POLITECNICO DI MILANO

School of Industrial and Information Engineering

Master of Science in Management Engineering

"Contribution of Emerging Technologies to Sustainable Development: Evidence from a Technology Foresight Survey"

Supervisor: Prof. Paolo Trucco. Co-Supervisor: Carol Maione.

Graduate Students:
Micaela Cherro (935901) Nicole Cherro (935902)

Academic year 2020/2021

ABSTRACT (ITALIAN VERSION)

A causa dell'emergere di nuove tecnologie e innovazioni e del loro potenziale impatto su una vasta gamma di settori, il Politecnico di Milano è stato ispirato a condurre un processo di Technology Foresight con l'obiettivo di perseguire il raggiungimento degli Obiettivi di Sviluppo Sostenibile (OSS), che sono fondamentali per costruire un futuro sostenibile ed equo poiché mirano a migliorare la vita delle persone, aumentare la prosperità e proteggere il pianeta. Attraverso un sondaggio di opinione, la comunità del Politecnico di Milano ha valutato l'impatto di cinquanta tecnologie e innovazioni dirompenti sui diciassette OSS delle Nazioni Unite.

Questo studio fornisce un'analisi approfondita dei risultati dell'indagine, la loro coerenza con la letteratura e altri rapporti di previsione e raccomandazioni in base alla potenziale rilevanza, alla maturità attuale e alla forza relativa dell'Europa delle tecnologie in oggetto. I risultati della ricerca potrebbero essere di rilevante utilità per guidare la pianificazione strategica in ricerca e sviluppo, industria e politica aziendale, nonché lo sviluppo di politiche locali, verso gli OSS.

ABSTRACT (ENGLISH VERSION)

Due to the emergence of new technologies and innovations and their potential impact on a wide range of areas, Politecnico di Milano was inspired to conduct a Technology Foresight process with the aim to pursuit the achievement of the Sustainable Development Goals (SDGs), which are critical for building a sustainable and equitable future as they aim to improve the lives of people, increase prosperity, and protect the planet. Through an opinion polling process, the community of Politecnico di Milano assessed the impact of fifty disruptive technologies and innovations on the United Nations' seventeen SDGs.

This report provides an in-depth analysis of the survey results, their consistency with literature and other foresight reports, and recommendations according to the potential relevance, current maturity, and Europe's relative strength of the technologies in scope. The outcomes of this study might be of relevant use to guide strategic planning in research and development, industry, and business policy, as well as local policy development, towards the SDGs.

ACKNOWLEDGEMENTS

The research was conducted with the support of the Politecnico di Milano's faculty members from the Department of Management, Economics and Industrial Engineering. The authors wish to especially thank Professor Paolo Trucco and Carol Maione for their guidance and encouragement as well as all the experts who were involved in the execution of the survey for this research project.

EXECUTIVE SUMMARY

INTRODUCTION

The world is changing faster than ever before. The increasing complexity and fast paced innovations are occurring in all aspects of life, economically, socially, and environmentally, and they need to be embraced in order to move forward. Advances in technology are not only allowing companies and people to improve quality of life, reduce costs, produce on larger scales and be able to reach much bigger and more sustainable competitive advantages, but also increasing the urge to adopt more sustainable practices in companies and to measure their progress towards such goals in recent years.

To better direct efforts and make better-informed policy and investments decisions, companies and organizations might adopt technology foresight strategies aimed at looking into the longer-term future of science and technology innovation.

TECHNOLOGY FORESIGHT

"Technology foresight is the process involved in systematically attempting to look into the longer-term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and emerging generic technologies likely to yield the greatest economic and social benefits". [1]

During the last years, this approach has diffused exponentially across the globe, attracting both developed and developing countries, and it is applied in widely diverse fields as a tool to assure flexibility and better reaction to unforeseen circumstances as well as for preparing for the long-term and the adaptation to future developments. The purpose of technology foresight is to ensure that technological innovation serves the common good through negotiation and discussion on the social implications of technology.

SUSTAINABLE DEVELOPMENT

The choice of the SDGs as a guideline for this study is justified by the fact that the SDGs are now widely recognized and used by policy makers, institutions and businesses.

In 2015 the United Nations launched the 17 Sustainable Development Goals 2015-2030 and COP21 adopted the Paris Agreement to limit global warming. These gave rise to an increasing global awareness to address the challenges of sustainable development. New economic models such as the Circular Economy and Doughnut Economics have come into practice since 2017 with the aim to eliminate waste and the continual use of resources.

Sustainable development consists of three main integrated pillars: the environment, the economy and society. A practice is deemed sustainable when all three of them are accountable for.

It is important to mention that, according to the fixed stock paradigm, the increase for demand of resources is due to three main factors:

- Population growth, urban expansion, and increased wealth
- Technological progress
- Changing of production and consumption patterns

In the expectation to attain these ambitious targets in every context, knowhow, technology, and financial resources from all members of society are needed. Furthermore, under the commitment to Leave No One Behind, countries have committed to fast-track progress for those furthest behind first.

SCOPE OF THE PROJECT

In this context, the following report consists of an exploratory analysis of the technology foresight of some emergent technologies with a special focus on their

related impacts on the sustainability dimensions – with reference to essential needs for the person, planet preservation, universal values protection, socio-economic growth, sustainable use of resources, and governance – and their alignment with the United Nations' Sustainable Development Goals (SDGs). [2] It acknowledges that technology innovation brings both benefits and unintended harms to society, and that the impacts technology innovation has on society are multi-dimensional and not limited to one aspect.

The Department of Management, Economics and Industrial Engineering from Politecnico di Milano conducted a survey in 2019 in which opinions from experts of its community were collected in order to carry out an analysis of the results about the impact of different technologies on sustainability issues and provide an understanding of which technologies are expected to be more relevant in the future in terms of their contribution to fundamental changes in society and the environment.

The methodology of opinion poll used by Politecnico made it possible to achieve the main goals of the survey:

- to expose the community of Politecnico di Milano to technology foresight objectives and challenges, creating awareness and engagement.
- to evaluate usability and effectiveness of tools and processes typically adopted in the technology foresight context.
- to gather useful elements to lead Politecnico in its path towards the definition of a center for technology foresight.

This report analyzes the survey results by conducting a series of data analysis and complementing it with the appraisal of literature, seeking to discover possible relationships among the technologies or trends that may be of interest. The study also pursues the integration of sustainability thinking at early stages of technology

development to assist the long-term decision-making processes, considering it not only relevant but also imperative. Forward looking thinking and activities from corporate levels and government units, can lead to a sustainable value creation more powerfully by changing viewpoints within these entities and thus affecting the innovation process.

SURVEY RESULTS

From the survey results it is possible to spot the ten technologies with the highest average absolute impact on one impact area:

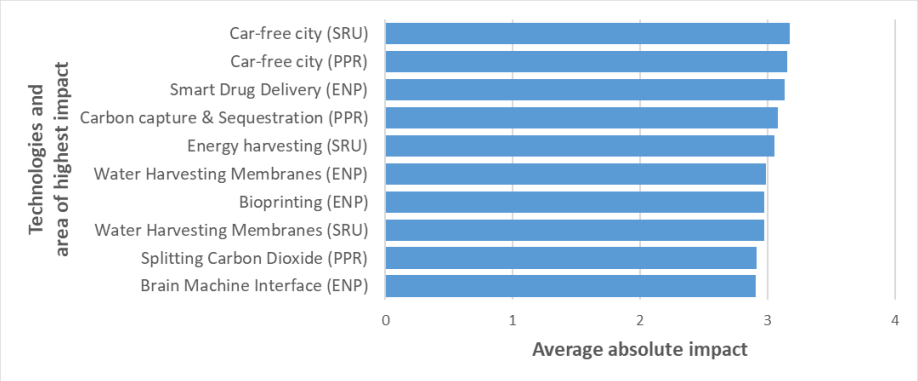


Figure 1 Executive Summary - Ten technologies with the highest average absolute impact on one impact area

Furthermore, the following is observed in the survey results:

- Technologies with more impact in general: *Water harvesting membranes, Car-free city, Energy harvesting, Automated indoor farming, Carbon capture and sequestration, Splitting carbon dioxide, Artificial photosynthesis, Bioplastic, Plastic Eating, Hydrogen.*
- Technologies with less impact in general: *4D printing*, *Holograms, Thermoelectric paint*, Spintronics, *Underwater living, 3D Printing of food, Hydrogels, Plant Communication, Carbon Nanotubes, Graphene transistors.*

Considering the technologies with higher and lower number of responses collected, the following can be underlined:

- Most-known technologies in general: *Car-free City, Driverless, Energy harvesting, Carbon capture and Sequestration, Augmented Reality, Flying cars, Brain machine interface, Hydrogen, Hyperloop, Emotion recognition*. Specifically, *Car-free city* is the technology that aroused the greatest number of responses, collecting more than 2000 evaluations overall.

- Least-known technologies in general: *Nanocellulose - Nanowood, Transient materials, Thermoelectric paint, Hydrogels, Spintronics, Bioluminescence, Nano-Optics, Molecular recognition, 2D Materials, Hyperspectral imaging*. The technologies that received the least number of evaluations still exceed 600 overall opinions.

In addition, by analyzing the survey results, it was found that most of the technologies under assessment act either as enablers or have no significant influence on the SDGs, except for eight technologies (*Flying cars, Blockchain, Artificial brain, Gene editing, Human enhancement, Emotion recognition, Smart tattoos, Humanoids*) which act also as inhibitors at least in one of the impact areas. Furthermore, some technologies depict wide controversies in their answers, as the benefits or risks that such technologies could bring depend on many different factors. Even more, no technology has a predominantly negative impact on the areas overall.

DISCUSSION

Specific attention has been given to some of the technologies with highest average impact on all SDG areas (***Smart Drug Delivery***, ***Car-free city***, ***Water Harvesting Membrane***, ***Carbon Capture and Sequestration***, ***Splitting Carbon***

Dioxide, ***Energy Harvesting***), and some others with highest negative opinions (***Gene editing***, ***Emotion Recognition***, ***Blockchain***, ***Flying Cars***).

Table 1 summarizes the values of the three indicators for each of the technologies selected for an in-depth analysis (ordered by likelihood of significant use by 2038, followed by current maturity):

Technology	*Likelihood of significant use by 2038*	*Current Maturity*	*European Position*
Gene Editing	5	2	4
Blockchain	5	2	4
Smart Drug Delivery	4	3	4
Splitting Carbon Dioxide	4	3	4
Energy Harvesting	4	3	3
Carbon Capture and Sequestration	4	3	4
Water Harvesting Membrane	4	3	4
Car-free City	4	2	N/A
Emotion Recognition	4	2	4
Flying Cars	3	2	3

Table 1 Executive Summary - Likelihood of significant use by 2038, Current Maturity, and European Position indicator values for the technologies subject to an in-depth analysis

Looking at table 1, it can be seen that none of the listed technologies have a low or very low likelihood by 2038. ***Gene editing*** and ***Blockchain*** are leading the list as the most likely technologies to reach widespread uptake by 2038, closely followed by all the others except for *Flying Cars*. The European position in these technologies is also strong, with the exceptions of *Flying Cars* and *Energy Harvesting* for which it is medium, but not leading. Instead, the current maturity of the chosen technologies is from medium to low, meaning that none of these technologies is fully mature, but are probably used in a limited number of applications as well as currently exploring ongoing research and potential use cases.

The Green Group (EN – MA)		*The Revolutionary Group (AI – DI – MO – BM)*
Main areas of impact: SRU and PPR	≠	Main areas of impact: ENP and SEG
Very high positive impact on SEG	=	Very high positive impact on SEG
No technology with negative average impact on a given impact area	≠	Some technologies with negative average impact on a given impact area
No technology with controversial answers	≠	Some technologies with controversial answers
Impact in UVP < than 1	≠	Impact in UVP > than 1
Impact in GOV < than 1	=	Impact in GOV < than 1

Table 2 Executive Summary - Main similarities and differences among the two clusters of technology sectors

The different sectors of technologies can be clustered in two groups according to their similarity of their impact on the SDG areas. The first group is made up by the Energy and Materials sectors and the second group, by Devices and Instruments, Mobility, Artificial intelligence and Biotechnologies and Medicine (though this last one was the least similar).

The first cluster is characterized by its predominant positive impact on Sustainable Resource Usage and Planet Preservation, while at the same time presenting a high socio-economic development potential for the future. Many of the technologies within this group are among those with highest absolute average impact on all SDG areas and almost none of them present a high percentage of negative opinions. This group could be named as "*The Green group*" due to its significant positive contribution to the environment.

On the other hand, the second group of technologies is described by its higher contribution to the Essential Needs for the Person and Socio-Economic Growth areas. The average positive impact of the different technology sectors on

Sustainable Resource Usage and Planet Preservation are lower than in the previous group. Differently from Energy and Materials sectors, at least one technology from each sector is assessed with a predominant negative impact in one impact area. These technologies contribute mainly to the economic development and advancement of society rather than to preserving the ecosystem, and this could be the reason why many of the technologies within this group account for negative opinions in the survey. Therefore, this group could be named as "*The Revolutionary group*", meaning they aspire to improve the everyday lives and activities of our society, while not accounting for the consequences on the environmental and social spheres.

The revolutionary group of technologies presents a high impact specifically on the Universal Values Protection area as the technologies within this set tend to promote the economic development yet tending to increase the social gap thus contributing to increasing social inequality. The reason for this is mainly that not everyone is able to access and make use of these technologies due to their high price, so they are generally accessible only to an elite part of the population. On the other side, the green group of technologies tend to have a positive impact on the UVP area, yet this is not especially depicted in the survey results.

A common trait of both groups is that the Governance impact areas has an almost neutral average score from the respondents 'opinions, while from the analysis conducted on each of the selected technologies as well as on each of the six technology sectors, it is identified that ideally the technologies foster the collaboration between business, academia, and industries around the world and the creation of partnerships as well. It can be said that perhaps the respondents may not have had the knowledge or may not have given this area significant relevance, or that simply there is a cultural lack of trust in the capacity of government bodies and policymakers to leverage on technological trends.

Regarding the current development of the technologies, all of them, regardless to which group they belong to, are mainly in their mid-stages of development, with Europe holding mostly a strong position. Moreover, the technologies from both groups have a high likelihood of significant use by 2038 (except for *Flying cars*).

In addition, the three pillars of the SDGs (environmental, social and economic) are interrelated and sometimes tradeoffs may arise. This means that improving one area may be done at the expense of another one, though this may not always be the case.

CONCLUSION

Based on the analysis conducted, a series of suggestions for the following steps on this and future technology foresight are provided:

→ the use of a more extensive technique in future technology foresight exercises would be suggested, such as collecting opinions from experts external to the institute.

→ A more detailed analysis should be conducted on Governance and Universal Values Protection impact areas.

→ Stimulate the awareness of those technologies that promise to be of relevance in the future due to their potential contribution to the SDGs but have not received much attention by the respondents.

→ Globalization, growing complexity, competitiveness, and rapid technological development have made it compelling for countries to specialize in technology and education in order to catch up and forge ahead, so the consideration of technology foresight practices is highly suggested.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Technology Sectors	
EN	Energy
BM	Biotechnologies and Medicine
DI	Devices and Instruments
MO	Mobility
MA	Materials
AI	Artificial Intelligence

Table 3 Acronyms of the technology sectors

Impact Areas	
ENP	Essential Needs for the Person
SRU	Sustainable Resources Usage
PPR	Planet Preservation
GOV	Governance
UVP	Universal Values Protection
SEG	Socio-economic Growth

Table 4 Acronyms of the Impact areas

Technology	ID	Description
Artificial Brian	Ab	The artificial brain term refers to a brain-inspired computer system build with physical components that processes and stores information like a human brain. This technology may be used to design computers that function like biological neural networks. As supercomputers reach a huge number of connections, that would allow a level of computing previously unattained and could revolutionize our lives, perhaps even more than the digital revolution.
Automated indoor farming	Af	Japanese companies are advancing fast in robotic indoor farming that is stable in any climate condition. At the same time, automation of outdoor farming is also progressing quickly. Guided by artificial intelligence systems, machines carry out classical farming tasks such as raising seedlings, replanting and harvesting but also animal husbandry. Some people think that, in the long run, agriculture could become fully automatized, first in areas with a lack of human workers and extreme conditions and then around the globe. This could have disruptive impacts in areas like food culture, sustainability, social fabric and, last but not least, employment.
Artificial Photosynthesis	Ap	Artificial photosynthesis is a chemical process that mimics the natural process of photosynthesis by converting sunlight, water, and carbon dioxide into carbohydrates (glucose) and oxygen. In the context of ever increasing fuel consumption and levels of CO_2,

		this field of research focuses on a "win-win" solution inspired by nature: artificial photosynthesis that both reduces CO_2 level in atmosphere and generates power.
Augmented reality	Ar	Augmented Reality (AR) means overlaying computer generated imagery (or even sound) on our perception of the real world. Doctors are using augmented reality to better guide them during surgery, and it is hoped that this will drastically reduce the time spent in the operating room. Gaming is another great fit for the technology. No longer would computer games be tied to the living room. We have already seen a glimpse of this with the Pokemon Go mobile app. The ultimate goal of the currently competing technological solutions is to have an unobtrusive device that seamlessly overlays the virtual world on top of the user's natural senses.
Bioplastic	Ba	Bioplastics are plastics that are used as a source of carbon renewable natural feedstock and fossil fuel in different proportions. These may include corn, rice, potatoes, palm fibre, tapioca, wheat fibres, wood cellulose and bagasse. Depending on their chemical composition and percentage of biobased ingredients, bioplastics may or may not be biodegradable. Bioplastics are used in different industries like food and beverage packaging, health care, textiles, agricultural, automotive or electronics. The main advantage of bioplastics is the fact that they

		leave a smaller energy footprint and they produce less pollution.
Blockchain	Bc	The blockchain is a technology that allows people who do not know each other to organize a network to keep trusted records. The most common application is that of a distributed ledger that keeps track of transactions. Using the blockchain, digital data can have an owner recognized by everyone in the network. The blockchain is also the technology at the core of cryptocurrencies like bitcoin. A blockchain is a data structure consisting of a linked list that is cryptographically secured so that its elements cannot be altered after they have been set. Unfortunately, it also comes with a cost, as the energy consumption for Bitcoin mining is estimated to be comparable to that of Ireland and increasing.
Bioluminescence	Bl	Bioluminescence is the natural ability of an organism to produce light. It is produced by a chemical reaction within the organism. Bioluminescence needs the molecule named luciferin, and oxygen. When they react together, light is produced. There are different types of luciferin. Some organisms form a molecule of luciferin and oxygen called a photoprotein that is waiting to be triggered. Bioluminescence is found in some insects, fungi, bacteria and marine animals. Researchers are currently trying to transfer bioluminescence and apply it in biology and medicine and in light production. At

		the same time, they are working on developing new light sources that could decrease the current load on worldwide energy consumption.
Brain Machine Interface	Bm	A brain machine interface (BMI), also known in some incarnations as a mind-machine interface, is a direct communication pathway between the brain and an external device. A BMI can both collect information from and feed it into the brain, for example by restoring a lost sense and enabling the brain to interact with the environment
Bioprinting	Bp	Bioprinting, sometimes called organic printing, is a particular application of 3D printing (or additive manufacturing - a set of technologies to build 3D objects by adding layer upon layer of material) that uses polymers or genetically engineered biomaterials to produce tissues and organs, some of them implantable in the human body. The advantage of bioprinting is individual adaptation of the material and fewer side effects, including implant rejection. Given the state of the art, only a few attempts of modest scale have been made to print organs or tissue of comparable complexity in terms of cellular structure.
Biodegradable sensors	Bs	Biodegradable electronics are electronic components with a limited lifetime subject to disappearing via hydrolysis or biochemical reactions. Such devices can be used as medical implants for temporary in-body sensing, drug delivery, tissue

		engineering, microfluidics, etc. Materials which naturally degrade via biological or chemical processes are routinely used in food and medication packaging. Degradable electronics can make such devices smarter and increase their functionalities (for instance for temperature or chemical monitoring). Temporary environmental sensors could also disappear after they are no longer needed, leaving no harmful traces in the environment.
Carbon capture & sequestration	Cc	Carbon is a vital element at the basis of our life on Earth. Yet carbon dioxide produced by human activities is one of the main greenhouse gases responsible for climate change. Managing carbon dioxide (CO_2) is one of the greatest social, economic and political challenges of our time. To avoid a loss of carbon to the atmosphere, it is captured for storage and further processing at the source of a high CO_2 output, such as smoke stacks in various industries and carbon-based power plants. Direct air capture technologies remove carbon from ambient air anywhere in the environment. In other cases, it is transported in pipelines for usage somewhere else, e.g. for injection into older fields to extract oil.
Car-free city	Cf	A car-free city relies primarily on public transport, walking, or cycling for transport within the urban area. Car-free cities greatly reduce petroleum dependency, air pollution, greenhouse gas emissions, automobile crashes, noise pollution, and traffic

		congestion. The innovation is to transform highly car-dependent cities or construct new car-free cities from scratch. The changes are happening fastest in European capitals that were designed hundreds or thousands of years before cars were ever built. In sprawling U.S. suburbs that were designed for driving, the path to eliminating cars is obviously more challenging. Building new cities from scratch based on walking distances for any important location combined with public transport could be an option for European regions.
Carbon Nanotubes	Cn	Carbon nanotubes (CNTs) are carbon-based, tube-shaped materials with nano-scale diameters. The special properties of these tube-shaped carbon molecules makes them valuable in nanotechnology, electronics, optics and other fields of materials science and technology. CNT are added to other structural materials due to characteristics such as exceptional thermal conductivity, but also for their mechanical and electrical properties. Silicon has been the material of choice in these areas, but its dominance may be challenged in the future by novel compounds. Such hopes have already been attached to carbon nanotubes by numerous researchers. Nevertheless, the industry is still years away from being able to manufacture nanotube-based chips at large scale.

Smart drug delivery	Dd	Smart drug delivery conerns the administration of a healing agent or pharmaceutical complex to humans or animals in order to reach a therapeutically operative range of medication. Advances in drug delivery technologies generally aim to increase the efficacy and absorption of a drug, while decreasing its side effects. Nanomaterials and new materials are revolutionizing the field. When a sensor embedded into a transdermal drug-delivery device detects a significant change, like an abnormal variation in temperature, the device will release drugs as programmed and precisely to the relevant location. Such treatment deployment will decrease the time spent in hospitals for patients suffering from cancer and chronic diseases, will improve appropriateness and continuity of case, and thus will substantially cut costs of healthcare delivery.
Driverless	Dr	For a long time, the driver was thought to be indispensable for any type of vehicle. This all changed when the DARPA (Defense Advanced Research Projects Agency) rand challenge proved that driverless vehicles were not only possible, but within our grasp. Surprisingly, self-driving technology was not descended from autopilot systems. Instead, it was an extension of autonomous robotics research. However, it turned out that all the sensors and computers needed to make a car self-driving are very expensive. Furthermore, real world behaviour of human drivers

		appears to be hard to anticipate and questions have arisen about how self-driving vehicles would handle ethical dilemmas. Despite the criticism, industry is moving ahead. As the transportation industry changes, it usually induces significant change in all other fields connected to it.
Energy harvesting	Eh	Energy harvesting (terms such as power harvesting, energy scavenging or ambient power are used synonymously) refers to the conversion, into practical quantities of electricity, of energy which is easily available in the environment, though typically in small quantities. For example, solar panels or thermoelectric devices applied to large sources of heat. Efficient energy harvesting techniques promise a variety of systems requiring minimum or no maintenance. This promises: virtually unlimited functioning for wireless sensor networks used in pollution, weather, fire, corrosion, structural and health monitoring; prolonged life for smartphone batteries; self-powered medical implants - and many other similar small but common gadgets whose combined power consumption is actually very large.
Emotion recognition	Er	Emotion recognition has been traditionally concerned with detecting emotions by applying advanced image processing algorithms to images of the human face. Applications of emotion recognition include marketing, smart devices that adapt to our mood, law enforcement (improved lie detectors), etc.

