Chapter 2
Bioeconomy: The Path to Sustainability

Abstract As the global environmental, geopolitical, and socioeconomic situation started to worsen, humanity became aware that the current economic model based on fossil resources is not a viable one and its shortcomings are being sensed all over the world (economic crisis, global warming, accentuated disparities, recurrent pollution incidents, etc.). In response, a general consensus was made about the necessity to reintroduce biomass as the core element for the future economic model allowing a sustainable development, along with dealing with the major issues being faced by humanity nowadays.

In this chapter, the various definitions around the bioeconomy concept are presented, as well as the urgent need elaborate an authoritative definition of this concept in order to synchronize the efforts of all possible contributors (legislators, scientists, industrialists, etc.) for a wider promotion and implementation of this new economic model through a gradual and smooth transition in raw materials from fossil to renewal resources.

The main aim of bioeconomy is primarily to conduct the various agricultural, forestry, and industrial activities in a sustainable manner. Thus, in order to ensure a successful transition to bioeconomy, the key endeavor is to find out different viable schemes to combine both sustainability and profitability. This is definitely the major challenge to face bioeconomy for the next couple of decades. The leading role of science and technology in this vital transition phase towards sustainable bioeconomy is emphasized.

2.1 Introduction

After analyzing the heavy legacy of the petroleum-based economy on mankind and the environment, the ultimate deduction is that the situation has to change, and an alternative economic model has to be proposed to repair mistakes of the past and pave the pathway for a better future, a sustainable and eco-friendly future, for generations ahead.

The utmost important keyword in this very vital endeavor is CHANGE. Indeed, this is the real challenge facing any economic model expected to replace the current fossil fuels-based one. The fear of change is deeply lodged in the psyche of both individuals and societies.

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No economic model will be able to take over if it is not, at least, as efficient as the current one. This is the only solution to overcome the intrinsic fear of change going all the way from the producers to the consumers. May be a fraction of them is ready to make minor concessions for some time, but no one will be willing to make serious concessions most of the time.

As the geopolitical, socioeconomic, and environmental situation started to deteriorate, humanity suddenly became aware about this "green stuff" around us. We could eat it, cure ourselves with it, feed it to livestock, and produce fuels and many other products from it. Humanity rediscovered then what was always around: BIOMASS.

At this point, we became aware that many commodities came from petroleum, but petroleum too came from biomass. So, what if we replace the petroleum by its source and petroleum-based economy by a biomass-based economy. Thus, instead of "preaching" urgent change to change-fearing population, let us use the comforting "go back to the source" speech.

2.2 What Is Sustainable Bioeconomy?

Defining bioeconomy is a crucial first step. This concept will be used to deal with worldwide population growth, depleting fossil raw materials, climate change, and many environmental problems. Thus, before analyzing bioeconomy and its implementation, the notion itself should be defined.

Although there are many viewpoints about sustainability, the notion itself is quite straightforward. Basically, it is about securing the needs of current generation without compromising the ability of the next one to secure its own needs.

As for bioeconomy or bio-based economy, many scientists, governments, and international institutions presented their own definitions. From those definitions, legislations, strategies, and policies will be developed and later implemented, and this is precisely why defining bioeconomy is crucial. The problem here is that bioeconomy is a multidimensional concept, and its definition basically depends on who's defining. Economists, industrialists, farmers, strategists, and ecologists will have a distinct, sometime contracting definitions of bioeconomy. Imagine decision makers adopting action plans for years ahead based on the "governmental" perception of bioeconomy, but industrials, on the other hand, have another vision of the whole concept. The implementation will be very difficult, especially within an international network (which is the case most of the time).

Here are the widely known (still to be widely accepted) definitions related to bioeconomy. According to the European Union, bioeconomy "*encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries*" [1].

Within the European Union, several countries pursuing their own national strategies aiming at developing bioeconomy and sustainability also adopted other definitions. For instance, the German Federal government defined the concept of bioeconomy in its national research strategy "BioEconomy 2030" as follows: "*The concept of bioeconomy covers the agricultural industry and all manufacturing sectors and their respective service areas, which develop, produce, process, reprocess or use them in any form biological resources such as plants, animals and microorganisms. Thus, it achieves a variety of industries such as agriculture, forestry, horticulture, fisheries and aquaculture, plant and animal breeding, food and beverage, wood, paper, leather, textile, chemical and pharmaceutical industries up to branches of energy industry*" [2].

Finland, one of the leading countries in implementing bioeconomy, also adopted its own definition. According to the Finnish bioeconomy strategy, "*bioeconomy refers to an economy that relies on renewable natural resources to produce food, energy, products and services*." The objectives of this strategy is to "*reduce dependence on fossil natural resources, to prevent biodiversity loss and to create new economic growth and jobs in line with the principles of sustainable development*" [3].

