scales and strategies.

We could distinguish three different scales (micro, meso, macro) based on different areas of use.

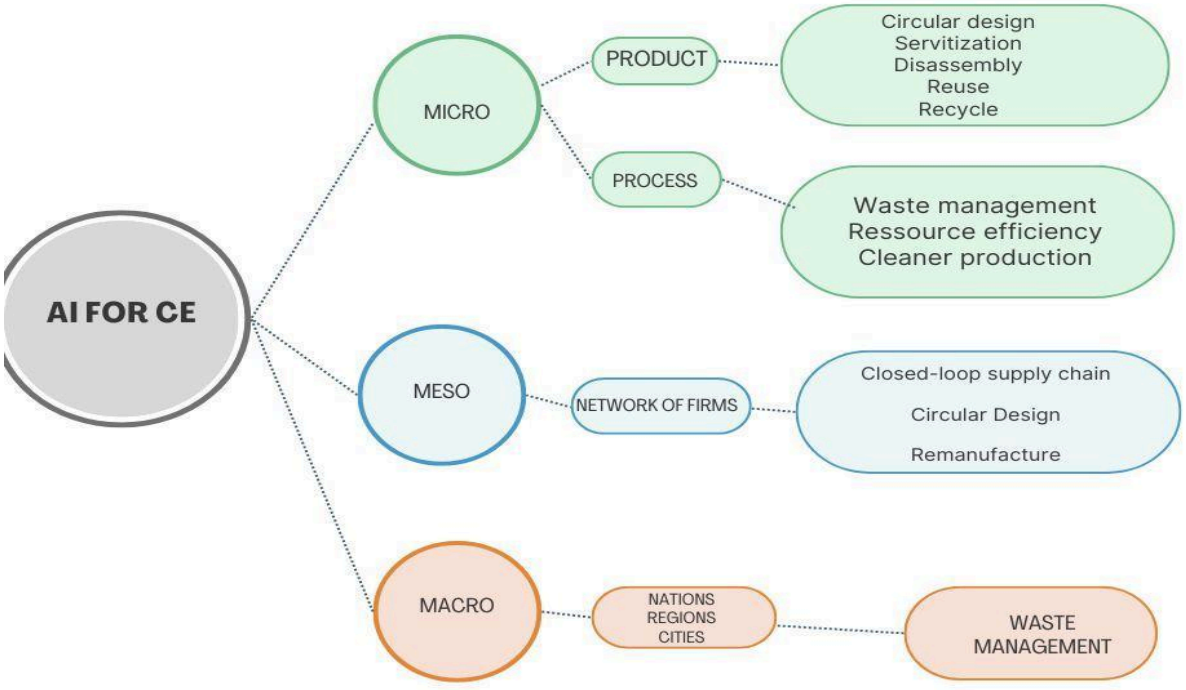


Figure 4 : Using AI in different dimensions of CE

The following are some fundamental solutions for how AI can contribute to achieving a CE :

Smart Waste Management (AI - powered waste sorting systems) AI plays a crucial role in various aspects of waste management, addressing challenges such as managing solid waste accumulation, predicting waste generation, monitoring trash containers, conducting compositional analysis, and enabling intelligent sorting.

Automated Product Design and Optimization Tools

AI in CE streamlines monitoring and boosts manufacturing efficiency. It provides advanced learning and faster decision-making, aiding precise material reuse decisions. This enhances circular product design by reducing resource consumption and increasing material productivity. AI integration spans the product life cycle, encompassing areas like design, operation, and management. These tools use AI to create sustainable and circular products that can be easily repaired, repurposed, or recycled. AI can help in designing products that are durable, modular, and can be easily disassembled.

Product Lifecycle Management AI revolutionises design by aligning customer preferences with product features, optimising manufacturing processes, and elevating customer service to foster smarter, sustainable product-service ecosystems. The use of AI can assist businesses in tracking the lifecycle of their products, from raw materials to disposal, to ensure their effective reuse, recycling, or repurposing. This practice can minimise waste and decrease the environmental impact of the production process.

Circular Supply Chain

CE plays a pivotal role in sustainable supply chain management, focusing on material reuse, recycling, and remanufacturing to improve product utilisation and manufacturing efficiency, while also dividing the life cycle of products and services within supply chains into five key stages: design and development, production, delivery, operation, and end-of-life. AI can assist businesses in creating a circular supply chain by optimising logistics and transportation, reducing waste, and ensuring that products are effectively recycled or repurposed at the end of their useful life.

Smart Energy Management Systems

AI can optimise energy consumption and waste reduction in buildings and communities through SEMs. AI has the potential to improve the effectiveness of the renewable energy

sector by autonomously identifying and forecasting patterns, performing tasks without the need for explicit human direction, optimising supply chain operations, and enhancing decision-making processes. AI algorithms can offer insights and recommendations to improve the energy efficiency of buildings and communities. Predictive analytics can be utilised to forecast energy demand and adjust energy distribution to balance the load. Energy usage data analysis can identify inefficiencies and optimise for greater energy efficiency. AI can detect and diagnose faults and malfunctions in the system and take corrective actions. Additionally, AI can be harnessed for the integration of renewable energy sources by forecasting the energy output from these sources and ensuring a balanced match between the generated energy and the energy demand.

AI-Driven Predictive Maintenance

Systems Human-centric approaches have gained significance in predictive maintenance, thanks to the integration of digital tools. This is particularly crucial as the workforce increasingly engages with emerging technologies like AI for monitoring equipment conditions in maintenance services. Predictive Maintenance is a technique that predicts when equipment or machinery is likely to fail, so that maintenance can be scheduled before the failure occurs. By using AI algorithms and machine learning models, predictive maintenance systems can provide more accurate and reliable predictions. AI can enhance these systems by providing real-time insights, accurate predictions, and root cause analysis. Predicting maintenance needs in advance and optimising maintenance schedules can minimise downtime and reduce maintenance costs, thereby improving the efficiency and reliability of the system.

AI-powered Marketplaces

The rise of platforms and the integration of AI tools into value chains are positioning companies that adopt AI-powered platforms for a competitive advantage. The fast-expanding B2B marketplaces, coupled with changing asset dynamics, emphasise the significance of this trend. These marketplaces facilitate the exchange of materials and reduce waste by matching waste producers with waste consumers. AI can;

- help optimise product design for circularity.
- assist in identifying the best match for waste producers and consumers, optimising the logistics of waste transportation, and reducing landfill waste.

• identify more recyclable materials or design products with modular components that can be easily disassembled and recycled.

• identify opportunities to reuse and recycle materials, reducing waste and minimising the need for new resources.

• provide personalised recommendations on circular products and services, incentivizing customers to participate in circular marketplaces.

• create digital marketplaces for circular products and services, making it easier for businesses and consumers to access and purchase circular products.

• develop new financial models that incentivize CE practices.

• facilitate collaborative consumption, enabling businesses and consumers to share resources and reduce waste.

Intelligent Recycling Systems

AI-driven waste management technology and robotic solutions are transforming waste recovery and recycling processes. This includes scalable waste-processing plants integrating vision-assisted robotics with cloud-based AI systems, AI-guided robotic solutions with advanced vision systems for waste identification, municipal AI-powered waste-sorting stations, AI-supported MRFs (materials recovery facilities) employing sorting robots and optical sorters, robotic arms with grippers for recyclable sorting, and real-time retail waste brand-level logo detection and recognition through AI computer vision to bolster extended producer responsibility efforts. AI can help identify the type of material, its composition, and the best way to recycle it. By using sensors and cameras to identify different materials, AI algorithms can sort waste streams in real-time, reducing the need for manual sorting. Analysing data on the chemical and physical properties of different waste streams, AI algorithms can optimise processing conditions, improving the efficiency and quality of the recycling process. Additionally, AI algorithms can identify defects and impurities in the properties and composition of recycled materials, ensuring that recycled materials meet industry standards. AI can also identify potential issues and take corrective actions, reducing downtime and maintenance costs.

AI-powered Circular Business Models

CE business models offer pathways to achieve sustainable development goals by optimising resource utilisation through actions like closing loops, reducing consumption rates, enhancing

resource efficiency, and minimising material use. Successfully embracing the CE necessitates a strategic shift in how companies generate and extract value, resulting in the creation of a novel value-generation system and the emergence of inventive business models. AI plays a pivotal role in establishing sustainable infrastructural elements to support the foundation of circular businesses. It can contribute to the creation of innovative circular business models, such as AI-based dynamic pricing, and aid in the development and optimization of recycling infrastructure, which is essential for a thriving CE . These models use data and analytics to identify new opportunities for circular business models e.g. product-as-a-service. AI can play a crucial role in supporting circular business models by providing insights into customer behaviour, optimising resource use, facilitating closed-loop systems, designing sustainable products, and optimising supply chains. AI can help in analysing data from various sources, identifying trends, and predicting future demand. AI can be used to analyse customer behaviour and preferences, providing insights that can be used to develop circular business models. By analysing data on purchasing patterns, product usage, and customer feedback, AI can help identify opportunities for; − circular product design, product-service systems, and closed-loop systems, to reuse, recycle, and reduce resource use, − for reducing waste and minimising the need for new resources, for closed loop systems, and improve logistics. − to design products that are more sustainable, recyclable, and repairable.

How make better decisions via AI processes

AI helps to solve problems through pattern recognition, prediction, optimisation, and recommendation generation, based on data from videos, images, audio, numerics, text and more. The development of an AI algorithm typically follows a process of data collection, data engineering, algorithm development, and algorithm refinement, to produce an output which can solve a particular problem. First, the required data is collected, through capturing images and other metadata. The data is then consistently labelled and engineered into a format which is machine-readable and an algorithm is developed. The algorithm is then refined in an iterative process, during which it gets trained on training data sets until it can infer its learning to new and unknown data, so it can be used in real life applications such as visual identification of a particular object.

Realising the potential of AI-enabled circular economy solutions requires awareness of both the maturity and the limitations of AI. For AI to prove solutions, such as the examples mentioned above, it not only requires the four steps of data collection, data engineering, algorithm development, and algorithm refinement, it also requires a clear understanding of the actual problem and what we specifically need AI to solve. Put simply, if humans cannot establish the relevant inputs and outputs clearly, a machine cannot solve a problem. Although not unique to the application of AI for the circular economy, there are challenges which will need to be addressed in order to scale up and capture the full potential of AI. These include: ensuring the development of AI algorithms is value-driven, so the technology is safe and beneficial to society; ensuring that the technology is held to account by humans; avoiding creating or reinforcing unfair bias; and incorporating privacy design principles for use of data. The transition to a circular economy can not be done by one company alone; it requires value chains and an entire network and ecosystem of partners to build trust and to work together.