		Companies will probably want to embed emotion recognition systems in toys, in smart TVs, in a smart home hub or in mobile phones - imagine a smartphone that can tell how you are feeling and offer up content, communication or app suggestions accordingly. Smart devices are our current reality, but sympathetic devices could be the future.
Flying cars	Fc	The idea of flying cars has been appealing to humans even before automobiles existed. As the means of transportation evolved and congestion became an issue, the dream itself evolved. Today, advances in the miniaturization of sensors, power storage, electric motors and artificial intelligence are seemingly aligning to finally bring the flying car close to reality. Smart cities are preparing for deployment of personal autonomous transportation in the hope of resolving their traffic issues. On the very long term, entire urban planning initiatives might develop on the idea that commuting without a road infrastructure will decongest our metropolitan areas allowing for a freer and more dynamic use of land.
4D printing	Fd	4D printing is conventional 3D printing (the latter term is often used synonymously with additive manufacturing) combined with the additional element of time and, sometimes, movement. 4D-printed objects can change shape or self-assemble over time if exposed to a stimulus - heat, light, water, magnetic field or other form of energy - that activates

		the process of change. Researchers around the globe have been developing various intelligent, programmable materials that can change their geometric configuration in a controllable way, in a reversible or irreversible manner. The best-known smart materials are hydrogels and shape memory polymers. 4D printing could prove useful in building smart infrastructure as well.
3D Printing of food	Fp	Additive Manufacturing (AM) are the technologies that build 3D objects by adding layer-upon-layer of material, whether the material is plastic, metal, concrete, food or one day human tissue. It is also called 3D printing. Common to AM technologies is the use of a computer, 3D modelling software (Computer Aided Design or CAD), machine equipment and layering material. Once a CAD sketch is produced, the AM equipment reads in data from the CAD file and lays downs or adds successive layers (layer-upon-layer) of liquid, powder or other materials to generate a 3D object. Many professional chefs are currently exploring the use of 3D printing for culinary purposes.
Gene editing	Ge	In genome editing, also known by the name of genome engineering, DNA is inserted, deleted, modified or replaced in an organism's genome. The usual approach to editing is through engineered nucleases (molecular scissors) which generate double-strand breaks (DSBs) in the genome at the targeted locations. These DBSs are repaired through

		nonhomologous end-joining (NHEJ) or homologous recombination (HR). The results are targeted mutations (edits). The opportunities for the application of gene editing are increasing drastically and with them the applications and ethical questions. Gene editing will find its way into many different applications, most of them still unimagined. There is a lot of creativity involved in imagining new uses and a lot of ethical concerns and regulation to consider.
Graphene transistors	Gt	Graphene has been called the nanomaterial of the new millennium. Electrically conductive, chemically stable and the world's strongest material, it consists of carbon atoms that are densely packed and arranged in a two-dimensional hexagonal pattern - a sheet with the thickness of a single atom. Since it was first isolated in 2004, scientists have found valuable physical and electronic properties that could enable applications, such as more efficient rechargeable batteries, and better and faster electronics. Next-generation, graphene-enabled computing technologies will not stop at crunching large amounts of data, however. These versatile materials hold a lot of promises for tech such as paper-thin gadgets and smart biomedical sensors.
Human Enhancement - Nootropics	He	Human enhancement (HE) can be described as the natural, artificial, or technological alteration of the human body in order to enhance physical or mental capabilities.There are many substances that are

		purported to have promise in augmenting human cognition by various means. These substances are called nootropics and can potentially benefit individuals with cognitive decline and many different disorders, but may also be capable of yielding results in cognitively healthy persons.
Hydrogels	Hg	Hydrogels are three-dimensional network structures able to imbibe large amounts of water. Hydrogels do not typically dissolve due to chemical or physical cross-links and/or chain entanglements. They exist naturally in the form of polymer networks such as collagen or gelatin, or can be made synthetically. Environmentally sensitive hydrogels can serve a wide variety of applications because of their ability to respond to environmental changes, typically by exhibiting changes in volume.
Hyperspectral imaging	Hi	Hyperspectral Imaging (HSI) is one of the powerful analytical imaging tools based on the detection of both spatial and spectral information within a single data set referred to as a HSI cube. Hyperspectral imaging creates images across hundreds of wavelengths and can be used to find objects, determine materials at a distance, or detect processes. Hyperspectral imaging holds promise for the use in fields ranging from security and defense to environmental monitoring and agriculture.
Hyperloop	Hl	The Hyperloop is a transportation system currently in development. It will use pressurized pods for

		passengers and it can also carry cargo in its vessel. Pods are accelerated progressively by an electric linear motor through a tunnel or tube from which the air has been removed (low-pressure environment). The pod then quickly lifts above the track using magnetic levitation, gliding at airline speeds due to ultra-low levels of aerodynamic drag. Hyperloop would not only alleviate traffic on highways for others, but also create a consistent and reliable commuting experience that would not be affected by factors like car accidents or crazy weather. Ultimately, proponents aim to create a world where distance no longer matters and where you will have the freedom to live and work wherever you want to.
Holograms	Ho	Displaying 3D images in a realistic manner without using glasses represents one of the fascinations for fields ranging from entertainment, design to medicine or intelligence. Optimistic scenarios predict only a few years until the next generation of holographic products, such as 3D holographic displays, becomes widely available. Further advances such as acoustic holograms could significantly improve ultrasound imaging, as well as medical treatment options. Touchable holograms could allow us to see holographic interfaces enabling new ways of interacting with devices, as well as a wholly new dimension added to virtual reality experiences.

Humanoids	Hu	Humanoids are machines designed to resemble humans in form and features, regardless of their intended use. Currently, humanoids are too expensive and complex to be an option for most robotics applications. Replicating the human shape requires extremely complex mechanics and algorithms. Humanoid robotics is one field of research where the long-term direction differs radically from the short-term one. Right now, humanoids are expensive to build and burdensome to deploy to such a degree that it is not worth using them in places where they are not required. Once humanoid robots reach a certain level of performance, there might be a radical shift in acceptance.
Hydrogen	Hy	The gravimetric energy density of hydrogen is about three times that of fossil fuels, rendering it excellent for combustion engines, as the hydrogen burns highly exothermically in the atmospheric air, releasing water, hydrogen peroxide and small amounts of nitrogen oxides. Hydrogen fuel cells are very attractive for vehicle propulsion and most big car companies are trying to adapt to this new technological solution. The production, storage and transportation of the hydrogen, as well as its usage as a fuel, are important steps in the exploitation of this alternative source of energy. However, while abundant, in a pure state hydrogen is limited and needs a substantial amount of

		energy and expensive materials to be produced at industrial scale.
Lab-On-A-Chip	Lc	A lab-on-a-chip (LOC) integrates laboratory functions such as chemical analysis within a single device of small dimensions. LOCs, which are a subset of micro-electro-mechanical systems (MEMS), can handle very small fluid volumes and thereby allow for high throughput analysis with fast responses. Microfluidics, i.e. the physics, manipulation and study of minute amounts of fluids, is an important basis of LOC development. Lab-on-a-chip technology promises a rapid improvement in healthcare due to better, faster diagnostics, especially in areas with poor healthcare infrastructure. At the same time, the technology may allow for a more active role of patients in monitoring their own health. In a similar way, LOC may enable citizens to engage in environmental monitoring, for example via citizen science projects.
Marine and tidal power	Mp	The oceans of the earth offer vast amounts of renewable energy. Technologies to harness the power of the seas are still at an early stage of development. Even the most advanced of them, tidal current and ocean wave, face considerable barriers. In different Foresight surveys, the exploitation of marine energy is very high on the agenda because harvesting energy may be possible on a large scale. For harvesting large amounts of energy, wave energy exploitation with wave parks seems to be the most

		promising approach. Using buoys and other more flexible technologies is a promising option for small-scale investments, testing and avoiding vulnerabilities. In the long run, the amount of energy harvested may also increase because of new generator technologies.
Molecular recognition	Mr	Molecular recognition can be thought of as the study of interactions between molecules. Studies in physical organic chemistry have demarcated and assessed the weak intermolecular forces involved when two molecules meet each other. From a medical perspective, molecular recognition is a central topic since it determines whether a compound possesses useful clinical properties. Of particular importance for clinical conditions are nanomaterials for biosensing applications based on molecular recognition, where the recognition component could be enzymes, DNA, RNA, catalytic antibodies, aptamers, and labelled biomolecules.
2D Materials	Mt	Two-dimensional materials consist of atomically thin-layered materials. Since the first 2D material, graphene, was discovered in 2004, a large amount of research has been directed towards discovery, prediction and synthesis of other 2D materials (for example, transition metal dichalcogenides and Xenes have recently joined the family of 2D materials), due to their unusual characteristics. Stacking different combinations of 2D materials leads to new materials

		with novel properties. Current research focuses on the fundamental properties of such heterostructures, made of different layers of 2D materials, and their applications in photovoltaics, semiconductors, light harvesting devices and post-silicon electronics.
Nanocellulose - Nanowood	Nn	Materials obtained from nanocellulose fibers might replace an entire range of polymers in different industries. These materials can be applied in nanocomposites, films and foams, surface modifications, and medical devices. One especially interesting material is nanowood that is stronger than titanium alloys and at the same time lighter. It can be used for cars, airplanes, or buildings.
Nano-optics	No	The light-emitting diode (LED) is a two-lead semiconductor light source device that has the ability to convert electricity into light. The main feature of LED lights is that they do not generate heat, in contrast to traditional tungsten bulbs. Furthermore, LEDs require only a small fraction of the energy necessary for regular bulbs to light up and do not contain toxic metals (e.g. mercury, used in fluorescent light bulbs). Nanotechnology integration in almost every step of LED production leads to the creation of nano-LEDs and nano-LED lights as bright as ordinary bulbs. One of the most significant next steps will be the progress of ultra-small and power-efficient circuit elements, such as modulators and detectors that use nano-LEDs.

Organ on a chip	Oc	An organ-on-a-chip is a multi-channel 3D microfluidic cell culture device that simulates the activities, mechanics, physiological response of entire organs and organ systems. An organ-on-a-chip is a type of an artificial organ. One day, they will perhaps abolish the need for animals in drug development and toxin testing.
Optoelectronic	Oe	Optoelectronics is a subfield of photonics, which is focused on combining electronics and light to transmit data. Light can carry far more data, far more rapidly than standard electronics. A single fiber in a fiber-optic cable, less than a human hair's width in diameter, can carry tens of thousands of conversations at once. Common optoelectronics devices (e.g. LEDs or solar cells) are capable of converting light into electrical energy and vice-versa. Further research in optoelectronics will open the way to develop many different optoelectronic devices. 5D data storage could soon become an invaluable asset for institutions with extensive historical archives and is expected to be commercialized by industry partners within the next five years. The technology can preserve documents and information and store it in space for future generations and could secure the last evidence of human civilisation.
Plant communication	Pc	Plant communication refers to communication between plants and other organisms, be they plants of the same or a different type, insects in the soil and

		in the air, or more sophisticated creatures. Plant communication also involves potential combinations with other, non-plant categories of capabilities. Recently a number of novel and surprising insights on the nature of plant communication have emerged, that could give rise to potentially important innovations. Both artists and engineers experiment with new solutions by combining plant, human and machine capacities. Other research teams are exploring ways to use plants as sensors. Research about the understanding of plant communication is still in its infancy.
Plastic eating	Pe	PET (polyethylene terephthalate) is both, one of the most commonly manufactured products around the globe - and non-biodegradable. As these plastics accumulate in landfills, water, and elsewhere around us, they have emerged as a serious environmental concern. Since turning PET (back) into oils has proven to be a tricky process, scientists have begun to look for bugs that could metabolize or digest the materials, turning them into biodegradable products. There have been recent signs of success, although the road to industrial plastic disposal processes remains long at this point. Still, there might be a dark side to this new world. Plastic is sterile, and therefore ideal for packaging food and for widespread use in many other products. If micro-organisms are evolving to colonize it, some of the plastics' desirable properties might become things of a bygone era as well.

Quantum computers	Qc	Quantum computers are based on the quantum mechanics principles and work instead with quantum-bits or qubits. IBM, Google, and Intel are making progress on quantum hardware. Quantum computers will be able to solve new classes of problems that are not able to be solved by today's supercomputers. The changes this will bring will be far-reaching, revolutionally, and hard to predict.
Splitting carbon dioxide	Sc	Carbon dioxide is a waste product gas - a greenhouse gas amassing in the atmosphere and directly contributing to global climate changes. Different methods for carbon capture and storage are currently being used to reduce the levels of CO_2 in the atmosphere. Scientists are looking for ways of splitting and converting carbon dioxide into fuels. Specifically, they are trying to create new, cheap, catalyst materials capable of high-specificity and high-conversion rates that can be applied in industrial-scale systems. At the same time, they are combining this technology with renewable energy devices that will enable them to reduce the levels of CO_2 in the atmosphere and, concomitantly, to store solar energy directly into liquid fuels.
Self-healing materials	Sh	Self-healing is the capability of materials to diagnose and to fully or partially heal (recover/repair) internal damages all by themselves. For a material to be autonomously self-healing, it is essential that the healing takes place without human involvement.

		Typically, self-healing materials detect degradation by initiating a repair/heal mechanism that reacts to micro-damage. This technology could be applied to almost any material and any domain, in situations where repair or replacement is challenging, such as offshore wind turbines, or even impossible, such as aircraft and satellites during flight.
Spintronics	Sp	Spintronics is a field of electronics concerned with the detection and manipulation of electron spin in solid-state physics. This differs from fundamental electronics in that in addition to electron charge, the electron spin is taken into account and exploited as a further degree of freedom with possible effects toward increasing the efficiency of data storage and transfer. Spintronics is a fundamental application in quantum computing, it is also used in the medical field to detec cancer.
Smart tattoos	St	Smart tattoos represent an all-in-one sensing platform, also known as paper skin , e-skin or electronic tattoos. They consist of wearable epidermal skin electrodes which enable real-time and simultaneous sensing of various environmental stimuli (pressure, touch or proximity) and physiological data (heart rate, breathing, blood alcohol and oxygen content, muscle activity, emotions). Key advantages of smart tattoos over conventional trackers include the large degree of skin conformability (skin is flexible and stretchable), the wireless interface for data collection,

		wireless power, disposability, and inexpensive microfabrication.
Smart windows	Sw	Smart windows can harness solar power and turn it into electric power with the help of other technologies incorporated between the glass sheets or covering the glass itself, regulating the building's need for heat or air conditioning. These windows use smart glass for which light transmission properties are altered when voltage, light or heat is applied. Generally, the glass changes from translucent to transparent, changing from blocking some (or all) wavelengths of light to letting light pass through. As soon as mass production starts, smart windows will be essential to smart home design. For the moment, most of the breakthroughs described are at the prototype level, waiting to be scaled up.
Transient materials	Tm	Transient materials are full-featured materials and components that terminate clean of residuals under specific conditions and in a controlled way. They differ from conventionally degrading materials primarily by their precisely determined process of self-dissolution that is controlled by a trigger. Normally, their compounds dissolve relatively easy under physical, chemical, or biological conditions and decay to physiologically and ecologically harmless breakdown products. A wide variety of implementations could be in electronics, medicine, and security technology.

Thermoelectric paint	Tp	Thermoelectricity works by converting temperature differences to electric voltage - and the other way around. To achieve this effect, however, thermoelectric materials have to be applied to the objects that act as heat source. Since the traditional solution uses solid-state devices for this purpose, it has typically been reserved for objects with flat surfaces. As many heat-giving objects do not have large plane exteriors, however, the traditional thermoelectric designs would be inefficient in these cases. So far, one solution has been flexible thermoelectric materials. These generate additional design/efficiency constraints, although they have shown promise in products such as wearables. The ideal material would be amenable for all types of surface - that is, it would be liquid and sticky.
Underwater living	Ul	The idea of human beings living below the water surface is often brought up as a potentially important part of the future of humanity, perhaps as an alternative to an Earth surface made inhabitable by overpopulation or catastrophe. Numerous underwater habitats have been designed, built, and used around the world since the early 1960s. Before human beings are able to live under water, the first step may be underwater gardens as theme parks or for harvesting under water by growing plants beyond sea food.

Wireless energy transmission	We	Wireless power transfer is the transmission of electrical energy without the use of cables. Wireless power transmission is useful when connections with normal wires are complex or impossible to make. This technology actually constitutes a foundational element to support other technologies where it is necessary to provide power without any contact such as micro-sensors, actuators, or other remote or small devices.
Water harvesting membranes	Wm	Water filtration on a nanoscale for desalination, direct solar desalination and atmospheric water generation are examples for technologies making use of new materials to contribute to the supply of fresh water in regions where it is a scarce resource. Passive systems and self-cleaning membranes will be a precondition for large-scale use.

Table 5 Name, ID and description of the 50 technologies selected for the Politecnico di Milano survey[1]

[1] Technology Foresight; 2021 [cited 2021 June 13] Available from: URL: https://www.foresight.polimi.it/survey/results.html?lang=en.

1 INTRODUCTION

The world is changing faster than ever before. The increasing complexity and fast paced innovations are occurring in all aspects of life, economically, socially, and environmentally, and they need to be embraced in order to move forward. This dynamism of the environment is accompanied by large amounts of data and therefore the need of information and communication technologies to cope with it. In our current age of innovation, there are more emergent technology-based "innovation platforms" than ever before. Breakthrough innovations, enabled by significant advances in technology, are not only allowing companies and people to improve quality of life, reduce costs, produce on larger scales and be able to reach much bigger and more sustainable competitive advantages, but also increasing the urge to adopt more sustainable practices in companies and to measure their progress towards such goals in recent years.

To better direct efforts and make better-informed policy and investments decisions, companies and organizations might adopt technology foresight strategies aimed at looking into the longer-term future of science and technology innovation. This allows us to understand the trends and identify the technologies that present a higher potential to make a significant impact in the upcoming years. Therefore, the practice of technology foresight contributes to the enhancement of societies in all its spheres. During the last years, this approach has diffused exponentially across the globe, attracting both developed and developing countries, and it is applied in widely diverse fields as a tool to assure flexibility and better reaction to unforeseen circumstances as well as for preparing for the long-term and the adaptation to future developments. [3]

Furthermore, technology foresight fosters collaboration among a wide range of stakeholders, such as industries, research communities, governments, and citizens. The cooperation and combination of heterogeneous disciplines and methodologies allows for a comprehensive set of viewpoints and ideas and

should foster the alignment of their interests towards the common agreed vision of the future. This process enables to envisage alternatives during decision making and be able to provide more complete solutions to issues in question.

On that account, foresight encompasses three characteristics: [3]

- openness to multiple futures
- participation of various groups of stakeholders
- orientation at policy action

Moreover, the purpose of foresight has begun to shift from merely predicting the future to shaping the future as a socially constructed process concerning knowledge on the future. Both the potential benefits, as well as the unintended negative impacts of future technology and innovations must be analyzed. The purpose of technology foresight is to ensure that technological innovation serves the common good through negotiation and discussion on the social implications of technology. This goes together with connecting the next generation of workers with education and experiences that increase expertise in order to grasp and manage the forthcoming technologies. [3]

1.1 SCOPE OF THE PROJECT

In this context, the following report consists of an exploratory analysis of the technology foresight of some emergent technologies with a special focus on their related impacts on the sustainability dimensions – with reference to essential needs for the person, planet preservation, universal values protection, socio-economic growth, sustainable use of resources, and governance – and their alignment with the United Nations' Sustainable Development Goals (SDGs). [2] It acknowledges that technology innovation brings both benefits and unintended harms to society, and that the impacts technology innovation has on society are multi-dimensional and not limited to one aspect.

The Department of Management, Economics and Industrial Engineering from Politecnico di Milano conducted a survey in 2019 in which opinions from experts of its community were collected in order to carry out an analysis of the results about the impact of different technologies on sustainability issues and provide an understanding of which technologies are expected to be more relevant in the future in terms of their contribution to fundamental changes in society and the environment.

This report further analyzes the survey results by conducting a series of data analysis and complementing it with the appraisal of literature, seeking to discover possible relationships among the technologies or trends that may be of interest. The study also pursues the integration of sustainability thinking at early stages of technology development to assist the long-term decision-making processes, considering it not only relevant but also imperative. Forward looking thinking and activities from corporate levels and government units, can lead to a sustainable value creation more powerfully by changing viewpoints within these entities and thus affecting the innovation process.

The paper is structured as follows: In the next chapter, relevant concepts of this research are defined; Thereafter, the methodology of the survey undertaken is

outlined. Both the quantitative and the qualitative results of the survey are presented and explained, to further analyze and discuss the resulting most relevant disruptive technologies, followed by the expectancy of European expansion of the highlighted technologies in the different sectors by 2038.

2 LITERATURE REVIEW

2.1 TECHNOLOGY FORESIGHT

2.1.1 DEFINITION

What is meant by "technology foresight"?

The most popular definition is: "Technology foresight is the process involved in systematically attempting to look into the longer-term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and emerging generic technologies likely to yield the greatest economic and social benefits". [1]

United Nations Industrial Development Organization (UNIDO), the specialized agency of the United Nations that promotes industrial development for poverty reduction, inclusive globalization and environmental sustainability, regards technology foresight as "the most upstream element of the technology development process. Technology foresight provides inputs for the formulation of technology policies and strategies that guide the development of the technological infrastructure and supports innovation, and incentives and assistance to enterprises in the domain of technology management and technology transfer, leading to enhanced competitiveness and growth." [4]

Therefore, technology foresight means a range of methods and tools to augment the vision capabilities of an organization in the medium and long term, starting from the identification of the development scenarios of certain phenomena or technologies and their related impacts. The objective is not the accurate prediction of the future, but the broad-spectrum analysis of all possible futures in order to orient action in the present towards the most desirable ones.

2.1.2 APPLICATIONS

Foresight is used as a practical tool in designing policies and strategies that exploit emerging and critical technologies. This is especially critical for the benefit of developing countries and countries with economies in transition. Currently, UNIDO is carrying out global and regional initiatives in Asia, Latin America, Central and Eastern Europe (CEE) and the Newly Independent States (NIS) on technology foresight.

The technology foresight initiative also provides suitable methodologies to promote sustainable and innovative development, fostering economic, environmental, and social benefits at national and regional levels. Its outcomes are policies and programs that deal with innovation, industrial growth and competitiveness. [4]

Innovation is a major source of competitive advantage for businesses in almost all industries and settings, since it drives efficiency, productivity, and distinctiveness in order to meet a wider range of requirements. Assessing an organization's internal technical assets and future demands prepares management for effective technology integration. At this stage in company growth, being competitive and remaining technologically attentive are almost identical. Companies must place a premium on their capacity to analyze their technical requirements, particularly as they pertain to achieving maximum efficiency while also considering their impacts both on the environment and society. [55]

For this reason, it is currently of utter relevance for all kinds of organizations to map the future of a technology and anticipate better new trends and their impact, becoming technology foresight exercise a useful tool to support the development of future technologies, to define the strategy development and to include anticipation, sensemaking and organizational learning. [1]

2.1.3 METHODOLOGIES

Methodology is "an operational framework within which…data are placed so that their meaning may be seen more clearly" (Leedy, 1997: 204) [5]. Foresight methodologies can be seen as frameworks to make sense of data through a structured process with a future vision. It is relevant to mention that in these areas of science and technology forecasting, the level of uncertainty is so high that precise and often accurate predictions are unlikely, so a noteworthy level of error is to be expected. Nevertheless, the cognitive advances provide a more rational base on which decision makers can base their work, and foresight exercises results can contribute to the prioritization on research.

The employment of a certain methodology can be influenced by many different factors, such as the availability of resources (mainly time and finance), the results to be obtained, the organizational context in which the exercise has to be carried out, and the target groups. Foresight exercises rarely rely on one single method, but a combination of methods is applied.

In general, the starting point of a technology foresight is to identify the technologies based on other recent finished foresight studies and evaluate them in an ***expert workshop***. The *Fraunhofer foresight*, for example, analyzed the results of the *European Union-funded RIBRI (Radical Innovation Breakthrough Inquirer)* project, and used quantitative approaches in order to evaluate and finally choose 51 topics to target. The assessment of future relevance was based on the Institute expertise, and validated with international experts, combining in this way "the neutral view of the outside world and the specific perspective of applied research".[2] The methods used were an ***online questionnaire*** and ***in-depth interviews*** to the latter ones.

