



C3-BIOECONOMY
Circular and Sustainable Bioeconomy

The bioeconomy as a tool for sustainable economic growth

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Abstract:

Technological development has made it possible to diversify the products obtained in the framework of the bioeconomy, from food, to forest products, textiles, energy, extracts, active compounds and a wide range of bioproducts. The new socio-economic context, in which it is essential to decarbonize and promote the circular economy, has furthered the development of the circular bioeconomy, especially within the new framework of the European Union Green Deal. The use of biomass generated in Spain, especially residual biomass from the agri-food, forestry and urban spheres, both from MSW and sewage sludge, constitute an opportunity for economic development. The technologies that are being developed make it possible to obtain basic chemical compounds, fuels, biopolymers, and compounds apt for different types of activities and functions, potential raw materials for new economic activity. The challenges and opportunities involved in the development of the bioeconomy in Spain are analyzed, as well as the need to carry out an analysis of the life cycle of the products that are going to be placed on the market, both those for end consumers and those supplied to industrial sectors. Traditional industrial sectors, such as energy, waste management, textiles, construction, packaging, motor vehicles, machinery and equipment, can represent opportunities for business for activities linked to the bioeconomy through the generation of bioproducts.

Key Words: Circular bioeconomy, bioproducts, industrial sectors, Green Deal

La bioeconomía como herramienta para el crecimiento económico sostenible

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Resumen:

El desarrollo tecnológico ha permitido diversificar los productos obtenidos en el marco de la bioeconomía, desde los alimentos, los productos forestales, los textiles y la energía, hasta los extractos y compuestos activos y una amplia gama de bioproductos. El nuevo contexto socioeconómico, en el que es imprescindible descarbonizar la economía o promover la economía circular, ha impulsado el desarrollo de la bioeconomía circular, especialmente en el marco del nuevo marco del Green Deal de la Unión Europea. La utilización de las biomásas generadas en España, especialmente las residuales procedentes del ámbito agroalimentario, del forestal, del urbano, tanto de los RSU como de los lodos de depuradora, son una oportunidad para el desarrollo económico. Las tecnologías que se están desarrollando permiten obtener compuestos químicos básicos, combustibles, biopolímeros, o compuestos con distintos tipos de actividad y funcionalidad, que pueden ser las materias primas para una nueva actividad económica. Se analizan los retos y las oportunidades para el desarrollo de la bioeconomía en España, así como



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la necesidad de realizar un análisis del ciclo de vida de cualquiera de los productos que se vayan a poner en el mercado, tanto los que vayan al consumidor final como los que se suministren a los sectores industriales. Los sectores industriales tradicionales como el de la energía, el de la gestión de residuos, el textil, el de la construcción, el del envase y embalaje, el de los vehículos a motor o el de la maquinaria y equipos, pueden suponer una oportunidad de negocio para las actividades ligadas a la bioeconomía, a través de la obtención de bioproductos.

Palabras clave: Bioeconomía circular, bioproductos, sectores industriales, Pacto Verde

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1. INTRODUCTION

The Bioeconomy encompasses the set of all economic activities related to the production, transformation and use, directly or indirectly, of resources of biological origin. It consists, according to *Ronzón et al (2020)*, of producing and transforming biomass for the supplying of food, feed, materials, energy and services related to citizens.

Traditionally the Bioeconomy has encompassed the production of food, forest products, textiles and energy. However, thanks to the development of different technologies the number of end products derived from it has grown, by obtaining extracts or active compounds, applied to nutrition and pharmacy, and their transformation into diverse biocomposites, such as bioplastics and biofuels.

Thus, the Bioeconomy constitutes a key activity in the European Union and in Spain. According to the Knowledge Bioeconomy Centre (KBC, 2020), belonging to the JRC, in 2017 it employed around 17.5 million people and generated approximately 614 billion euros of added value. This represents around 8.9% of the EU-27 workforce and generates 4.7% of the EU-27 GDP. In Spain, according to the same source, it generated a sales volume of €219 million in 2017, representing added value of €65 million. In addition, it employed 1.42 million people. Therefore, as a country, we represent 8% of employment, 10% of sales, and 11% of the value added of the Bioeconomy Community.

In recent months, the Circular Bioeconomy has been considered an important component in the framework of the architecture of the Green Deal advanced by the President of the European Commission (Ronzón *et al* 2020). This new concept arises from the interaction between the Bioeconomy and the Circular Economy, and common aspects, including the improved use of resources, eco-efficiency, reduced carbon footprints, lower demand for fossil fuels, and waste recovery (Carrol and Dammer, 2018). However, as they indicate in their work, the Circular Economy is not complete without the Bioeconomy, and vice versa.

The European Green Deal has been identified by the European Commission as a way to endow the EU with a sustainable economy, with the understanding that the realisation of this objective will transform climate and environmental challenges into opportunities in all policy areas, achieving a fair and integrative transition for all (EU, 2020). In this article we will endeavour to show why the Bioeconomy lies at the centre of these new policies.

2. THE GLOBAL AND EUROPEAN SOCIO-ECONOMIC CONTEXT

2.1 Climate change

Over the course of the 20th century, and particularly in the last two decades, we have observed a continuous increase in average global temperatures. The years 2015 to 2018 saw the highest average temperatures since measurements were taken and records are available. The global average annual temperature today is (EU, 2019) 0.85°C higher than at the end of the 19th century. This fact was already analysed at the beginning of this century by Crowle (2000), who concluded that the warming during the last century is unprecedented, and that only about 25% of the increase could be attributed to natural variability, while the rest, most of it, is due to increases in greenhouse gases.

Cramer *et al* (2018) have shown, on the shores of the Mediterranean, that the globally accepted projection that warming by the middle of the



century may stand at 2°C above pre-industrial levels, is, actually, likely to be exceeded. This rise in temperature will be accompanied by extreme meteorological phenomena, such as longer droughts, higher concentrations of rainfall and floods, etc. All these circumstances will have a devastating effect on nature and will bring about irreversible changes in many ecosystems, with the consequent losses in of biodiversity. It will also translate into huge costs to our economy and undermine our countries' ability to produce food.

2.2 The Circular Economy

Global economic development over the course of the 20th century has occurred in parallel with a growing and uninterrupted demand for natural resources: building materials, biomass, fossil fuels and minerals of all kinds, including industrial ones. This accumulated demand has triggered higher-than-normal growth, especially due to the burgeoning economic development of China, Brazil, Mexico, etc. (Krausmann *et al*, 2009). These authors concluded by pointing to the need to improve efficiency in the use of raw materials and decoupling economic growth from the consumption of materials and energy.