AI can help unlock circular economy opportunities by improving design, operating business models, and optimising infrastructure :

Design circular products, components and materials

Circularity requires more features to be taken into consideration for the design of products, components, and materials, such as disassembly, upgradability, or recycled content. Add to this list of features the wide choice of materials and the possibilities of manipulation of structures with 3D printing and other manufacturing techniques, and the design options become countless. AI technology can be a helpful tool to enable designers to manage this complexity when making decisions. A continuous feedback process where designers test and refine AI generated design suggestions could lead to a better design outcome in a shorter time period. Design of new materials can help to substitute harmful chemicals and materials. To design a new material, material scientists need to evaluate a significant amount of data about the structure and properties of materials, which AI could analyse quickly to suggest new materials. In addition, by training an algorithm to analyse known chemical data, AI could

potentially be used to predict the toxicity of chemicals or materials where it is not known in a more economic and efficient way.

Based on theoretical and empirical results, this thesis introduces a roadmap for data driven circular value creation by AI. Roadmap for circular value creation by AI. This roadmap can be used as a tool by practitioners to understand the steps they need to take to achieve circular value creation. First, they need to identify the best circular solution based on the ReSOLVE framework and choose the aspect that best suits their business. After that, they should identify the use of data that is generated through their processes that benefits CE principles. Next, they should choose the most suitable AI applications according to data-driven solutions based upon which they can decide what type of innovation is needed for their BM transformation. Finally, they need to choose partners based upon their BM and activities and expand their ecosystem.

Design thinking strategy can be useful for creating innovative circular product :

1.EMPATHIZE -> innovation should be human centered -> recognize the need for low cost materials and combine sustainability and use of AI.
2.DEFINE -> innovation should solve a problem -> design for recycling or waste sorting optimization.
3.IDEATE -> innovation is born from a clash of ideas -> brainstorming ideas : low cost materials, AI, sustainability, circularity.
4.PROTOTYPE -> innovation should be brought to life -> build an ecommerce platform for circularity based in AI systems.
5. TEST -> innovation should be refined -> use for testing AI tools like review analysis and download tools.

A company using AI for materials development to accelerate the material design process is Citrine Platform. Working with materials data, Citrine Platform uses algorithms and AI technology to develop new chemicals and materials for high performance applications. For

example, using the platform to find a 3D printable, aerospace-grade aluminium alloy enabled the possible candidates for the alloy to be narrowed from 10 million to only 100. Using AI technology that is adaptive and sequentially learns as experiments progress can enable companies to augment the traditional 'trial and error' process, and improve and optimise their design and innovation process for materials. Applying similar AI techniques more broadly could lead to the rapid prototyping and design of materials, components and products which can be used and reused and safely circulated in the economy.

Operate circular business models

Developing successful and profitable circular business models requires the organisation of business functions such as marketing, pricing, and sales, after sales services, customer support, logistics, and reverse logistics, underpinned by circular economy principles.

A compelling use case in which AI is used to support price setting, forecast demand, and to create trading platforms for secondary resources, components and products, is Stuffstr. Stuffstr buys and collects used products from consumers and sells them in second hand markets. An AI algorithm helps Stuffstr to set competitive prices for the seller, while offering Stuffstr a good margin on the second hand market.

Stuffstr offers consumers the opportunity to buy back used household items, with an initial focus on clothing and apparel, in exchange for vouchers, which can be spent at the original apparel retailer. As part of this process, Stuffstr collects the products and re-sells them through existing secondary markets.

Stuffstr contributes to a circular economy by boosting re-use of apparel by giving it a second life. The service offers consumers a low hassle solution for getting rid of unused stuff, with a financial incentive. The concept increases awareness for the value of unused clothing and also encourages consumers to sell back items they no longer need or want so they can be circulated

Stuffstr uses AI algorithms for the pricing of both the products they buy from consumers and the products they sell in secondary markets. The backend of their service uses machine

learning to ensure a consistent classification of all re-sale items. Finally, AI helps refine Stuffstr's sales strategy through constant experimentation and rapid feedback loops.

For retailers, Stuffstr solves real business problems by providing an additional revenue stream as well as an improvement in consumer loyalty. Stuffstr itself generates revenue by reselling used apparel and servicing fashion brands by ensuring that their products are only sold in certain secondary markets. For consumers, the company pays for used and/or unwanted apparel in a transparent and convenient manner.

Optimise infrastructure to ensure circular product and material flows

A key feature of a circular economy is that materials and products are not consumed and disposed of, but used over and over again. This requires reusing, repairing, remanufacturing, and recycling of technical products and winning back nutrients from biological waste streams for which an efficient and extensive infrastructure for collecting, sorting, separating, treatment, and redistribution is needed.

ZenRobotics, for example, works with cameras and sensors, whose imagery input allows AI to control intelligent waste sorting robots. These robots can reach an accuracy level of 98% in sorting myriad material streams, from plastic packaging to construction waste.

ZenRobotics uses AI to improve and optimise infrastructure for a circular economy.

Founded in 2007, ZenRobotics was the first company to apply AI and robotics in a demanding waste processing environment. The company combines AI and robotics to recover recyclables from waste. Contributing to a circular economy

ZenRobotics's technology allows greater flexibility in waste sorting, enabling operators to react quickly to changes in a waste stream and increasing the rate of recovery and purity of secondary materials by using AI.

Waste is monitored by cameras and sensors. The AI software, called ZenBrain, analyses the sensor data, creating an accurate real-time analysis of the waste stream. Based on this analysis, the heavy-duty robots make autonomous decisions on which objects to pick, separating the waste fractions quickly with high precision.

ZenRobotics waste sorting solutions offer opportunities to improve performance and efficiency of waste sorting. This increases the value that can be generated from material streams through improved recovery rates and overall quality of outputs.

"Intelligent robotic systems can process almost any given waste stream, and sorting capabilities can be redefined for every new market situation—even on a daily basis. Furthermore, increased flexibility in recognition gives plant operators the possibility to explore new use cases."

[12]

5. Explainable Artificial Intelligence (XAI)

Due to lack of Transparency and Explainability, AI algorithms can be complex and opaque, making it challenging to understand how they arrive at specific decisions or recommendations. This lack of transparency can hinder trust and acceptance of AI systems. Ensuring transparency and explainability in AI models and providing clear insights into their decision-making processes is crucial.

Artificial intelligence (AI) and machine learning (ML) have demonstrated their potential to revolutionise industries, public services, and society, achieving or even surpassing human levels of performance in terms of accuracy for a range of problems. However, their most successful offering in terms of accuracy—deep learning (DL) is often characterised as being "black box" and opaque.

Since, the applications of advanced AI and ML, including DL, are now growing rapidly, encompassing the digital health, legal, transport, finance, and defence sectors, the issues of transparency and explainability are being recognized increasingly as critically important.

For example, a search in Google Trends (https://trends.google.com/trends/) reveals that in the last decade publications using the terms "DL" and "explainable AI" (XAI) both grew significantly, but while the curve for DL is now in a saturation stage over the last 3 years or so, the curve for XAI is growing exponentially starting precisely 3 years ago.This is not

coincidental and demonstrates that as the huge increase in interest towards DL starts to saturate, interest towards XAI is gearing up trying to address open research and acceptability questions.

Top explainable AI (XAI) startups

Stardog

Founded in 2006, Stardog is a software company that has developed Voicebox, an AI-powered data assistant for businesses. Voicebox lets employees ask questions about company data and get clear, explainable answers quickly. Accessing insights locked away in enterprise databases often requires coding skills or waiting on data analysts. Voicebox simplifies this by letting anyone query data stores through natural conversation. Users can ask business questions like "What were our top selling products last quarter?" and Voicebox serves up the answer along with relevant charts or tables.

Anthropic

Founded in 2021, Anthropic is a startup working on safe artificial intelligence (AI) systems that are trustworthy and helpful. They bring together experts in machine learning, physics, ethics, and product design to create AI that works reliably for real-world uses. Many existing AI tools have flaws that lead to biased results or cause other unintended harm. Anthropic develops methods to improve AI safety so these systems remain under human control. Their teams rigorously test for risks during training to prevent errors down the line.

Anthropic's first product is Claude – a conversational assistant focused on being truthful, harmless, and honest even when faced with tricky questions. Most chatbots try to make up answers even when wrong. Claude admits what it does not know to establish clear trust with users.

Reality Defender

Founded in 2021, Reality Defender offers a platform that detects deep fake videos, images, and audio to stop fraud. Deepfakes use AI to make fake content that looks and sounds real. Many companies face issues with false user profiles or altered documents. Reality Defender

lets groups upload media to scan for deep fake manipulation. Their technology gives each file a risk score to show the likelihood it's fake.

Users can set up email alerts for any high-risk content found. The platform generates PDF reports with details on what factors flag a file as an AI-created fake. Reality Defender also allows reviewing visual forensics online to inspect indicators within images and video. By spotting doctored files and synthetic impersonations early, Reality Defender aims to help corporations, government groups, and social platforms control malicious misinformation and fakes. Their API allows partners to check user-generated content at scale. **[17]**

Explainable Artificial Intelligence has experienced a significant growth over the last years, as the figure 4 illustrates. This is due to the widespread application of machine learning, particularly deep learning, that has led to the development of highly accurate models but lack explainability and interpretability. **(2)**

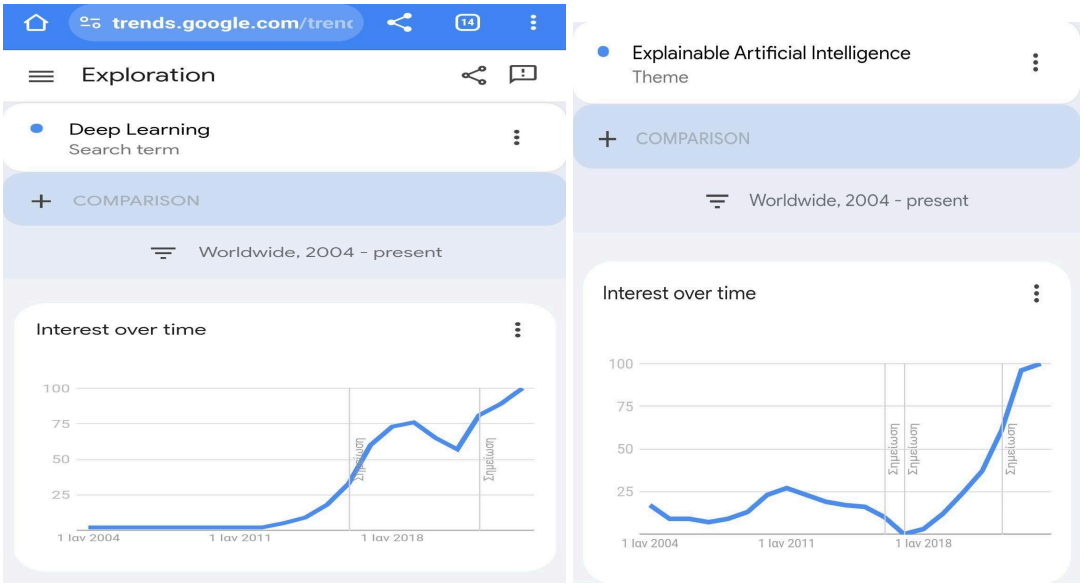


Figure 5 illustrates the interest evolution towards two terms according to Google Trends : (a) deep Learning (DL) (b) Explainable Artificial Intelligence (XAI)

The first methods of AI, such as decision trees, symbolic AI, expert systems, fuzzy logic, forms of artificial neural networks(ANNs), support vector machines(SVMs) and radial -basis function(RBF).

