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Life Cycle Assessment and bioeconomy

BIOS4YOU
AR 2.0

BIO-INSPIRED STEM TOPICS FOR ENGAGING YOUNG GENERATIONS
THANKS TO THE USE OF AUGMENTED REALITY

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Contents

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General topic of the learning path	Big Data, IoT and Smart Cities for sustainable development
Specific name of the learning unit	Smart data for smart cities: digital technologies and SDGs
Age of the target users	14-18 years
Requirements for the learner	Basic digital skills (use of the cloud, data research, presentation tools). General knowledge of the environment, energy and global citizenship. Ability to work in a team and communicate effectively. Curiosity about technological innovation and social impact.
Description of the learning unit	This unit guides students in discovering the world of **Big Data**, the **Internet of Things (IoT)** and **Smart Cities**, with a strong link to the **Sustainable Development Goals (SDGs)**. Through **augmented reality** tools, simulations and collaborative projects, students analyse data, design solutions for smart cities and assess the impact of emerging technologies on urban quality of life and the environment. The course is divided into three phases: **Explore – Execute – Enhance**, integrating immersive activities and interactive formative assessments.
Subject: Parties involved	Computer Science, Technology, Civic Education, Geography, Science

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Keywords	Big Data, Internet of Things, Smart Cities, Cloud, digital skills, SDGs, urban sustainability, open data, digital citizenship, augmented reality, data literacy.
Key qualifications, skills and knowledge that can be acquired	• Understanding of the data life cycle: collection, processing, visualisation. • Ability to analyse datasets and draw operational conclusions. • Basic knowledge of IoT and urban digital infrastructure. • Collaborative design of smart solutions based on real data. • Awareness of the role of technology in sustainability processes. • Development of transversal skills: problem solving, critical thinking, digital communication.
Resources and didactic aids used	• AR platforms (e.g. CoSpaces Edu, Merge EDU, Assemblr, ZapWorks). • Public datasets (e.g. Eurostat, World Bank, regional open data). • Apps and simulators for visualising data flows, IoT networks, cloud infrastructures. • Online collaboration tools (e.g. Google Workspace, Padlet, Canva). • Educational videos, case studies and informative articles.
Assessment criteria and evaluation	• Understanding of Big Data, IoT, Smart Cities and SDGs. • Effective use of AR platforms, cloud tools and data analysis. • Quality, innovation and consistency of the project developed in a group. • Ability to identify sustainable objectives and propose targeted technological actions. • Clarity of presentation, correct use of technical language and multimedia supports. • Quizzes and AR dashboards for progress monitoring and continuous feedback from teachers and classmates.

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1. What is bioeconomy?

Bio-economy represents a socio-economic system that links and connects economic activities that take into account all renewable bio-resources from both the soil and the sea in order to produce food, materials and energy.

In general, bio-economy is based on 4 macro-sectors:

- Agrifood
- Forestry
- Bioindustry
- Marine bioeconomy
-

The bioeconomy, therefore, encompasses the primary production and industrial sectors. Through and union of these two sectors, a path is created in which communities migrate towards a prosperous and environmentally friendly economy, in which dependence on fossil fuels and non-renewable resources is reduced.
This process is aimed at improving and limiting the loss of biodiversity and the transformation of the subsoil.

Figure 2. Population growth

In addition, global population growth, climate change and a reduction in the resilience of ecosystems has resulted in the need for change, which translates into an increase in the use of renewable biological resources, a decrease in waste generation and greenhouse gas emissions, and in turn an increase in benefits for human health and the environment.

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2. The bioeconomy at European level

In Europe, the bio-economy sector has already achieved a very high value while also stimulating the creation of numerous jobs. Above all, the European food sector has seen numerous changes and is still booming today.
The 'European Bioeconomy Strategy', currently under review, will unlock the potential of available biological resources in the various sectors of the bioeconomy in a sustainable and socially responsible manner.

Figure 3. Europe and Bioeconomy

The package of regulations and directives is based on a broad programme of concrete actions and measures that will contribute to the so-called life cycle of products, i.e. an increased focus on recycling and reuse of products, which in turn will contribute to benefits for both the environment and the economy.

A particular focus is on the Mediterranean area, which always sees a high level of water stress characterising climate change having a major impact on agriculture.