2 Foresight-Fraunhofer_EN: Future topics with relevance to application-oriented research 2021.

Another example is the aforementioned European Union-funded RIBRI study, in which the aim was to assess the possible impact of the breakthroughs on global value creation and solutions to societal needs. Firstly, a set of interviews to 35 experts from 22 European countries has been made to enhance the descriptions of the future Global Value Networks (GVNs) of the F*innish Radical Technology Inquirer (RTI)* study, and afterwards the results have been discussed and refined in an expert and EU policy-makers workshop. In parallel, through machine learning algorithms combined with human evaluation, 100 radical Innovation breakthroughs (RIBs) in technology have been brought about. These have been submitted to further assessments by ***consulting experts*** from Europe and beyond, and PhD students specialized in the RIB areas, as well as ***analysis of related patents and publications***. [3]

Evidently, evoking expert knowledge is essential for technology foresight exercises in order to base it on the best available evidence and judgement. This is the reason why the **expert panel method** is of the most frequently used.

[3] European Commission. 100 Radical Innovation Breakthroughs for the future 2019.

2.2 SUSTAINABLE DEVELOPMENT

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [2]

In the late 18th century, population growth trends indicated an inability to supply enough food to satisfy demand. Resource extraction causes scarcity of some materials like coal, with possible implications on local economies.

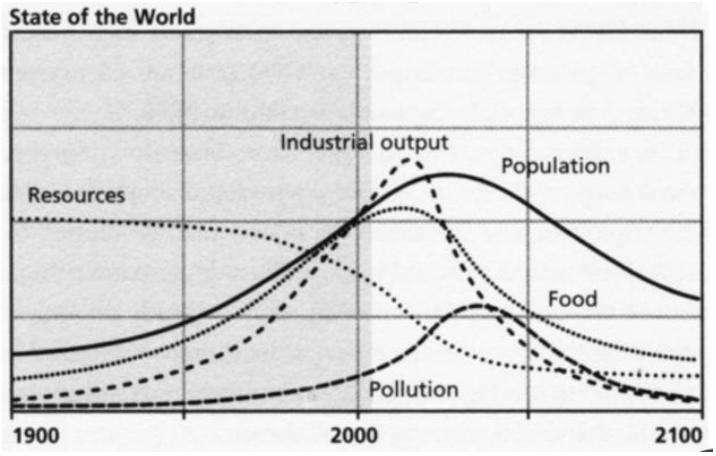


Figure 2 World development scenarios

Figure 2 is a world development scenario technique result that compares the planet's ability to supply resources and absorb pollution with the human ecological footprint throughout time. Due to these concerning predictions and the evident warning issue,

In response to a growing awareness of the depletion of resources, the need for the economic system to fit itself to the ecological system with its limited pools of resources was identified. In 1987 the first definition of sustainable development was issued by the United Nations and in the year 2000 the same organization launched the eight "Millennium Development Goals 2000-2015". The Millennium Development Goals (MDGs) identified fundamental values essential to

international relations and set priorities for achieving these principles around the world by 2015. This consisted of the following statements: [6]

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender equality and empower women
4. Reduce child mortality
5. Improve maternal health
6. Combat HIV/AIDS, malaria, and other diseases
7. Ensure environmental sustainability
8. Global partnership for development

By 2009 the nine Planetary Boundaries concept was born, which are defined as those boundaries within which humanity can continue to develop and prosper in the future, and 2010 brought the first scientific definition of sustainability: "Sustainability refers to the ability of humans and human society to continue indefinitely within a finite natural world and its underlying natural cycles. At the center of this dynamic is human economic activity and its relationship with and impacts on the natural environment". [5]

Later, in 2015 the United Nations launched the 17 Sustainable Development Goals 2015-2030 and COP21 adopted the Paris Agreement to limit global warming. These gave rise to an increasing global awareness to address the challenges of sustainable development. New economic models such as the Circular Economy and Doughnut Economics have come into practice since 2017 with the aim to eliminate waste and the continual use of resources.

Sustainable development consists of three main integrated pillars: the environment, the economy and society. A practice is deemed sustainable when all three of them are accountable for.

It is important to mention that, according to the fixed stock paradigm, the increase for demand of resources is due to three main factors:

- Population growth, urban expansion, and increased wealth
- Technological progress
- Changing of production and consumption patterns

In order to cope with these practices such as reusing and recycling of materials and their substitution could be implemented in order to mitigate the threat of mineral depletion. Remembering that a large number of commodities have fixed stocks, price setting can be handled as a way to change the demand. Furthermore, new technologies can offset the pressure of depletion and higher consumption trends may foster technology development.

2.2.1 AGENDA 2030'S SDGS

The 2030 Agenda for Sustainable Development is a United Nations' General Assembly Resolution adopted by all United Nations Member States in 2015. It provides a shared blueprint for peace and prosperity for people and the planet, now and into the future.

The Sustainable Development Goals (SDGs), also known as the Global Goals, were adopted by all United Nations Member States in 2015 by the General Assembly Resolution A/RES/70/1. They provide a way to assess sustainable development. Its aim is to provide a better world by 2030, by ending poverty, fighting inequality and addressing the urgency of climate change. Therefore, it calls for the collaboration of society as a whole to follow its guidelines in order to accomplish this. Achieving the SDGs requires the partnership of governments,

private sector, civil society and citizens alike to make sure a better planet is left for future generations. [7]

At the core of the agenda are 17 SDGs. These understand that eradicating poverty and other forms of deprivation must be combined with efforts to improve health and education, minimize inequality, and boost economic development. while also combating climate change and protecting oceans and forests.

These SDGs are integrated, as they acknowledge that action in one area will exert influence on the other areas, and are balanced, meaning that they balance social, economic and environmental sustainability aspects. The 17 SDGs have been grouped in six macros areas as proposed within the research project "The World in 2050" created in order to support the implementation of the United Nations Agenda for 2030 as follows: [8]

ESSENTIAL NEEDS FOR THE PERSON (ENP)

Figure 3 SDGs under the Essential Needs for the Person impact area

1. No poverty: end poverty in all its forms everywhere.

2. Zero hunger: End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

3. Good health and well-being: Ensure healthy lives and promote well-being for all at all ages.

UNIVERSAL VALUES PROTECTION (UVP)

Figure 4 SDGs under the Universal Values Protection impact area

4. Quality education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

5. Gender equality: Achieve gender equality and empower all women and girls.

10. Reduced inequalities: Reduce inequality within and among countries.

SUSTAINABLE RESOURCES USAGE (SRU)

Figure 5 SDGs under the Sustainable Resources Usage impact area

6. Clean water and sanitation: Ensure availability and sustainable management of water and sanitation for all.

7. Affordable and clean energy: Ensure access to affordable, reliable, sustainable and modern energy for all.

12. Responsible consumption and production: Ensure sustainable consumption and production patterns.

SOCIO-ECONOMIC GROWTH (SEG)

Figure 6 SDGs under the Socio-economic Growth impact area

8. Decent work and economic growth: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

9. Industry, innovation and infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

11. Sustainable cities and communities: Make cities and human settlements inclusive, safe, resilient and sustainable

PLANET PRESERVATION (PPR)

Figure 7 SDGs under the Planet Preservation impact area

13. Climate action: Take urgent action to combat climate change and its impacts.

14. Life below water: Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

15. Life on land: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

GOVERNANCE (GOV)

Figure 8 SDGs under the Governance impact area

16. Peace, justice and strong institutions: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.

17. Partnerships for the goals: Strengthen the means of implementation and revitalize the global partnership for sustainable development. [2]

Each of these goals have specific targets, typically, between eight and twelve, with their corresponding indicators, between one and four, used to measure progress toward each target. The targets are either "outcome" targets (circumstances to be attained) or "means of implementation" targets.

In the expectation to attain these ambitious targets in every context, knowhow, technology, and financial resources from all members of society are needed. Furthermore, under the commitment to Leave No One Behind, countries have committed to fast-track progress for those furthest behind first.

The SDGs build on decades of work by countries and the UN, including the UN Department of Economic and Social Affairs. The United Nations Department of Economic and Social Affairs (UNDESA Division)'s for Sustainable Development Goals (DSDG) provides substantive support and capacity-building for the SDGs and related thematic issues, such as water, energy, environment, oceans, urbanization, transportation, science and technology, the Global Sustainable Development Report (GSDR), alliances, and Small Island Developing States (SIDS). The DSDG is a central player in the assessment of the 2030 Agenda's implementation through the UN framework, as well as advocacy and outreach programs related to the SDGs. To make the 2030 Agenda a reality, broad ownership of the SDGs must be translated into a firm commitment to achieve the global goals by all stakeholders. The aim of the DSDG is to assist in the facilitation of this engagement.

The choice of the SDGs as a guideline for this study is justified by the fact that the SDGs are now widely recognized and used by policy makers, institutions and businesses.

3 POLITECNICO DI MILANO SURVEY

3.1 CONTENT AND METHODOLOGY

The first technology foresight exercise carried out by Politecnico di Milano was developed with a one-time survey of opinions that ran from October 21st of 2020 until December 21st of 2020.

The survey was created by a group of researchers within the University. It consisted of a series of questions presented to Politecnico's community at large, collecting anonymously opinions from 814 participants. The aim was to collect their opinions and reach a conclusion about how selected potential future technologies and innovations may impact on the global sustainable development goals.

The survey was presented in the form of an online questionnaire, through the preparation of an ad hoc platform. Each respondent was provided with an account which granted them access to the questionnaire. At login, they could see the technologies under analysis with their description, grouped into six different categories: biotechnology and medicine (BM), devices and instruments (DI), artificial intelligence (AI), energy (EN), materials (MA) and transport and mobility (MO). Some technologies belong to more than one category and in this case, they have been reduced to a primary and a secondary category. In order not to introduce a possible polarization, the distribution of innovations in the main panel was changed at each access to the survey, thus making sure that the first innovations were always different. For what is more, no filtering was made on the answers.

Therefore, the survey collects the community's opinion on the possible impact that technologies and innovations, identified as disruptive in the next 10 to 20 years, will have on the Sustainable Development Goals (SDGs) in the 2030 Agenda for Sustainable Development adopted by all United Nations Member States.

The 50 technologies and innovations subject to the survey are a selected set of those identified in recent foresight studies carried out by prestigious European institutes (i.e., Fraunhofer Institute, Imperial College of London), as well as from the list of 100 Radical Innovation Breakthroughs of the future, created by the European Commission in 2019, from which the categorization of the technologies was maintained. Table 6 depicts the technologies together with the sector to which they belong (the description of each technology is present in the Glossary):

ID	Technology	Category	ID	Technology	Category
Ab	Artificial Brain	DI	Hl	Hyperloop	MO
Af	Automated indoor farming	AI	Ho	Holograms	DI
Ap	Artificial Photosynthesis	EN	Hu	Humanoids	BM
Ar	Augmented reality	AI	Hy	Hydrogen	MO
Ba	Bioplastic	MA	Lc	Lab-On-A-Chip	BM
Bc	Blockchain	AI	Mp	Marine and tidal power	EN
Bl	Bioluminescence	EN	Mr	Molecular recognition	BM
Bm	Brain Machine Interface	AI, BM	Mt	2D Materials	MA
Bp	Bioprinting	BM	Nn	Nanocellulose - Nanowood	MA
Bs	Biodegradable sensors	DI	No	Nano-Optics	DI
Cc	Carbon capture and sequestration	EN, MA	Oc	Organ on a Chip	BM
Cf	Car-free city	MO	Oe	Optoelectronic	DI
Cn	Carbon Nanotubes	MA	Pc	Plant communication	DI
Dd	Smart drug delivery	BM	Pe	Plastic eating	MA
Dr	Driverless	MO, AI	Qc	Quantum Computers	DI
Eh	Energy harvesting	EN	Sc	Splitting carbon dioxide	MA
Er	Emotion recognition	AI	Sh	Self-healing materials	MA
Fc	Flying cars	MO	Sp	Spintronics	MA
Fd	4D Printing	MA	St	Smart tattoos	BM
Fp	3D Printing of food	MA	Sw	Smart windows	MA
Ge	Gene editing	BM	Tm	Transient Materials	MA
Gt	Graphene transistors	MA, DI	Tp	Thermoelectric paint	MA
He	Human Enhancement - Nootropics	BM	Ul	Underwater living	BM, MA
Hg	Hydrogels	MA	We	Wireless Energy Transmission	EN
Hi	Hyperspectral imaging	DI	Wm	Water Harvesting Membranes	MA

Table 6 List of the 50 disruptive technologies and innovations (ID, name and category) of the survey

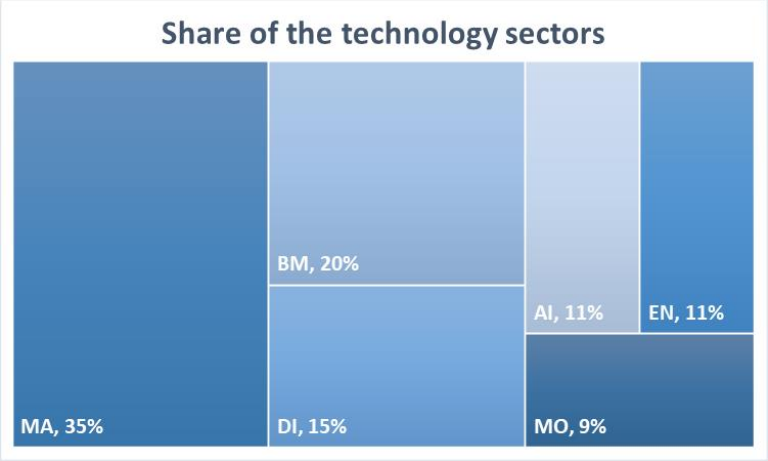


Figure 9 Share of each sector of technologies and innovations

For each technology the professionals were asked to provide their opinion on the kind of impact (Positive, Negative, No impact, Don't know) they considered each of these technologies would have in each SDG area, as conveyed in the literature review chapter: Essential Needs for the Person (ENP), Planet Preservation (PPR), Universal Values Protection (UVP), Socio-Economic Growth (SEG), Sustainable Resource Usage (SRU), and Governance (GOV). The following is an example of a question from the survey conducted:

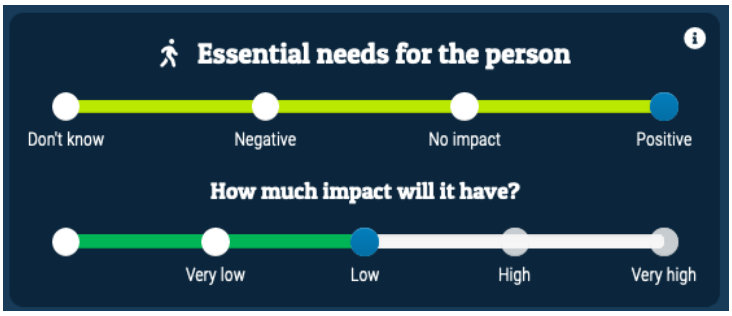


Figure 10 Example of question from the Politecnico di Milano survey

The experts were asked to state whether they considered if the technology in question would have a negative, positive or null impact in the future on each of the six areas of the SDGs and whether they believed the impact would be very low, low, high or very high. The sample questions were: "What do you think the impact of these technologies in these areas will be in 10 - 20 years?"

A general overview and some appropriate and authoritative bibliographic references were made available for each of the 50 technologies in order to provide the survey participant with basic and general elements on the technology, regardless of their context or previous knowledge (an example is present in the Annex).

In addition, each participant was given complete autonomy over the number of technologies to be reviewed and the order in which they were evaluated; they were also asked to express their opinions on the technologies based on their interests and not just their technical skills. In this light, each participant was able to share their thoughts on a subset of the impact areas and technologies. Furthermore, respondents were given the option of dividing the questionnaire compilation into separate time sessions, due to the time commitment needed.

Moreover, the participants were allowed to see how many opinions had already been voiced for each technology on the main screen and were also given the option of changing their views before the survey was closed. Also, at each access to the survey, the technologies were presented in a new random order, to avoid a polarization towards specific technologies.

Being the survey long (evaluation of 50 technologies in the six SDG sectors) and intended for a high number of participants, the methodology of opinion poll used by Politecnico made it possible to achieve the main goals of the survey:

- to expose the community of Politecnico di Milano to technology foresight objectives and challenges, creating awareness and engagement.
- to evaluate usability and effectiveness of tools and processes typically adopted in the technology foresight context.
- to gather useful elements to lead Politecnico in its path towards the definition of a center for technology foresight.

3.2 DESCRIPTIVE STATISTICS

The survey carried out made it possible to collect a total of 50,698 impact assessments, expressed by 816 active participants. The answers were collected anonymously and all of them were taken into consideration. The average number of collected opinions per technology is 1011.

The group of experts was embodied by the extended community of Politecnico di Milano to include different points of view among the opinions. Researchers, professors, assistants, PhD students and students within the university were included not as experts of a technological area, but as people used to look ahead and imagine solutions for today's and tomorrow's problems on the pursuit of the global sustainable development goals. However, the group of experts selected may not represent a heterogeneous group as they come from similar backgrounds and same community. In figure 11 it can be observed the composition of the survey's active respondents:

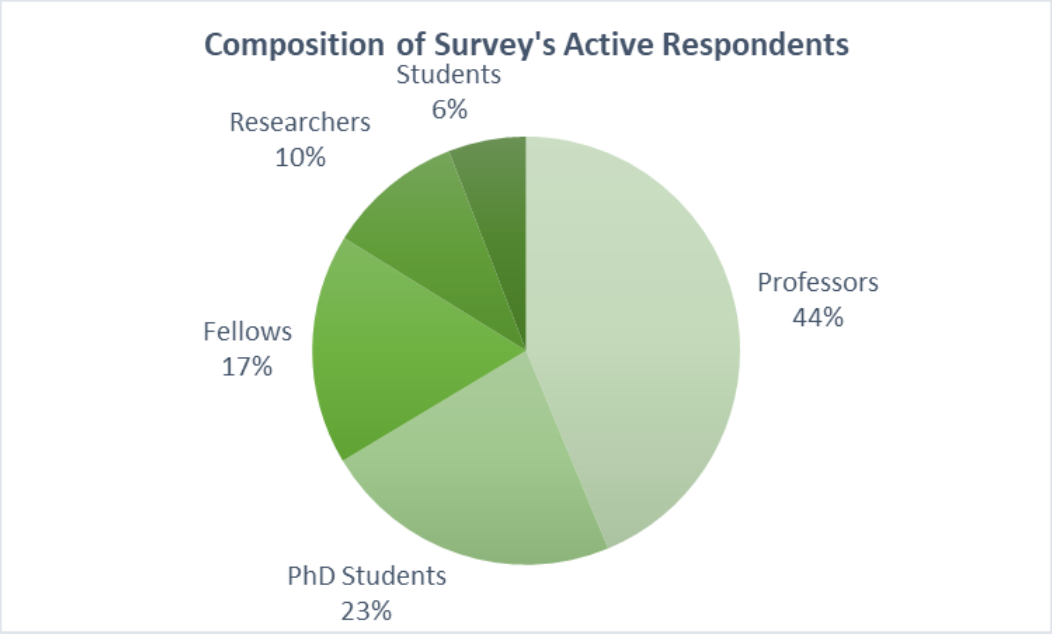


Figure 11 Composition (%) of Survey's active participants

The fact of not requiring the completion of assessments for all impact areas and for all technologies, associated with a random positioning of technologies on the page, led to an uneven distribution of responses, depicted in figures 12 and 13:

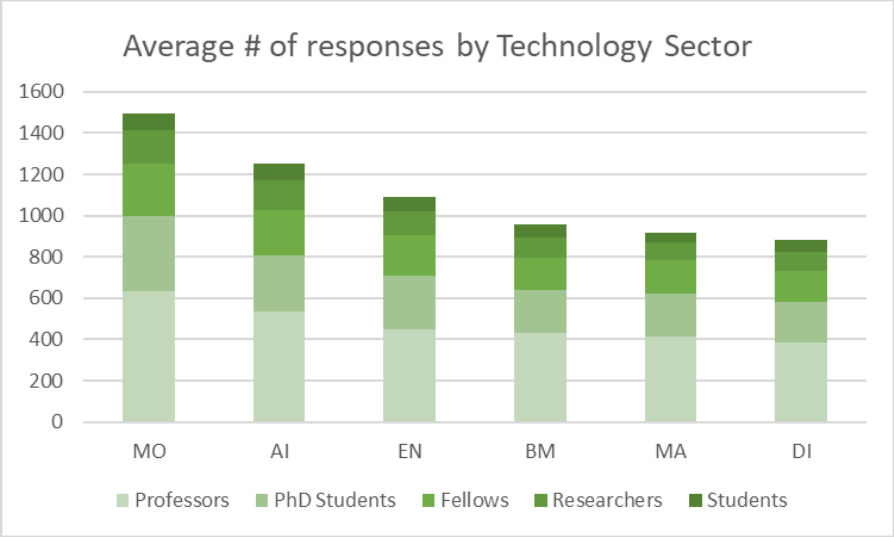


Figure 12 Average number of responses by Technology Sector and by class of Experts

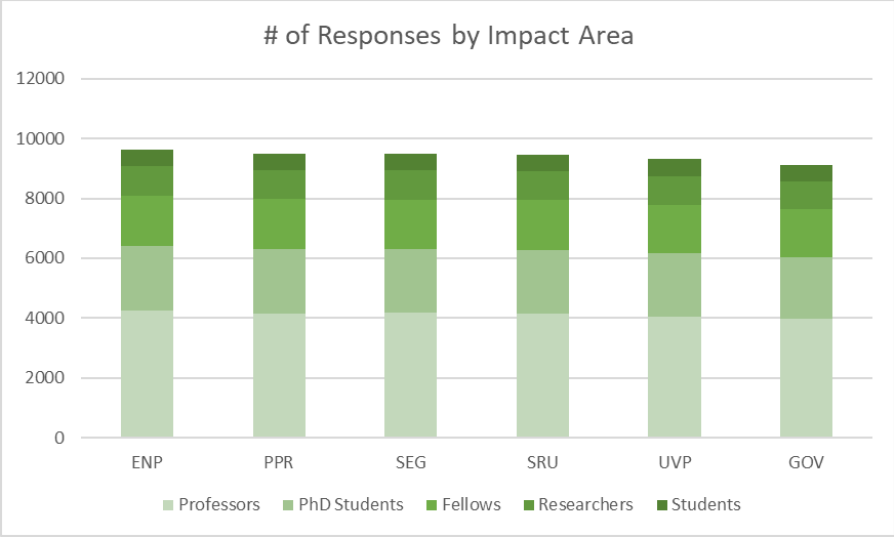


Figure 13 Number of Responses by Impact Area and by class of Experts

In addition, considering the technologies with higher and lower number of responses collected, the following can be underlined:

- Most-known technologies in general: *Car-free City, Driverless, Energy harvesting, Carbon capture and Sequestration, Augmented Reality, Flying cars, Brain machine interface, Hydrogen, Hyperloop, Emotion recognition*. Specifically, *Car-free city* is the technology that aroused the greatest number of responses, collecting more than 2000 evaluations overall.

- Least-known technologies in general: *Nanocellulose - Nanowood, Transient materials, Thermoelectric paint, Hydrogels, Spintronics, Bioluminescence, Nano-Optics, Molecular recognition, 2D Materials, Hyperspectral imaging*. The technologies that received the least number of evaluations still exceed 600 overall opinions.

The number of collected responses for each technology is present in the Annex.

3.3 SURVEY RESULTS

In this section a summary of the results of the survey conducted are presented and explored. To understand the meaning of the results, table 7 details the score range given for each type of impact selected by the respondents in the survey. It Is also important to remark that figures 14, 15, 16 and 17 were done with the average absolute impact, and so without distinguishing between positive and negative impact (table 7). Instead, from figure 18 until the end of this chapter, the average values were calculated taking into account the corresponding negative and positive signs (table 8).