In the last few years, explainability has become an important issue due to high performance of accuracy and interpretability.

The issue of explainability is an open research question for some of the most successful (in terms of accuracy) forms of ML such as SVMs, DL and many of ANNs, as Figure 5 illustrates.

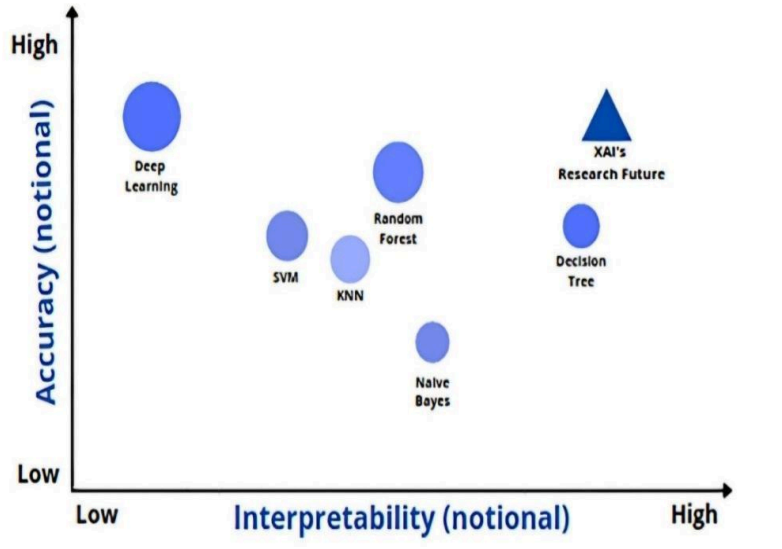


FIGURE 6 : Accuracy vs interpretability for different machine learning models.

The five main perspectives for the need for XAI

•Regulatory perspective: Black-box AI systems are being utilised in many areas of our daily lives, which could be resulting in unacceptable decisions, especially those that may lead to legal effects. Thus, it poses a new challenge for the legislation. The European Union's General Data Protection Regulation (GDPR) is an example of why XAI is needed from a regulatory perspective. These regulations create what is called the "right to explanation," by which a user is entitled to request an explanation about the decision made by the algorithm that considerably influences them. For example, if an AI system rejects one's application for a loan,

the applicant is entitled to request justifications behind that decision to guarantee it is in agreement with other laws and regulations. However, the implementation of such regulations is not straightforward, challenging, and without an enabling technology that can provide explanations, the "right to explanation" is nothing more than a "dead letter".

•Scientific perspective: When building black-box AI models, we aim to develop an approximate function to address the given problem. Therefore, after creating the black-box AI model, the created model represents the basis of knowledge, rather than the data . Based on that, XAI can be helpful to reveal the scientific knowledge extracted by the black-box AI models, which could lead to discovering novel concepts in various branches of science.

•Industrial perspective: Regulations and user distrust in black-box AI systems represent challenges to the industry in applying complex and accurate black-box AI systems. Less accurate models that are more interpretable may be preferred in the industry because of regulation reasons. A major advantage of XAI is that it can help in mitigating the common trade-off between model interpretability and performance, thus meeting these common challenges. However, it can increase development and deployment costs.

•Model's developmental perspective: Several reasons could contribute to inappropriate results for black-box AI systems, such as limited training data, biased training data, outliers, adversarial data, and model overfitting. Therefore, what black-box AI systems have learned and why they make decisions need to be understood, primarily when they affect humans' lives. For that, the aim will be to use XAI to understand, debug, and improve the black-box AI system to enhance its robustness, increase safety and user trust, and minimise or prevent faulty behaviour, bias, unfairness, and discrimination. Furthermore, when comparing models with similar performance, XAI can help in the selection by revealing the features that the models used to produce their decisions. In addition, XAI can serve as a proxy function for the ultimate goal because the algorithm may be optimised for an incomplete objective. For instance, optimising an AI system for cholesterol control while ignoring the likelihood of adherence.

•End-user and social perspectives: In the literature of deep learning, it has been shown that altering an image such that humans cannot observe the change can lead the model in producing a wrong class label. On the contrary, completely unrecognisable images to humans can be recognizable with high confidence using DL models. Such findings could raise doubts about trusting such black-box AI models. The possibility to produce unfair decisions is another concern about black-box AI systems. This could happen in case black-box AI systems are developed using data that may exhibit human biases and prejudices. Therefore, producing explanations and enhancing the interpretability of the black-box AI systems will help in increasing trust because it will be possible to understand the rationale behind the model's decisions, and we can know if the system serves what it is designed for instead of what it was trained for. Furthermore, the demand for the fairness of black-box AI systems' decisions, which cannot be ensured by error measures, often leads to the need for interpretable models **(6)**

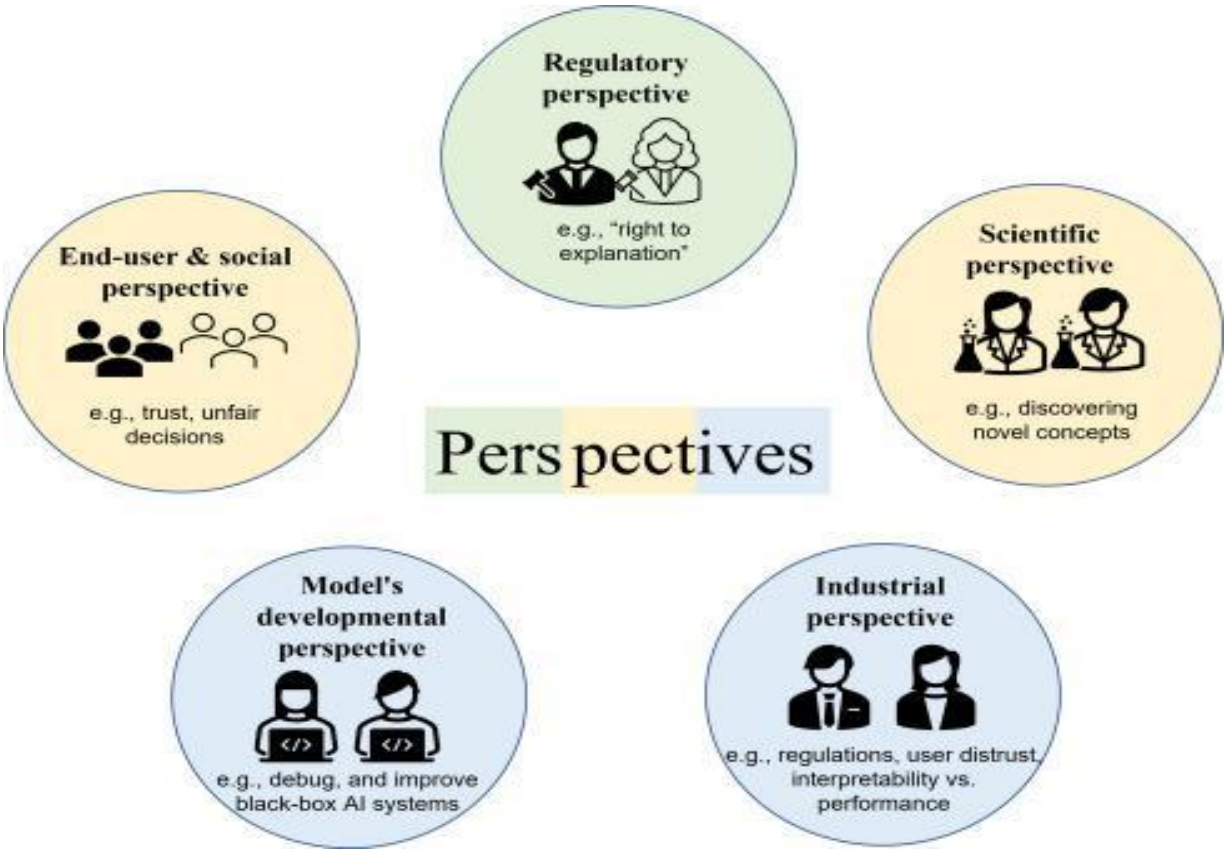


Fig. 7 : The five main perspectives for the need for XAI **(6)**

Critical importance of XAI

Explanations are essential for users to effectively understand, trust and manage powerful artificial intelligence applications.

Unfortunately, most of the models that have been built with ML and DL, named as 'black-box' by scholars because their underlying structures are complex, non-linear and extremely difficult to be interpreted and explained to laypeople. This opacity has created the need for XAI architectures that is motivated mainly by three reasons, : i) the demand to produce more transparent models; ii) the need of techniques that enable humans to interact with them; iii) the requirement of trustworthiness of their inferences. Additionally, as proposed by many scholars, models induced from data must be liable as liability will likely soon become a legal requirement. Article 22 of the General Data Protection Regulation (GDPR) sets out the rights and obligations of the use of automated decision making. Noticeably, it introduces the right of explanation by giving individuals the right to obtain an explanation of the inference/s automatically produced by a model, confront and challenge an associated recommendation, particularly when it might negatively affect an individual legally, financially, mentally or physically. By approving this GDPR article, the European Parliament attempted to tackle the problem related to the propagation of potentially biased inferences to society, that a computational model might have learnt from biased and unbalanced data. **(3)**

XAI introduce three basic terms to indicate the opposite of the "black box" :
Transparency : a model is considered to be transparent if it has the potential to be understandable.
Interpretability: is defined as the capacity to provide interpretations in terms that are understandable to a human.

Explainability : is related with the notion of explanation as an interface between humans and an AI system. An AI system is considered to be explainable if it is accurate and comprehensible to humans.

Four reasons supporting the necessity to explain the logic of an inferential system or a learning algorithm were suggested in :

• explain to justify - the decisions made by utilising an underlying model should be explained in order to increase their justifiability;

• explain to control - explanations should enhance the transparency of a model and its functioning, allowing its debugging and the identification of potential flaws;

• explain to improve - explanations should help scholars improve the accuracy and efficiency of their models;

• explain to discover - explanations should support the extraction of novel knowledge and the learning of relationships and patterns.

XAI aims to help humans to understand why a machine decision has been reached and whether or not it is trustworthy. Consequently, XAI is inevitably a paradigm on how to bridge machine intelligence and human intelligence, with the goal being to enable and widen the acceptance of AI systems by human subjects. In this sense, XAI can be interpreted as “AI for people”.

The research initiative of XAI raises concerns of giving such intelligent systems too much power without the ability to explain the decision-making process lying underneath such complex systems to domain experts (e.g., medics, lawyers, financial experts, etc.) in terms, and in a form, understandable to them.