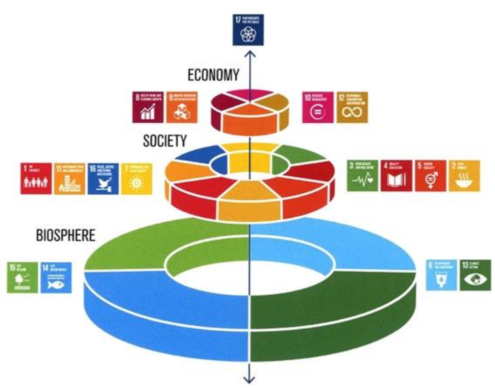

Figura 4. Il sistema bioeconomico

This phenomenon also leads to social and economic stress, which in turn gives rise to geopolitical instability, creating migratory phenomena, both internally, from rural to urban areas, and externally, particularly towards Europe.

To try to solve these problems, two important initiatives have been created at European level: PRIMA and BLUEMED.

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- PRIMA, a European initiative in which Italy is leading. This initiative aims to make water and food supply systems more efficient, convenient and sustainable.
- BLUEMED is a set of initiatives also led by Italy and aims to create new ‘blue’ jobs and sustainable industrial growth in the area's marine-maritime sectors. BLUEMED has been activated in the EU countries of the Mediterranean area.

Moreover, the recent pandemic caused by COVID-19 has made even more evident the need to rethink the economic development model in a logic of greater attention to sustainability and respect for the environment.

In light of this, the bio-economy, in particular the circular economy, will be and will continue to be important in the transformation of the European development model, in order to have a fair and inclusive economic and social transaction.

3. Bio-economy at the Italian level

In Italy, the entire bio-economy sector has taken on considerable importance and is having very high revenues and employing many people.

Specifically, if we analyse each sector of the bioeconomy in Italy, agriculture is a very important sector. It contributes around EUR 31 billion (2.3%) to the value of GDP. In addition, the development of rural areas, plays a fundamental role especially in peripheral areas, which are characterised by difficult access to services of public interest compared to cities and smaller towns.

In the Italian context, rural diversification is very important, in fact, thanks to new tools, both digital and economic, rural areas can enjoy new life, redeeming themselves. In addition, thanks to the variety of territories and a rich, millenary culture, Italy boasts an unparalleled variety and

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richness in terms of food traditions. This characteristic represents the strength of Italian agriculture, which makes Italy competitive in agricultural and food markets.
In the Italian bio-based and circular economy, in terms of efficient resource management, protection of biodiversity and soil, sustainable land management, production of ecological and social services, valorisation and reuse of residues and waste, as well as in terms of production of bioenergy and organic products, through the adoption of sustainable production models and the efficient use of renewable resources, agriculture and forestry play a key role.

The Italian food industry, on the other hand, represents the second largest manufacturing sector in Italy and the third largest in Europe, after Germany and France. This sector, even though it has small, family-run companies, has been able to establish itself as a globally competitive sector thanks to its territorial excellence, and has also held its own during times of crisis in the domestic market.

Figure 6. The food sector in Italy

In general, the food industry can find enormous opportunities in terms of innovation and growth in the bioeconomy sector. In this regard, it is important to highlight the work done by the national Agrifood Technology Cluster 'CL.A.N.', i.e. a multi-stakeholder network formed by the main players of the agrifood sector at national level, consisting of industrial groups, research centres and institutions. This cluster made an important contribution with the elaboration of a shared technology development roadmap. The objectives of this strategy are:

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- obtaining new food and/or animal feedstuffs, ingredients and/or bioactive compounds with high nutritional value from by-products generated in industrial processing in the agro-food sector;
- adopting innovative processes to utilise waste by-products of the industrial transformation process in order to sell them on the market as new products for food, feed and the agricultural sector;
- reduce disposal costs by identifying new revenues with agro-food by-products;
- evaluating techniques to recover low-cost by-products and their functional components with limited environmental impact.

As far as forests are concerned, Italy's forest area is 11 million hectares, equivalent to 37% of the total national land area. This surface area requires continuous improvement. It is also worth noting that carbon absorption by managed forests covers 10% of the national Kyoto target for reducing CO_2 emissions.

An important role in the forestry sector is played by the wood and wood processing industries, even though 80% of the wood used is imported from other countries. Therefore, one of the primary objectives that the sector must set itself is to increase the degree of self-supply. Solid biomass fuels, on the other hand, represent the main source of renewable energy on a national scale, making bioenergy a very dynamic segment within the forest/wood sector.