Extent and type of impact of the selected technology	**Score range**
Very high positive impact	[3, 4]
High positive impact	[2, 3]
Low positive impact	1
Very low positive impact	[0 - 1]
No impact	0
Very low negative impact	[-1-0]
Low negative impact	[-2, -1]
High negative impact	[-3, -2]
Very high negative impact	[-4, -3]

Table 7 Score range and definition for the impact assessment of a technology in an impact area

Extent and type of absolute impact of the selected technology	Score range
Very high impact	[3, 4]
High impact	[2, 3]
Low impact	1
Very low impact	[0 - 1]
No impact	0

Table 8 Score range and definition for the absolute impact assessment of a technology in an impact area

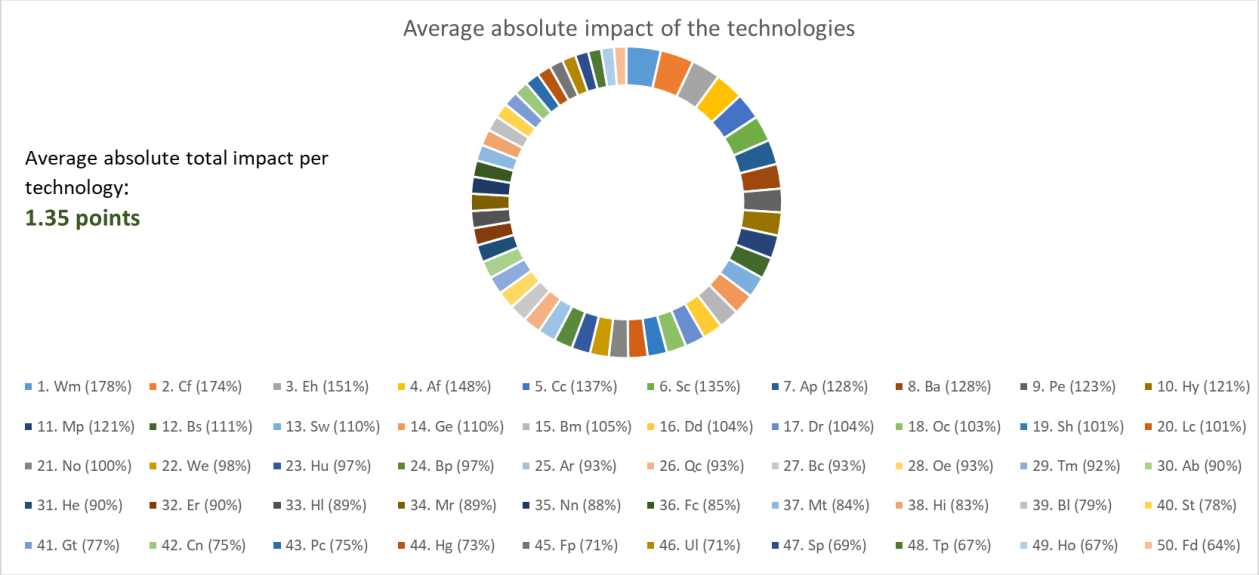


Figure 14 Average absolute total impact of the technologies in the six impact areas

From figure 14, the following conclusions can be reached:

- Technologies with more impact in general: *Water harvesting membranes, Car-free city, Energy harvesting, Automated indoor farming, Carbon capture and sequestration, Splitting carbon dioxide, Artificial photosynthesis, Bioplastic, Plastic Eating, Hydrogen.*

- Technologies with less impact in general: *4D printing*, *Holograms, Thermoelectric paint*, Spintronics, *Underwater living, 3D Printing of food, Hydrogels, Plant Communication, Carbon Nanotubes, Graphene transistors.*

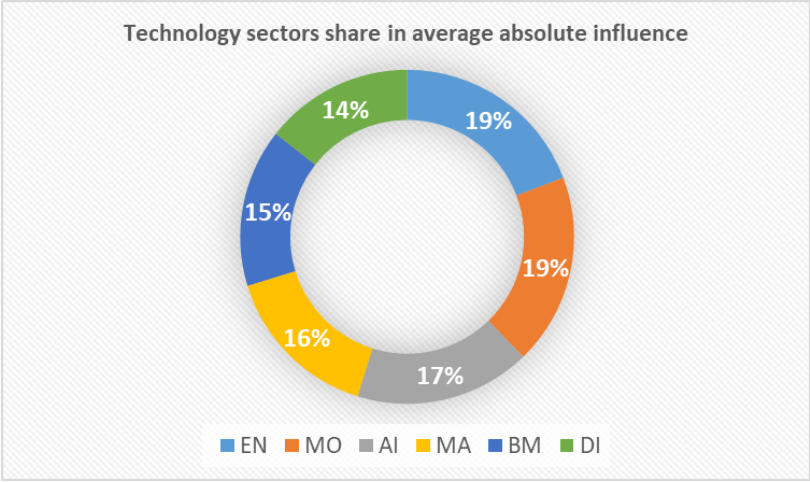


Figure 15 Technology Sectors share in average absolute impact

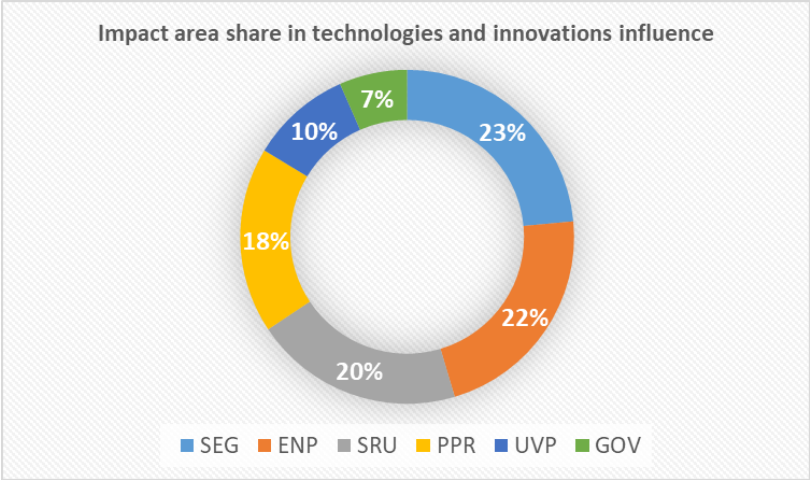


Figure 16 Impact area share in Technologies and Innovations average absolute influence

From the survey results it was possible to spot the ten technologies with the highest average absolute impact on one impact area:

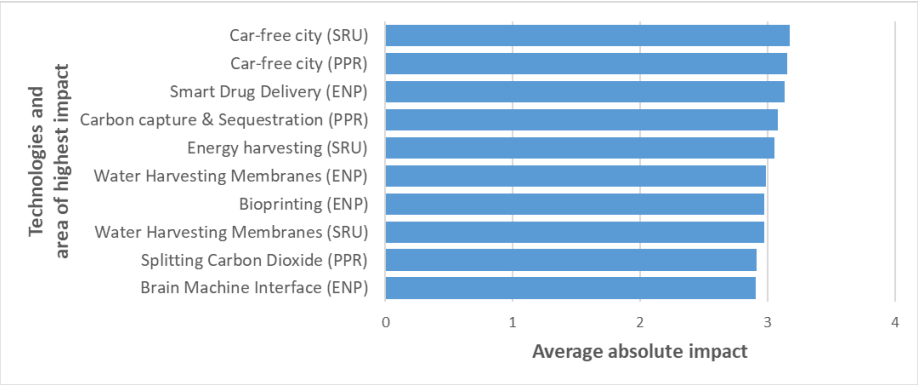


Figure 17 Ten technologies with the highest average absolute impact on one impact area

It is interesting to highlight that the impact areas that appear in figure 17 are SRU, PPR and ENP, and there are two technologies that appear twice in the list: *Car-free city* and *Water harvesting membranes.*

Figure 18 shows the technologies' classification in the different SDG impact areas, according to the area in which they have achieved the highest average value:

Socio-economic Growth
- Quantum Computers
- Artificial Brain
- Optoelectronic
- 2D Materials
- Augmented Reality
- Wireless Energy Transmission
- Carbon Nanotubes
- Hyperloop
- Graphene Transistors
- Blockchain
- Spintronics
- 4D Printing
- Holograms
- Hyperspectral Imaging
- Flying Cars
- Emotion Recognition
- Underwater living

Sustainable Resources Usage
- Car-free City
- Energy Harvesting
- Artificial Photosynthesis
- Bioplastic
- Plastic Eating
- Marine and Tidal Power
- Hydrogen
- Smart Windows
- Automatic indoor Farming
- Self-healing Materials
- Nano-Optics
- Nanocellulose - Nanowood
- Bioluminescence
- Thermoelectric Paint
- 3D Printing of Food

Essential Needs for the Person
- Smart Drug Delivery
- Bioprinting
- Water Harvesting Membranes
- Brain Machine Interface
- Lab-On-A-Chip
- Biodegradable Sensors
- Organ on a Chip
- Molecular Recognition
- Driverless
- Gene Editing
- Human Enhancement - Nootropics
- Hydrogels
- Smart Tattoos
- Humanoids

Planet Preservation
- Carbon Capture and Sequestration
- Splitting Carbon Dioxide
- Transient Materials
- Plant Communication

Figure 18 The 50 technologies of the survey grouped by impact area according to the one for which each has obtained its highest average impact value

It can be seen that none of the technologies have the highest average value in neither GOV nor UVP impact areas.

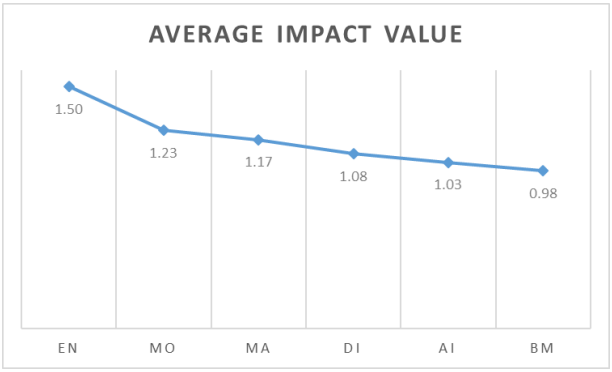


Figure 19 Average impact value divided by technology sector

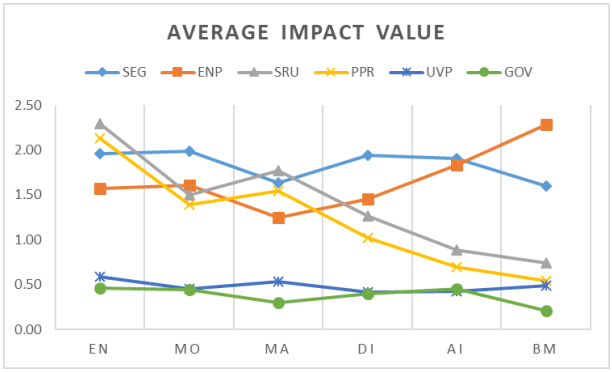


Figure 20 Average impact value of each impact area divided by technology sector

Figures 19 and 20 show that:

→ the EN technology sector has the highest average impact value (1.5) across all the impact areas, followed by MO (1.23).

→ The BM technology sector is the one with the lowest overall average impact value (0.98).

→ the EN technology sector has the highest results in SRU, PPR and SEG, outstanding from the other sectors in the first two with an average impact value of 2.3 and 2.13 respectively, followed by MA with barely an average impact value of 1.54 and 1.77 accordingly.

→ BM is considered as the most important technology sector for the ENP and has almost a neutral value for PPR and SRU.

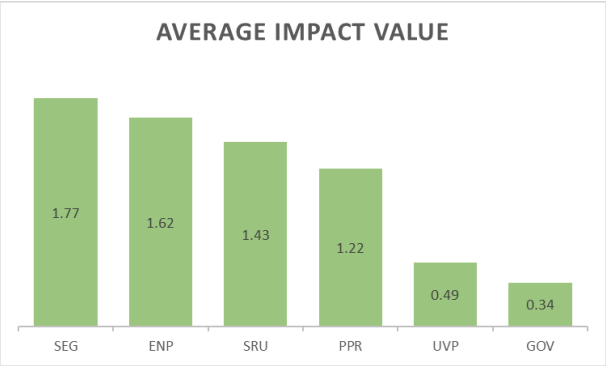


Figure 21 Average impact value divided by impact area

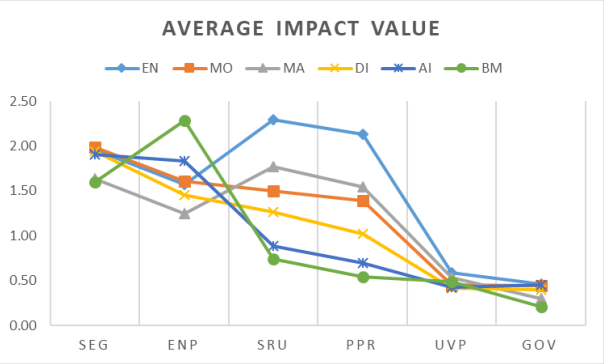


Figure 22 Average impact value of each technology sector divided impact area

Figures 21 and 22 show that:

→ the SEG impact area has the highest average impact value (1.77), followed by ENP (1.62).

→ in UVP and GOV all the technology sectors have the most similar average values. Moreover, these impact areas are the ones with lowest impact values, laying below 1.

→ PPR and SRU are the impact areas with the highest differences regarding the influence of the different technology sectors. A relationship can be seen between these two areas: in both impact areas, the technology

sectors follow the same order and the average value of each of the sectors are almost the same; in all the technology sectors, SRU has higher average impact values than PPR.

→ ENP area is highly positive influenced by BM technology sector. Moreover, for ENP impact area the order in which the technology sectors impact differs from all the other impact areas, being BM and AI the ones with the highest average values, the contrary in the PPR, SRU and SEG impact areas.

→ there is a predominant negative relationship between SEG and PPR/SRU impact areas, except in AI and BM technologies groups in which additionally the impact is the most different of the aforementioned SDGs.

→ two different categories could be made as a relationship between the technology sectors of EN and MA can be observed, as well as between DI, MO, AI and BM (a bit less this last one) on how they impact on the different SDG areas.

Entering more into detail, figures 23 and 24 illustrate the percentage of positive, neutral and negative opinions collected per each technology sector and per impact area:

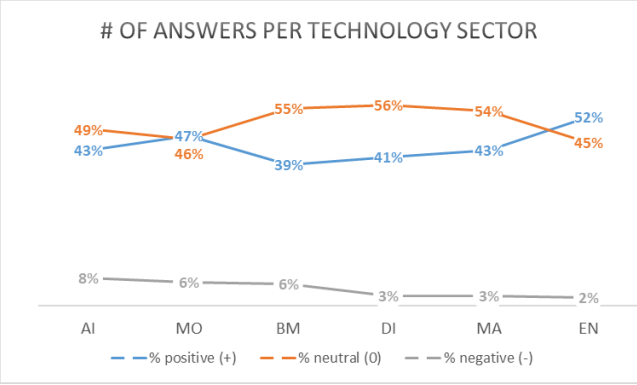


Figure 23 Percentage of positive, neutral and negative answers per technology sector

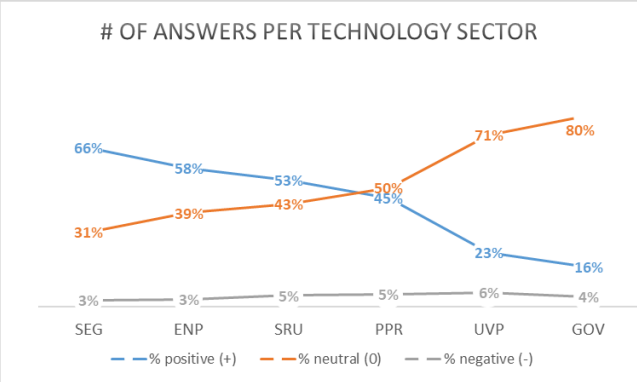


Figure 24 Percentage of positive, neutral and negative answers per impact area

Table 9 shows the technologies and area of impact with the highest percentage of positive opinions:

Technology	Technology Sector	Impact Area	% positive votes	Average votes (+)
Cf	MO	SRU	90%	3.510
Wm	MA	ENP	90%	3.294
Cf	MO	PPR	89%	3.539
Eh	EN	SRU	88%	3.417
Dd	BM	ENP	88%	3.552
Cc	EN	PPR	86%	3.535
Cc	MA	PPR	86%	3.535
Bp	BM	ENP	86%	3.440
Hy	MO	SRU	86%	3.144
Sc	MA	SRU	85%	3.339

Table 9 List of technologies and area of highest percentage of positive opinions

From table 9 it can be observed that:

→ none of these technologies belong to the groups of AI nor DI;

→ all of these technologies correspond to the ones with highest average absolute impact in either all or only one impact area;

→ the SDG area that present more positive responses is SRU, while SEG, UVP and GOV are not present, even though SEG impact area has the highest overall average impact value.

Instead, table 10 shows the technologies and area of impact with the highest percentage of negative opinions:

Technology	Technology Sector	Impact Area	% negative votes	Average votes (-)
Fc	MO	PPR	32%	-2.569
Ge	BM	UVP	31%	-2.878
Fc	MO	SRU	31%	-2.500
Er	AI	UVP	27%	-2.768
UI	BM, MA	PPR	26%	-2.282
He	BM	UVP	25%	-2.514
Er	AI	ENP	20%	-2.791
Bc	AI	SRU	20%	-2.412
Bc	AI	PPR	18%	-2.367
Bm	BM, AI	UVP	17%	-2.694

Table 10 List of technologies and area of highest percentage of negative opinions

From table 10 it can be observed that:

→ none of these technologies belong to the groups of EN nor DI and only one belongs to MA;

→ none of them correspond to the ones with highest average absolute impact;

→ SEG and GOV are not present in table 10;

→ The negative impacts are considered to be significant as the average of all are above 2 points;

→ The AI sector is the one presenting more negative opinions and in 4 different SDG areas;

→ UVP, PPR and SRU appear to suffer from potential negative impact from specific technologies, mainly *Flying cars, Blockchain* and *Emotion Recognition* which present a high number of negative opinions on 2 of the 6 SDG areas; both *Flying cars* and *Blockchain* in PPR and SRU impact areas, while *Emotion Recognition* in UVP and ENP. Nonetheless, negative and positive responses on *Blockchain* for SRU and PPR areas were balanced. Instead, for *Flying cars* (in both PPR and SRU) and *Emotion Recognition* (in UVP), negative responses were significantly more than the positive ones. The balance on the negative and positive answers for the technologies listed in table 10 can be seen in the boxplots present in the Annex.

In summary, the overall impact of the selected technologies is positive to very positive in most of the impact areas, with the exception of eight technologies (*Flying cars, Blockchain, Artificial brain, Gene editing, Human enhancement, Emotion recognition, Smart tattoos, Humanoids*) in which at least one area of negative impact is observed. Even more, no technology has a predominantly negative impact on the areas overall.

4 DISCUSSION

In this chapter, an extract from the 50 technologies are individually discussed, derived as follows on the basis of the survey results:

- Examples of technologies with highest average impact: ***Smart Drug Delivery***, ***Car-free city***, ***Water Harvesting Membrane***, ***Carbon Capture and Sequestration***, ***Splitting Carbon Dioxide***, and ***Energy Harvesting;***
- Examples of technologies with highest negative opinions: ***Gene editing***, ***Emotion Recognition***, ***Blockchain***, and ***Flying Cars.***

For each technology a brief description is provided, and the survey results in the different SDG impact areas are analyzed and compared with other relevant technology foresight exercises, as well as their consistency with literature review. Moreover, the technologies are assessed in terms of their likelihood of significant use in the year 2038, the European position on its capability in research and innovation on them, and their current maturity, based on the report "100 Radical Innovation Breakthroughs for the future" conducted by the European Commission in 2019.

The value of the indicators from the report were defined through expert consultation, and for the last two also a Scientometric analysis was developed, evaluating the position of EU in terms of publications and patents for the European position, and the level and dynamics in publications and patents of such innovations for their current maturity. The indicators provide a qualitative assessment with a scale from 1 to 5, with 1 indicating very low/poor likelihood of implementation by 2038/European position/maturity, and 5 very high/good likelihood by 2038/European position/maturity [9].

Furthermore, a dedicated section for the analysis of the relationship between each technology sector and the impact areas is present, followed by a cross-technology sector comparison, which allowed some inferences to be formed

about the influence of the selected technologies on future wealth production and social requirements. After the analysis, it is expected to provide a conclusion in terms of the future relevance to applied research of the different technologies and innovations, to speed up the evolvement towards one or more of the Sustainable Development Goals.

4.1 OVERVIEW OF THE SELECTED TECHNOLOGIES

Table 11 summarizes the values of the three indicators for each of the technologies selected for an in-depth analysis (ordered by likelihood of significant use by 2038, followed by current maturity):

Technology	*Likelihood of significant use by 2038*	*Current Maturity*	*European Position*
Gene Editing	5	2	4
Blockchain	5	2	4
Smart Drug Delivery	4	3	4
Splitting Carbon Dioxide	4	3	4
Energy Harvesting	4	3	3
Carbon Capture and Sequestration	4	3	4
Water Harvesting Membrane	4	3	4
Car-free City	4	2	N/A
Emotion Recognition	4	2	4
Flying Cars	3	2	3

Table 11 Likelihood of significant use by 2038, Current Maturity, and European Position indicator values for the technologies subject to an in-depth analysis

Looking at the list of the technologies in table 11, it can be seen that none of them have a low or very low likelihood by 2038. ***Gene editing*** and ***Blockchain*** are leading the list as the most likely technologies to reach widespread uptake by 2038, closely followed by all the others except for *Flying Cars*. The European position in these technologies is also strong, with the exceptions of *Flying Cars* and *Energy Harvesting* for which it is medium, but not leading. Instead, the current maturity of the chosen technologies is from medium to low, meaning that none of these technologies is fully mature, but are probably used in a limited number of applications as well as currently exploring ongoing research and potential use cases.

BIOTECHNOLOGIES AND MEDICINE

1. Smart drug delivery

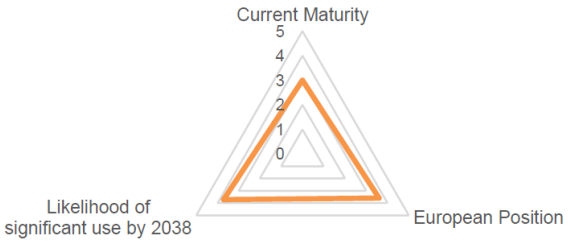


Figure 25 RIB score of Smart drug delivery

This technology collected 1069 opinions, slightly higher than the average one (1011), and achieved the highest average absolute impact on the ENP. Even more, this technology also reached a significant average value in SEG impact area.

Smart Drug Delivery concerns the administration of a healing agent or pharmaceutical complex to humans or animals in order to reach a therapeutically operative range of medication [10]. Nanoparticles are revolutionizing the field, allowing the detection of sick cells and being the vehicles necessary for the efficient delivery of the coated drug. A sensor inside a transdermal drug-delivery device detects an abnormal variation which provokes the release of the drug from the device precisely to the relevant location. In this way, the concentration of the drug is kept at desirable doses and the need for repeated doses is avoided.

Electronic ingestible pills or injectable devices will provide the possibility to monitor the patient health and/or treat many diseases (e.g. diabetes), being Its most potential application the treatment of cancerous tumors. One of the major problems in injecting medication such as chemotherapy is that the medication

affects the entire body instead of only the sick cells, leading to possible severe side effects. Advances in drug delivery technologies generally aim to release drugs as close as possible to the interior of a tumor, increasing the efficacy and absorption of the drug, while decreasing its side effects [10]. The precision and little invasiveness achieved from the targeted therapy, will decrease the frequency of the dosages taken by the patient, and fluctuation in circulating drug levels [11]. All this will reduce the time patients suffering from cancer or other diseases spend on hospitals, as well as the costs of healthcare. These benefits could explain the very positive impacts on ENP and SEG from the survey results.

Thanks to other technology, *3D printing*, powerful and safe drug delivery systems have been developed. An example is the "micro-rockets" created at the University of Sheffield in England, which are made of silk scaffolds and are both biodegradable and safe for a biological system [9]. Moreover, doctors take advantage of *3D printing* for investigating how to target cancerous tumors more efficiently; they can do this by filling a plastic 3D shape printed tumor with the drugs used in the treatment and observing the flow of the liquid. This depicts the presence of interdependency among technologies.

The future of *Smart drug delivery* still remains a challenging one; there are different types of vehicles according to their properties and application, and great deal of knowledge of how each component works to achieve such goals should be entailed. Europe has a strong capability for research and development in this outstanding innovation and this strength should be fully exploited by leveraging on 3D printing and Nanotechnology as well.