XAI models derived from deep neural networks can also help in understanding the mechanisms of intelligence in the human brain. The ultimate goal of XAI could be redefined as the pursuit of fully understanding how human intelligence originates from neurons. **(1)**

The purpose of an explainable AI (XAI) system is to make its behaviour more intelligible to humans by providing explanations. There are some general principles to help create effective, more human understandable AI systems : The XAI system should be able to explain its capacities and understandings ; explain what it has done, what it is doing now and what will happen next. However, every explanation is set within a context that depends on the task, abilities and expectations of the user of the AI system**. (4)**

As figure 3 reveals, XAI is a facet application of artificial intelligence committed to developing models and algorithms that provide clear and understandable explanations for their decisions. Unlike traditional opaque AI systems, XAI aims to enhance transparency and interpretability, enabling users to grasp the rationale behind AI- generated outcomes. The central goal is to narrow the gap between complex machine learning processes and human understanding, fostering trust and accountability in AI applications.

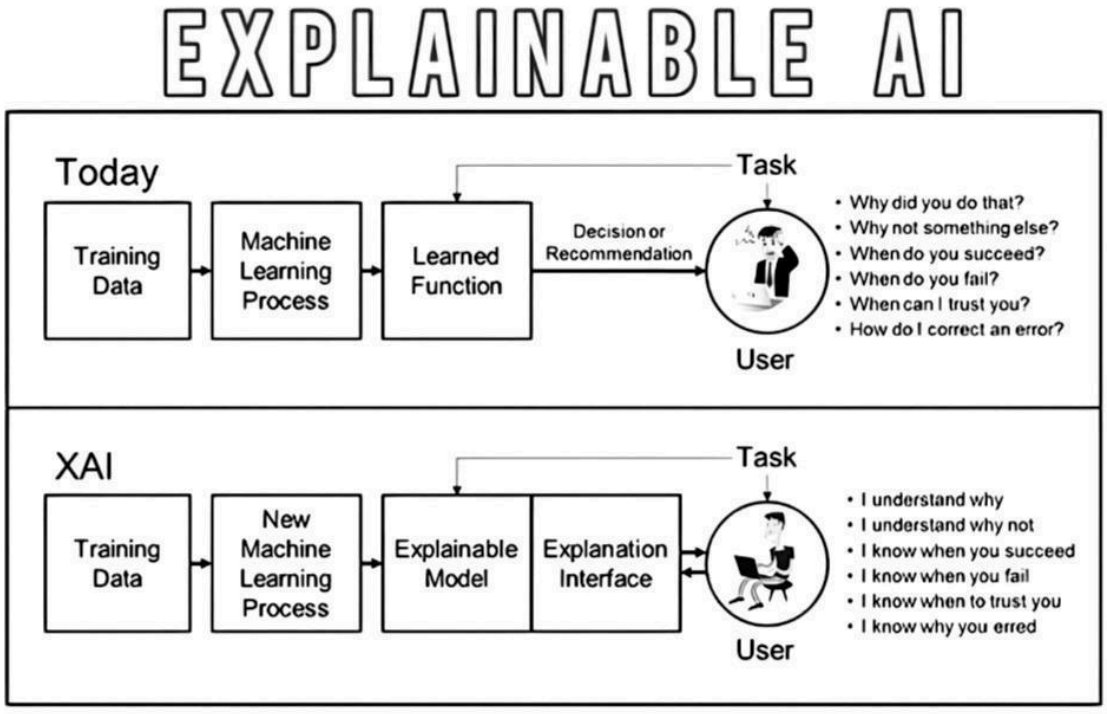


Figure 8 : XAI vs traditional opaque AI systems.

To the best of our knowledge, we should attempt to review a wider body of literature that has led to the definition of four clusters: (I) reviews focused on specific aspects of XAI, (II) the theories and notions related to the concept of explainability, (III) the methods aimed at explaining the inferential process of data-driven and knowledge-based modelling approaches, and (IV) the ways to evaluate the methods for explainability. Many studies within XAI have focused on improving the quality and widening the variety of explanations for several types of learning approaches with data.

Development of new methods for explainability

More than 200 scientific articles were found that aim at developing new methods for explainability. Over time, researchers have tried to comprehend the inner mechanics of data driven, knowledge-driven models in various ways. From an examination of these articles, two main criteria exist for discriminating methods for explainability:

• scope - it refers to the scope of an explanation that can be either global or local. In the former case, the goal is to make the entire inferential process of a model transparent and comprehensible as a whole.

• stage - it refers to the stage at which a method generates explanations. Ante-hoc methods are generally aimed at considering explainability of a model from the beginning and during training to make it naturally explainable while still trying to achieve optimal accuracy or minimal error; post-hoc methods are aimed at keeping a trained model unchanged and mimic or explain its behaviour by using an external explainer at testing time.

Taking into account the articles examined, we propose additional criteria:

• problem type - methods for explainability can vary according to the underlying problem: classification or regression;

• input data - the mechanisms followed by a model to classify images can substantially differ from those used to classify textual documents, thus the input format of a model

(numerical/categorical, pictorial, textual or times series) can play an important role in constructing a method for explainability;

• output format - similarly, different formats of explanations useful for different circumstances can be considered by a method for explainability: numerical, rules, textual, visual or mixed.

Evaluation of methods for explainability

The proposal of many methods for explainability pushed authors to focus also on their evaluation. Different evaluation metrics were proposed and found in the literature as well as different types of evaluation were conducted. A thorough review of these studies led to the identification of two main ways to evaluate methods for explainability

: • objective evaluations - it includes research studies that employed objective metrics and automated approaches to evaluate methods for explainability;

• human-centred evaluations - it contains those studies that evaluated methods for explainability with a human-in-the-loop approach by involving end-users and exploited their feedback or informed judgement.

In summary, an high-level structure of a current state-of-the-art in XAI is depicted in figure 4. This sequence usually starts from input data that is then used for modelling purposes, employing connectionist data-driven learning or symbolic reasoning knowledge-based paradigms. After a model has been formed, then a XAI method is applied for its analysis, knowledge discovery, supporting its interpretability. This phase provides the end-users of these models with one or more “explanators” for the purpose of its explainability. Eventually, very few scholars have proposed approaches for evaluating such layer of explainability, either proposing formal, objective metrics or involving human-centred evaluation with model designers and end-users **(4)**

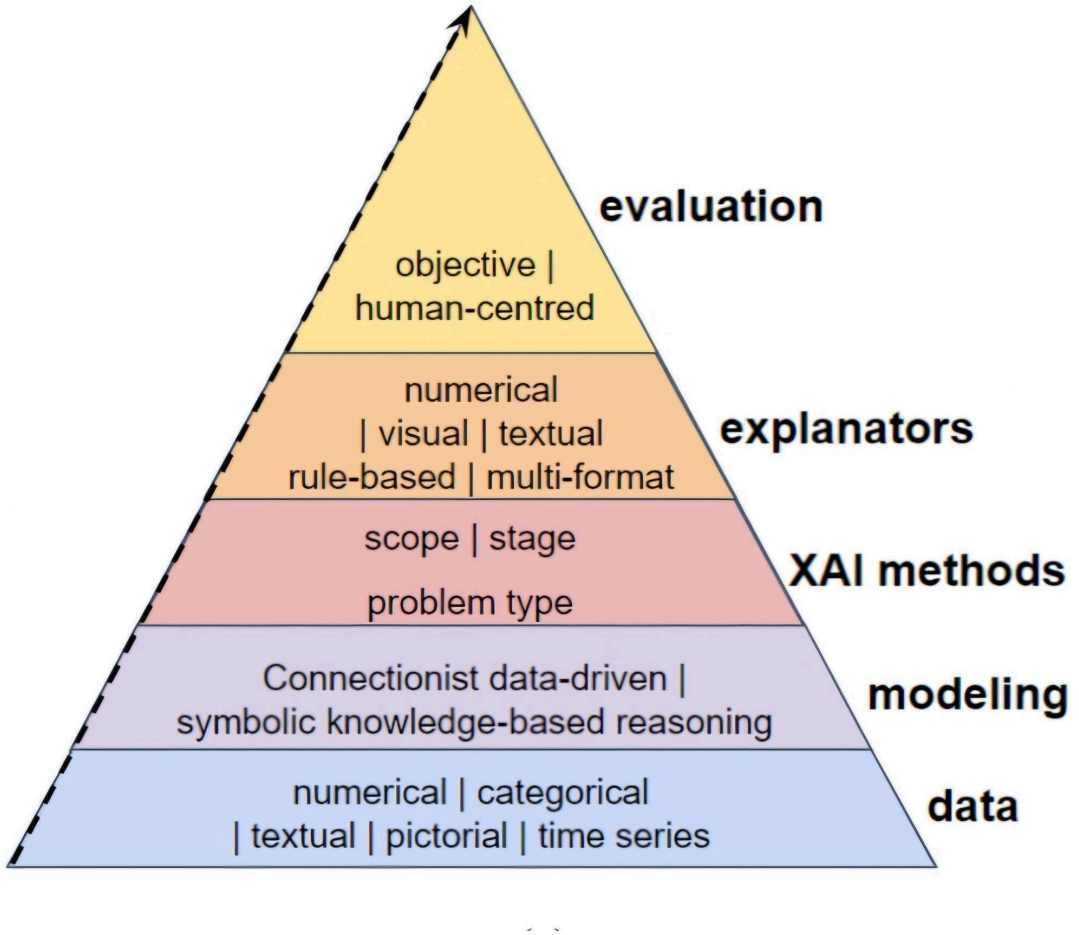


Figure 9 : State of art frameworks for XAI **(4)**

Explainable AI for circular economy : Opportunities and challenges.

<u>New trend : How to form AI explainability framework to environmental management</u>

Explainable AI (XAI) in environmental management research requires a holistic focus on three main aspects: input, AI model and output. Generalizable AI networks with expected behaviour from the human perspective are required for application fields. Smart trash bins are examples of solutions to sort waste using AI perception power. Explainable networks can

facilitate the robotization of waste sorting in material recovery facilities. Moreover, XAI can be used to enforce environmental protection regulations and detect unlawful activities related to waste disposal and handling. Input data augmentation is critical to AI network generalizability and prevention of overfitting as a common issue in application fields, including environmental management research. The first framework pillar is a systematic input data augmentation using four strategy groups to assist newcomers to the AI field and subject matter experts in environmental management. Augmentation strategies can be deployed individually or combined depending on available waste data and the use case. Smart augmentations are state-of-the-art image transformations that optimally combine geometric, photometric and functional transformations.

The second component of the explainability framework focuses on monitoring AI networks and their kernel weight histograms. This component is critical to environmental management research since complex and deep AI networks are developed and trained on large datasets containing many everyday object categories.