If no decarbonisation and resource usage control strategies are undertaken, said authors predicted an alarming decline in biodiversity and nature; and, in the short term, of some resources, such as land, fresh water, fish, oil and gas of fossil origin, precious metals and those for industrial use, etc. This same team, a few years later, (Krausmann *et al*, 2017) concluded that, to reduce future demand for materials and energy, and Greenhouse Gas Emissions (GGE), it will be necessary to dissociate services from conventional supplies and material flows through, for example, the more intensive use of available resources, longer service lives, and more efficient designs.

In parallel to these scientific works, the Ellen MacArthur Foundation for the Circular Economy published, in 2012, its document "Towards the Circular Economy", which began with the following text: "in the face of sharp increases in the volatility of the world's economy, and signs of resource depletion, the

justification for a new economic model is growing stronger. Many argue that the time is right to take this 'Circular Economy' concept one step further".

In recent years our society has gone from a linear economy, in which we extract raw materials to incorporate them into production processes, obtaining products that go to the market, and disposing of the waste from this after use; to a recycling economy in which we seek to reuse part of the waste from the production and usage chain; to a Circular Economy (Figure 1).

The transition from a linear economy to the Circular Economy requires a progressive reduction in the use of natural resources and an increase in the use of renewable resources. And it entails a different approach to each of the phases of the production process and the service life of products. Below is a summary of some of the essential points (COM, 2020, 98 final):

- Obtaining raw materials: priority must be given to obtaining secondary raw materials; that is, those obtained through the recovery of materials and raw materials from the waste generated in production processes
- Ecodesign: the design of the product, from the outset, must be based on:
 - maximising its service life through the repair and reuse of products that are already in use
 - facilitating the recovery of materials and raw materials after the product's service life
- Production: using secondary raw materials and minimising both waste and the consumption of raw materials
- Use (service life): maximised product durability must be sought, facilitating its repair, maintenance and reuse
- Waste treatment: a focus on its recycling, facilitating its transformation into secondary materials and raw materials originating a new production process.

modern, prosperous, resource-efficient and competitive, climate-neutral society by 2050 (COM 2019). It proposes a set of transformative policies:

- Climate neutrality in 2050, which aims to reduce emissions between 50-55% by 2030.
- Clean, accessible and safe energy, promoting decarbonisation of the energy system.
- A clean and Circular Economy, based on a new industrial strategy aimed at developing a low-emissions activity, and with sustainable, climate-neutral and circular products and services.
- Sustainable and smart construction, renovation and mobility.
- The health system will seek a transition to a Circular Economy with more efficient production systems, better storage and packaging, healthy consumption, reductions in food losses and waste, more sustainable agricultural transformation and transport, and better-informed citizens.
- Preserve and restore ecosystems and natural capital, based on a new biodiversity strategy, as well as reductions in pollution.

The Circular Economy has been boosted again in the European Union; specifically, by reformulating the Circular Economy package (EIB, 2020).

In Spain, in June 2020, the Spanish Circular Economy Strategy was adopted. In addition, in the months of June and July two drafts of the Waste Law and the Climate Change Law were presented. In the first case, when addressing bio-waste, the obligation of separate collection was established for municipalities starting in 2023. With regards to plastics, the prohibition on single-use plastics is slated for July 3, 2021. The rest of single-use plastics are to be reduced by 50% in 2026, and by 70% in 2030. The second proposes reduction dates and targets similar to those in Europe.

All these policies lead us to a scenario, in the short term, in which it will be necessary to strive for the comprehensive use of resources of biological origin.



What until now were by-products or waste must be recovered and transformed into new products destined for the market. In this way, we simultaneously achieve three objectives: improve efficiency in production processes, extend the economic life of natural resources, and reduce the carbon footprint of all products. In addition, we promote industrial synergy, generating new value chains in the economy.

3. BIOMASS TRANSFORMATION OPPORTUNITIES

The launch of the European Bioeconomy Strategy in 2012 triggered a series of studies to quantify the possibilities of this new area of knowledge and the economy. For this, it was essential, as indicated by M Barek *et al* (2014), to generate a procedure and a set of databases that would make it possible to quantify the availability of biomass in Europe. In fact, this JRC group published the working procedure and biomass flow in Europe (Gurria *et al*, 2017). They distinguished three large groups of waste, according to their origin: agricultural, fishing and forestry biomass.

In a later work, the same group (Camia *et al*, 2018) stated that agriculture generates 956 Mt of biomass, of which 46% is residual. Part of it may have economic value (for example, when used for animal bedding, or for bioenergy production), although they indicated that it is also important as a provider of ecosystem services, by maintaining organic carbon levels in the soil, and preventing erosion. In the forestry field, they stated that 32% of total aerial woody biomass corresponds to branches, stumps and crowns, as a whole, considered other wood components, representing around 95 Mt per year. Another area described is the total production of macro and microalgae, gauged at 0.23 Mt of wet biomass in 2015 (which corresponds to approximately 0.027 Mt of dry weight).

Thorenz *et al* (2018) carried out a study using similar sources, quantifying agricultural waste in Europe at 107 Mt. Their results identify wheat straw as the most promising source in the agricultural sector, followed by corn stubble,

barley straw and rapeseed straw, which feature a total lignocellulose concentration of more than 80% dry matter. In forestry, the bark from the waste of two species of conifers - fir and pine - is the most promising source, being approximately 70% lignocellulose. They also estimated that only 8% of the total waste was being exploited.

More abundant are the studies that quantify the biomass that can be used for conversion into bioenergy, incorporating other products, such as urban solid waste or sewage sludge; some works (Scarlat *et al.*, 2018, and the Commission's own publications). The provisioning of biomass for bioenergy (i.e. primary energy) in the EU reached 140 Mt in 2016. Of this, 96% came from the EU, and the remaining 4% was imported from non-EU countries. Biomass from the EU is mainly converted into energy in the Member State where it is produced, with only 7.2% being so converted in another Member State.

Hamelin *et al* (2019) conducted a study to estimate biomass production in the EU and indicate its geographical locations. They include four major biomass-generating activities: agriculture (straw, manure, pruning waste, permanent plantations); forestry (forest waste), the management of urban vegetation (waste from the management of urban green areas and roadside vegetation); and food waste (from agro-industrial food processes, including biodegradable municipal waste). In Figure No. 2 we present the results.

In Spain we can use a combination of studies to quantify the biomass available, among which we can highlight those from the IDAE (2011) and BIOPLAT-SUSCHEM (2017), as well as data from the INE (2018) when quantifying sewage sludge. Within the residual biomass categories we can consider the following groups:

- Residual agricultural biomass, consisting of crop residues such as straw, stems, leaves, silage, as well as that from pruning, which comes to 30.5 Mt
- Forest biomass, from forest crops (mainly woody species produced through cultivation activities on forest lands, harvesting, and, if necessary, from the



processing of harvested raw materials; non-wood forest crops, such as aromatic or medicinal plants, are also considered), forest exploitation (silvicultural operations involving forest masses) or forest residues (cleaning and maintenance of forest masses and green spaces), was evaluated at 18.7 Mt per year.