On the other hand, based on their report entitled "The Bioeconomy to 2030: designing a policy agenda," the OECD countries consider that "*the application of biotechnology to primary production, health and industry could result in an emerging bioeconomy*" which "*is likely to involve three elements: advanced knowledge of genes and complex cell processes, renewable biomass and the integration of biotechnology applications across sectors*" [4].

One concept, one definition. This would be perfect to "harmonize" and "synchronize" the efforts of all possible contributors for a worldwide promotion and implementation of this new economic model. But, this will be very difficult to achieve. First, because the concept in itself depends on the perspectives of the contributors and their involvement context. For instance, what is the worth of a sustainable production if not followed with a sustainable consumption? Second, and more importantly, who has the uncontested authority to define bioeconomy?

For the present book, bioeconomy means the sustainable extraction, exploitation, growth, and production of renewable resources from land and sea and their eco-friendly conversion into food, feed, fuels, fibers, chemicals, and materials, to be consumed and recycled in a sustainable manner.

2.3 The Shift to Sustainable Bioeconomy

2.3.1 Bioeconomy: Necessity or Luxury?

As we've diagnosed in Chap. 1, humanity and the planet are sick; a severe case of intoxication with fossil fuels (and addiction to them). Thus, sustainable bioeconomy is more than a necessity. We have to join force to heal ourselves and the planet. Forget about the moon or Mars, we are born here and we will die here on this beautiful green earth.

Now that the disease has been realistically identified, the next step is to find the cure and quickly start the therapy. The cure has been found. It's called *sustainable bioeconomy*, and it is exclusively made out of biological resources from both land and sea. Nevertheless, despite finding the cure, starting the treatment is taking too much time for two main reasons. First, the disease was falsely diagnosed or at least underestimated right from the start. Second, the initial treatments were localized whereas the therapy should be generalized to the whole body of this sick planet. How should we proceed then to use this cure of sustainable bioeconomy?

We all agree that the treatment of a severe case of combined intoxication and addiction is a long, sometime painful, process. Humanity suffered (and still do) from prolonged exposure to petroleum and fossil fuels, and their consumption became almost compulsive. The healing process is composed of two phases: (1) detoxification and (2) rehabilitation.

The first phase aims at gradually reducing the exposure to fossil fuels. At this advanced stage, it is out of question to abruptly stop using fossil fuels as raw material. The current economies are too dependent and too weak for such drastic approach. Besides, the cure of sustainable bioeconomy is not mature yet and could not be administered except at small and gradual doses. The second process is rehabilitation which aims to cease the recourse to fossil fuels and replace it by the use of renewable bioresources through a wide implementation of bioeconomy. By the time earth regains its "sobriety," little or no petroleum will be left, so no worries about relapse.

In layman's terms, we should continue, while reducing, the use of fossil raw materials and promote, while increasing, the use of renewable raw materials. It is indeed a compromise more than necessary to make sure that all the contributors, whether promoting bioeconomy or benefiting from it, work together in order to attain the same objective: start a green industrial revolution to secure a sustainable future.

2.3.2 Raw Material Change

The term raw material refers to unprocessed organic or inorganic materials or substances used as feedstock for the primary production of energy, fuels, and various intermediates and end products. At a basic level, the change in economic models, national strategies, and international policies could be summarized in one single notion: change in raw material. This change consists of a *gradual shift* from the use of extracted nonrenewable resources to the use of harvested renewable resources.

2.3.2.1 From Fossil to Renewable Raw Material: An Anxious Transition

From the very beginning, securing a constant supply of raw materials at reasonable prices has been the main strategy for any industry to ensure high revenues and great competiveness. But, as the competition became fierce, whether between industrials or between countries, more attention was given to the price, and not the source, of the raw material. From this point, the recourse to relatively cheap fossil nonrenewable materials became a must to be able to compete, either nationally or worldwide. Despite the disastrous consequences related to the extraction, transportation, and use of fossil raw materials, as discussed in Chap. 1, industrial complexes continued to expand and nothing alarmed them until, somehow, they figured that there is a shortage in those precious fossil raw materials.

On the other hand, the steady increase in the world population, the rapid growth of emerging markets like China and India, along with the development of very efficient conversion technologies, strongly deteriorated the raw material supply situation during the previous decade [5]. For many industrialized countries, the dependency on nonrenewable fossil resources as raw material is very advanced and alarming too as most of those developed countries depend on raw material imports [6].

The reaction of most industrialized countries towards the proven shortage in those fossils resources was very symptomatic. Instead of searching for new sources of raw material that are renewable in order to secure a continuous flow of raw supply, they are "advising" to keep relying on other still abundant fossil resources, as if abundance means infinite.

Thus, as the petroleum resources are depleting, a gradual replacement is already planned, but then again with other fossil raw materials. First, they think that it is necessary to increase the lifespan of petroleum exploitation. Thus, the first action to take is to improve the yields of current petroleum deposits and produce more until finding a cheaper resource.