Such networks impose unreasonably high computation costs to application fields outside computer science, in which real-world problems have narrower but deeper scopes. Monitoring weight histograms can explain the contribution of network layers to the final prediction of AI networks. Observing the concentration of weights around zero indicates the possibility of implementing leaner variants of deep AI networks, which is preferable for deployment on edge devices.

Monitoring AI networks can be continued by experimentation on optimal network parameters that explain fluctuations in predicting target outputs.

The third pillar of AI network explainability is monitoring AI network outputs regarding interpretability and robustness. Critical features leading to output predictions are identified using noise tunnel, gradient SHAP and occlusion strategies. The robustness of AI network outputs is explained and monitored by generating counterfactual image examples that mislead state-of-the-art networks. Adversarial attacks, including FGSM, PGD, minimal perturbation and feature ablation, challenge networks to predict wrongly with high

confidence levels. The three aspects of the proposed XAI framework contribute towards establishing responsible AI in cross-disciplinary fields, including environmental management research.

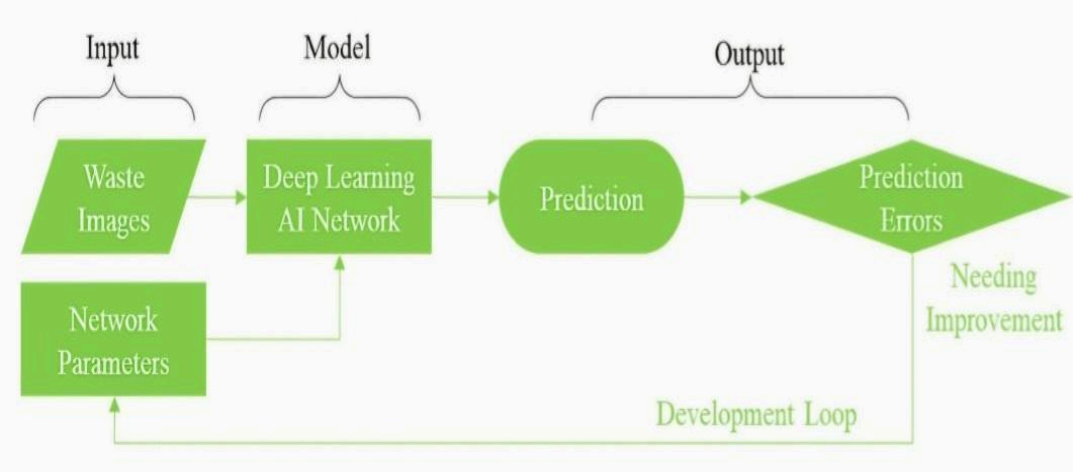


Figure 10 : Triadic structure of AI networks input, model and output.

The implementation of AI networks in environmental management research is fast growing. However, the tension between performance and explainability remains, even for state-of-the-art networks. This study proposes an explainability framework with a triadic structure focusing on input, AI model and output. The framework is a non-trivial departure from the trend in existing XAI methods, including “SHAP” and its variants, which mainly emphasise output explanations.

There are opportunities for future research based on current limitations. Specialised input datasets for different aspects of environmental management research are required to generate context-specific augmentation strategies that maximise the generalizability of AI networks. Moreover, advanced visualisation tools are required to clearly explain the contribution of network layers and related parameters to AI predictions. Finally, output

explainability needs improvement to include more criteria than interpretability and robustness. **(9)**

XAI for production routine and processes

XAI holds great potential for enhancing operators in modern factories, revolutionising the way they interact with AI systems and improving their decision-making capabilities. By providing understandable and transparent explanations for the outputs of AI models, XAI empowers operators to gain deeper insights into the underlying processes and logic behind AI-driven recommendations or predictions.

This enables operators to make informed judgments, validate AI-generated suggestions and identify potential errors or biases in the system's output. With XAI, operators can trust AI systems as reliable assistants, leveraging their expertise while retaining control and accountability. The ability to understand and interpret AI's reasoning fosters collaboration between operators and AI systems, leading to more effective problem-solving, optimised processes and improved overall factory performance. XAI serves as a valuable tool in bridging the gap between human operators and intelligent machines in order to maximize efficiency and productivity in modern factory settings.

Potential applications of XAI in product optimization are as follows:

1. Feature Importance Analysis: XAI techniques can identify the most influential features or factors affecting product performance, allowing businesses to prioritise and optimise those aspects for enhanced product quality.

2. Failure Analysis and Predictive Maintenance: XAI techniques aid in identifying potential failure modes, understanding failure causes and predicting maintenance needs. This enables operators to proactively address maintenance issues, reducing downtime and optimising product performance.

3. Continuous Improvement and Iterative Optimization: XAI enables operators to continuously monitor and evaluate product performance, identifying areas for improvement

and iterative optimization. By understanding the factors contributing to product success or failure, operators can drive ongoing enhancements and innovation.

By enhancing transparency, trust, and collaboration between operators and AI systems, XAI paves the way for more efficient, cost-effective, and high-quality process operations.

Methods like questionnaires, user stories, user journey, and personas play a crucial role in exploiting XAI for product and process optimization. These methods facilitate a deeper understanding of user needs, preferences, and experiences, which are essential for designing and implementing effective XAI systems.

1. Questionnaires: valuable tools for gathering quantitative and qualitative data from users. They help in capturing user perspectives, expectations and feedback related to product or process optimization, collecting valuable insights that inform the development of XAI models.

2. Personas: represent fictional archetypes of target users, based on real user research. They provide a human-centred perspective, helping businesses empathise with and understand the needs and motivations of different user groups. Personas facilitate the creation of XAI systems that meet various user requirements, ensuring, in the case of CNHi, the optimization of the XAI web app interface for different maintenance profiles.

3. User Stories: they provide a narrative description of users' interactions with a product or process. They capture users' goals, motivations, and pain points, highlighting key aspects that need to be considered for optimization. User stories also help in identifying specific areas where explainability is crucial to enhance user trust and decision-making.

4. User Journey: maps to visualise the end-to-end experience of users throughout their interaction with a product or process. These maps illustrate touchpoints, pain points, and opportunities for optimization. Understanding the user journey helps in designing XAI systems that provide relevant explanations at the right moments, ensuring a seamless and trusted user experience.

As a result, we are sure that a XAI platform scrap management system by the use of sensors can help minimise production scrap, restore and reuse material, collect scrap material in order to separate and manage scrap adequately for remake, resell or recycle.

6. Barriers to the use of AI in the transition to a CE

Despite the potential benefits of using AI in CE, there are several obstacles that need to be addressed. Firms encounter obstacles when adopting CE and digitization business models, such as data management issues and high adoption costs. Regulatory gaps, limited environmental education, lack of conservation culture, and low market demand pressure pose further challenges to CE-driven digitalization. Technological and strategic barriers, as well as negative consequences of disruptive technologies, like predictability issues and data quality variations, hinder CE adoption. Governmental support is often lacking, compounded by insufficient data on material flows, hampering policy efforts to address environmental concerns.

Here are some of the basic obstacles of using AI in CE:

Data quality/ Data volume/ Data privacy and security: To effectively use AI for CE, high-quality data is required. This includes data on resource flows, waste streams, product life cycles, and other factors. However, such data may not always be available, or it may be difficult to obtain. Additionally, the data collected may not always be relevant or applicable to the specific context in which it is being used. To effectively implement AI technology in a CE, large amounts of data are needed. However, such data may not be readily available, especially in developing countries or in industries that are not yet fully digitised. Data privacy and security are also significant concerns when using AI for CE. The collection and processing of personal data may raise privacy concerns, and the use of AI may increase the risk of data breaches and cyber-attacks.

Bias and discrimination: AI algorithms can be biased if they are trained on incomplete or biased data. This can result in unfair outcomes, particularly for marginalised or vulnerable communities.

Lack of technical expertise: The development and implementation of AI applications require technical expertise, including data science, machine learning, and programming. There may be a shortage of people with these skills, making it difficult for some organisations to adopt AI technology.

Cost: The development and implementation of AI applications can be costly, particularly for smaller businesses and organisations with limited resources.

Ethical considerations: The use of AI in a CE raises ethical questions regarding privacy, data security, algorithmic bias, potential impact on employment, and the displacement of workers, as well as the impact on social and environmental justice. Addressing these concerns is crucial in building trust in AI technology and ensuring that its benefits are widely shared.

Dynamic structure of economies and societies: AI models may not always be able to account for external factors that can affect CE outcomes, such as changes in policy, market conditions, or consumer behaviour. Additionally, AI models may not always capture the social and economic concerns related to the CE. To overcome these limitations, it is essential to use AI in conjunction with other tools and approaches and to develop context-specific and tailored AI models that meet the needs and goals of specific communities and regions. Moreover, it is important to use AI in a responsible and transparent manner and incorporate social and ethical considerations into its development and implementation.

Strategies to enhance AI's contribution to circular economy

To maximize the strengths and opportunities of AI while mitigating its weaknesses and threats, several strategic actions can be proposed:

(A) Enhance Data Availability and Quality

1. Digitise Data Capture: Implement advanced technologies to digitally capture more diverse and extensive datasets. This will provide a richer foundation for AI learning, improving the models' ability to recognize complex patterns and relationships.

2. Concept Drift Detection To address deficiencies in data quality, it is recommended to conduct thorough model maintenance, allowing for modifications when alterations in the database are observed. One method of exploring this issue is through the study of concept drift. The central objective of this approach is to identify and, consequently, address alterations within the system that can result in a reduction in the performance of AI models .
3.Comprehensive Data Examination: Regularly review and clean data sets to identify and correct errors and biases. This ensures the reliability and accuracy of the data, leading to more robust AI models.

4. Facilitate Data Sharing: Establish frameworks for data sharing between researchers, companies, and other stakeholders. This can be achieved through data sharing agreements and collaborations, while maintaining strict data privacy and security protocols. Enhancing data availability and quality is fundamental to AI's success in sustainability. By ensuring data integrity and encouraging data sharing, AI models can be trained on richer and more accurate datasets, leading to better performance and more reliable results.

(B) Promote Collaborative Efforts

1. Shared Infrastructure for SMEs: Small and medium enterprises (SMEs) can reduce costs by building common infrastructures and sharing resources. Collaboration on topics like cybersecurity and AI business value can lead to collective improvements.

2. Public-Private Partnerships: Encourage partnerships between academia, industry, and policymakers to promote knowledge exchange and develop innovative solutions for sustainability challenges. Promoting collaborative efforts is crucial for leveraging AI's full potential. By pooling resources and expertise, various stakeholders can overcome individual limitations, leading to more robust and innovative solutions for circular economy strategy.

(C) Adopt Explainable AI and Ethical Standards

1. Explainable AI (XAI): Invest in developing and implementing XAI techniques such as layer-wise relevance propagation. These methods improve the transparency of AI decisions, making them more understandable and trustworthy.

2. AI Ethics: Develop and adhere to ethical guidelines for AI usage. Transparent AI ethics can help mitigate social concerns and legal risks, ensuring that AI applications are aligned with societal values. Adopting explainable AI and ethical standards is vital to gaining public trust and ensuring that AI applications are effective and socially responsible. By making AI decisions more transparent and adhering to ethical guidelines, stakeholders can address concerns related to AI's impact on society.