MOBILITY

1. Car-free city

This technology collected the highest number of opinions (2028), almost twice of the average number (1011), and is one of the innovations with greatest positive

impact on several SDG areas according to the results of the survey, prevailing in SRU and PPR.

The innovation relies primarily on walking, cycling or public transport within the urban area, rather than using private cars (especially combustion cars). The purpose is to reduce the car-dependency or to construct the cities from scratch, designing them for people and not for cars; this means, based on walking distances instead of for driving. Cars are being phased out of neighborhoods in an increasing number of cities with a significant reliance on automobiles, such as Chengdu, Copenhagen, Hamburg, Helsinki, Madrid, Milan, and Paris [12]. Most European cities of any size include at least a small car-free area, almost always in the old heart of the city, but no European cities are yet fully car-free. These cities are repurposing streets for people, changing road spaces into cycling and walking paths, which will contribute to more sustainable urban communities. The design of new cities from the early stages based on walking distances to any key place combined with public transportation should be the goal, as it is currently the case in some Asian places.

Countries and localities are enacting new legislations to speed up the process. Some regulations include car-free Sundays, banned cars with alternatively odd or even-numbered plates on certain days, investments in cycling infrastructure and pedestrianization, restriction of parking spaces, considerable increases in public transport provision. among others. However, as the European capitals were designed hundreds or thousands of years before cars existed, the transition towards car-free cities is faster than in other places around the world, such as the U.S., as by being designed for driving, the elimination of cars turns to be more challenging.

Car-free cities have the potentiality to significantly reduce traffic-related air pollution, greenhouse gas emissions, noise pollution, petroleum dependency, automobile accidents and traffic congestion, making it critical for tackling the

global climate crisis and simultaneously improving health and wellbeing, which could explain its high positive impact opinions on ENP, PPR and SRU. On car-free days, for example, NO_2 levels have been recorded to drop by up to 40%. Premature mortality and morbidity are anticipated to decrease as a result of these reductions [13].

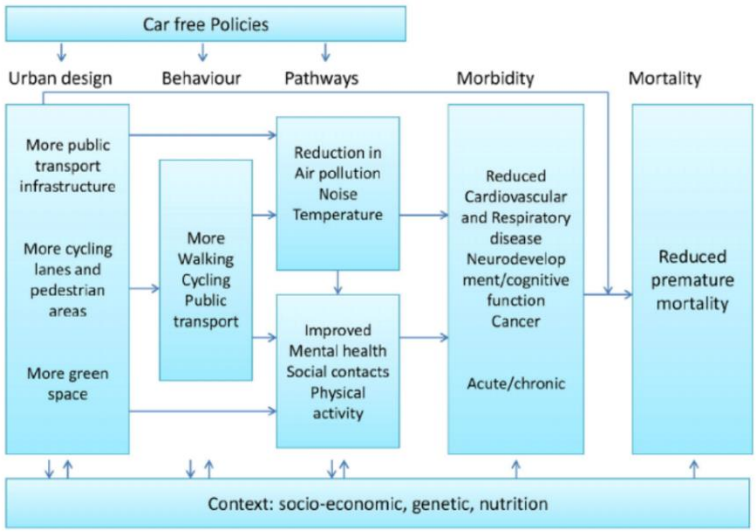


Figure 26 Linkage between urban and transport planning, environmental exposures, physical activity and health

As depicted in figure 26, as the number of automobiles declines, so does the need for parking spaces and road space, opening chances to expand green space and green networks in cities, which can have a variety of health benefits. These initiatives are expected to lead to increased levels of active mobility and physical exercise, which will help to enhance public health and give more opportunity for people to connect in public spaces. Furthermore, if implemented on a wide enough scale, such projects can have good distal impacts as well as mitigate climate change by reducing CO_2 emissions.

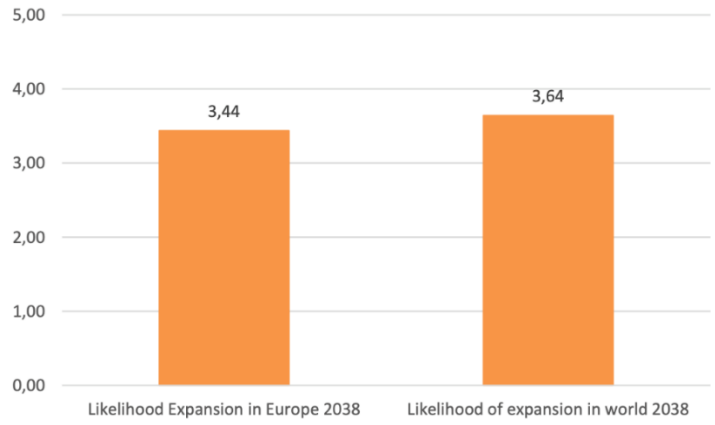


Figure 27 Likelihood of Car-free city by 2038

Multiple policy packages appear to be critical in moving car-free plans in most of these cases. Cities are not just prohibiting or regulating the use of private automobiles, but they are also creating a viable alternative and an appealing counterfactual reality to which the public sphere may move. Public transportation, bike infrastructure, green spaces, and pleasant and secure pedestrian spaces are all policy tools being packaged in larger plans for auto limits. The success of these initiatives in boosting alternate modes of transportation and reducing vehicle use varies, but the government plays a crucial role in its success.

Currently, 60% of Parisians do not own a car, compared to 40% In 2001. In Norway, diesel vehicles are banned from municipal roads to reduce air pollution for specific hours, and completely from 2025 [13]; some vehicles exempt from the ban, such as emergency vehicles, taxis and transport for disabled people. The number of cities adopting this approach is increasing.

Furthermore, this innovation has been encouraged by Covid-19 world pandemic. The pandemic has caused the necessity of the development of a new way of working known as Smart Working, which has proved that it is possible to work from home, at least some days of the week, granting many benefits for the planet and

the society by reducing the need for travelling to work for a vast majority of the population and consequently unintentionally deriving towards car free cities.

MATERIALS

1. Water Harvesting Membranes

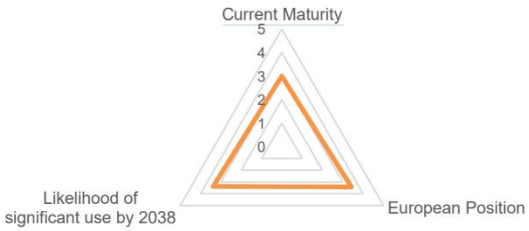


Figure 28 RIB score of Water Harvesting Membranes

This technology collected 1041 opinions, slightly higher than the average one (1011), and represents the technology with highest average absolute impact overall. It achieved its highest average value on the ENP and also reached a significant positive average value in the SEG impact area.

This technology refers to water vapor selective membranes, which are able to separate the water present in the air before cooling it. The purpose of using this selective membrane is to contribute to the supply of fresh water in those areas where this resource is limited, by taking advantage of the considerable amount of water vapor in the air. Globally, 2.1 billion people lack access to water, while 4.5 billion people have inadequate sanitation and clean water source [14], the latter leading to risks of diseases and illnesses. Therefore, the development of this precise technology is of crucial importance as water scarcity is an issue which requires urgent action. This could be the reason for which this technology has accomplished its highest average impact in the ENP area.

Nowadays, worldwide researches are giving considerable attention to it given its potentiality to contribute to improve living standards. Examples of this technology

are water filtration on a nanoscale for desalination, direct solar desalination, and atmospheric water generation. Thanks to the new materials used by these technologies, less energy is used for condensing the water vapor as well as the other gases present in the air, as the cooling of the air can be avoided. The energy savings obtained corresponds to the 60% [10]. Besides, not only benefits in terms of energy savings are achieved, but also in terms of water quality thanks to the possibility to filter pollutants and pathogens. This allows the production of economic potable water by the energy savings which could reduce water's price, accomplishing a massive impact on the global economy.

The benefits of this technology coincide with the fact that it has the highest average absolute impact for all the impact areas overall the technologies, and that there are almost no negative answers for this technology in none of the impact areas. The results from Politecnico's survey match with the ones of the Fraunhofer technology foresight, as the latter one depicted a strong agreement that progress in this technology would make a relevant contribution to environmental protection in 2030. In the Fraunhofer technology foresight, this technology was classified as "Hot-shot", meaning that it is of medium relevance today but given its potential increase in significance, preliminary research or start-up funding is required.

2. Carbon capture and sequestration

This technology belongs primarily to the Energy sector, and for this reason the discussion of it is present in the Energy section.

3. Splitting Carbon Dioxide

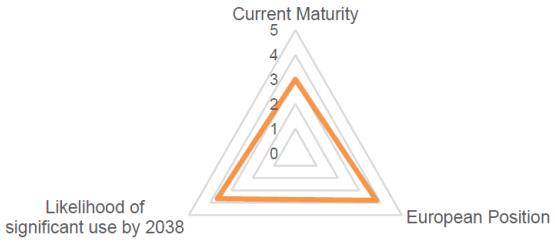


Figure 29 RIB score of Splitting carbon dioxide

Carbon is a critical element that underpins human existence on our planet. Nonetheless, carbon dioxide (CO_2) generated by human activity is one of the most significant greenhouse gases (GHG) contributing to climate change. CO_2 management is presently one of the most pressing social, economic, and political issues. Researchers are currently working on a novel way for lowering CO_2 emissions, either by dividing the gas into carbon and oxygen or by utilizing CO_2 as a feedstock for synthetic fuel production, instead of storing it, planning to utilize it directly by dividing it. [9]

Splitting carbon dioxide technology presents a significant relevance for areas such as material sciences, mechanical, process and environmental engineering, as well as in the planet and space. Because of this, this technology belongs to the group of "Long runners", which are those topics that are now "very relevant" on average and are expected to be extremely significant in 2030, meaning their impact is expected to grow over the years [15].

As seen in figure 29, *Splitting carbon dioxide* is in a medium stage of maturity and Europe holds a leading position in this technology [9]. However, according to the number of survey responses, it is not among the most-known technologies, but it does provide reliable results as there are no controversies in the opinions of the respondents on any of the impact areas. Furthermore, this technology is among those with more impact in general in all SDG areas, with a remarkable positive

impact on the environmental related goals (SRU and PPR) based on the survey opinions.

Currently, scientists are specifically attempting to develop novel, low-cost catalyst materials with high selectivity and conversion rates that can be used in industrial-scale systems [9]. Some recent outcomes include the first low-cost CO_2 splitting method that employs earth-abundant materials developed by researchers at Ecole Polytechnique Fédérale de Lausanne. This technique may be used to convert solar energy and store it while lowering CO_2 levels at the same time. As a result, CO_2 splitting is inextricably linked to carbon sequestration. Another recent development is the Swiss Federal Institute of Technology´s solar reactor-powered thermochemical process, which succeeds in splitting CO_2 into carbon monoxide and oxygen with an efficiency of 83% [16]. In the North Carolina State University, the same has been achieved with a 98% conversion efficiency [17]. Another interesting accomplishment is the new technology that allows to make biofuel using CO_2 by the Ulsan National Institute of Science and Technology and that is able to be used by vehicles with diesel engines.

ENERGY

1. Energy Harvesting

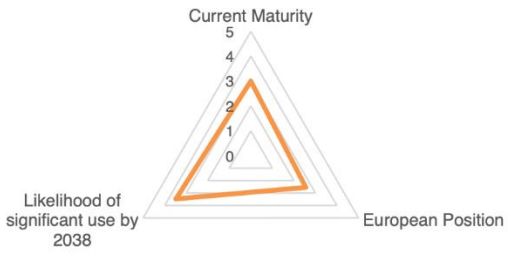


Figure 30 RIB score of Energy Harvesting

The results from the survey for *Energy harvesting* presented a high positive impact on many SDG areas (SRU, PPR, SEG, ENP, in decreasing order), while also being

one with the highest average positive impact on UVP and GOV areas, even though the score for these two yields lower than 1. Moreover, 65% of the answers of this technology were positive, reaching an average of positive values of 3 points.

Energy harvesting (also known as "Power harvesting," "Energy scavenging," or "Ambient power") is the process of converting readily accessible energy from the environment (usually in small quantities) into useful amounts of electricity. Small autonomous devices, such as satellites, laptops, wearables, body implants, RFID, most wireless applications and sensor network nodes, can be self-sufficient with this technology. Particularly, muscle motion has been the subject of a number of recent announcements in this field, contributing to PPR and SRU as it consists of generating electricity from day-to-day human motion [18]. Solar cells and electro dynamos, two very developed energy collecting technologies, account for the majority of harvesters on the market. Many new technologies, on the other hand, are gaining market penetration and enabling power in previously unattainable places, such as thermoelectric - generating power from heat - and piezoelectric energy harvesters, which are expected to reach similar market share for industrial sensing applications by 2022 [19].

The velocity of climate change and rising resource scarcity are two evident drivers for the dissemination of energy harvesting technologies, both of which have a beneficial impact on all clean technology sectors. Other motivations stem from the fact that energy harvesting may be viewed as an enabler technology for a variety of new applications, such as wireless networks, which are at the heart of the IoT and Big Data worldwide developments. Because energy harvesters provide no real advantage when used alone, compatibility between system components and coordination between value chain suppliers are critical to success. Furthermore, as compared to wired or battery-powered systems, energy harvesting reduces energy usage. Although the energy consumption of a single

sensor, for example, may be insignificant, the large numbers with which they are deployed translate into significant amounts. As a result, rising energy prices boost the value of energy collecting technologies.

This technology has a major impact on the dimensions of environment and society and is expected to have an even higher impact on them in the near future as it has high influence in agricultural and nutrition sciences as well as in material science and environmental engineering [19]. In Fraunhofer technology foresight report, *Energy harvesting* is under the group of technologies considered to be "Social shapers", which are those activities that have the potential to become extremely important owing to their contribution to society and the environment's future development [15].

It is evident that energy harvesting solutions can assist in meeting global energy needs by catching otherwise wasted energy. This is good for the environment as well as the financial health of businesses and individuals. As a result, energy harvesting technologies are now being used to increase the energy efficiency of household and business equipment. A downside is that energy harvesting technology is not yet suitable for powering mesh wireless networks in remote or extreme locations, which makes it particularly harmful for applications in high-impact contexts like forest fire prediction. [20]

Given that the requisite of lower-power electronics and more efficient energy collection and storage are now sufficiently economical, dependable, and long-lasting for a wide range of applications, the technology has reached a tipping point [19]. IDTechEx (a consultancy that provides market research, business intelligence, and events on emerging technology to its clients in over 80 countries since 1999) stated that energy harvesting technologies have a reasonably clear socio-economic relevance and the total market for energy harvesting devices, including everything from wristwatches to wireless sensors will rise to over $2.6 billion in 2024 [19].

From figure 30 it can be seen that Europe´s capacities show weakness in this technology, and due to the fact that energy harvesting likelihood of significant use by 2038 is high, more research and development would be highly suggested in this field. [11].

Efficient energy harvesting techniques offer a range of devices that require little or no maintenance and are powered by locally accessible materials. Although this technology is applied mainly for small devices, it allows highly efficient production, transmission, and net "use" of energy for common gadgets that have a very large, combined power consumption, thus positively contributing to the SEG and ENP areas, while also to PPR and SRU as seen in the survey results as it is a "clean" energy technology.

In addition, policymakers may have a significant impact on the market uptake of energy harvesting technologies for wireless networks. Governments may send strong signals to consumers and businesses by defining minimum safety and quality requirements for the deployment of energy harvesting systems and serving as a launching customer. For instance, they could prescribe the adoption of energy harvesting technologies in public procurement activities and wireless networks powered by energy harvesters could be installed in public infrastructure. Companies like EnOcean experience that diffusing innovation to government buildings is very hard as there is no basis for introducing innovation, because government officials are often very conservative [20]. To tackle this, governments could initiate programs and regulations which set minimum requirements for adopting innovative solutions in their procurement.

2. Carbon capture and sequestration

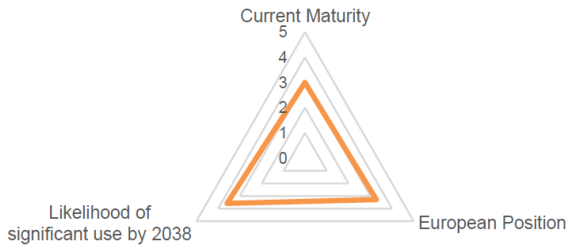


Figure 31 RIB score of Carbon capture and sequestration

Global climate change is triggered by carbon dioxide (CO_2), which is a waste product emission. To avoid it being lost to the atmosphere and lower CO_2 levels and hence its consequences, many methods are implemented. Carbon is collected for storage or subsequent processing at sources of high CO_2 emission, such as smokestacks in different industries and carbon-based power plants. When combined with carbon storage, direct air capture can serve as both a CO_2 removal technique and a kind of climate engineering if done on a big scale [9]. The Intergovernmental Panel on Climate Change (IPCC) and other international organizations have concluded that CCUS can play a crucial role in achieving ambitious CO_2 emissions reductions [21].

Direct air capture methods such as absorption, adsorption, and membrane gas separation, extract CO_2 from air or flue gas. Carbon capture, use, and storage technologies can capture more than 90% of CO_2 emissions from power plants and industrial facilities [9]. Carbon can then be either stored (CCS) or used (CCU). These two go hand in hand, as CCU technologies and infrastructure provide support and accelerate CCS solutions [22]. Because CO_2 or extracted carbon interacts exothermically with metal oxides, it might be stored minerally or in deep geologic formations, or in certain situations, it is transported through pipes to be used elsewhere [9]. Currently, new storage solutions are being explored. Scientists at Trent University in Canada have discovered a fast technique to make magnesite, a material that absorbs CO_2 from the environment and stores it

permanently. On the other hand, new applications for CO_2 CCU may alleviate some of the issues and expenses associated with storage, though not the costs of collection. For example, Covestro, formerly Bayer Material Science, recently opened a plant in Germany that makes foams from CO_2[23].

The survey opinions suggest the highest impact to be on PPR, coherent with the fact that this technology contributes to combat climate change and its impacts. In addition, it is one of the technologies that presented the higher average score on this SDG area, after *Car-free city*. The results also account for a medium average positive impact on ENP and this is explained by the increased social well-being because of the improvement on air quality and the consequential benefits of reducing GHG emissions. It should be noted, however, that CO_2 is a very inert chemical, which poses a significant difficulty on the implementation of these technologies. As a result, converting collected gas into industrial goods generally requires a significant amount of energy.

From figure 31 it can be seen that there is a high expectancy of use of this technology by 2038. As fossil fuels are expected to meet a majority of the world's energy demand for several decades, carbon capture is considered as the only realistic option to accomplish substantial decarbonization in the industrial sector, since it can deliver 14% of the worldwide greenhouse gas emissions reductions needed by 2050. Therefore, the surprising growth of renewable energy probably will not make up for the expected increases in emissions from other sources [24]. Moreover, CCS technologies promise to solve the climate problem independent of drawn-out political disputes and without changing production and consumption patterns, which is a critical factor.

Nevertheless, another source states that critics claim these technologies are prohibitively costly, pose certain dangers, and have unclear outcomes, so some controversy is present with regards this technology´s expectancy of use in the future. However, If CO_2 could be put to industrial use as the ones previously

mentioned, the resulting revenues could make carbon capture financially viable [25]. This may not be depicted in the survey opinions as the impact on SRU resulted in an above average positive impact, unless only those cases in which clean energy is used when implementing the technique of carbon sequestration are considered [23].

As of 2020, there are at least 26 commercial-scale carbon capture projects in operation throughout the globe, with 21 more in the early stages of development and 13 in advanced stages of development that have reached front end engineering design (FEED) [22]. The US leads in this field, while Europe holds a strong position as seen in figure 31. In general, this technology is still in its early stages of development, but it is highly known, depicted by the fact that it was the fourth most voted technology in the survey.

While carbon capture and storage has been sluggish to gain traction, CCU appears to hold greater hope, owing to its revenue-generating potential. CCU's long-term viability will be determined by today's technological investment decisions. Companies and governments who give the necessary assistance now may be in a better position to reap the advantages of CCU in the future and the survey results show this as there is an average 2-point positive impact on SEG area [23]. Opportunities remain to improve performance, reduce costs, discover new uses for CO_2, and implement regulatory frameworks and international standards to provide certainty in permitting and operation of CCUS projects [21].

To ensure that CCS can be deployed in the 2030 timeframe, increased R&D efforts and commercial demonstration are essential over the next decade. A supportive EU framework will be necessary through continued and strengthened use of auctioning revenues. Some recommendations include policy assistance focused on increasing capture rates in key energy-intensive industries, allowing theoretical potentials to be demonstrated. Furthermore, to aid scale-up, initial emphasis should be placed on industrial clusters where diverse CO_2 sources may be

blended into greater volumes. In addition, EU state aid laws (for example, environmental state aid standards) should make it easier for member states to spend on CCS infrastructure development and political decisions should be taken on the market and finance models that will be used for CCS development, both in terms of capital investment and operating funding [26].

The main challenge resides in that capture, on the one hand, and transit, storage, or usage, on the other, must be created concurrently: industry must capture pollutants in order to store them (or use). Countries need to commit to transportation and storage infrastructure so that companies can commit to capturing emissions, and vice versa. Furthermore, existing economic, regulatory, and political impediments must be addressed through policy as barriers remain to the deployment of this technology at scale. For the time being, CCS technology and infrastructure have not reached technological maturity levels that allow for considerable reductions in industrial GHG emissions. These hurdles are solvable, but they need careful cooperation among various businesses, EU and EEA member states, and, in certain circumstances, foreign nations [26].

4.3 EXAMPLES OF TECHNOLOGIES WITH HIGHEST NEGATIVE OPINIONS

BIOTECHNOLOGIES AND MEDICINE

1. Gene editing

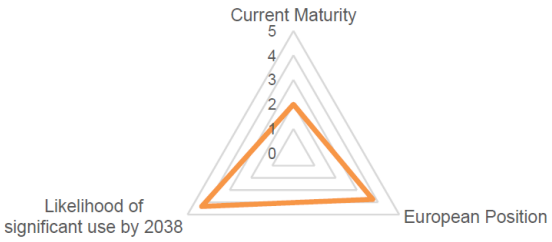


Figure 32 RIB score of Gene editing

Gene editing technology has the greatest negative impact on UVP (-2.87), as derived from the survey responses, and is also one with the highest percentage of negative opinions (31%).

Gene editing is an engineering tool through which it is possible to change an organism's DNA; genetic material can be inserted, removed or altered in the genome. There are two different types of genome editing: somatic and germline. The first one affects only the patient being treated and only some of his cells, while the second one affects all of the cells in an organism, including eggs and sperm, and so it not only affects the patient being treated but his descendants as well.

This technology can serve therapy, prevention and enhancement purposes. Therapeutic gene editing can only apply to somatic genome editing, as therapy can only refer to individuals who are suffering from a disease; an embryo, can be a carrier of a gene that will lead to a disease, but does not suffer from a disease with physical symptoms nor personal and social experience of illness. Between prevention and enhancement there are no defined limits as such intervention can serve for both purposes.

This technology achieved a significant positive impact on the ENP, which can be deducted from the fact that it gives the possibility to treat and prevent diseases or impairments. This technology has the potential benefit of eliminating the genes responsible for some of the diseases created from mutations in a single gene, for which today there are more than 10,000 according to the World Health Organization (WHO) [27], and so make our future world disease free. However, experts say that editing one gene may unintentionally head off changes in another, and nowadays scientists do not yet understand how to make precise fixes without also introducing unwanted and possibly dangerous changes [28]. Furthermore, the health of patients' subject to germline gene editing intervention should be monitored for several years to obtain accurate assessment on the side effects in future generations.

From the UVP point of view, one of the reasons for which this technology has a high consensus on its negative impact on this impact area, could be due to the fact that, as stated above, altering the germ cells can be used for interventions not related to preventing or treating diseases, but to enhance human capabilities instead, outside the correction of anomalies (e.g. "gene-doping") [29]. Germline gene editing is the most controversial type of gene editing due to the fact that changes are inherited and that it can be used to create "designer babies" by modifying genetic traits of a person and shaping it according to medical, societal and personal preferences, as for example, the eye color. All in all, germline gene editing disrupts human dignity, identity, diversity, equality, social justice and solidarity [12].