- Biomass from livestock waste, with this including manure and slurry, bedding for animals and chicken manure. Although there is currently significant demand in the agricultural sector, especially the most solid ones, they can also be allocated for transformation. In Spain they are assessed at 72 Mt per year.
- Residual biomass from fishing and aquaculture, not quantified separately in any of the documents that we have been using as a reference.
- There are special biomasses, from the meat value chain, to which little attention is usually paid, as they are subject to complex regulations: they are By-products of Animal Origin Not Intended for Human Consumption (SANDACH), which include everything from animal carcasses from farms, to seizures from slaughterhouses, to by-products from the meat industries. The volume that is produced in our country, and its richness in certain ingredients (fats, proteins, enzymes and hormones), can warrant its consideration. In Spain, 350 t of this group of by-products are produced per year.
- Residual biomass from the agri-food industry, which includes both non-edible products, such as discarded skins, shells or fish parts, as well as products that do not reach the market because they do not comply with hygiene or quality requirements, such as waste generated in the production processes necessary to obtain food and beverages (cheeses, fats, oils, wine, beer, frozen foods, canned goods, etc.). In Spain, production of 83 Mt per year was estimated.
- Residual biomass from the wood, paper and textile industries, which is estimated, in Spain, at 6 Mt.

- The fermentable fraction of urban solid waste, which includes all organic components, which it will be mandatory to separate in our municipalities as of 2023, as well as sewage sludge. Together they represent around 26 Mt of products.
- Sewage sludge represented 1.2 Mt of dry matter in 2018, which is managed through agricultural use (87%), energy recovery (5.5%) and landfill disposal (7.5%).

Technological platforms, meanwhile, describe the potential use of crops that can be exploited to obtain biomass, which they estimate amounting to some 39.4Mt. They are grouped into herbaceous and woody ones. Herbaceous plants can be classified, according to the main product obtained from them, into:

- Alcoholigenic (alcohol-producing). Types used for the production of bioethanol from processes involving the alcoholic fermentation of simple sugars, with these including starches and insulins.
- Lignocellulosics. Herbaceous species rich in lignocellulose (cellulose, hemicellulose and lignin) and featuring high production.
- Oil-producing plants. Species from which oil-rich fractions (seeds or fruits) are harvested, which are used for the production of biodiesel and other biofuels, as well as other products (for example, for the manufacture of biopolymers, or the preparation of compounds for cosmetics).

Woody crops can also be lignocellulosic (the majority) or alcohol-producing.

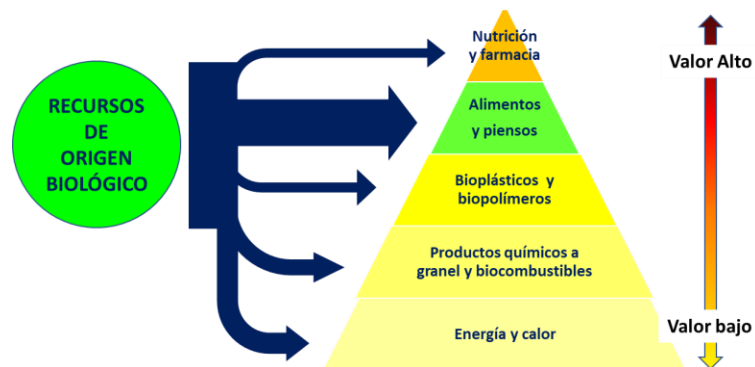
The KBC (2020) has published the biomass flows forming part of the Bioeconomy. According to this information, in Spain 56,246 Mt of biomass are produced annually, which, together with 19,051 Mt imported, and 272 Mt of unknown origin, make 75,569 Mt available. Of this amount, 47,237 Mt go to the food system, 518 Mt to the production of biomaterials, and 27,814 Mt are lost or have unknown destinations. Of those processed, 4,351 Mt are exported. All these figures expressed refer to dry matter. It is evident that we have residual

biomass at our disposal that could be recovered and exploited. In order to have a vision of the future, we must delve deeper into the group of chemical products that are currently being obtained from this raw material.

4. THE POSSIBILITIES OF BIOMASS TRANSFORMATION

Most of the biological resources from agricultural, livestock, extractive fishing and aquaculture activities are used for human consumption; directly or indirectly, after preparation, or after transformation, of varying intensities, it becomes food for consumers. However, the end uses of all these resources of biological origin may vary. In Figure 2 we present a synthesis of their possible uses in the framework of the Bioeconomy. It is possible to extract different compounds with a high added value for the specialised nutrition or pharmacy sectors. They can also be transformed into bioplastics and biopolymers, or bulk chemicals, or biofuels. The last option is to transform these resources into energy or heat if there is no possibility of using it in another way.

Figure 2. Possible uses of biomass within the framework of the Bioeconomy



As shown in the figure, as one goes down the pyramid, the value of the products obtained drops. For this reason, in the use of Biomass, the cascade principle, from the field of waste recovery, is applied: extracting from the biomass, first, the ingredients or products of the greatest value.

Traditionally, food production has been the Bioeconomy's main activity.

In the food sphere, the potential for development and innovation in this sector is unlimited. We will mention them, although we will not go into them in this review. We will classify them according to the objectives they pursue:

- Responding to the diversity and differentiation of consumer demand, in different markets and with reference to different cultures, values, interests, experiences, age groups, nutritional needs and even social commitments.
- Respond to social challenges in terms of sustainability (circularity of processes, environmental footprints, bioplastics, eco-designs, etc.), food safety (with reduced allergens or specific toxicities of certain groups, technologies, such as Blockchain, or pressures and new materials or additives that can, in turn, extend product lives), or nutrition and health (incorporating functionality into some ingredients, or new ingredients with additional functionalities, or reducing the use of certain components)
- Maintain a cost/quality/service ratio allowing them to be a dynamic and competitive sector in the national market and abroad, having the opportunity to work in the organizational sphere, and on the integration of new technologies, both classical (biotechnology, nanotechnology and ecology) and emerging (automation, robotics, sensor-related). Artificial Intelligence, or in the improvement of food preservation, with different combinations of temperatures, pressures, or the incorporation of additives.