(D) Create Regulatory and Incentive Frameworks

1. Incentivize Data Sharing: Create incentives for companies to share data by offering benefits such as tax breaks or research grants.

2. Robust Regulation: Implement regulations that balance the need for data privacy and security with the benefits of data sharing. Effective data governance frameworks are essential to foster innovation while protecting stakeholders' interests. Implementing regulatory and incentive frameworks is essential to guide the responsible development and deployment of AI. By incentivizing data sharing and establishing robust regulations, stakeholders can ensure that AI development aligns with societal values and circularity goals.

By adopting these strategies, the potential of AI to contribute to sustainability efforts can be improved, addressing both current weaknesses and future opportunities. These measures can also mitigate threats and ensure that AI developments align with global sustainability goals.

SWOT ANALYSIS

SWOT ANALYSIS is evaluated with regard to the common guideline 'maximizing strengths and opportunities, transforming weaknesses into strengths, and minimizing threats'

I form a SWOT analysis that can be useful for further research.

AI helps to simplify decision making, workflow automation and predictions.

AI gives great opportunities to increase future productivity, increase awareness of AI and build a strategy for environmental protection and circularity.

The problem is that very often the data are insufficient and there is a lack of specialized worldwide regulation and legislation.

We have to take care of the following threats :ethical and legal problems, privacy issues, technical issues, security vulnerabilities, misuse of AI, economic risk due to high cost and inaccurate data and results.

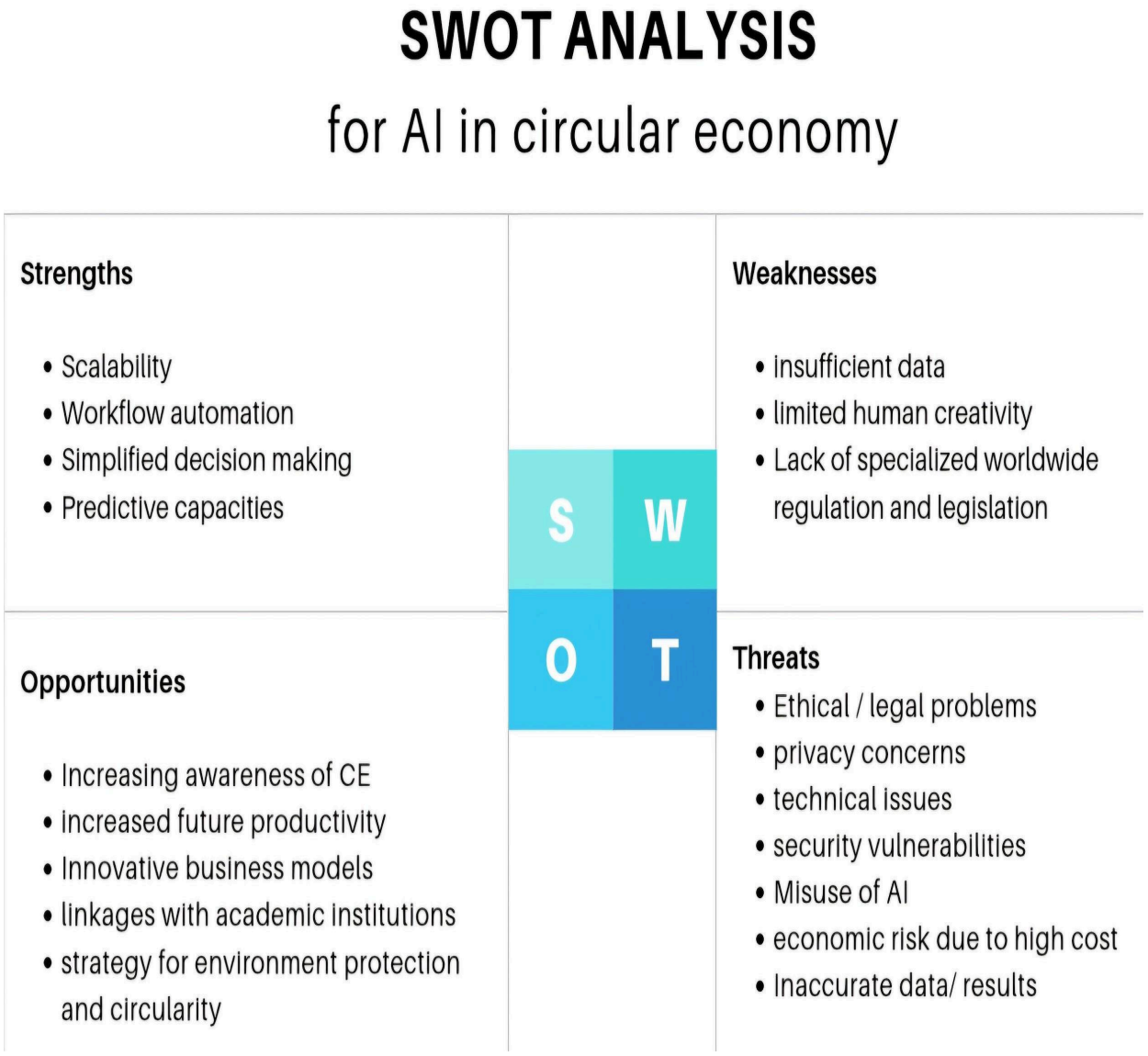


Figure 11 : SWOT analysis of AI in CE

Generator of innovation in Circular economy

Business opportunities in circular economy arise from the successful combination of selection and use of new technology (AI, XAI etc) - business model (B2B, B2C) & revenue model (subscription, brokerage etc.) while simultaneously studying the selected market and following a business plan which constantly analyzes the team work progress and the environment.

We can find a new business model that uses AI in a circular economy by finding a problem that can be solved in circular economy and create a new circular business model or find a new design for circular product or a new way to optimise infrastructure in CE. Also, important is to find where we will address our business plan, which will be the business model, which AI new tool we will use and which will be the revenue model.

As innovation, creation and science are difficult issues, some entrepreneurs instead of inventing new business models, they just copy a successful business model from abroad and they focus more on the execution of the business plan.

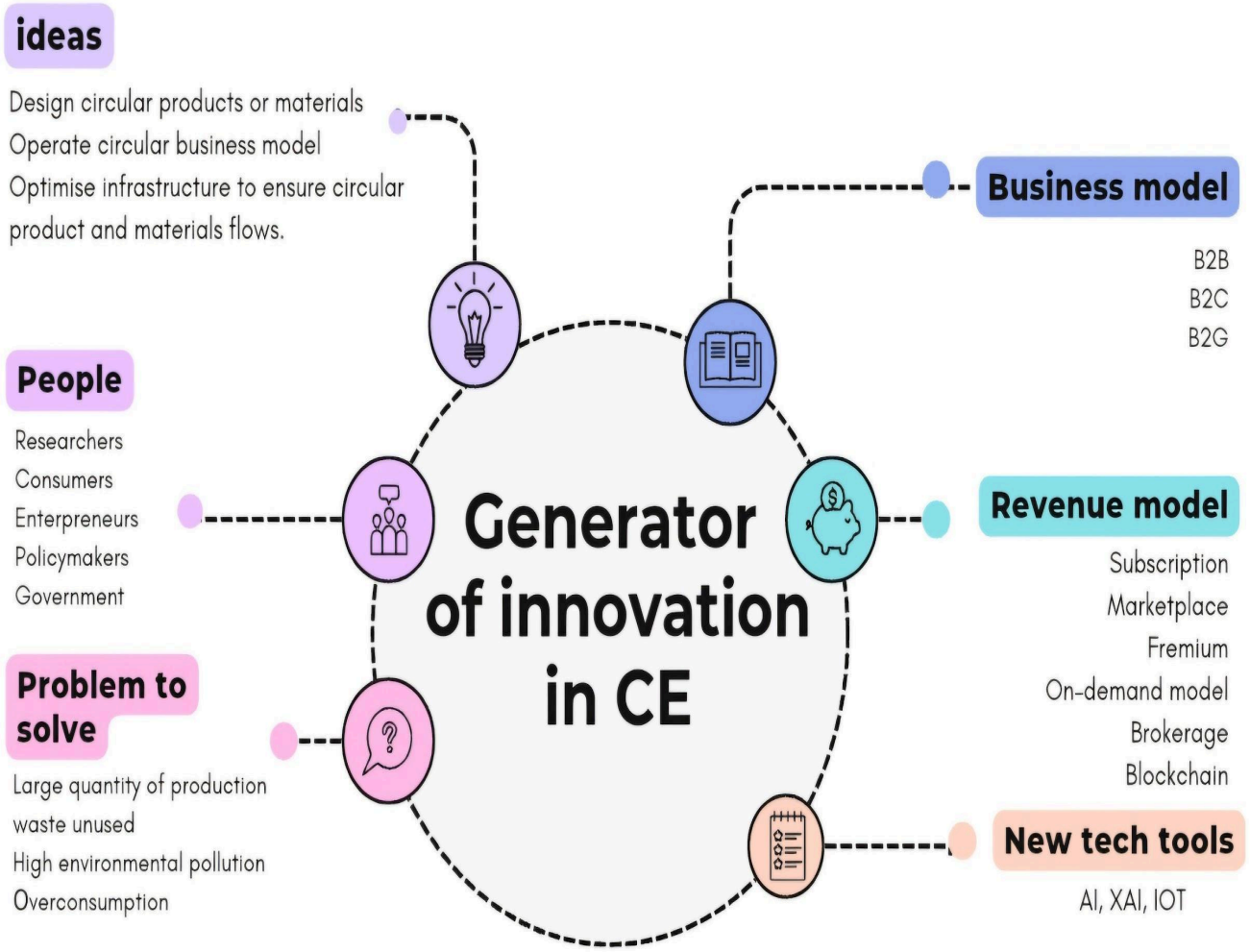


Figure 12 : Generator of innovation in circular economy

My questionnaire and evaluation of results

I sent a questionnaire to 5 AI entrepreneurs and 10 factories and asked them to answer the same questions regarding Circular economy and AI.

I question them if they use AI, if they plan a compliance strategy for CE, if they know AI applications to the CE, if they would invest in AI and which business opportunities they find in CE and AI.

The questions and the answers were the following :

1. *Do you use AI tools and at which stage?*

12 replied that they don't use it, two that they use in the production process and one in the supply chain.

2. *Do you plan a strategy for CE ?*

12 replied that they don't plan any strategy for CE, two that they use for recycling and remanufacturing and one for remaking defective products.