Moreover, situation gets worse due to its high cost. There are many different procedures for gene-editing, but still, they all require large amounts of money, and because of this, gene-editing can increase the economic disparity between the rich and the poor. A former molecular biologist and founder of Human Genetics Alert stated: "Once you start creating a society in which rich people's

children get biological advantages over other children, basic notions of human equality go out the window (…) What you get is social inequality written into DNA" [27]. Rich people will have an unfair advantage in the economic competition due to the possibility to buy this technology over the other classes, and by changing the genes they can make their descendants to become smarter and "improve" their physical characteristics, leading to more wealth and lack of economic mobility [27]. This could explain the survey positive impact results in the SEG impact area and the negative ones in the UVP area [13].

In the European Union, germline gene editing for clinical purposes is banned, but regulation is still lacking as it is not clear if the ban applies to germline gene editing research as well. However, regulation for the application of this technology in only medical interventions is still hard to cover as definitions of "healthy", "disease" and "disability" are often not clear and can change over time and among societies.

The European Group on Ethics (EGE) provides high quality advice on all the aspects of EU legislation and policies, where ethical, societal and fundamental rights issues intersect with the development of science and new technologies. This independent advisory body reports to the President of the European Commission. One of the topics in which the EGE is working on is the genome editing, for which the following recommendations were given in March of 2021:

- Engage in global governance initiatives and create a platform for information sharing and inclusive debate on germline genome editing;
- Establish a public registry for research on germline genome editing;
- Protect social justice, diversity and equality;
- Ensure adequate competencies in expert bodies. [29]

Adding to the results of the survey, it can be said that the reason why *Gene editing* could have had high positive impact in the GOV impact area by stimulating global partnership for the regulation of the application of germline gene editing in humans as well as protecting universal values; instead, this is not the case.

Germline editing should only be used in those cases in which there is no other available option to provide a healthy outcome from the patient with a disease [11]. It is needed to find a way to regulate appropriately the usability of the germline gene editing technology in order to support the future sustainable development goals, specifically those related to ENP and UVP.

ARTIFICIAL INTELLIGENCE

1. Emotion Recognition

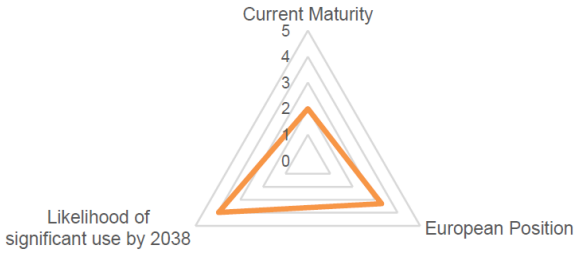


Figure 33 RIB Score of Emotion Recognition

Emotion Recognition is a technology used for analyzing feelings through different sources, as pictures and videos, in order to identify and understand human emotions. It is used for example to improve customer service, marketing purposes, decide which people to interview, monitor students' attention, improve lie detectors for law enforcement, adapt smart devices according to our mood, etc. This technology requires computer vision to precisely identify facial expressions, and machine learning algorithms to analyze and interpret the emotional content of those facial features.

It is expected that in the near future this technology will be ubiquitous and incorporated in all of our devices [30]. Today, the market for emotion-recognition technology is worth roughly $21.6bn, and it is predicted that this value will be more than double by 2024, reaching $56bn [15], supporting the fact that its impact on the SEG area is the highest average value in the survey.

On the other hand, it has been claimed that *Emotion Recognition* is not accurate enough and so that is being misused. The reasons behind its inaccuracy are that it is built assuming that external expressions are indicators of internal emotions, and that facial expressions are similar across cultures and so it is universal. Both assumptions have been proved by researchers not to be true [31]. Recent studies have shown that *Emotion Recognition* reproduces distortions that more likely damage minority communities; for example, assigning more negative emotions to black men than white men [32]. Apart from the lack of accuracy, ER does not explain the reason behind an emotion [15].

In addition, this technology arises concerns about privacy issues due to both the collection and the processing of personal data. Cameras used for emotion recognition can be anywhere, also in a personal mobile phone, and there is no transparency on which system a person's data will be processed, who will control it and for which purposes. For example, knowing an individual's emotion in a given time provides the possibility to manipulate people and force them to perform a certain action.

To avoid serious effects, particularly discrimination on skin color and ethnic origins, the dataset should be representative. The technology is developing without the people's acceptance and is attempting international human rights standards. The main harms that this technology generate in people are a possible restricted access to services and opportunities, deprivation of privacy rights, and lack of freedom of expression and opinion. The extreme exposure of people due to this technology and its related serious effects, might not be desirable, and could

explain the reason why this technology has a high negative impact value in both UVP and ENP. [17]

The AI Now Institute (a research institute at New York University studying the social implications of artificial intelligence) recommended that the use of this technology in decisions that impact people's lives and access to opportunities should be banned. Until then, AI companies should stop selling this technology. In Europe, it will always be considered a high-risk application if it is used in areas of employment, education, law enforcement, migration and border control [33]. This level of risk corresponds to an adverse impact on people's safety or their fundamental rights. To manage and ensure trust and protection of safety and fundamental rights, the EU proposed mandatory requirements covering: the quality of data sets used; transparency and the provision of information to users; human oversight; technical documentation and record keeping; robustness, accuracy and cybersecurity. These requirements will allow national authorities to investigate if the use of the AI systems put on the market complied with the law [33].

2. Blockchain

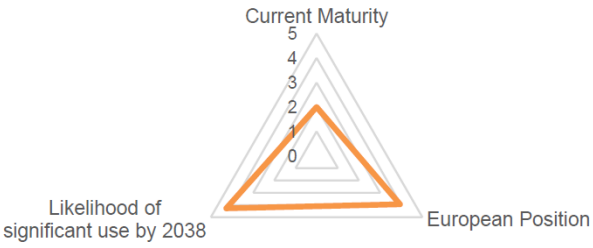


Figure 34 RIB Score of Blockchain

This technology is in an early phase of development, and it is widely known for its application to cryptocurrencies. This technology is one of the technologies with certain discrepancy on the survey results on PPR and SRU impact areas; in both, the number of positive and negative results are almost the same (20% - 18%, 24%

- 20%, respectively), as well as their corresponding average values, which lay between 2.3 and 2.7 in absolute value.

Starting from the interpretation of its negative impact, an analysis carried out by Cambridge University evidenced that if Bitcoin – the most popular cryptocurrency – was a country, it would consume more electricity per year than the whole Argentina, given the immense energy consumption of the main mining method of the cryptocurrencies: Proof-of-Work [34]. Researchers say that bitcoins' mining uses around 121.36 TWh of electricity per year [35], and in March of 2021 its estimated consumption reached 130 TWh [36]. This energy consumption is also higher than the one from all the technological giants combined (e.g. Google used 10 TWh in 2019 [36]). Furthermore, a study published in Nature Climate Change journal in 2018, claimed that "bitcoin could alone produce enough CO_2 emissions to push warming above 2ºC within less than three decades" [37]. However, there are methodological issues, not enough data and variable conditions, and so other researchers claim that all of these estimates are not completely reliable.

The high electricity consumption from cryptocurrencies is by design, and as long as the price of the cryptocurrencies increases, so will the energy consumption [35]. Furthermore, apart from the high energy requirements of the computational systems required for mining, Blockchain also contributes to electronic waste given that the mining hardware becomes obsolete quickly (approximately 1.5 years). Compared with alternative payment methods, studies show that Bitcoin transactions consume about a thousand times more energy than a credit card transaction, and that it generates 135 g of electronic waste per transaction, which represents 30,000 g more than a Visa transaction [38].

Given its increasing popularity, it will be crucial to find a way to reduce the energy consumed per transaction verification. Elon Musk – Tesla CEO – has already expressed his concern about cryptocurrencies' environmental impact and said

that he will not accept them as payment, as neither will Greenpeace accept them for donations [34].

Different options have been suggested, such as assessing the consensus algorithms and their energy impact and efficiency, and choosing the more sustainable one. The Ethereum cryptocurrency - the second cryptocurrency with the highest value – already uses much less energy than Bitcoin due to its smaller size of its market, and is also planning to transit its consensus algorithm from Proof-of-Work to Proof-of-Stake, which is more energy efficient reducing at least 99.95% in total energy use from the current one [39]. However, engineers are working to see how to make the transition without compromising the safeness of transactions and without putting at risk people that already own Ethereum. Although the transition is still uncertain, it is expected for the first half of the year 2022 [40]; if it happens to succeed, it Is expected that Ethereum will raise its value and people's attention, and could consequently not only overpass Bitcoin but also encourage Bitcoin and other cryptocurrencies to transit to a greener computational methodology. The main disadvantage of Proof-of-Stake is that it is new, and so less well-tested, and requires a much more complex network design. This leaves space for a second option to reduce carbon footprint of cryptocurrencies: shifting to greener sources of energy for Proof-of-Work mining. However, due to the decentralized nature of bitcoin, the localization of miners to examine the electricity mix used makes it difficult to translate the energy consumption into carbon emissions [41].

As *Emotion Recognition*, *Blockchain* also raises concerns about privacy and data protection as the more personal data are stored on the blockchain, the easier it is to identify a user. A further issue is that given its immutability, *Blockchain* is an obstacle to exercise the "right to be forgotten", a legislation from the European Union's General Data Protection Regulation (GDPR)[42]. These blockchain effects impact negatively on UVP.

Even more, there is the issue of accessibility and equity, as for the lack of access or practical knowledge on how to use it that part of the population can have, increasing the digital divide and so negatively impacting SDGs under UVP and ENP areas. To tackle this, the European Commission is already thinking for initiatives dedicated on skills development to ensure that the high level knowledge will be available [43].

On the other hand, *Blockchain* is also seen as a key enabling technology for achieving the SDGs, as it can make existing consumption and production processes more accountable, transparent, traceable and cyber-resilient. Derived from this, it is a powerful tool to keep track of greenhouse gas emissions in real-time and in an accurate way. "The blockchain is accepted by public groups and private companies as a future infrastructure for honest business" [9].

The European Commission has already announced that it wants to leverage on *Blockchain* technologies to help climate change. An application in which *Blockchain* could enhance sustainability is the management of the supply chain; Nowadays, there are standards to guarantee their environmental responsibility, but in many regions they are expensive and not completely reliable. Through Blockchain smart contracts, the entire supply chain information will be visible, traceable and verifiable by every party in the supply chain, as well as secured, time-stamped and trustful given that it cannot be modified. In this way, *Blockchain* will provide reliable sustainability assessments and allow consumers across the supply chain to make greener choices. In turn, such transparent and timely reporting will incentivize actors in the supply chain to consider their overall environmental and societal impacts of their actions, thus positively impacting on SRU and PPR.

For what is more, *Blockchain* technology could also provide a higher operation efficiency in global partnerships. Being a decentralized network, it has been argued that it could lead to economic and environmental benefits, as from the

assumption that peer-to-peer transactions could make better use of resources. However, all these possible benefits need to be confronted with the Blockchain's energy consumption [38].

With respect to the GOV impact area, *Blockchain* technology seems to have a positive impact at least in the European Union, which is in accordance as well with the survey results (0.92 average impact, the second highest of all the technologies in this area, and 42% positive answers, the highest of all the technologies in this area); this is as recently, the European Commission has co-initiated many initiatives to promote the development, monitoring and standardization of *Blockchain* technologies, as for example the European Blockchain Partnership and the European Blockchain Observatory and Forum. Other key activity which the European Commission aims for is to develop partnerships with UN agencies and international financial institutions. [44]

By now, *Blockchain* applications are in an experimental stage and under not yet defined regulation. The EC hopes to elude legal and regulatory fragmentation. The EU is providing grants in Blockchain research and innovation and supporting investment in *Blockchain* startups through the new AI & Blockchain Investment fund [43].

MOBILITY

1. Flying Cars

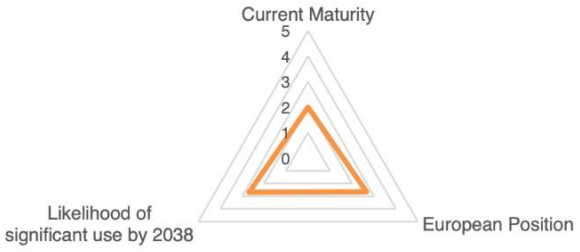


Figure 35 RIB score of Flying cars

Flying cars - vertical takeoff and landing aircrafts (VTOLs) - are a disruptive technology that has presented increasing development in the last few years. It appears to be in its infant stage of maturity, with a low likelihood of significant use by 2038 and an average European position. However, according to a Morgan Stanley analysis the global market for on-demand, short-distance urban air travel could top $850 billion by 2040 [45], which reflects the potential of increasing development of this technology in the near future also supported by the fact of the recent advances in lithium-ion batteries that are crucial to this mean of transportation. The survey results depict this fact as the SDG area of SEG is the one with the highest average impact opinions with 1.4 points. Furthermore, the results show a positive impact only on one other SDG area, ENP, as this technology would contribute to the well-being of the population by improving quality of life [26], given that, for example, they are presented as a convenient solution to decrease travel times.

However, this kind of technology is meant for an elite part of the population that is wealthy enough to endure its high costs. For *Flying cars* to be accessible to a wider range of the population, economies of scale in their production would be needed, otherwise this technology remains a utopic scenario and as a luxury for a few. Moreover, flying vehicles are a political risk because they could allow affluent elites to further exclude themselves from common institutions and ordinary experiences, further dividing society. In summary, flying vehicles' high-speed transportation service will enable elites to meet their twin need for hyper seclusion and hyper access. At its most fundamental level, democracy is a means for achieving the required agreement for long-term collective action to address society's most serious problems. Yet, when the most powerful citizens live fundamentally separate lifestyles, forming consensus or a single intent is difficult. Flying automobiles will aggravate this divide by amplifying the worst characteristics of wealth, power, and privilege. Therefore, this is the reason why

the survey results yield a negative average impact on UVP. The government's participation is critical in addressing the issue of inequality.

The technology also poses a substantial environmental risk due to the massive shift in settlement patterns to low density areas. First, because it will allow for the development of previously undeveloped territories that were previously undesirable due to distance and travel time constraints. The loss of key environmental services, such as carbon sequestration and flood risk reduction, occurs when agricultural or wooded land is developed for commercial or residential use. For example, the Environmental Protection Agency estimates that an acre of wetland can store between 1 million and 1.5 million gallons of water [46]. It makes little difference that the majority of flying automobiles will be battery-electric vehicles as any savings in direct emissions from electric vehicles will be compensated by indirect emissions from lower-density regional land use. And second, distance increases emissions as it makes walking inconvenient to reach places and transport service are impossible or prohibitively expensive [47]. Due to the few alternatives, people become reliant on private automobiles, and the reduced density equals lengthier car journeys. Therefore, longer VTOL journeys will not be a replacement for car journeys, but rather a supplement, increasing overall energy and resource consumption associated with everyday mobility. As a result, comparing the energy efficiency of a lengthier VTOL journey to that of an electric car is pointless because a large fraction of longer journeys would never be conducted without the technology. Consequently, in terms of emissions and resource usage accounting, VTOLs should be viewed as an extra entrainment rather than a marginal one when compared to a terrestrial option. The survey results with prevailing negative impact opinions on SRU and PPR support these claims.

Additionally, a study conducted by the automotive company Uber proved that for short flights, "the VTOL is less energy efficient than automobile travel per mile

because it spends less time in the more efficient cruise mode while the power required for vertical takeoff and landing remain constant" [48]. Also, the energy needed for takeoff and landing is greater for VTOLs than traditional helicopters. However, another study found that, because it will most likely be utilized under a transportation-as-a-service business model where service providers want to optimize usage rates, the VTOL is expected to contain three passengers and one pilot (i.e., four people), while ground-based automobiles are most likely to be privately owned, with an average passenger/occupant load of 1.54 people. Hence, for a scenario of 100 km point-to-point travels, VTOL GHG emissions are 35% lower than ICEVs, but 28% higher than battery electric cars (BEVs). When base-case emissions per PKT are normalized for predicted loading, VTOL burdens (with three passengers) are 52% and 6% lower, respectively, than for the ICEV and BEV (with 1.54 passengers). Still, VTOLs have greater energy consumption and GHG emissions than ground-based vehicles during short journeys (up to 35 km), which account for the majority of trip frequency for conventional automobiles, but VTOLs offer fast, predictable transportation and could have a niche role in sustainable mobility for longer journeys.

As previously stated, there is no reason to expect that supporting elite seclusion and higher land use will lead to significant positive externalities. Flying automobiles are more likely to weaken democracy and exacerbate global warming than to provide widespread social benefit. However, because of this technology's severe political and environmental repercussions, the government may impose appropriate regulations such as usage levies, zoning limitations, and airspace limits to curb demand and protect virgin lands, limit air travel and create incentives to promote economies of scale in order to increase the benefits of using this technology and reduce its negative impacts on inequality, land usage and planet preservation. Nonetheless, rather than financing elites' hypermobility preferences, grants should be used to promote transportation initiatives that benefit the greatest number of people, primarily through increasing the

geographic reach, frequency, and quality of public transportation. Furthermore, air traffic control (ATC) systems and procedures will need to be dramatically upgraded to accommodate the deployment of flying automobiles. Additional infrastructure, manpower, and the ultimate automation of many ATC duties for low-altitude flight will be required to safely accommodate flying automobiles and drones.

Because of the many obstacles, it is difficult to predict when or if VTOLs will start providing regular commercial service. Despite the fact that VTOLs confront economic, regulatory, and safety hurdles, they may play a specialized role in a long-term transport system, as they appear to have a specialized function in sustainable transportation in terms of energy utilization and hence GHG emissions for long journeys.

4.4 REMARKS ON TECHNOLOGY SECTORS

4.4.1 ENERGY

The Energy sector not only has the highest percentage of positive results and the lowest percentage of negative results overall but is also the only technology sector for which the percentage of positive responses exceeds by most the percentage of the neutral ones. Moreover, it is the technology sector with the highest total average impact value, with a score of 1.5. Within the 10 technologies with the highest total absolute impact, 3 belong to this sector, while none of the technologies within this sector appears in the list of the 10 with highest percentage of negative opinions. Moreover, these technologies are some of the most-knowns by the respondents according to the number of responses collected, except for *Bioluminescence* which falls within the 10 least-known, coinciding with the EC Radical Innovation Breakthrough report, in which this specific technology has a European position equal to 0 [9], suggesting that there is lack of research and development on this technology.

From the survey results, this sector appears to be most beneficial for the environment related sustainable goals (SRU and PPR), impact areas for which it has achieved a significant higher value compared to the other sectors, given that the technologies comprised in the Energy sector have the potentialities to stop global warming by significantly reducing the energy consumption and the carbon footprint [15]. It is interesting to notice that all of the technologies within this sector have their highest average impact value in SRU (except for *Carbon Capture and Sequestration* and *Wireless Energy Transmission*, which have their highest average impact value in PPR and SEG, respectively).

Today, little research is applied to some of the technologies within this sector which could rapidly grow in importance, such as *Artificial Photosynthesis*. Energy solutions are becoming a geostrategic asset given the pressure from climate

change, making it crucial the push for more research and development activities in these technologies in order to exploit the benefits that the technologies under this sector could provide. Most importantly, systems based on Energy technologies should get to the point where costs are low enough in order to decrease the demand and consumption of fossil fuels. In this way, energy scarcity could be softened, which is one of the biggest global conflicts. [9, 15]

4.4.2 ARTIFICIAL INTELLIGENCE

The potential benefits of Artificial Intelligence technology sector for our society are many, from improved medical care to better education, as well as economic growth and enhance EU innovation [33], portrayed in the survey results by obtaining its maximum average impact value in SEG area, followed by ENP. The survey results also match the EC Radical Innovation Breakthrough report, as here AI is described as "a cluster of innovations that will have a huge impact on the future world economy and society" [9].

However, certain technologies within this sector create risks that should be addressed to avoid unwanted outcomes. This sector has the highest percentage of negative answers, raised mainly on the PPR and SRU areas, which could be explained given the energy requirement and carbon footprint of the large computing centers required by the vast computational resources for AI technology. Research and product design will be needed to design more efficient cooling systems for the data centers, improve the energy efficiency and use renewable-energy in information and communications technologies [49]. Moreover, certain technologies within AI have significant negative answers also in UVP, which can be explained by the socio-economic inequalities within and across countries that certain technologies could generate [27]. More specifically, within AI there are some technologies, such as *Emotion Recognition, Blockcha*in and *Brain Machine Interface* which came up to be within the 10 with highest percentage of negative responses for specific SDGs from all of the survey

technologies, and the first two in more than one impact area. These two also count with high controversial answers of their effects on ENP, GOV and UVP for *Emotion Recognition*, and on PPR and SRU for *Blockchain*.

Innovations within this sector are relatively immature today but it is expected by many that they will develop fast and find important use by 2038 [9]. Legislative action will be needed to adequately address both the benefits and risks of AI systems. The European Commission has announced its proposal for a new regulatory framework on Artificial Intelligence to address risks related to user safety and fundamental rights, providing AI developers, deployers and users with clear requirements and obligations of the specific uses of AI systems [50]. The regulatory proposal of the European Commission follows a risk-based approach of four levels: Unacceptable, High, Limited and Minimal Risk. Specifically, there will be strict obligations for the AI systems categorized as High-risk to be allowed to be on the market, with the aim to ensure Europeans trust what the AI provider offers. The requirements for the High-risk AI systems will be:

- "Adequate risk assessment and mitigation systems;
- High quality of the datasets feeding the system to minimize risks and discriminatory outcomes;
- Logging of activity to ensure traceability of results
- Detailed documentation providing all information necessary on the system and its purpose for authorities to assess its compliance;
- Clear and adequate information to the user;
- Appropriate human oversight measures to minimize risk;

- High level of robustness, security and accuracy."[4]

Moreover, figure 36 details the process that high-risk AI systems will be subject to if they are put on the market [50]:

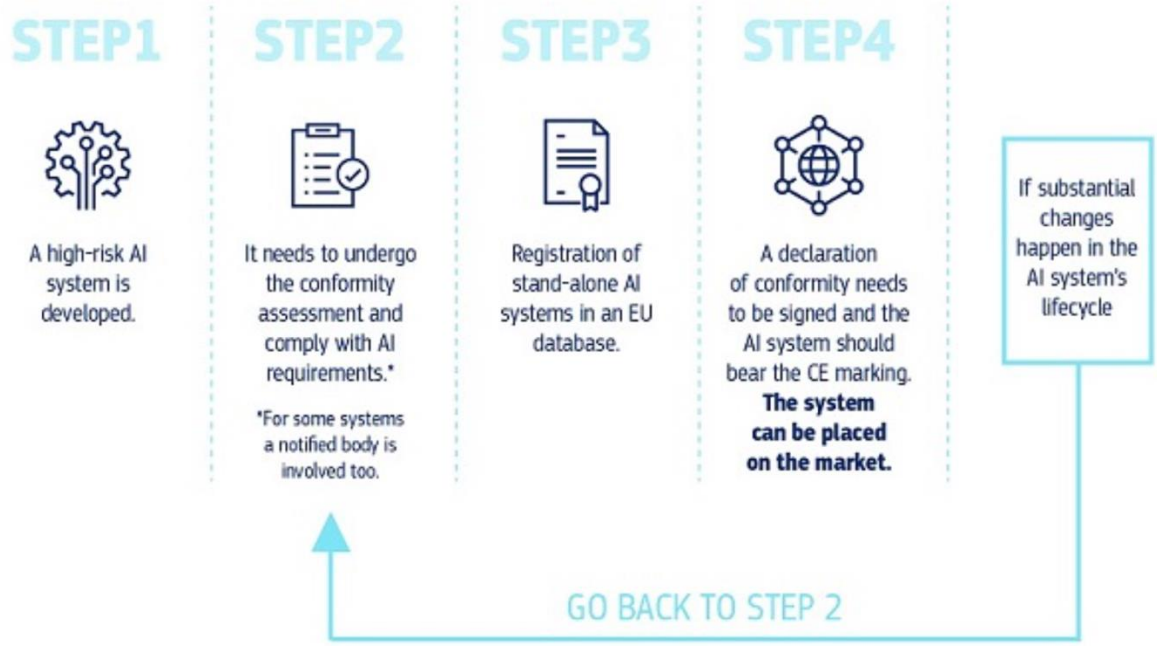


Figure 36 Steps to be followed by providers of high risk AI systems

The new regulatory framework could enter into force in the second half of 2022 in a transitional period, where standards would be mandated and developed, and in the second half of 2024 could become applicable to operators with the standards ready [50].