We are going to focus more on the potential of biomass in terms of its transformation into products other than food, following the work of Iffland et al (2015). As this same team pointed out in another similar document (Aeschelmann et al, 2017), it is possible to obtain any oil by-product from biomass, using different metabolic routes. In this summary we have also taken into consideration the work of BIOPLAT-SUSCHEM (2017), Pietrowsky et al (2018), Parisi et al (2018), Villarán et al (2018), the OECD (2018), JRC (2019) and Patinha Caldeira et al, 2020. The by-products that we can obtain will be classified into several groups:

- Fuels:



- o Biomethane, or biogas (CH_4) is created through anaerobic microbial processes, from different raw materials (carbohydrates, fats and proteins).
- o Bioethanol: obtained through different processes, raw materials and microorganisms that can USE C5/C6 sugars. Ethanol can also be acquired through anaerobic procedures.
- o BTL (Biomass to Liquid) is a synthetic fuel obtained through a multi-stage process that begins with pyrolysis.
- o Biodiesel: generated through a transesterification reaction based on different sources of triglycerides of plant or animal origin, including soybean, rapeseed and palm oil. It is a substitute for diesel derived from petroleum.
- o Vegetable-based fuel oils: certain vegetable oils can be added directly to the diesel used by motor vehicles. In theory, they can be used directly as gasoline.
- o Hydro-treated vegetable oils: a product that comes from hydrogenated vegetable oils. It can be considered similar to biodiesel, but with a longer useful life.
 - Basic chemical compounds (building blocks).
- o Acetic acid: a basic compound for the production of PVA (polyvinyl acetate), when it reacts with ethylene to form vinyl acetate monomers. The processes for obtaining it are varied, although they are usually based on an acidogenic fermentation.
- o Lactic acid: produced through biomass fermentation processes. It is the basis for the formation of polylactic acid (PLA), which can replace polystyrene of fossil origins.
- o Succinic acid: an intermediate product of the citric acid cycle and an end product of the anaerobic metabolism of glucose.
- o 1,3-propanediol (PDO): can be obtained from the fermentation of glycerol, or using glucose as a raw material. It can be used as a base material for the production of PTT (polytrimethylene terephthalates) fibres.

- o 1,4-butanediol (BDO): another important basic chemical as it can replace ethylene glycol for the acquisition of thermoplastic Polybutylene terephthalate (PBT). It can be obtained from succinic acid or the fermentation of sugars with *E. coli*.
- o 5. Hydroxymethylfurfural (HMF): produced from the dehydration of sugars like fructose and glucose. It is a very versatile intermediate product when it comes to synthesizing polymers, offering multiple possibilities. For example, it can be used to produce furandicarboxylic acid (FDCA), which, in turn, can be used to replace PET in bottles, polyamides, polyurethanes, thermosets, and plasticizers.
- o Ethylene: this monomer can be obtained through the fermentation of glucose producing ethanol, which is then dehydrated by means of catalysis. It has also been produced from the fermentation of lignocellulosic materials.
- o Monoethylene Glycol (MEG): a basic compound for the manufacture of polymers such as PEF and PET. It can also be used alone; for example, to de-ice aircraft, or as a heat transfer agent. It can be synthesized from biomass in several ways; for example, from ethylene, or via glucose and ethanol.
- o Isoprene: various raw materials can be used to form biobased isoprene; e.g. glycerol, CO₂ or glucose with various microorganisms. In the chemical industry it is used as a starting material to obtain rubber, pesticides and tires. Furthermore, together with bio-based acrylic acid, a reaction can be induced to produce terephthalic acid, which is one of the monomers used in the synthesis of PET.
- o Acrylic acid: can be produced from glycerol, as a by-product of the creation of biodiesel. It can be used to form polyacrylic acid, which is an important component in adhesives and coatings. In addition, it can form various copolymers.
- o 2,5-furandicarboxylic acid (FDCA): can be obtained through the oxidation of HMF. It features a structure very similar to terephthalate acid, one of the monomers used to obtain PET, which allows it to obtain its furan analogue, PEF.



- o Para-xylene (pX): obtained from HMF, causing a reaction with ethylene. It is an important building block for polyester production. In turn, the oxidation of p-xylene gives rise to terephthalic acid, which is an important precursor of PET.
- o Terephthalic acid (TPA): can be obtained from P-xylene, or with a cycloaddition of acrylic acid and isoprene of biological origin. TPA is one of the monomers used to make, among other compounds, the following polymers: Poly(trimethylene terephthalate) (PTT), which is used mainly in textile fibres; PBT (Polybutylene terephthalate), a technical polymer for special applications; and PET (polyethylene terephthalate), used in packaging such as bottles.
 - Materials for the production of biopolymers:
- o Polyethylene: the polymerization of ethylene makes it possible to produce polyethylene.
- o Polybutylene succinate (PBS): can be obtained through various polymerization techniques, from 1,4-butanediol and succinic acid. It is a polyester with mechanical properties comparable to polypropylene, but it is biodegradable. In addition, it has thermoplastic possibilities and can be combined with other polymers, such as PLA, changing its properties.
- o Polylactic Acid (PLA): produced mainly through the formation of the lactide dimer and subsequent ring-opening polymerization. PLA is an aliphatic thermoplastic polyester with a wide range of applications (e.g., food service items, woven and non-woven fibres, 3D printing) and can be processed with standard equipment in the petrochemical industry.
- o Polyhydroxyalkanoates (PHA): can be obtained by fermentation using a large number of substrates (glucose, maltose or sucrose, for example). It is a polyester, with differential characteristics depending on the length of the chains, which may be thermoplastic or elastomeric.
- o Polyamides or nylons: can be obtained from castor oil.
- o Polyethylene Furanoate (PEF): uses 2,5-FDCA as the monomer, and even the other ethylene glycol monomer can be replaced by BDO to create a new

polymer: PBF. It can replace PET in products like bottles; they feature greater thermal stability, but, at the same time, a lower melting point, so it can be processed at low temperatures.

- o Polyethylene terephthalate (PET), made from building blocks, is a well-known biopolymer due to its use for the production of bottles and fibres.
- o Polymers obtained from cellulose and starch. Cellulose gives plants their structure, so it is very stable, while starch is a reserve material. Both are, basically, composed of glucose. However, while starch easily breaks down into glucose, in the case of cellulose and hemicellulose fusion with phenolic acids and acetyl groups impede this, requiring the intervention of certain bacteria and fungi to break the bonds within these materials. From there one can obtain:
 - Pure cellulose, the basis for the production of fibres (Rayon, Modal, Lyocel) and films (cellophane and sponges)
 - Derivatives of celluloses, whose ethers are used as additives, viscosity-increasing agents, and ethers that can be used as thermoplastic foams and composites, or composite materials.
 - Polymers made from starch.
- o Alkyl glucosides, with a surfactant action: the reaction of glucose with long-chain alcohols. The result is a product with the capacity to form emulsions by combining oil and water phases.
- o Hydraulic oils and lubricants: vegetable oils could be used for this purpose.
 - Active compounds, which can be extracted for their use as ingredients and additives in the food industry mainly, although they can also be used in pharmacy and agribusiness. The range of ingredients with functional activity that we can find is immense, so we will only refer to large groups of products:
- o Carotenoids, which are the red, yellow, orange, and purple pigments in fruits and vegetables, divided into carotenes and xanthophylls. They have applications in specialized nutrition and pharmacy to prevent photosensitivity, genetic damage and neoplastic transformations.