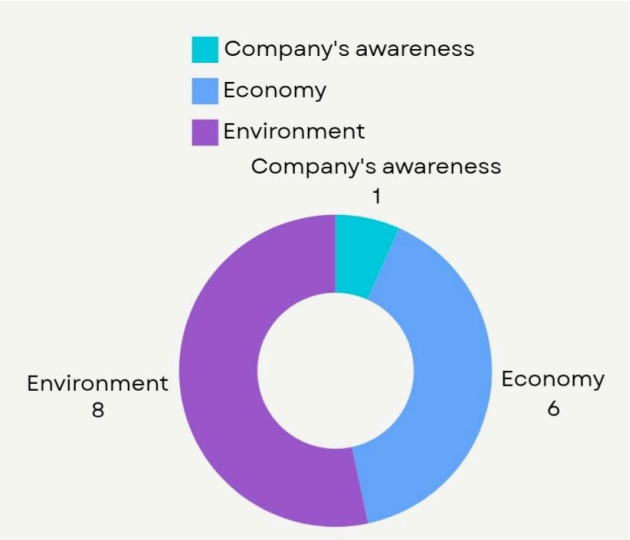
3. *Do you know about AI applications to CE?*

13 replied that they don't know, one knows big data Ocean platform and other knows AI collection digital.tools.

4. *Do you believe that it's worth investing in AI ?*

11 replied that it's really worth investing in AI and the rest 4 replied no.

5. *Do you believe that CE Actions would have positive impacts to*



6. *Could you imagine an application of XAI to CE ?*

14 replied no and one replied that XAI could help to find smart solutions to the production process.

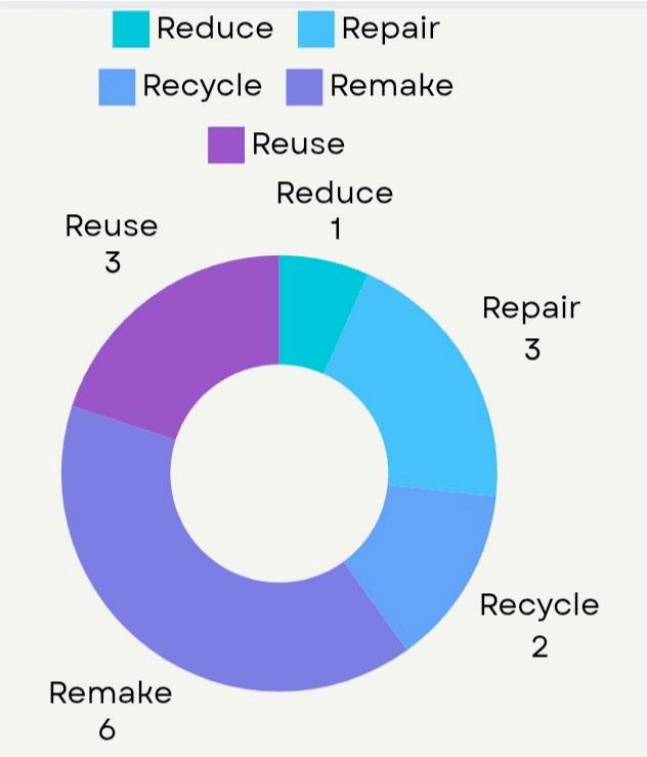
7. *Do you know a startup that uses AI for CE business?*

Two replied Cyclefi and Holistic.

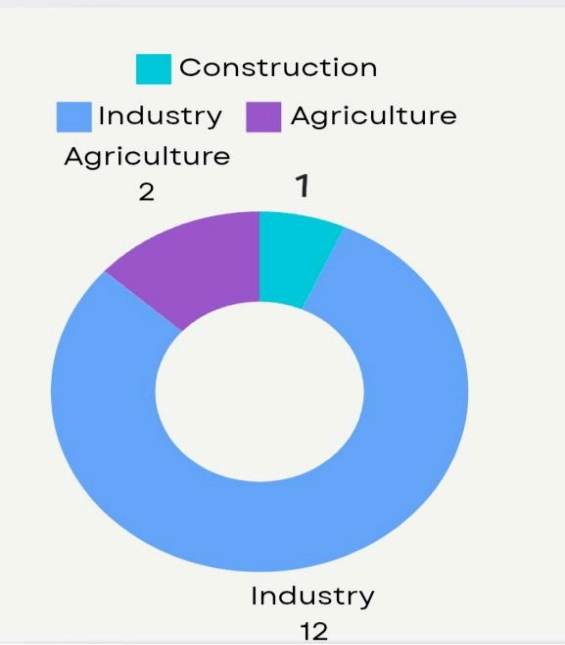
8. *Do you believe that companies and consumers are well informed about the values of CE ?*

All replied no !

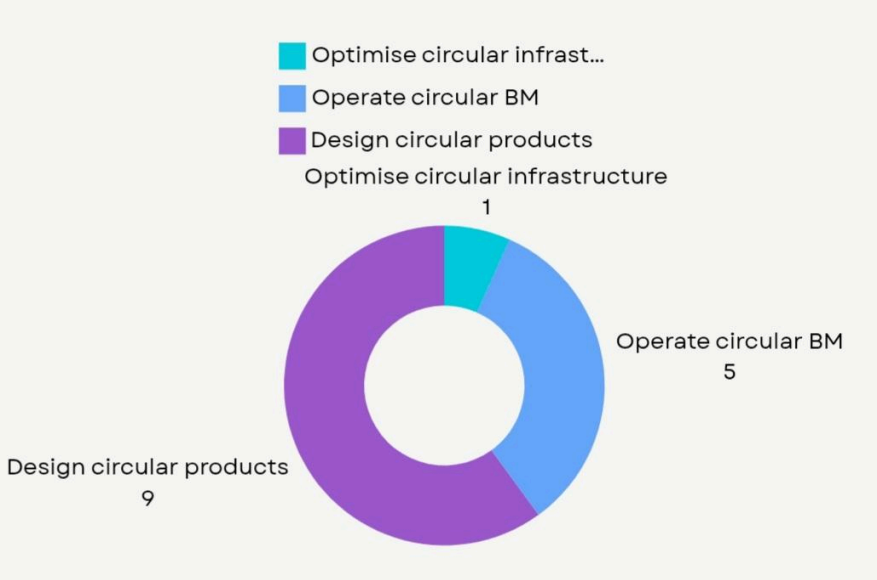
9. *Which principle of CE do you find more valuable and profitable?*



10. *In which sector do you think AI applications could have the greatest efficiency and effectiveness ?*



11. In which aspect of CE would you propose to use AI ?



I wish I could have more email addresses to obtain more opinions and help my results.

The answers helped me to understand the value of AI for circular economy strategy. Factories and entrepreneurs are not well informed in Greece and they don't use AI tools but they are willing to be informed and invest in AI as they recognize the value of AI for the economy and environment. They mostly find business opportunities in circular product designing by using the principle of remaking new products.

I would propose to build a web page with a database with the companies in Greece that use AI, company name, AI tool, function and contact information.

So all companies could exchange information and knowledge and be a bridge between scientists, technologists and entrepreneurs to meet and develop new AI systems in circular business strategy.

Summary of Findings

The thesis emphasizes the transformative potential of artificial intelligence AI in advancing circular economies for sustainable resource management. It highlights how AI can optimize resource use, enhance recycling processes, and reduce waste effectively. The integration of AI in circular economies promises not only environmental benefits but also economic and social advantages, aligning with global sustainability goals. Future research should focus on ethical considerations and technological advancements to fully realize AIs potential in this field, ensuring a balanced approach towards ecological conservation and economic growth.

Call to Action for Further Research and Implementation

The thesis proposes different limitation areas for further research :

• A larger set of companies are required to be examined empirically for further validation and generalisability.

• Further investigation on the concept of circular entrepreneurship.

• Detailed insights into the role of data in circular ecosystems.

The promising synergy between Artificial Intelligence (AI) and the circular economy demands a collective call to action for further research and implementation.

Researchers are urged to delve into unexplored areas, investigating the nuanced intersections of AI with circular design, decentralized platforms, and behavioral interventions for sustainable choices. Robust interdisciplinary collaborations must be forged to bridge knowledge gaps, integrating insights from environmental science, technology, ethics, and social sciences.

Policymakers are called upon to craft adaptive regulatory frameworks that balance innovation with ethical considerations, fostering an environment conducive to AI driven sustainability initiatives.

Businesses should champion responsible AI adoption, embracing circular practices, and contributing valuable case studies for shared learning.

Together, let us follow this transformative journey, unlocking the full potential of AI in realizing a circular economy that harmonizes economic prosperity with environmental responsibility. The time for collaborative action is now!!

On February 10 and 11, Paris hosted an international summit on artificial intelligence. With this major event, France and Europe aim to position themselves as competitors to the United States and China. So they decide that it's important to invest in artificial intelligence research, build regulation in order to trust AI results and use AI more for public prosperity.

The EuroHPC Joint Undertaking (JU) has decided to set up artificial intelligence (AI) factories across Europe. The aim of the AI Factories is to create a single service centre for users, including start-ups, small and medium-sized enterprises (SMEs) and scientific users, to facilitate access to its services, as well as skills development and user support.

The project "Pharos: The Greek AI Factory for Accelerating AI Innovation" is an initiative that establishes a national hub for AI research, development, and application. Designed to harness the capabilities of the upcoming Greek national supercomputer DAEDALUS, Pharq1os is positioned as a strategic pillar in Greece's and EU's journey towards AI democratisation, sustainability and innovation.

Pharos aims to create a trusted, sustainable AI ecosystem in Greece that bridges the gap between academia, industry and the public sector, by promoting ethical AI innovation, focusing on critical sectors, such as Health, Culture & Language and Sustainability.