In addition to wood products, attention must also be paid to non-wood forest products and forest-related ecosystem services. The former, such as mushrooms, truffles, herbs, cork, etc., have a strong link to traditional knowledge, local economies and forest management practices. In fact, the economic activities related to this sector are growing and the production of wild products has become more structured and more important than wood production, in terms of direct and indirect income opportunities, job creation, visibility and development potential for rural areas. With regard to ecosystem services, although these are not, or are only marginally, included in official national accounting systems, they are increasingly recognised as an important component of forest ecosystems.
The biobased industry is that component of the bioeconomy that uses renewable biological resources in innovative industrial processes to produce goods, products and services from biomass. It operates on two fronts; one therefore concerns industrial sectors that traditionally use biological resources as the main material and others for which biomass is part of the raw material portfolio.

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Thanks to the countless research projects in this field, the use of green catalysts and microbes, Italy can now boast a key role in the bio-industry. In this sector, there are remarkable developments in biomass, biofuels, bio-plastics, organic pharmaceutical and cosmetic products, biological materials for residential construction, anaerobic digestion processes, production of essential amino acids for animal feed and much more.

Chemistry based on biological resources is one of the few sectors in which our country is a leader in a highly technological context and in which major private investments have been made, significant projects for the reconversion of industrial sites hit by the crisis into bio-refineries for the production of biological products, particularly bio-chemicals, from renewable resources. This sector is also characterised by a network of large, medium and small enterprises.

Almost every region in Italy is characterised by having a coastline. To be precise, Italy has more than 8,000 km of coastline, which can count on multiple marine resources.

To date, there are many sea-related activities that are connected to the bioeconomy. These include, for example, fishing and aquaculture, the use of seaweed, microbes, enzymes, by-products and organic waste from fishing and the processing of aquaculture products, bio-monitoring and bio-remediation of sedimentary seawater systems. In addition, the number of people employed is always growing, placing Italy second in Europe in the fisheries sector.

4. Bioeconomy in everyday life

Even in everyday life, there are many actions we can take to initiate and stimulate the development of the bio-economy.
Some examples are listed below:

- **Bags and gloves for fruit and vegetables** - The switch from traditional plastic products to biodegradable and compostable ones contributes to reducing the production of waste that cannot be easily recycled and to increasing the collection of organic waste.
- **New cold-pressed oils** – is a vegetable oil based on olives and tomatoes, extracted solely through mechanical processes.

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- **Shopping bags, waste bags** - biodegradable ones, thanks to their dual use, facilitate the separate collection of organic waste by reducing the risks of dispersion into the environment. Due to their biodegradability, compostability, transparency, and resistance to moisture and pathogens, they have proven to be a key tool for facilitating the separate collection of organic waste and the production of high quality compost.
- **Catering articles** - biodegradable and compostable catering articles simplify post-consumer disposal. Such items can, in fact, be disposed of with the organic fraction in composting facilities.
- **Packaging items** - these can be disposed of with organic waste. Some of these are:

  - Compostable paper and food trays
  - Extruded and woven nets
  - Non-food packaging such as: toilet paper, kitchen paper, napkins, magazine films, etc.
  - Compostable labels: fruit labels are one of the main pollutants in compost.

  - Compostable capsules - these can be collected with organic waste and sent for industrial composting process.

  Mulching film – this organic, biodegradable mulching film is an agronomically and environmentally efficient alternative to traditional mulching film. It decomposes in the soil in such a way that it does not require removal at the end of the growing season and allows for efficient weed control and equivalent agronomic yields in terms of both quantity and quality.
- **Biogas** – is an organic gas produced by anaerobic digestion of biomass that can be used as a fuel for electricity and heat production or as a fuel as a result of a biomethane refining process.
- **Digested pellets** – is an organic fertiliser rich in nutrients, elements such as nitrogen, phosphorus and potassium, produced by anaerobic digestion of agricultural biomass.
- **Lubricants** - ideal solution for active machinery such as agricultural, forestry, marine or urban machinery. These offer advantages in terms of both performance and environmental impact and safety.
- **Bioethanol** – are biochemical substances and renewable energy sources derived from the fermentation of sugar components starch by-products of mainly sugar cane plants. New generation biofuels from lignin or other

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biomasses such as algae.

- **Bio-innovation in recipes** - the use of natural products to replace products derived from chemical synthesis processes, to support the diversification of products and diets.

To move towards a circular bio-economy, however, it is not only necessary to use solutions and machinery that facilitate this process, what is necessary is to inform and educate society about this change.
Awareness and dialogue must be stimulated, and innovation in social structures must be supported in order to promote more conscious behaviour.
More knowledge about what people consume would improve people's health and lifestyle, stimulating a demand that drives sustainable innovation on the part of companies.
To implement this process, it is necessary for citizens to become actors in the bioeconomy.
We need to change the concept and the demand for products that the market requires by encouraging citizens to reuse, re-use and recycle products.
The bio-economy also represents a challenge to reconnect environment, economy and society, generating economic value together with new values and a new cultural approach.