- o Phenolic and flavonoid compounds: they have shown a great variety of biological applications: antioxidant, antimicrobial, anti-inflammatory, immunomodulatory, antiviral, anti-proliferative, anti-mutagenic, vasodilator and for the prevention of coronary and neurodegenerative diseases.
- o Inulin, with its prebiotic effects, improving the intestinal absorption of minerals, reducing the risk of arteriosclerosis.
- o Glucosinates, as metabolites of brassicaceae, with a preventive effect on colon cancer.
 - Vegetable derivatives obtained from the biofermentation of agricultural by-products, using microorganisms and biocatalysts (other microorganisms and enzymes) yielding a fluid from which purified products are extracted. The final products that can be obtained are of a diverse nature. We will refer to some groups of them:
- o Biological enzymes or catalysts responsible for various metabolic processes. Some examples of enzymes obtained are: amylase, lignocellulase, pectinase, tannase, protease, lipase and invertase.
- o Organic acids, which can be used in different sectors (food, pharmaceutical, energy, industrial, etc). Using some species of fungi or bacteria, lactic acid or citric acid have been obtained.
 - Other products. We have not mentioned other common uses of biomass that could be improved through the incorporation of processing and preservation technologies. We will refer to two of them:
- o Animal feed. This is a common use to which many classes of plant biomass are put. However, they do not undergo stabilization and preservation treatments, to preserve their ingredients.
- o Fertilisers. Many types of biomass, both vegetable and animal, are used for fertilizers. Again, there is an opportunity to transform these by-products into specific biofertilizers for certain productions or specific areas.

5. THE TECHNOLOGIES AVAILABLE FOR THE TRANSFORMATION OF BIOMASSES

In the previous section we identified a wide variety of types of biomass. In addition, within each typology there is a range of heterogeneous products, in terms of their origin, size, moisture content, density and uniformity. Sometimes they may contain inert or unusable material. All this makes their collection, transportation and handling difficult. As a consequence, the use of all these raw materials will require pre-treatments and transformations to condition them and facilitate their recovery. These include size, moisture and densification reduction, and the removal of unwanted components.

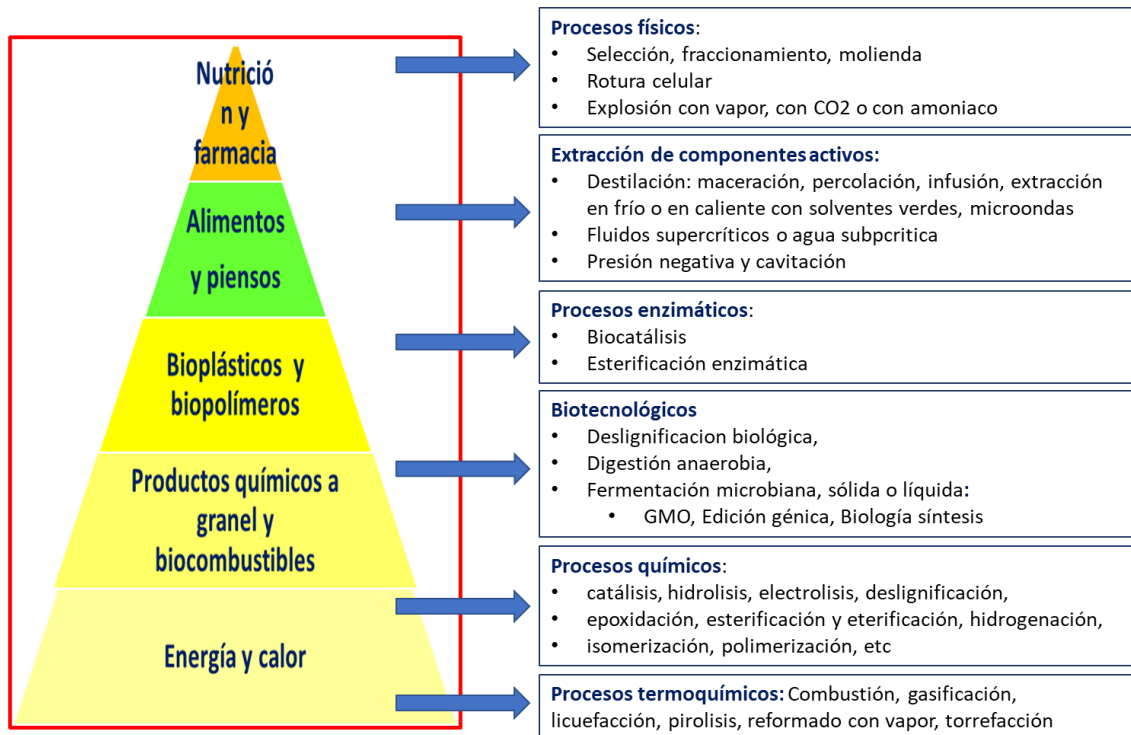
In Figure 3 we present a non-exhaustive summary of the technologies that can be applied to the recovery of biomass within the framework of the Bioeconomy. We have indicated some of the initial physical treatments, and then listed the physical extraction, enzymatic, biological, chemical and thermochemical ones. The sources used for the preparation of this summary are: House of Lords (2014), Villaran *et al* (2018), OECD (2018), BIOPLAT (2017) and Patinha Caldeira *et al* (2020).

Applying the principle of cascade use, the first option would be to obtain bioproducts with some type of functionality. The possibilities presented are the traditional ones, based on cold or hot maceration and extraction with solvents, in which the use of green solvents, such as water or ethanol, or "Natural Deep Eutectic Solvents", is frequent. Sometimes yields are improved through the incorporation of ultrasound or microwaves. Cold compression is also used in the production of oils.

To reduce the consumption of solvents, and improve the efficiency of the processes, other technologies are also employed, such as supercritical fluids, like carbon dioxide, and extraction using electrical pulses or subcritical water. Other options available are negative cavitation pressures, which allow for the extraction of polyphenols, alkaloids, polysaccharides and flavonoids. These

techniques, which are efficient at the laboratory level, can be financially problematic when attempts are made to scale them to the industrial sphere.

Figure 3. Summary of the technologies to be used for the development of the Bioeconomy



Another way to obtain biomass derivatives is to subject the raw material to microbial fermentation processes. However, it is often necessary to break down cell walls to facilitate the action of microorganisms and improve efficiency. In this case, physical or physical-chemical processes are used, such as pressure or explosion with steam, CO₂ or ammonia; for example, in the case of steam, saturated steam is injected at high pressures (0.7 to 5 MPa), increasing the temperature (160-260 °C). After a few minutes, or seconds, the pressure is suddenly reduced and the biomass undergoes destructuring, accompanied by the degradation of hemicellulose and a significant part of the lignin. The mixture obtained can be subjected to a hydrolysis treatment, with an excess of water, usually in the presence of a catalyst, by means of which polysaccharides present in the biomass can be hydrolysed, releasing C₅ and C₆ sugars, together with their isomers and oligomers.