Benefits of the project:

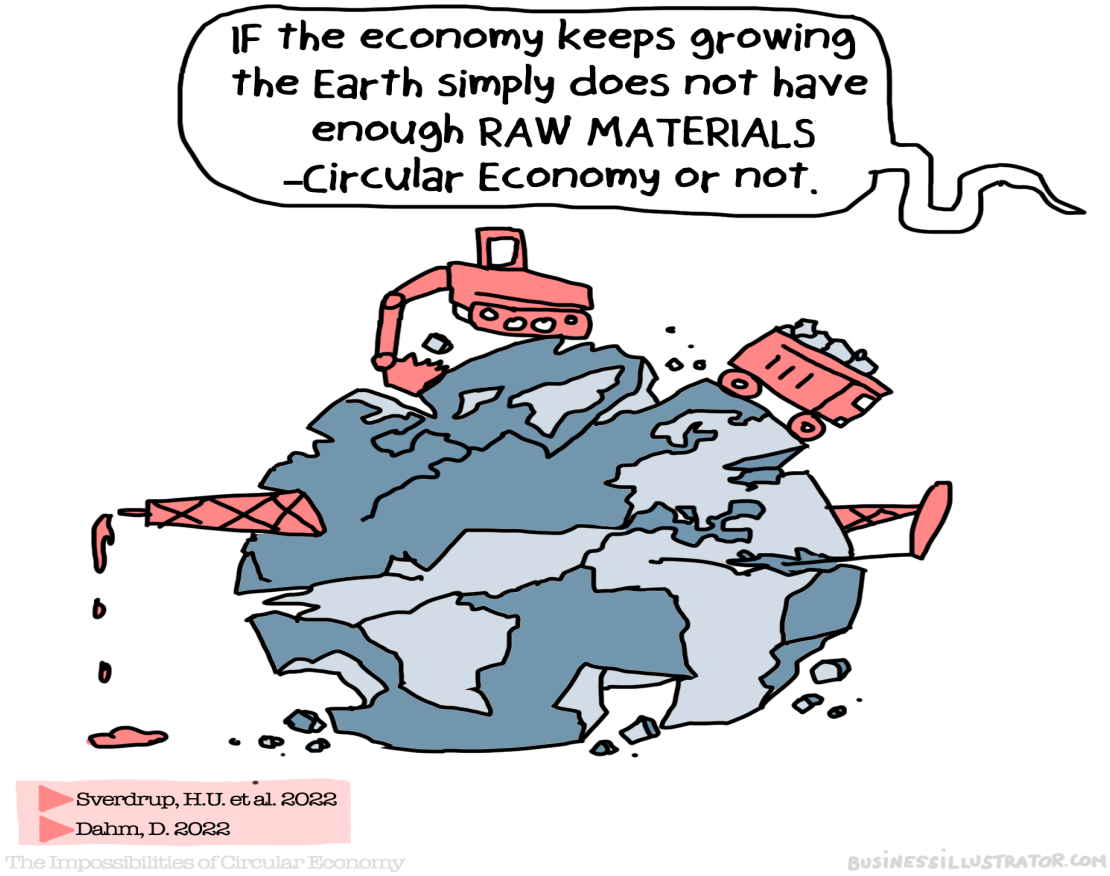
- For Startups & SMEs: Access to cutting-edge AI tools and support for scaling AI solutions.
- For Researchers: Opportunities to collaborate on AI projects with access to DAEDALUS.
- For the citizens: AI-driven advancements in health, culture and sustainability will contribute to Greece's and EU's digital transformation goals.

Led by the National Infrastructures for Research and Technology - GRNET and supported by a consortium including leading academic institutions, research centers and industry partners, Pharos will integrate state-of-the-art technologies, responsible AI principles, and innovative services to empower startups, SMEs and researchers. Collaborative engagements with other EU initiatives ensure Pharos' integration into the European AI landscape. (16)

CONCLUSIONS

- The circular economy (CE) is an emerging economic model that offers significant potential for reducing resource consumption and environmental impacts.
- AI supports the transition from a linear economy to a CE by embracing recycling, reusing and remanufacturing strategies. Based on the principles of circular economy such as Reuse - Recycle - Remake & Repair, we find new practices such as waste prevention management system, sustainable product design, recycling new methods which generate new employment opportunities.
- AI plays a pivotal role in advancing the CE by offering various advantages through its algorithms. AI can be an enabler and accelerator of the transition to a circular economy. This paper suggests that AI technologies can be applied to three key aspects of a circular economy: design circular products, components and materials operate circular business models and optimise infrastructure to ensure circular flows of products and materials. The global economic opportunity artificial intelligence can bring by 2030 has been estimated at USD 13 trillion.
- AI-driven circular design tools and methods further enhance product circularity.By using data collection, circular product design and digital tools for circular economy and utilizing new tech such as machine learning, AI and XAI is maximizing the efficiency and effectiveness.
- The issue of explainability, i.e. the need for XAI is particularly important, and the increasing interest in this domain shows promising potential. As the development of AI systems accelerates, resulting in increased computational power and expanded generalization capabilities, their prospective utilization within the sustainability sector represents a significant field of investigation.
- It's crucial to invest in AI tech research and that the entrepreneur should collaborate with AI specialists.

- France and Europe aim to position themselves as competitors to the United States and China. So they decide that it's important to invest in artificial intelligence research, build regulation in order to trust AI results and use AI more for public prosperity.
- The successful startups would be defined from the innovations in AI.
- The business success would be a mixture of innovation in AI and new tech evolution, of execution of a good business plan and of the passion and persistence of the business team.
- Using case studies and potential use cases in this paper as inspiration, stakeholders can explore relevant opportunities for circular economy applications of AI, based on a sound understanding of what AI can and cannot do, as well as an appreciation of how circular economy principles could apply to their area of interest or industry. Circular economy experts, and businesses with circular economy strategies can explore how AI could be used to accelerate their circular economy ambitions. Equally, organisations and individuals with technical knowledge and expertise in AI can consider how their specific areas of work could be applied for a circular economy.
- Further research is also necessary to make progress in this direction. In particular, there is great value in exploring how AI can improve circularity in specific sectors through detailed technical approaches.
- As a conclusion, we notice crucial advantages for industry, economy and society, if all people concerned, such as the industry leaders, the policy makers and last but not least the consumers, collaborate in order to improve the circular economy.



7. Sources

The sources used in this master's thesis consist mainly of published articles with a research framework, bachelor's - master's - doctoral theses, magazines such as startupper mag , books for AI and entrepreneurship, conferences and electronic sources.

Sources not from published articles are information from personal knowledge and professional experience. Most sources we⁰qre retrieved by searching Google scholar and various scholarly websites such as ResearchGate listed in the bibliography, which are reliable tools for finding published scholarly material.

The sources were selected according to their relevance to the topic and relative to how recent they are, since techniques in the field of AI machine vision are updated faster. Due to this, in the majority of cases, sources mainly from the last three years were used.

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ANNEX 1

Εγγεγραμμένες startups - Elevate Greece

Startup	Industry	Technology	Region	Employee count	Total funding €	Website
AlongRoute Data I.K.E.	Environment & Energy (GreenTech, CleanTech)	AI, Data Analytics - Big Data	Central Macedonia	-	-	
Argo Technologies SMPC	Environment & Energy (GreenTech, CleanTech)	AI, Cleantech, IoT, Software	Central Macedonia	1	33K	
ARTIO.Tech P.C	Environment & Energy (GreenTech, CleanTech)	AI, Data Analytics - Big Data, IoT, Sensors, Software	Central Macedonia	3	-	
COMPETENCE CENTRE FOR A SUSTAINABLE AND RESILIENT BUILT ENVIRONMENT	Environment & Energy (GreenTech, CleanTech)	AI, Cloud Computing, Data Analytics - Big Data, Diagnostic/ Imaging, IoT, Other, Sensors, Software, Web or Mobile Application	Western Macedonia	5	-	
Cyclefi P.C.	Environment & Energy (GreenTech, CleanTech)	AI, Blockchain, Cleantech, Cloud Computing, Data Analytics - Big Data, Distributed Ledger, Hardware, IoT, Networks, Sensors, Software, Web or Mobile Application	Attica	2	-	
DIGISEC S.A.	Environment & Energy (GreenTech, CleanTech)	AI, Cloud Computing, IoT, Robotics	Attica	12	-	
ECOWAVEDYNAMIS	Environment & Energy (GreenTech, CleanTech)	AI, Cleantech, Sensors	North Aegean	4	-	
ENERGY CONSULTING & APPLICATIONS P.C. (ENERCA)	Environment & Energy (GreenTech, CleanTech)	AI, Blockchain, Cloud Computing, Data Analytics - Big Data, Hardware, IoT, Sensors, Software, Web or Mobile Application	Central Macedonia	2	-	
ENEXAN P.C.	Environment & Energy (GreenTech, CleanTech)	AI, Cleantech, Software, Web or Mobile Application	Peloponnese	2	-	
EUNICE LABORATORIES ΜΟΝΟΠΡΟΣΩΠΗ ΑΝΩΝΥΜΗ ΕΤΑΙΡΕΙΑ	Environment & Energy (GreenTech, CleanTech)	AI, Cleantech, Data Analytics - Big Data, Hardware, IoT, Sensors, Software, Web or Mobile Application	Attica	12	-	
EV Loader	Environment & Energy	Blockchain, Cleantech, Distributed Ledger,	Attica	5	-	

Startup	Industry	Technology	Region	Employee count	Total funding €	Website
	(GreenTech, CleanTech)	Hardware, IoT, Networks, Sensors, Software, Web or Mobile Application				
EXM P.C.	Environment & Energy (GreenTech, CleanTech)	AI, Blockchain, Cloud Computing, Data Analytics - Big Data, Hardware, IoT, Networks, Sensors, Software	Attica	6	-	
GREEN AND GO PC	Environment & Energy (GreenTech, CleanTech)	AI, Data Analytics - Big Data, Diagnostic/ Imaging, IoT, Networks, Software, Web or Mobile Application	Central Macedonia	40	-	
HOLISTIC	Environment & Energy (GreenTech, CleanTech)	AI, Data Analytics - Big Data, IoT, Sensors	Attica	10	-	
Home Automation and More Private Company	Environment & Energy (GreenTech, CleanTech)	AI, Data Analytics - Big Data, Hardware, IoT, Sensors, Software, Web or Mobile Application	Central Macedonia	4	-	

ANNEX 2

QUESTIONNAIRE OF SURVEY (google form)

AI & Circular Economy

How can AI contribute to the circular economy strategy?

Do you use Artificial Intelligence tools and at which stage of production?

answer

Have you planned a compliance strategy for the circular economy ?

answer

Do you know some AI applications to the Circular Economy?

answer

Do you believe that it's worth investing in AI ?

answer

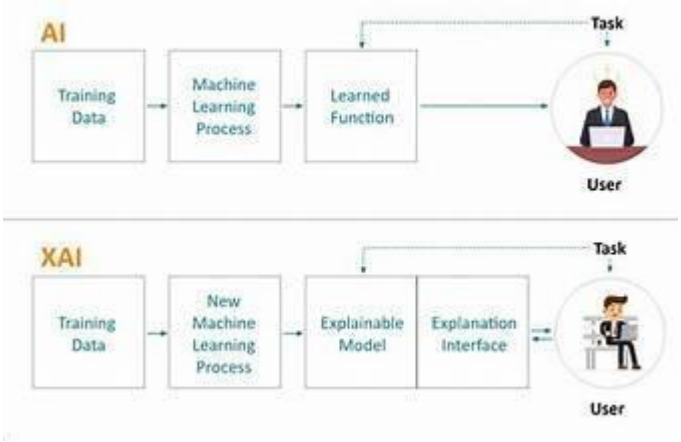
Do you believe that circular Economy Actions would have positive impacts to

economy

company's awareness

environment

Could you imagine an application of XAI (explainable artificial intelligence) to CE ?



answer

Do you know a startup that uses AI for circular economy business?

answer

Do you believe that companies and consumers are well informed about the values of CE ?

Very well informed

moderate

little

not at all

Which principle of circular economy do you find more valuable and profitable?

reduce

repair

remake

reuse

recycle

In which sector do you think that AI applications could have the greatest efficiency and effectiveness?

industry

constructions

agriculture

In which aspect of CE, you would propose to use AI ?

design circular product

operate circular business models

optimise circular infrastructure