4.4.3 BIOTECHNOLOGIES AND MEDICINE

This technology sector is the one with the lowest overall average impact value, with a score of 0.98. It prevails in its positive impact in ENP with the highest average impact value of this area with 2.3 points. Actually, all the technologies within this sector got their highest average impact value in this area, except for *Underwater*

4 Shaping Europe's digital future. Regulatory framework on AI; 2021 [cited 2021 June 20] Available from: URL: https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai.

living, which achieved its higher average value in SEG. Most of its responses were given to ENP, SEG, UVP and GOV. From the survey results it can be deducted that respondents do not see any relationship between this sector and the impact areas of SRU and PPR, given the very few and neutral answers given in these areas.

This sector is the one with the lowest percentage of positive answers, and together with MO is the second one with the highest percentage of negative answers. However, *Smart Drug Delivery* has the third place in the list of the technologies with highest average absolute impact in an individual area (figure 17, section 3.3), and is the technology with the highest average absolute impact in ENP; Moreover, *Gene editing* and *Bioprinting* fall within the 10 with highest percentage of positive answers, also for the ENP area. What is important also to highlight is that within the 11 technologies from this sector, 4 of them appear within the 10 with highest percentage of negative answers, from which 3 appear for their negative impact in the UVP; these technologies are: *Gene editing*, *Human enhancement* and *Humanoids*. In addition, for these three technologies negative impact values predominate also in GOV and SEG areas. These technologies have very similar positive and negative effects and understanding how to make use of them while limiting their harmful impacts, such as increasing the social inequalities and decreasing the social and economic growth by being replaced by robots or "Smart babies", should be the main focus of attention.

The fourth technology within this sector that falls within the 10 with the highest percentage of negative answers is *Underwater living*, which appears in this list for its negative impact in SEG; however, as mentioned above, it is in this area that this technology achieved its highest average value, meaning that there is a contradiction among respondents, and not only for this impact area but for all of them. Until now, living underwater is economically unreasonable and requires also being very sustainable, including a circular use of resources. This technology has

very low maturity and likelihood of use by 2038, indicating that are only first speculations. The main application for this technology would be the training of astronauts and aquanauts; for cities or villages seems to be far away [9].

Summing up, this sector promises very advantageous opportunities for the ENP, but careful attention must be given to the sustainable goals under UVP and SEG. Some of the technologies appear to be very beneficial mostly for treating and overcoming diseases, but lack of regulation and the high prices could attempt against justice and equality, expanding the socio-economic disparity. Most of them are now in an early phase of development, being their current maturity of 2 points, but some of them – and the most crucial ones in terms of expected negative impacts - have an elevated likelihood of significant use by 2038, and so they should be of relevant importance for applied research and regulation today.

4.4.4 MOBILITY

This technology sector is the one grouping the fewest number of technologies (5) and the second one after AI with the highest percentage of negative responses (6%) (together with Biotechnologies and Medicine). However, this sector is placed second regarding the average impact on all SDG areas with a score of 1.23 points after the energy technology sector. The responses showed the highest positive impact on SEG, followed by ENP for the person. It is relevant to mention that all 5 technologies under this group accounted for the highest number of opinions. It should be noted that *Car-free city* is the most popular (based on the number of collected opinions) one and the second one with the highest average absolute impact after *Water harvesting membranes*, with its major impact on SRU. On the other hand, *Flying cars* is the technology with highest percentage of negative votes in the survey obtaining a remarkable 32 and 31 percent for PPR and SRU respectively. However, it is among those with a significant impact on socio-economic development.

Transport has become a key contributor to climate change as the number of travels has risen - both in Europe and worldwide, projections show that passenger transportation will expand by 42% by 2050, while freight transportation will increase by 60% [51]. This is excellent news for passengers and business, but it places a strain on the transportation system and the environment. If nothing is done, transportation will overtake energy as the greatest source of emissions, jeopardizing the EU's ability to fulfill its total emission reduction targets. So, looking for more sustainable solutions is a pressing matter.

Some measures such as car free cities are already being implemented, though there is still a long way to go, and hurdles involve the need for infrastructure or their design from initial stages in order to achieve this. Furthermore, regulations and policies are key regarding the implementation of cleaner practices. For instance, all EU nations should support and encourage the adoption of programs to internalize the external cost of transportation, suggesting a larger application of the "polluter pays" concept. The adoption of alternative fuels in all forms of transportation must be enhanced in a coordinated and synchronized manner. Purchase subsidies, registration tax benefits, ownership tax benefits, business tax benefits, VAT and other financial benefits, municipal incentives, and infrastructural incentives are among the numerous incentives offered by EU nations to encourage the adoption of electric cars. In most nations, there is a strong link between the incentives given and the number of plug-in electric vehicles on the road and, predictably, there is a low proclivity to acquire electric automobiles in nations where no incentives are available. [51]

Apart from *Driverless* technology, this sector is comprised of emerging technologies in their early stages of development, yet they are all highly expected to be used by 2038 [9]. So mainly, along with technological advances, governments play a fundamental role in the development of better practices regarding mobility, especially currently as these technologies are mainly in their

initial stages. State entities can either create opportunities and incentives for those technologies with positive impacts as well as pose barriers to those such as *Flying cars* that are mainly not desirable from a sustainable point of view.

4.4.5 DEVICES AND INSTRUMENTS

This group of technologies is the one with the highest percentage of neutral votes (56%) in the survey conducted at Politecnico di Milano. On top of this, none of the technologies under this group is between the most-known or even the least-known technologies. They are also not between the technologies with highest and only one is among those with lowest average impact (*Holograms)*, despite the fact of having the highest number of neutral opinions in general. Moreover, none of the technologies present a high number of negative responses as well, with *Artificial brain* being the one with the highest percentage of negative responses (13%). Furthermore, the highest average positive impact for this technology sector result to be on SEG impact area followed by ENP and SRU. Three of the technologies belonging to this group, *Quantum computers, Artificial brain* and *Optoelectronics*, are the ones ranked as the technologies with highest average positive impact on SEG according to the survey results. Nevertheless, DI is in fourth place regarding the average impact value on all SDG areas with a 1.08 positive average impact, more than AI and BM technology sectors.

The reason why the DI sector may have been the most neutral voted could be because the technologies under this group, even though for most of them Europe holds a strong leading position, present a very low level of current maturity (except for *Holograms*) [11]. Therefore, lack of knowledge, interest, resources, or research may have been the motive behind the survey results. Nevertheless, these technologies account for a high likelihood of use by 2038 [11] and their impact on several SDG areas suggest that further investigations on this field in the future are worthwhile, supported also by the high absolute relevance of applied research 2030 stated by the Fraunhofer study [16]. As of yet, these topics are

generating little attention in applied research today, but they could increase in importance very quickly, so they are grouped under the term "Future options" by the Fraunhofer institute, especially *Quantum computers*. Some others are already of great relevance today and could become even more important in the future ("Long runners") such as *Optoelectronics* which is considered to have great impact for wealth development.

4.4.6 MATERIALS

This technology sector is the one with the highest number of least-known technologies (six) in general (technologies with lower number of responses). Five technologies, *Water Harvesting Membranes, Carbon capture and sequestration Splitting Carbon Dioxide, Plastic Eating* and *Bioplastics*, result to be within the ten technologies with most impact according to the survey while nine technologies of this sector are within the ten technologies with less impact in general. In addition, this sector present one of the lowest percentages of negative impact responses (3%) and has a prevailing percentage of neutral impact submissions (54%). No controversies are reported in the opinions of the survey respondents. Furthermore, it is the third sector with highest overall positive impact on the SDGs with a score of 1.17 points. It is worth to highlight that Materials is the sector with the highest impact on UVP but the one with less impact on SEG and ENP. Moreover, it is ranked as the second one with most impact on SRU as well as on PPR. Five of the technologies in this sector are within those technologies with highest impact on a specific SDG area, in particular on PPR and SRU. Only *Underwater living* is between those technologies with highest percentage (26%) of negative impact opinions on a specific SDG area (PPR). A last remark is that this is the technology sector that accounts for the highest share of technologies in the survey and that most of them have individually their highest impact on SRU and only one technology on PPR, even though this sector is the second one with most impact as a whole on this SDG area.

Although advanced or alternate materials do not have a specific role in the Sustainable Development Goals, they are critical for the correct and efficient implementation of the SDGs, and this is clearly observed from the survey results as the technologies belonging to this sector showed a remarkable impact on them. Advanced Materials have already begun to become an important element of the modern world's industries and economic sectors and their increasing usage in sectors such as manufacturing processes, healthcare, energy, the environment, and many others has made them extremely helpful and necessary for attaining the United Nations' Sustainable Development Goals. By reducing the use of fossil fuels, advanced materials are contributing heavily to environment conservation, as depicted in the survey by the high average impact on SRU and PPR areas. [52]

This technology sector distinctly allows to observe the impact on the three pillars of the SDGs (environmental, social and economic). The areas of Materials Science, Engineering, and Technology are responsible for the fourth industrial revolution, which has enabled breakthroughs in mining and materials extraction thanks to advances in nanotechnology and materials research. As a result, it plays a critical role in generating global wealth and eradicating poverty, particularly in developing nations. Furthermore, nanotechnology applications on innovative and sophisticated materials have the potential to speed up technical advancements that would increase food security, supply and production, therefore reducing hunger as food fortification will be possible due to the increased shelf life of food items, which will be beneficial in resource-scarce parts of the world. Advanced materials also offer a wide range of uses in the healthcare industry, allowing for new materials with enhanced characteristics, and they may play a significant role in ensuring that people all over the globe live healthy lives. Additionally, many novel ways to dealing with the issues of water pollution and disinfection have emerged as a result of recent advances in materials and the field has showed significant promise in terms of assisting humanity in meeting the worldwide demand for clean water, as for example nanofibrous membranes that

have the potential to increase water purification efficiency [53]. New materials are also indispensable to fulfill the demand for clean energy and make possible a sustainable world. Nonetheless, the survey results do not allow to observe this as the average impact on ENP area results to be not so high as expected and it is the sector with less contribution to this sphere.

With regards to this sector´s impact on UVP, which is the highest one compared to the other sectors, advanced or alternate materials is a relatively young field of study that is rapidly developing and there is a rising focus on materials research and nanotechnology as materials find a wide variety of uses in different sectors and economic domains. As a result, promoting excellent scientific education and training the next generation of materials scientists and experts is extremely important. For example, with the goal of making excellent scientific education accessible, the IAAM operates numerous publication projects including worldwide open access publications, Advanced Materials Letters and Advanced Materials Proceedings. These projects follow the Diamond Open Access concept and provide open access to scientific literature. As a result, IAAM ensures that all students receive a high-quality education [53]. Therefore, this sector of technologies provides opportunities and potential for quality and accessible education. Because of this, the sector is also facilitating the enhancement of economies and creation of jobs, and people's disparities in scientific knowledge, interactions, and opportunities are being decreased as a result of it.

The survey results show an almost neutral impact on the GOV area. Still, materials science is a discipline that has facilitated collaboration between business, academia, and industry around the world. The International Association of Advanced Materials (IAAM), for example, conducts consortiums and conferences targeted at fostering high-level partnerships between academics and business leaders in their Fellow Summit, which is an exclusive international meeting for the world's most distinguished scholars, scientists, policymakers, and

government officials with the aim to explore how the science of materials might help the UN achieve the Sustainable Development Goals for 2030 [53]. On top of that, materials science and its developments are leading to new and creative technical breakthroughs, which will help to grow the economy and create a wealthy society with strong institutions.

It should also be noticed that *Spintronics* and *Plant communication* technologies although they received positive average opinions, they are among the ones with least number of responses. This may be due to the fact that these very early emerging technologies are assessed as highly immature and could be seen as the most speculative ones, as the confidence of their development and subsequent score of likelihood of significant use by 2038 is only medium [9]. Still, they are particularly interesting from a foresight point of view.

Finally, there are a variety of other different possibilities that sustainable materials might provide in the future such as developing new products with lower environmental and health impacts, supporting circular economy transition and materials efficiency strategies, by eco-design approaches. Furthermore, it may contribute to avoid in some cases potential negative social and environmental impacts associated with the extraction of the raw material and allow better management of the supply risks of some limited resources.

4.5 CROSS SECTORS SIMILARITIES AND DIFFERENCES

The Green Group ***(EN – MA)***		***The Revolutionary Group*** ***(AI – DI – MO – BM)***
Main areas of impact: SRU and PPR	≠	Main areas of impact: ENP and SEG
Very high positive impact on SEG	=	Very high positive impact on SEG
No technology with negative average impact on a given impact area	≠	Some technologies with negative average impact on a given impact area
No technology with controversial answers	≠	Some technologies with controversial answers
Impact in UVP < than 1	≠	Impact in UVP > than 1
Impact in GOV < than 1	=	Impact in GOV < than 1

Table 12 Main similarities and differences among the two clusters of technology sectors

As already introduced in the survey results section (section 3.3), the different sectors of technologies can be clustered in two groups according to their similarity of their impact on the SDG areas. The first group is made up by the Energy and Materials sectors, while the second group by Devices and Instruments, Mobility, Artificial intelligence and Biotechnologies and Medicine (though this last one is the least similar).

The first cluster is characterized by its predominant positive impact on SRU and PPR, while at the same time presenting a high socio-economic development potential for the future. Many of the technologies within this group are among those with highest absolute average impact on all SDG areas and almost none of them present a high percentage of negative opinions. This group could be named as "*The Green group*" due to its significant positive contribution to the environment.

On the other hand, the second group of technologies is described by its higher contribution to the ENP and SEG areas. The average positive impact of the different technology sectors on SRU and PPR are lower than in the previous group. Differently from EN and MA sectors, at least one technology from each sector is assessed with a predominant negative impact in one impact area. These technologies contribute mainly to the economic development and advancement of society rather than to preserving the ecosystem, and this could be the reason why many of the technologies within this group account for negative opinions in the survey. Therefore, this group could be named as "*The Revolutionary group*", meaning they aspire to improve the everyday lives and activities of our society, while not accounting for the consequences on the environmental and social spheres.

The revolutionary group of technologies presents a high impact specifically on the UVP area as the technologies within this set tend to promote the economic development yet tending to increase the social gap thus contributing to increasing social inequality. The reason for this is mainly that not everyone is able to access and make use of these technologies due to their high price, so they are generally accessible only to an elite part of the population. On the other side, the green group of technologies tend to have a positive impact on the UVP area, yet this is not especially depicted in the survey results.

A common trait of both groups is that the GOV impact areas has an almost neutral average score from the respondents 'opinions, while from the analysis conducted on each of the selected technologies as well as on each of the six technology sectors, it is identified that ideally the technologies foster the collaboration between business, academia, and industries around the world and the creation of partnerships as well. It can be said that perhaps the respondents may not have had the knowledge or may not have given this area significant

relevance, or that simply there is a cultural lack of trust in the capacity of government bodies and policymakers to leverage on technological trends.

Regarding the current development of the technologies, all of them, regardless to which group they belong to, are mainly in their mid-stages of development, with Europe holding mostly a strong position. Moreover, the technologies from both groups have a high likelihood of use by 2038 (except for flying cars).

In addition, another trait should be underlined. The three pillars of the SDGs (environmental, social and economic) are interrelated and sometimes tradeoffs may arise. This means that improving one area may be done at the expense of another one, though this may not always be the case. For instance, in a nation like South Africa, where there are relatively few wealthy people, redistribution of money to lower groups leads in a large loss in wealth among the rich. As income rises, lower income groups have larger environmental impacts per dollar, resulting in a net increase in environmental impacts. In a wealthy nation like Saudi Arabia, on the other hand, income redistribution implies that a smaller number of poorer people rise through the ranks to higher spending groups, resulting in fewer impacts per dollar. [54]

5 CONCLUSION

While emerging technologies and innovations, in fields such as artificial intelligence, have immense promise, they also come with risks which must be considered, such as intensifying inequality. In order to change the world for better, attention should be put in increasing their benefits while controlling the possible negative impacts. The societal benefit or harm is a consequence of how the technology is used, therefore a better and more refined starting point would be to see technology as neither intrinsically good nor detrimental, but rather as a neutral element that gains importance by its application.

The foresight method has been intended as a comprehensive view into the future that evaluates new and existing technologies while also showing societal trends and linkages between technological and sustainability subjects. The findings provide a solid knowledge basis as well as various foundations for future initiatives with topics including collaboration of businesses, politics, and governments. Nevertheless, although the survey results were mostly consistent with literature and other foresight reports, a mismatching impact assessment on governance was noticeable, as it was considered to be merely influenced by the technologies while in fact these usually promote the creation of partnerships and could significantly increase the need for governance processes in their development and introduction.

In addition, from the survey results a positive correlation between technological innovation and economic performance could be observed, as all technologies resulted to have a positive impact on Socio-Economic Growth. Moreover, the results indicate that there is a need for societal dialogue and ethical reflection on responsible pathways for exploring these developments as many of the technologies were accounted for having a negative impact on Universal Values Protection. Besides, interdependencies between the technologies for their

development and impacts on the SDGs are present, so careful attention should be put when further deciding to foster a certain technology.

In some of these technology sectors, Europe already holds a strong position. These strengths should be fully exploited. In other areas, however, capacities in Europe are weak and therefore efforts should be stepped up. Additionally, some restrictions need to be updated in order to avoid ambiguity and help accelerate progress towards one or more of the Sustainable Development Goals.

To conclude, a series of suggestions for the following steps on this and future technology foresight are provided:

→ Given the goal of this initial exercise at Politecnico di Milano, the methodological decision made is realistic and entirely justifiable, but the use of a more extensive technique in future technology foresight exercises would be suggested, such as collecting opinions from experts external to the institute.

→ A more detailed analysis should be conducted on Governance and Universal Values Protection impact areas, as the results of the survey did not achieve to provide reliable outcomes.

→ Stimulate the awareness of those technologies that promise to be of relevance in the future due to their potential contribution to the SDGs but have not received much attention by the respondents, such as the ten least-known technologies according to the survey results.

→ Globalization, growing complexity, competitiveness, and rapid technological development have made it compelling for countries to specialize in technology and education in order to catch up and forge ahead, so the consideration of technology foresight practices is highly suggested.

REFERENCES

[1] Hussain M, Tapinos E, Knight L. Scenario-driven roadmapping for technology foresight 2017.

[2] THE 17 GOALS | Sustainable Development; 2021 [cited 2021 March 6] Available from: URL: https://sdgs.un.org/goals.

[3] Pietrobelli C, Puppato F. Technology foresight and industrial strategy. Technological Forecasting and Social Change 2016; 110: 117–25 [https://doi.org/10.1016/j.techfore.2015.10.021]

[4] Technology Foresight | UNIDO; 2021 [cited 2021 March 4] Available from: URL: https://www.unido.org/our-focus/advancing-economic-competitiveness/investing-technology-and-innovation/competitiveness-business-environment-and-upgrading/technology-foresight.

[5] Gurel-Atay E, Kahle L. Communicating Sustainability for the Green Economy. All Faculty Scholarship 2013.

[6] Research Guides: UN Documentation: Development: 2000-2015, Millennium Development Goals; 2021 [cited 2021 March 6] Available from: URL: https://research.un.org/en/docs/dev/2000-2015.

[7] UNDP. Sustainable Development Goals | UNDP; 2021 [cited 2021 March 4] Available from: URL: https://www.undp.org/content/undp/en/home/sustainable-development-goals.html.

[8] SDG_Guidelines_AUG_2019_Final.

[9] European Commission. 100 Radical Innovation Breakthroughs for the future 2019.

[10] Technology Foresight; 2021 [cited 2021 June 13] Available from: URL: https://www.foresight.polimi.it/survey/results.html?lang=en.

[11] Pharmaceutica Webinars 2021 | Pharmaceutica Online Events | Novel Drug Delivery Systems Online Webinar | Scientific Webinars on Pharmaceutica | Best Pharma Podcasts 2021 | Clinical Trials Webcast | Pharmaceutica Online Conferences | Pharma 2021 Live Events | Pharmaceutica Conferences 2021; 2021 [cited 2021 June 16] Available from: URL: https://novel-drugdelivery-systems.pharmaceuticalconferences.com/events-list/smart-drug-delivery-systems.

[12] Amrich M. Could Europe's Car-Free Zones Become Long-Term Solutions? A Look at Three Cities' Efforts; 2021 [cited 2021 June 3] Available from: URL: https://www.triplepundit.com/story/2020/could-europes-car-free-zones-become-long-term-solutions-look-three-cities-efforts/120501.

[13] Nieuwenhuijsen MJ, Khreis H. Car free cities: Pathway to healthy urban living. Environment International 2016; 94(September 2016): 251–62 [https://doi.org/10.1016/j.envint.2016.05.032] [PMID: 27276440]

[14] OUP Academic. Review of sustainable methods for atmospheric water harvesting; 2020 [cited 2021 June 13] Available from: URL: https://academic.oup.com/ijlct/article/15/2/253/5718410.

[15] Foresight-Fraunhofer_EN: Future topics with relevance to application-oriented research 2021.

[16] Howson S. Solar reactor splits carbon dioxide into fuel. Chemistry World 2017 Mar 9.

[17] Scientific American. Why not split harmful carbon dioxide into harmless carbon and oxygen?; 2021 [cited 2021 June 19] Available from: URL: https://www.scientificamerican.com/article/splitting-carbon-dioxide/.

[18] Research & Development World. Research & Development World; 2021 [cited 2021 June 19] Available from: URL: https://www.rdworldonline.com/.

[19] IDTechEx. Energy Harvesting and Storage 2014-2024: Forecasts, Technologies, Players; 2013 [cited 2021 June 19] Available from: URL: http://www.idtechex.com/en/research-report/energy-harvesting-and-storage-2014-2024-forecasts-technologies-players/365.

[20] Kristina Dervojeda, Diederik Verzijl & Elco Rouwmaat, PwC Netherlands, and Laurent Probst & Laurent Frideres, PwC Luxembourg. Clean Technologies: Energy harvesting. European Union: Directorate-General for Enterprise and Industry, Directorate B "Sustainable Growth and EU 2020", Unit B3 "Innovation Policy for Growth".; June 2014.

[21] Niass T. Accelerating Breakthrough Innovation in Carbon Capture, Utilization, and Storage _0.

[22] Center for Climate and Energy Solutions. Carbon Capture | Center for Climate and Energy Solutions; 2021 [cited 2021 June 19] Available from: URL: https://www.c2es.org/content/carbon-capture/.

[23] Biniek K, Davies R, Henderson K. Why commercial use could be the future of carbon capture. McKinsey & Company 2018 Jan 12.

[24] Indian firm makes carbon capture breakthrough. The Guardian 2017 Jan 4.

[25] Climate Home News. Carbon capture and storage: time to bury the myth?; 2012 [cited 2021 June 19] Available from: URL: https://www.climatechangenews.com/2012/10/02/carbon-capture-and-storage-time-to-bury-the-myth/.

[26] jjansen. RB2019_03_An-enabling-framework-for-carbon-capture-and-storage-in-Europe.

[27] Genetic Editing Module.

[28] Marcus AD. Gene Editing in Embryos Isn't Safe or Effective for Clinical Use Yet, Report Says. The Wall Street Journal 2020 Sep 3.

[29] ege_ethics_of_genome_editing-opinion_publication.

[30] Don't look now: why you should be worried about machines reading your emotions. The Guardian 2019 Mar 6.

[31] The problem with emotion-detection technology; 2021 [cited 2021 June 2] Available from: URL: https://www.theneweconomy.com/technology/the-problem-with-emotion-detection-technology.

[32] European Data Protection Supervisor. TechDispatch #1/2021 - Facial Emotion Recognition; 2021 [cited 2021 June 3] Available from: URL: https://edps.europa.eu/data-protection/our-work/publications/techdispatch/techdispatch-12021-facial-emotion-recognition_en.

[33] European Commission. New rules for Artificial Intelligence – Q&As 2021 Apr 21.

[34] Mcdonnell T. Ethereum's recovery is tied to it becoming more energy-efficient. Quartz 2021 May 21.

[35] Bitcoin consumes 'more electricity than Argentina'. BBC News 2021 Feb 10.