The next phase is the application of biotechnologies that, at low temperatures and speeds, and with the action of microorganisms and/or specific enzymes, degrade the biomass's fermentable substrate. By means of fermentation those raw materials that contain a large percentage of carbohydrates can be transformed, either in simple form, or in the form of starch polymers or cellulose and hemicellulose polysaccharides. In aerobic fermentation, one of the main products obtained is bioethanol, but it is also possible to produce a wide variety of products that are especially valuable to the industry: xylitol, succinic acid, itaconic acid, lysine, 1,3-propanediol, etc. The other biochemical process, anaerobic digestion, occurs in the absence of oxygen, and biomass decomposes into an aqueous suspension of solid products and gaseous products known as biogas, used for electricity or thermal energy. This transformation process can be applied to any type of biomass, especially those with a high moisture content.

Improvements in the efficiency of biotechnological processes often hinge on the availability of microbial populations adapted to the fermentation of certain substrates, as well as the use of precise action enzymes. Hence, technologies for genetic modification, gene editing, or synthetic biologies are essential to improve the technical results of the processes.

Sometimes the biomass is subjected to a composting process to obtain a biofertilizer. This consists of the aerobic decomposition (with oxygen) of organic waste, such as vegetable and animal waste and slurry, through the massive reproduction of thermophilic aerobic bacteria that are naturally present anywhere. Subsequently, fermentation is continued by other species of bacteria, fungi, and actinomycetes. If progress is made in the degradation processes of organic matter, we can obtain humus, which is also used for the production of compost.

In the fermentation processes, primary products are obtained: buildings blocks or biogas. In the first case, it is necessary to apply biochemical



technologies to advance in the synthesis of bio-derivatives apt for release on the market. Some of the reactions will be those of esterification, etherification or transesterification.

Another recovery option is the use of thermochemical processes, which involve the thermal decomposition of the components of the biomass and a release of energy in the form of heat, or the production of intermediate biofuels. There are two main thermochemical processes that transform lignocellulosic biomass into energy and chemicals associated with biorefinery facilities: gasification and pyrolysis. In the first case, the biomass is partially oxidized at high temperature (usually in the range of 600-900 °C), transforming mainly into a gaseous mixture composed of CO, CO₂, N₂, CH₄, H₂ and H₂O, in different proportions, depending on the technology used and the gasifying agent. The second is a thermal degradation of biomass in the absence of oxygen, in which synthesis gas is generated for fuel, bio-oils, activated carbon and light hydrocarbons (mainly olefins and paraffins).

6. THE BIOECONOMY: CHALLENGES AND OPPORTUNITIES

Limitations affecting the carrying out of business projects in the field of the Bioeconomy can be identified in three areas: procurement logistics, technological difficulties, and the comparative costs of the transformation of resources of fossil origin versus those of biological origin.

In terms of the logistical needs involved in the concentration of by-products and waste, the descriptions of biomass provided indicate that, except in the case of urban solid waste and sewage sludge, other raw materials are dispersed throughout the territory. In the case of agricultural and livestock waste, this is especially relevant. In all these cases we have resources that feature limited energy concentration and, frequently, high humidity percentages. For all these reasons, the logistics involved in the collection and transport to a concentration site for the subsequent extraction of functional ingredients for their transformation into new bioproducts has an economic cost that increases final production costs.

Technological difficulties are concentrated in certain categories of biomass, especially those containing high levels of lignocellulose. The technical problems surrounding the conversion of lignocellulosic biomass into bioproducts have proven to be so unsolvable that only a handful of these biorefineries have become commercially viable, and most of them remain problematic facilities (OECD, 2018). According to this publication, around 40-60% of the total operating cost of a typical biorefinery is related to the raw materials chosen. However, the most significant cost of second-generation cellulosic biofuels may be the conversion of woody biomass into fermentable sugars.

This explains why the development of first-generation biorefineries, which used resources that can be designated for human consumption (cereals, corn, sugar cane, soybean oil or palm oil) as raw materials, was very rapid, while that of second-generation facilities (crop residues, forest products, MSW, etc.) has been more limited.

Kircher (2019) has analysed the opportunities entailed by the Bioeconomy, dedicating an entire chapter of his work to comparing the costs of transforming resources of biological origin to those of fossil origin, concluding that complexity and processing costs are significant competitive hurdles. Fossil fuels and basic chemicals are produced by simply refining mineral oil or processing natural gas (methane). At the same time, the efficiency of the processes must be considered, both in technical terms and in terms of labour: while the carbon from fossil raw materials becomes almost entirely the end product, in the case of those from biomass the carbon efficiency of these processes is lower. Moreover, the intensity of work, in the former case, is lower as compared to the latter.

To illustrate his conclusions he presents a comparative analysis of the number of steps required in each of the production routes of two specific products (ethanol and ethylene) obtained from fossil resources relative to biological resources. In addition, he distinguishes between the categories of biomass used, according to whether they contain lignocellulosic elements or not. He concludes



that more links are needed to obtain the same products, which explains the technical complexity, the labour intensity, and, ultimately, the production cost.

All this leads Kircher (2019) to conclude that the competitiveness of all these products will depend on the price of oil and of biomass. Therefore, we can conclude that as long as a barrel of oil is inexpensive it will be difficult to promote the development of the Bioeconomy, if only economic and market aspects are taken into account.

Notwithstanding the foregoing, we must take into account the opportunities related to each of the challenges.

- Regarding logistics and provisioning, we must remember the policies that will be implemented in Spain and the EU in the coming years, to reduce the waste generated, or to transform it and to recover it, in order for it to ultimately become secondary raw materials, thereby promoting industrial synergy. Legal pressure will force the use of these resources.
- In terms of technologies, we must consider that knowledge related to petroleum chemistry has been developed in the last 120 years, and has allowed for systematic innovation, making it possible to have a huge range of products that meet our needs. Science and innovation related to the Bioeconomy has a much shorter history: around 20 years. Therefore, the development of an efficient Bioeconomy requires an expansion of knowledge and its transfer to the market through innovation. Currently, in the EU and Spain we have had and, we will continue to have, tools to finance the generation of knowledge and innovation. Specifically, we can point to the following:
 - The EU has featured the 8th Research and Innovation Framework Programme, H2020, with a specific area for the financing of the Bioeconomy, for both the generation of knowledge and the promotion of innovation. Within this framework, there has been a public-private collaboration initiative (Biobased Industries), focused on the Bioeconomy, which has financed 118 projects over

the last 6 years, and has a budget of € 3.7 billion. In the next period scheduled, within the framework of Horizon Europe, an increase in general funding and the maintenance of this public-private initiative have been announced. For the next period slated, the farm-to-table strategy, which is included in the Green Deal, addresses the financing of the Bioeconomy as one of the priorities to be considered.