5. What is the LCA?

Figura 7. LCA

LCA, Life Cycle Assessment is the tool that analyses the life cycle and thus the environmental behaviour of a product or service during all its phases. In fact, a product is said to be analysed from cradle to grave, i.e. from the extraction and processing of raw materials, through production, transport, use phase and end of life.

The life cycle is a process of analysis that is given by the succession of all those steps involved in the creation of the product, its use and its disposal. It is characterised

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by the absence of waste.

Specifically, the environmental impact of a product is determined by the input and output flows of each phase of the entire life cycle. By input streams we mean the resources used, such as energy, water, etc., while by output streams we mean emissions into the air, water and soil. The LCA tool aims to quantify the environmental impacts occurring at these stages. The aim is to improve the environmental performance of both the product and its life cycle phases.

In general, products are composed of innumerable parts, each part in turn having its own life cycle. The objective of the LCA is to add up all the life cycle analyses of each part and determine the final life cycle of the complete product.

Figure 8. Renewable resources

LCA, to be carried out, needs to follow specific standards. We are talking about ISO 14040-14044. This set of standards describes the procedure to be followed when carrying out a study, which is characterised by 4 distinct phases:

- objective and scope, in which a detailed process tree including all inputs (resource inputs) and outputs (emissions) is developed;

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- inventory analysis, which involves the collection of all data relating to individual processes;
- impact assessment, in which the environmental impacts on health, resources and ecosystem quality are examined;
- interpretation, i.e. the results in relation to predefined objectives.

6. What are the phases of a product's life cycle?

There are 7 phases in a product life cycle analysis: design, raw materials, material processing and production, packaging, transport, use phase, end of life.

- The first phase is the design phase. In this phase, the characteristics of the product and consequently the environmental impact of the entire life cycle are defined. It is important to remember that it is precisely during the design of a product that waste can be limited, for example by optimising the use of resources, reducing packaging or making the product disassemble. A quality product will certainly have less environmental impact because it can be easily repaired or reused in another context. Furthermore, a product that can be easily disassembled facilitates the reuse and recycling of different parts.
- The second phase concerns raw materials. All objects are produced from materials derived from nature. In nature, it must be specified that there are renewable and non-renewable resources. The extraction or harvesting of these raw materials has a considerable impact on the environment due to the energy resources used, as well as causing their continuous depletion. The reuse of products and materials through recycling is one way of addressing the issue of scarcity of raw materials, but even more important is the reduction of their use.
- The third phase consists of material processing and production. Specifically, these are two well-related phases. In general, depending on the products, they are considered separately or as a single stage in the life cycle. The process that takes place in materials processing is a transformation of raw materials into semi-finished products to create finished products. In the production phase, on the other hand, the environmental impact of the product realisation and engineering phase is analysed.
- The fourth stage involves the packaging of the product. In general, packaging is that part of the packaging that protects and preserves the product. The function of packaging and wrapping is also much more specific as it provides numerous specifications on characteristics and function. In addition, packaging has now become an excellent marketing tool and is very often overused to the point of being superfluous.
- The fifth phase is transport. In life cycle analysis, transport is to be considered from two

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different perspectives. In fact, not only the transport of the finished product from the storage facilities to the shops must be considered, but also the transport of the raw materials that were necessary to create the product itself. Transport is calculated according to the vehicle used and its use of fuel.

- The sixth phase is that of use; this differs according to the type of product. The impact of the product comes from its use, operation, cleaning and maintenance of it.
- The seventh and last phase is the end of the product's life. This phase is linked to the first phase, that of design, as it is in the first phase that it is established whether a product can be de-assembled, recycled, etc... If so, it can be reused several times, even in different clothes and with different functions, or it can be recycled, thus saving raw materials. In the worst case, however, the product ends up in landfills or is incinerated.

7. What is eco-design?

Figura 9. Ecolabel

To date, numerous improvements have been made in the field of product design taking into consideration the environmental impact they may have within the planet.

For example, eco-labels, or ecolabels, give information on the environmental performance of a product in overall terms or on a specific aspect. Several eco-labels use LCA as a product assessment tool.

There are three types of ecolabels:
the first type are eco-labels. The product or service certified by an independent body meets a set of threshold levels of environmental performance. The best known type 1 ecolabel is the European ecolabel, whose logo consists of a daisy. There are also national ecolabels.