[36] Jewers C. The true cost of Bitcoin as Bitcoin passes $60,000; 2021 [cited 2021 June 3]

[37] Mora C, Rollins RL, Taladay K, *et al.* Bitcoin emissions alone could push global warming above 2°C. Nature Clim Change 2018; 8(11): 931–3 [https://doi.org/10.1038/s41558-018-0321-8]

[38] Blockchain and the environment.

[39] BusinessToday.In. Big change coming in Ethereum! To give huge advantage against Bitcoin. Business Today 2021 May 25.

[40] This breakthrough could make Ethereum more environmentally friendly than Bitcoin. Fortune 2021 May 24.

[41] Bitcoin - Wikipedia; 2021 [cited 2021 June 19] Available from: URL: https://en.wikipedia.org/wiki/Bitcoin.

[42] Dorri A, Jurdak R, Kanhere SS. Protecting the 'right to be forgotten' in the age of blockchain; 2019 [cited 2021 June 19] Available from: URL: https://theconversation.com/protecting-the-right-to-be-forgotten-in-the-age-of-blockchain-104847.

[43] Shaping Europe's digital future. Blockchain Strategy; 2021 [cited 2021 June 4] Available from: URL: https://digital-strategy.ec.europa.eu/en/policies/blockchain-strategy.

[44] Shaping Europe's digital future. Blockchain for climate action; 2021 [cited 2021 June 4] Available from: URL: https://digital-strategy.ec.europa.eu/en/policies/blockchain-climate-action.

[45] Satariano A. Inside the High-Stakes Race to Build the World's First Flying Taxi. The New York Times 2019 Nov 5.

[46] EPA Wetlands Programs. Functions & Values of Wetlands.

[47] Center for American Progress. Flying Cars Will Undermine Democracy and the Environment - Center for American Progress; 2021 [cited 2021 June 19] Available from: URL: https://www.americanprogress.org/issues/economy/reports/2020/05/28/481148/flying-cars-will-undermine-democracy-environment/.

[48] Hoehner CM, Barlow CE, Allen P, Schootman M. Commuting distance, cardiorespiratory fitness, and metabolic risk. Am J Prev Med 2012; 42(6): 571–8 [https://doi.org/10.1016/j.amepre.2012.02.020][PMID: 22608372]

[49] Vinuesa R, Azizpour H, Leite I, *et al.* The role of artificial intelligence in achieving the Sustainable Development Goals. Nat Commun 2020; 11(1): 233 [https://doi.org/10.1038/s41467-019-14108-y][PMID: 31932590]

[50] Shaping Europe's digital future. Regulatory framework on AI; 2021 [cited 2021 June 20] Available from: URL: https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai.

[51] 2019-transport-in-the-eu-current-trends-and-issues.

[52] Advanced Materials Research | Scientific.Net; 2021 [cited 2021 July 7] Available from: URL: https://www.scientific.net/AMR.

[53] IAAM. Advancement of Materials to Sustainable and Green World | IAAM; 2021 [cited 2021 June 21] Available from: URL: https://www.iaamonline.org/advancement-of-materials-to-sustainable-and-green-world.

[54] Inequality - OECD; 2021 [cited 2021 June 27] Available from: URL: https://www.oecd.org/social/inequality.htm.

SURVEY RESULTS

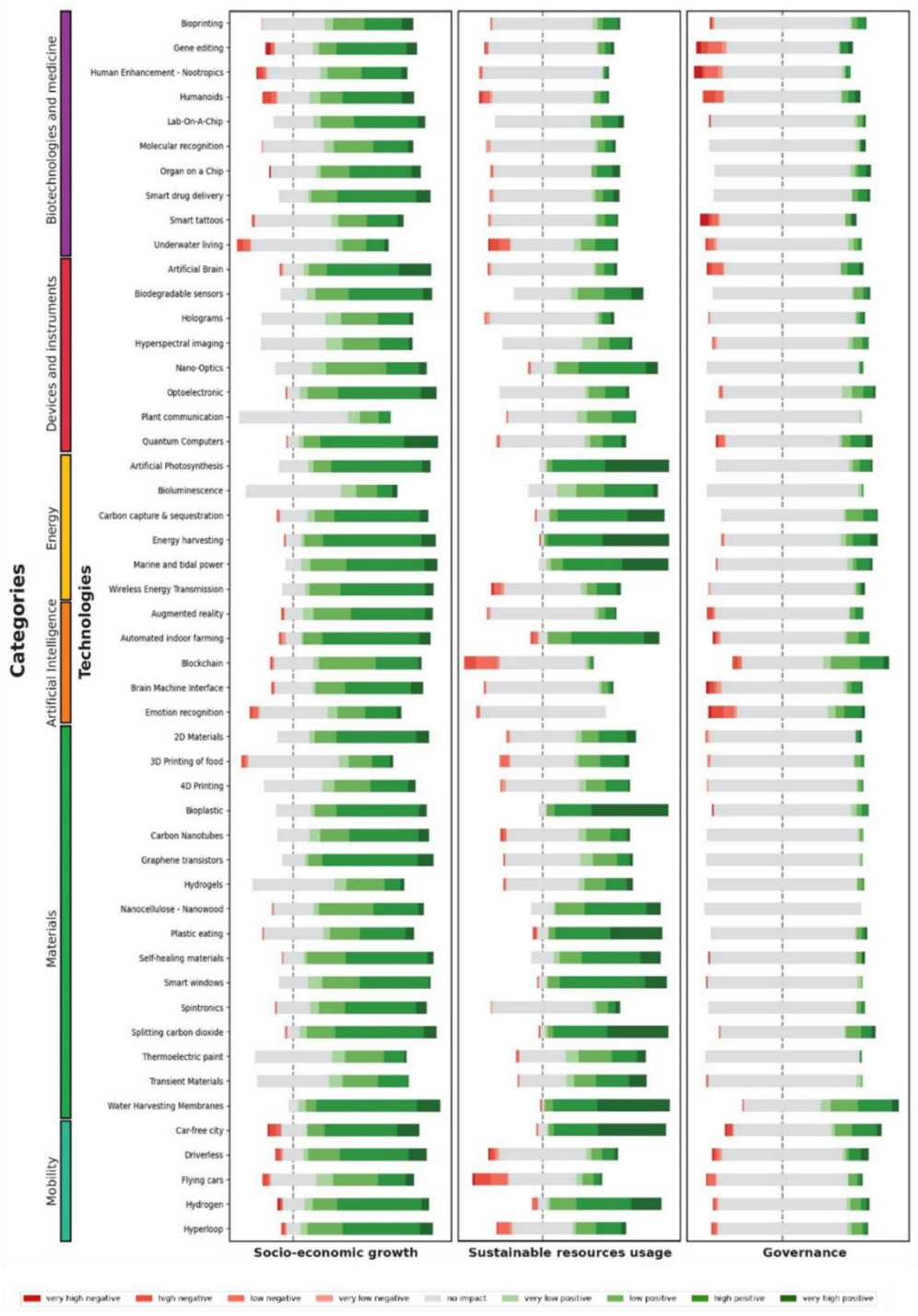


Figure 37 Distribution of impact assessments by technology (Likert scale) for the impact areas Socio-economic growth, Sustainable resources usage and Governance.

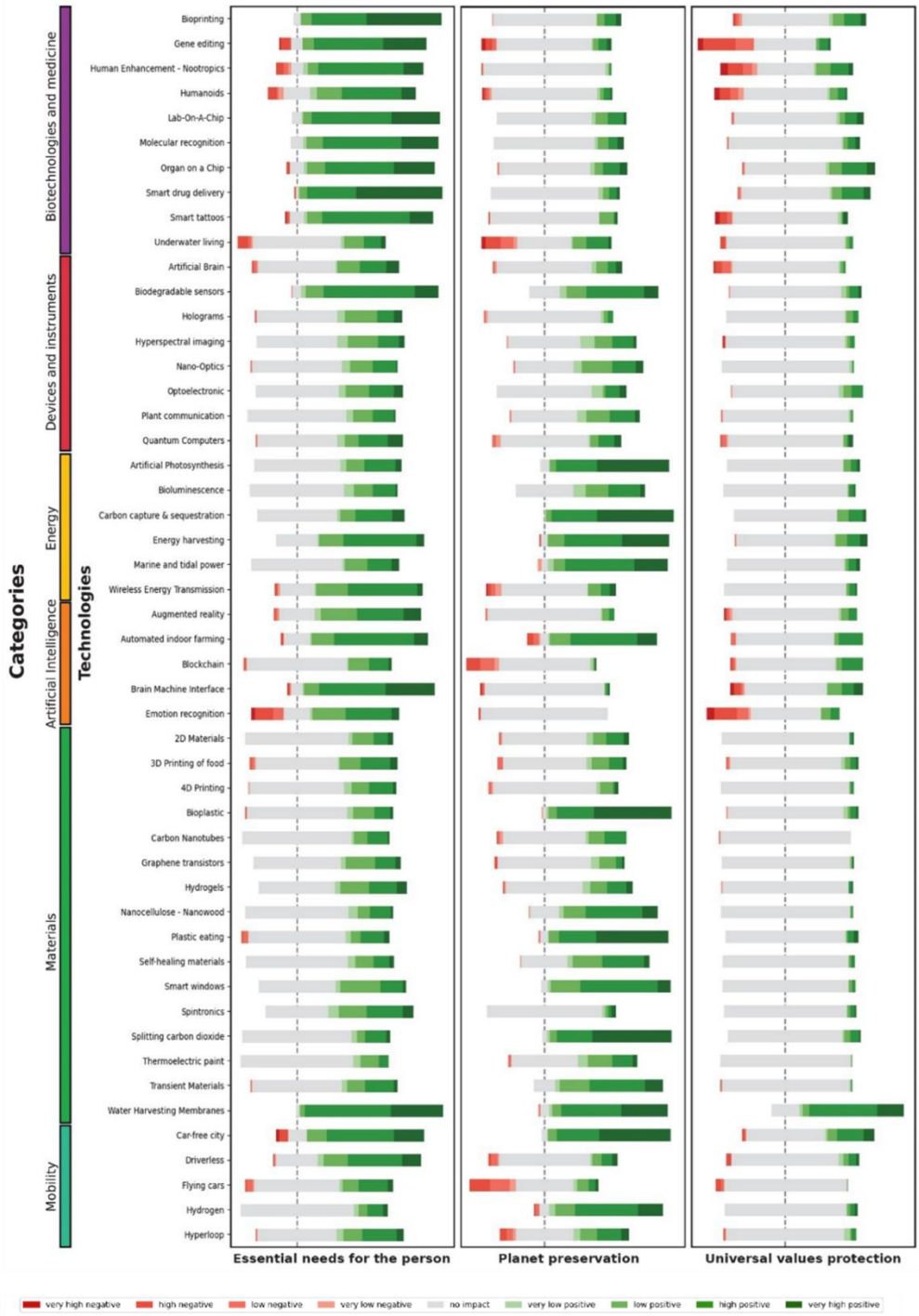


Figure 38 Distribution of impact assessments by technology (Likert scale) for the impact areas Essential needs for the person, Planet preservation and Universal values protection.

EXAMPLE OF SURVEY QUESTION

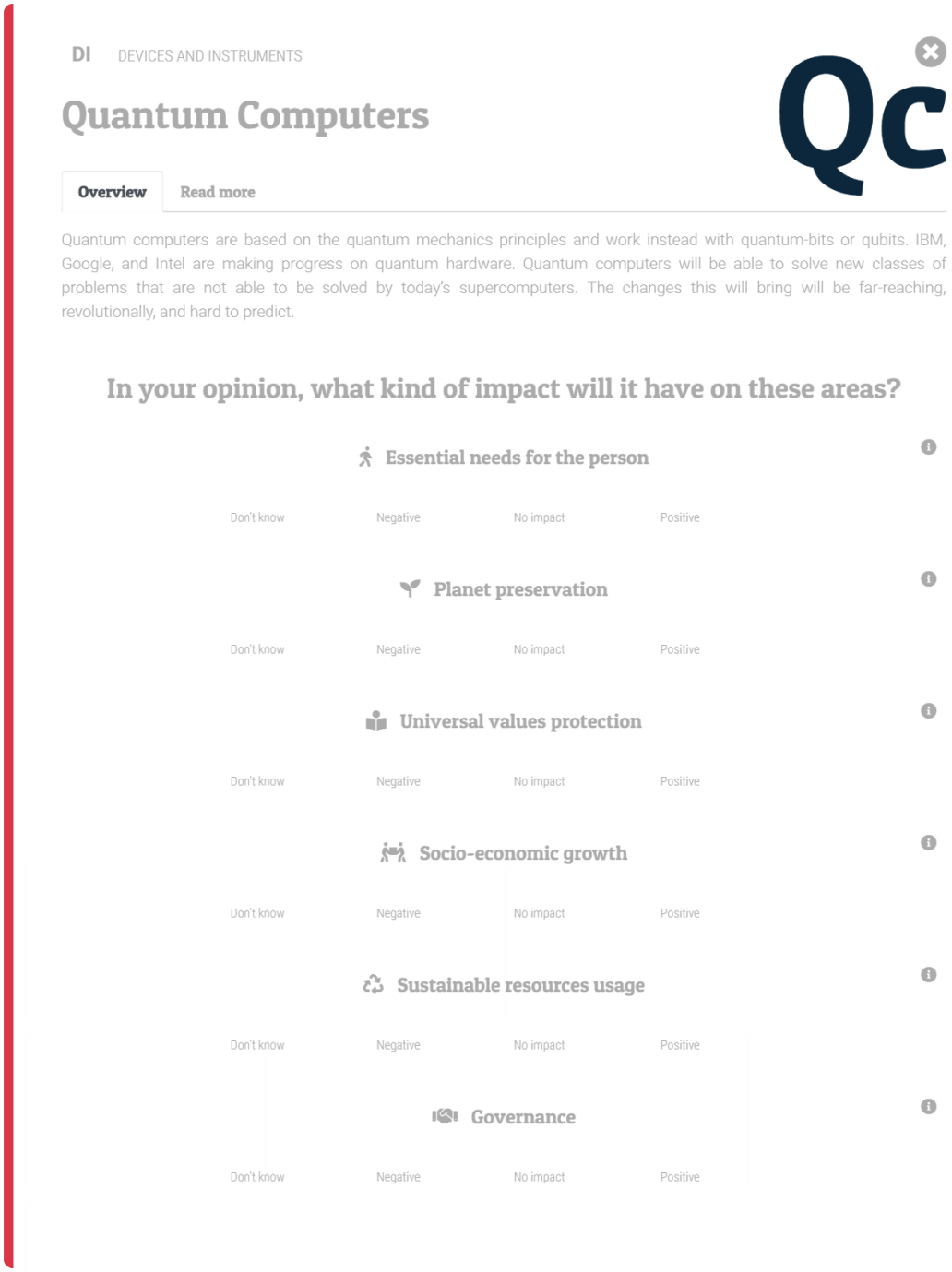


Figure 39 Example of survey question

NUMBER OF COLLECTED OPINIONS PER TECHNOLOGY

Technology	# opinions	Technology	# opinions	Technology	# opinions
Cf	2028	**Sw**	1052	**He**	880
Dr	1627	**Wm**	1041	**Oc**	865
Eh	1363	**Ba**	1032	**Cn**	852
Cc	1342	**We**	1024	**Pc**	842
Ar	1340	**Bc**	1010	**Gt**	810
Fc	1335	**Ap**	1010	**Oe**	798
Bm	1274	**Fd**	1009	**Hi**	797
Hy	1268	**Pe**	990	**Mt**	790
Hl	1220	**Sh**	989	**Mr**	777
Er	1214	**Ho**	981	**No**	737
Sc	1126	**Ab**	976	**Bl**	728
Fp	1120	**Hu**	953	**Sp**	715
St	1100	**Ge**	932	**Hg**	711
Mp	1081	**Bs**	901	**Tp**	705
Dd	1069	**Bp**	900	**Tm**	678
Af	1065	**Lc**	899	**Nn**	675
Qc	1054	**Ul**	886		

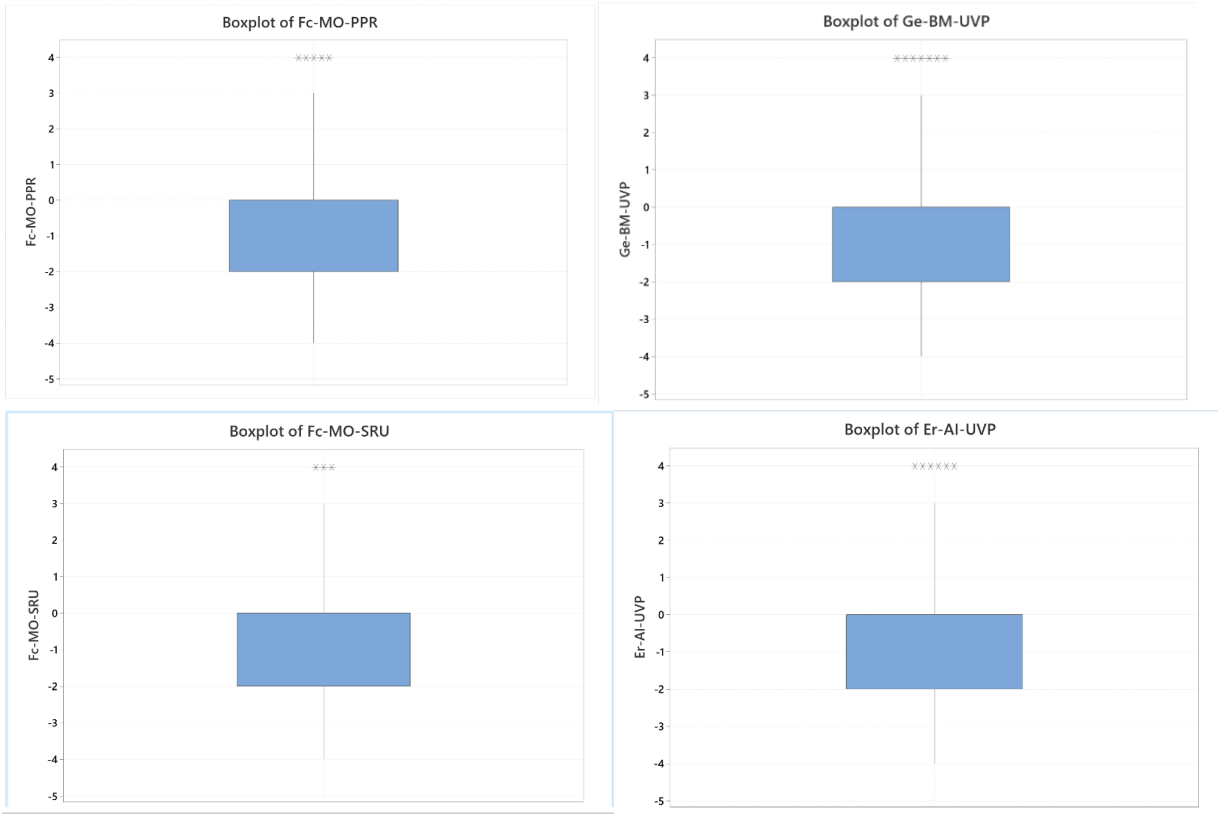
Table 13 Number of collected opinions per technology

10 TECHNOLOGIES WITH HIGHEST TOTAL AVERAGE ABSOLUTE IMPACT

Technology	Technology Sector	Average absolute impact	Average Impact	Average positive impact	% positive votes	Average negative impact	% negative votes	% neutral votes
Wm	MA	2.405	2.327	3.132	75%	-2.139	2%	23%
Cf	MO	2.348	2.178	3.154	70%	-2.593	3%	27%
Eh	EN	2.034	1.985	3.001	66%	-2.389	1%	33%
Af	AI	1.990	1.616	2.899	62%	-2.491	8%	31%
Cc	EN, MA	1.852	1.775	3.007	59%	-2.139	2%	40%
Sc	MA	1.819	1.712	3.028	57%	-2.772	2%	41%
Ap	EN	1.725	1.688	2.997	55%	-1.700	1%	43%
Ba	MA	1.724	1.630	2.943	55%	-1.979	2%	43%
Pe	MA	1.656	1.492	3.040	50%	-2.383	3%	46%
Hy	MO	1.626	1.512	2.862	53%	-2.404	2%	45%

Table 14 Details on the survey results of the ten technologies with highest total average absolute impact

10 TECHNOLOGIES WITH HIGHEST PERCENTAGE OF NEGATIVE OPINIONS PER IMPACT AREA



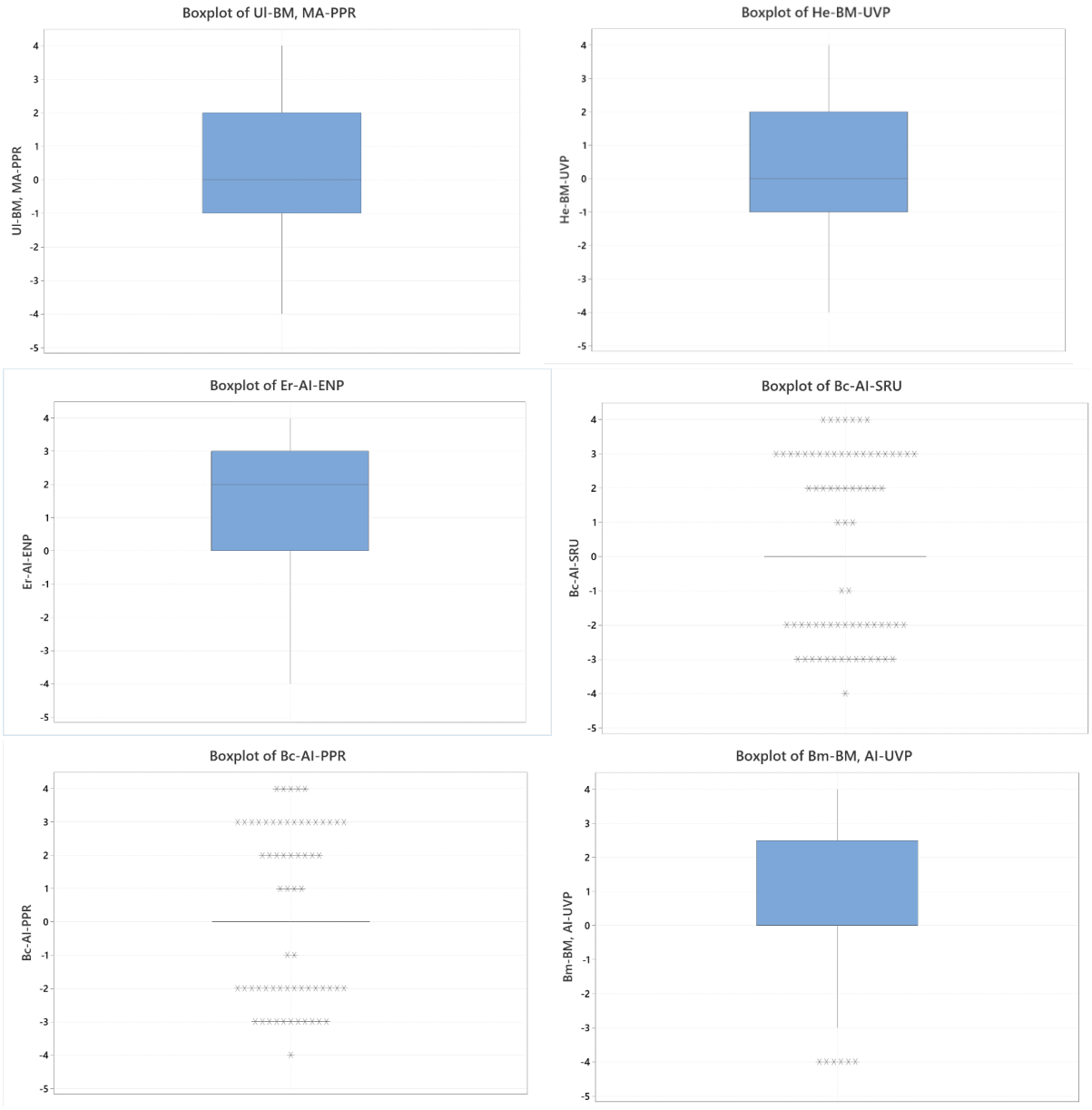


Figure 40 Distribution of the survey answers on the ten technologies with the highest percentage of negative results