- The Spanish National R&D plan does not include specific sectoral programs. However, hitherto it has incorporated the generation of knowledge and innovation in the Bioeconomy area as priorities. Both in the calls of the State Research Agency and in those of the CDTI (Centre for the Development of Industrial Technology), the Bioeconomy has been consolidated as the second leading area of research and innovation when it comes to capturing resources, after Health. In the future National Plan, forecasts envision the Bioeconomy continuing to play an important role, in accordance with the EU's priorities. Rural development programmes, meanwhile, have thus far included the financing of projects that bolster the development of the Bioeconomy as one of their most important objectives.
- At the CCAA (Spanish regional governments) level, all the RIS3 have considered the Bioeconomy to be strategic, with varying degrees of preference for either primary production or agri-food transformation. Hence, programmes to finance innovation by drawing on regional development funds have been open to financing this area of activity.
- Biobased products, with higher production costs, will face difficulties when it comes to competing in a context of open markets. However, one must take into consideration a series of facts:



- Trends in demand and, especially, distribution, which favour their differentiation in the market through the offering of products entailing reduced GGE.
- European policies, which will promote the labelling of all types of products, to include information clarifying the sustainability of the production process, considering the entire value chain. GGE and carbon footprints will figure prominently on these labels, and it is clear that biobased products boast reduced carbon footprints.
- One of the factors that has the greatest impact on the production cost of any industrial product is the amortisation of the investment, in which financial costs are especially relevant. Investment in projects to develop the Bioeconomy will be particularly prioritized in the coming years, at both the European and national levels.

7. LIFE CYCLE ANALYSIS AS A BASIS FOR PRODUCT DEVELOPMENT

The European Bioeconomy has been built on the principles of efficiency and sustainability (Lainez et al, 2018; Lainez and Periago, 2019). Therefore, it seeks the maximum use of biomass while recognising that the use of resources must guarantee their availability for future generations. The Bioeconomy arose and stands as an alternative to the use of fossil, non-renewable resources, to mitigate the consequences of the systematic use of these types of resources, the most important effect being climate change. Therefore, any biomass recovery project must be combined with a reduction in the impacts, and especially, of the carbon footprints of the final product obtained, obtaining comparative advantages with respect to the same product derived from raw materials of fossil origin.

Kircher (2019), in his study of the Bioeconomy, cites examples in which the carbon footprint of organic products is significantly lower than those of fossil origin. However, he also indicates that obtaining biofuels and biopolymers under

the conditions considered in the examples cited, cannot be achieved without traces of

Greenhouse Gases (GHG). Emissions are generated primarily by agriculture and processing. The use of renewable energy is more effective in processing. Therefore, he concludes that investors placing their trust in bio-based products and processes should carefully analyse the source of raw materials and the energy intensity of a particular process and examine the potential for integration into emissions-free energy systems.

The use of biomass for different purposes is promoted and supported by national and global Bioeconomy policies and strategies, as a consequence of the premise that obtaining biodegradables generates less greenhouse gas than with their fossil-based counterparts. Though the Bioeconomy can be seen as a solution to these global challenges, it can also have adverse impacts on the environment, in terms of land degradation, losses of biodiversity, and a decreased capacity to provide ecosystem services, which need to be analysed (Pursula et al 2018).

Moldan *et al* (2012) when describing environmental sustainability, posit six major areas to take into account within this concept:

- Climate systems (covering the climate and climate change, risk management, mitigation and adaptation).
- Human settlements and habitats (covering cities, urban development, and transportation).
- Energy systems (covering energy use, energy conservation, renewable energy, energy efficiency, and bioenergy).
- Terrestrial systems (encompassing natural and managed ecosystems, forestry, food systems, biodiversity, and ecosystem services).



- Carbon and nitrogen cycles (covering sources and sinks, feedback, processes and links to other systems).
- Aquatic systems (encompassing marine and freshwater ecosystems, fisheries, currents, and biodiversity).

From a scientific point of view, many approaches have taken to measure sustainability. However, at this time Life Cycle Analysis is considered the most objective way to analyse the sustainability of production processes.

The analysis of a product's life cycle is a tool for characterizing the integral environmental footprints of products and production systems. It is viewed as a key tool to ensure a transition towards more sustainable production and consumption patterns. As Notarnicola *et al* (2016) and Holden *et al* (2018) point out, life cycle thinking is increasingly used to assess systems' sustainability.

It is an approach used to evaluate products, processes and services in terms of their place in the world, the full life cycle required for them to serve society and the environment, and the social and economic consequences of that service. The method has been recognized as the leading approach to incorporating sustainability into decision-making in the United States (NRC, 2014), Europe (JRC, 2012), and elsewhere in the world. The quantitative tool used to implement life cycle thinking is Life Cycle Assessment (LCA), which is formalised by an international standard: ISO 14040/14044.

The JRC has been working to define standards for applying LCA to different value chains of the Bioeconomy. The analyses carried out show a high variability in the results published (Cristóbal *et al*, 2016). The individual studies reviewed differ from each other with respect to several methodological assumptions: the definition of system boundaries, functional unit, energy recovery, carbon emissions, and storage and allocation methods. All these differences have a considerable impact on environmental results, whose general interpretation and comparison become quite complex. Furthermore, the way

the results are presented varies significantly. All these issues point to a great need for methodological harmonization and coherence for the LCA of Bioeconomy value chains. Similar conclusions were reached by Martin et al (2018)

8. THE IMPACT OF THE BIOECONOMY IN DIFFERENT SECTORS

The JRC keeps updated data on the importance of the Bioeconomy in the European Union and in each of the Member States at its Knowledge Bioeconomy Center. The latest data available is for 2017. In Spain, according to the same source, it generated a sales volume of €219 million in 2017, representing added value of €65 million. In addition, it employed 1.42 million people. We can see that the agricultural and food sectors in Spain are very important, both in terms of employment (81%) and in terms of added value in the Bioeconomy as a whole (78%). It is surprising that some sectors, such as electricity of biological origin, are barely developed in our country.

The specific results for each of the subsectors making up the Spanish Bioeconomy are presented in Table 1. The percentages represented by each of the subsectors are shown, in terms of employment and added value, as well as the added value per person employed in each of the sectors. The most obvious conclusion that we can draw from this information is that the specific weight of the Spanish Bioeconomy continues to be supported by the classic sectors. The biochemicals and bioplastics sectors are less developed, as is the case with bio-based electricity and liquid biofuels.