The second type is the self-declaration. For this type of label, there is no third-party certification but the user is still required to follow the international standard ISO 14021.

The third type is the Environmental Product Declaration (EPD). It is a document with which the company chooses to inform customers, suppliers and all interested parties about the environmental performance of its products. To obtain this label, the applicant company must carry out an LCA study following a set of pre-established requirements. This study is then verified by an external body.

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8. Augmented Reality (AR) Integration

This is the beginning of an augmented journey into the world of Life Cycle Assessment (LCA) and the bioeconomy, an educational path that combines science, technology and sustainability thanks to the power of augmented reality (AR).

During the initial phase, Explore, students explore the life cycle of common products in AR: from raw material collection to production, from everyday use to disposal. Through 3D animations, informative labels and dynamic data, the real object is transformed into an interactive narrative. Crucial elements such as CO_2 emissions, water consumption and energy used in each stage of the process are displayed. This approach not only captures attention, but also stimulates critical thinking and environmental awareness.

In the Execute phase, the journey evolves into a design project. Divided into groups, students are invited to imagine and build an alternative bio-based product, selecting natural materials, renewable sources and low-impact processes, all within an interactive AR platform. For example, they design compostable packaging inspired by fruit peel, or a technical fabric derived from vegetable waste. Each design choice generates real-time simulations, displaying the comparative environmental impact of the fossil-based product and the new bioeconomic solution. Teachers and classmates can provide immediate feedback thanks to visual dashboards integrated into the AR environment.

The Enhance phase takes the educational possibilities even further, transforming learning into a multisensory and gamified experience. Students immerse themselves in simulated AR environments such as biorefineries, sustainable forests or circular cities, where they can experiment with material and energy flows by modifying parameters, simulating scenarios and noting changes. The experience is enriched with interactive puzzles, augmented quizzes, sustainability badges and group challenges in which the team that designs the most efficient cycle gets the highest score. Assessments are no longer static but integrated into the experience: every decision and every AR project generates traceable data that helps teachers monitor learning, participation and skills development.

At the end of the course, students will not only have understood the fundamentals of LCA and the bioeconomy, but will also have acquired advanced digital skills, systemic thinking, design skills and a clear vision of the role that technology – and their creativity – can play in building a more sustainable future. With augmented reality, the life cycle is no longer an abstract concept, but a journey to be experienced first-hand. And every design choice becomes a concrete step towards a more conscious, circular and fair world.

10. Conclusion: The Future of AR in Vision Science

Integrating Augmented Reality (AR) into bio-inspired vision research transforms how students learn, experiment, and innovate. Through immersive 3D simulations, interactive visual mapping, and AI-

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powered analytics, AR bridges the gap between biological vision science and engineered optical systems.

By experiencing hands-on AR-enhanced learning, the next generation of scientists and engineers will be better equipped to develop advanced bionic vision technologies, AI-driven robotic sensors, and augmented optical interfaces, shaping the future of bio-inspired innovation.

Phase	Description
Explore	Introduction to the concept of Big Data: volume, variety, velocity. With the help of augmented reality (AR), students visualise how large data streams are collected, analysed and used in the real world. Through immersive examples, they explore the difference between structured, semi-structured and unstructured data in AR, simulating the transformation of raw data into useful information. They use 3D models and augmented concept maps to trace the main sources of data (digital devices, social media, sensors, online transactions). Assessment of initial digital skills through AR quizzes and interactive workshops to tailor the teaching approach to students' prior knowledge.
Execute	Design smart environments in AR (e.g. connected home, digital school), simulating data flows from sensors, actuators and mobile devices. Each group can modify parameters and measure the impact in real time. Simulate in AR how data is transferred, stored and processed in the cloud. They represent simplified cloud architectures in 3D to understand the concepts of SaaS, PaaS and IaaS. Analyse real or simulated data sets related to the Sustainable Development Goals (e.g. SDG 3 – Health, SDG 11 – Sustainable cities) and visualise them through AR graphs and dashboards. Each team proposes sustainable actions based on data analysis.
Enhance	Interactive virtual environments (e.g. forests, coastal cities, power plants) to understand complex climate and energy systems. Modify energy parameters in their AR models (e.g. change energy sources or building materials) and visualise the effects on emissions or thermal comfort in real time. They accumulate points by solving interactive quizzes on the causes, effects and solutions of climate change and complete group design challenges, advancing to higher levels in the design of sustainable energy systems. 3D models with enhanced AR, answer dynamic quizzes and reflect on the future role of augmented reality in scientific, environmental and engineering understanding.

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