Table 1.- Comparison of the working population, added value and added value per working person in the different sectors of the Bioeconomy in Spain in 2017 (own work, based on KBC, 2020)

	% Working population	% differential value	Added value / working person
Agriculture	52.4	45.9	40,287
Food and drink	28.7	32.2	51,709
Wood and furniture	5.7	4.1	33,487



Paper	3.2	5.2	75,317
Biotextiles		2.2	31,638
Forest production	1.3	1.5	55,899
Biochemicals and bioplastics	2.6	5.7	102,415
Fishing and Aquaculture	2.9	2.5	39,732
Bioelectricity	0.1	0.3	100,919
Liquid biofuels	0.0	0.3	474,216

Pietrowsky *et al* (2018) conducted an analysis of the Bioeconomy in Europe. In addition to the abundance of sectoral data, they describe the importance of the different classes of chemical compounds originated by biomass. With this data we created Table 2, in which we include the importance of each of these chemical groups, which orients us with regard to sectors that will be able to benefit from them.

Table 2.- The importance of the classes of biobased chemical products produced in Europe (own work, based on Pietrowski *et al*, 2018)

Product classes	% of the total
Commodities (building blocks)	35.1
Fertilizers	33.3
Polymers	5.4
Detergents	5.4
Vegetable oil	3.6
Adhesives	3.6
Fibres	3.2
Paints	0.9
Dyes and pigments	0.5
Agrochemicals	0.3
Other biobased chemicals	8.7

The JRC has carried out an analysis of the current state of affairs as regards biobased products, both technological and market-related, focused on the following groups: basic chemicals, solvents, polymers for plastics, paints, coatings, inks and dyes, surfactants, cosmetics and personal care products,

adhesives, lubricants, plasticizers (and stabilizers for rubber and plastics) and artificial fibres. From a list of 350 products, 50 were selected. A detailed market assessment of those selected was carried out, covering the EU's production, price, business volume, consumption, trade, the use of raw materials and agricultural land requirements. Based on the analysis of the 50 products, market information on the product categories was collected, covering EU production and market share, dependence on EU imports, future market size, private investment, the importance of Member States and the EU to production, level of maturity, and a SWOT analysis (Spekreijse et al, 2019).

It is a valuable document to check both a given category or a specific product. In the case of categories, a summary sheet of all the information gathered is presented.

In 2018 the Boston Consulting Group produced a circular Bioeconomy Guide for CEOs in which they estimated the impact of the Bioeconomy, globally, at 7.7 trillion between 2018 and 2030 (BCG, 2019). In their view, it generates business opportunities to:

- Create new markets, access new consumer segments, and develop new value chains.
- Provide companies with a business with less environmental impact, attracting other types of talent and new consumers.
- Mitigate the regulatory risks that companies will face in the areas of climate change and waste management, placing companies at the forefront of the sustainability demanded by society.

This paper also identifies the sectors in which a more substantial increase in business opportunities related to the Bioeconomy is expected. For each of them the growth of the Bioeconomy-related market is estimated, in billions of dollars, between 2018 and 2030. Reference is also made to the materials on which this growth will be based. We cite them below:



- Bioenergy and biofuels sector. It is expected to go from 150 to 200, with special attention to solid bioenergy, including wood pellets obtained from by-products and liquid biofuels, including biodiesel, biomethane, ethanol of cellulosic origin and "direct" renewable fuels.
- Food waste, for which growth is estimated at 2,300 to 2,600, in which mention is made of the reuse of waste, and the recycling of organic nutrients, and silk, satin and orange peel rayon fabrics.
- The Pharmaceutical sector, which is expected to grow from 250 to 750, with some areas singled out, such as vaccines from medicinal plants, cancer treatments featuring compounds synthesized from plant substances, and Blockchain technology associated with the production of proteins as a basis for medical treatments.
- The Textile sector, with an increase in value from 400 to 700, in which high-technology fibres obtained from biomass and biological waste; and compostable textiles, including Locel, are considered.
- Construction and construction materials sector, in which an increase from 350 to 700 is projected for wood-based and circular structures, composites reinforced with natural fibres, and bio-based insulating materials.
- Container and packaging sector, with an expected growth of 400 to 500, in which the products identified are recyclable flexible packaging paper and cardboard, paper packaging that replaces plastics (for example, beverage packaging cardboard), recyclable bioplastics and biodegradable starch-plastic blends.
- Motor vehicles and components sector, expected to go from 250 to 550, identifying as products natural fibres like car parts, compostable interior lining based on bioplastics and dandelion-based tires in a closed-circuit system.
- Other forest products sector, with an estimated growth of 150 to 200, featuring bio-lubricants and enzyme-based additives as examples of products.

- In the machinery and equipment sector, they anticipate market growth of 50 to 100, including bioprocess and agricultural engineering as examples.

The MacKinsey on Climate Change Report (2020) also merits special attention, in which reference is made to the development possibilities of some specific sectors, particularly transport, both automobile and air.

9. CONCLUSIONS

The promotion of the Circular Economy, decarbonisation, and the mitigation of climate change are major work strategies promoted by European policies and by many countries, including Spain, poised to bolster the development of the Bioeconomy in the coming years.

In Spain the production of 27,814 Mt of dry matter from residual biomass is estimated to be lost, or its ultimate destination is unknown.

The production of biological resources has traditionally been undertaken with a view to obtaining food to meet people's needs. In addition to continuing to supply food, the Bioeconomy can make use of residual biomass to obtain a great diversity of products, including basic chemical compounds, or building blocks, materials for the acquisition of biopolymers, active compounds, biofermentation derivatives, or fuels.

There is a wide range of technologies available for the recovery of biomass, and their efficiency is continuously being improved. These include physical, active component extraction, biotechnological, chemical and thermochemical processes.

The challenges for the development of the Bioeconomy are the logistics involved in provisioning, and the technological difficulties and the comparative costs entailed by the transformation of resources of fossil origin compared to those of biological origin. Faced with them, opportunities will be generated by changes in the social perception of the importance of sustainability, which will



translate into a modification of demand patterns. Furthermore, European policies, especially those stemming from the Green Deal, will limit certain traditional products' access to the market, and, at the same time, favour investments in the development of Bioeconomy projects.

These projects must be executed guaranteeing the environmental sustainability of the investment and the production process. The tool to carry out this impact analysis will be Life Cycle Analysis.

The development of the Bioeconomy will occur as a result of the placement on the market of products in new economic sectors in which, until now, the presence of bioproducts has not been significant. The waste management and recovery sectors stand out, especially waste from: food, the pharmaceutical industry, textiles, construction and construction materials, containers and packaging, motor vehicles and components, bioenergy and biofuels, other forest products, machinery and equipment.

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