The second action is to start exploiting unconventional fossil resources "resembling" petroleum including tar sand and oil shale. Adopting this strategy will make "*democracies much less dependent on oil flowing from countries like Saudi Arabia, Iran, Iraq, or Venezuela*" [7]. What about their dependency on nonrenewable oil? Is the "democratic" oil better than the "autocratic" one?

In the meanwhile, natural gas will play an increasing role as a raw material for the production of end products. Coal, on the other side, will be considered a long-term replacement, considering "its large reserves and availability in important industrial countries" [8]. The real reason, however, is that the prices of petroleum and natural gas are going to soar, which will make coal cheaper [9]. Thus, considering coal as a replacement knowing its disastrous mining activities [10] and the effects of burning coal [11] on the climate is just wrong.

Proposals to mitigate coal-related environmental problems by carbon dioxide capture and underground storage will have limited impact, considering the massive scale of exploitation and subsequent emissions. Indeed, after immobilizing CO_2, the gas must then be released from the capture medium for sequestration (storage) while limiting the energy consumption. This is where current capture technologies run into problems [12]. As well, it is still unclear how the natural carbon sinks will evolve as climate and atmospheric composition continue to change [13].

All this clearly illustrates how important and delicate is this matter of raw material change. Every decision, no matter how insignificant it could appear, has to be taken after deep discussions, heated ones if necessary. The objective is to reach a consensus between all possible contributors in the field (scientists, industrialists, ecologists, economists, strategists, and decision makers). Even one of us promoting bioeconomy we have to be pragmatic: defend our opinions and visions with cold hard facts and still be ready to make compromises.

Here is one hard fact. Biological resources are only renewable if the rate of regeneration is faster than the rate of exploitation [14], and it is only under this conditions that biomass could be proposed as a renewable raw material. The main distinction is that, at a certain level of utilization, renewable resources can potentially be sustained forever. Climate change, soil quality deterioration, and water pollution are directly affecting biomass production yields in various ecosystems in the world. This will severely disturb or at least delay the worldwide implementation of bioeconomy unless it manages to adapt itself the changing circumstances provoked by the complex climate change phenomenon.

Here is another important and decisive fact; a large-scale breakthrough in the utilization of renewable raw materials is only conceivable in the event of a significant change in the price ratio of fossil to renewable sources.

2.3.2.2 Addressing the Challenges Gradually and Quickly

Bioresources have been exploited by mankind to provide food, energy, and other necessity goods for many millennia. During the last century, a transition to fossil resources occurred in modern societies which changed the status of biomass use. Nowadays, mankind is going back to bioresources as a sustainable alternative to depleting fossil resources. It seems like an easy endeavor but it is not. Indeed, the previous transition from a preindustrial economy to the current fossil-based economy took more than 100 years although the preceding model was a sustainable one (*aka.* premodern bioeconomy [15]).

Now, if we take into consideration the disastrous legacy of the fossil-based economic model, on the one hand, and the current worldwide pressure on food, energy, and water supply, on the other, modern bioeconomy will need at least more than a century to take over and be fully operational. The problem is that time do not play in our favor. Serious decisions have to be taken and effective action plans have to be implemented urgently to mitigate climate change, water pollution, and soil degradation.

Thinking about going back to the old sustainable model (premodern bioeconomy) is a waste of time. It is not just a matter of lowering the current state of prosperity and welfare, the old model could not simply feed 7 billion people, let alone provide sufficient energy supply for the industrial and transportation sectors.

Thus, the most practical strategy is to combine the two previous models and “synthesize” a new model: *sustainable* like the old one and *efficient* like the current one. These are the two main objectives for modern bioeconomy. Such approach will benefit from the know-how cumulated by mankind for centuries, especially the experience gained from previous mistakes, thus saving us precious time as we will repair the mistakes of the past while building the better future.

Basically, bioeconomy cannot succeed unless it satisfies the needs of three “big babies”: industrials, consumers, and the environment.

1. Industrials have a huge appetite for raw material and energy, and they are not expected to induce any measure of change susceptible to reduce their revenues, at least willingly. Profitability is their main concern and bioeconomy has to take this attitude very seriously because without the industry, it will remain as an abstract notion.
2. Consumers and their growing requirements for food, energy, and clean water. Bioeconomy has to satisfy those basic needs worldwide, but also it has to retain the level of prosperity and welfare for consumers in developed nations and to meet the aspiration of consumers from developing countries to reach the same level of welfare.
3. The environment, the most patient of the big babies, is the easiest to please. It just needs to be left alone. All it asks from us is to limit our wastes and emissions to tolerable levels that could be dealt with using its arsenal for biological and geological resources.

Nonetheless, bioeconomy has to seriously consider the environmental factor because being patient does not mean that it will indefinitely bear our mistakes further. The current level of tolerance is very low after decades of abuse. The “reaction” of the environment, revealed by scientists decades ago, is starting to become visible to all mankind including global warming, severe storms, flooding, desertification, and, last but not least, sea level rise.

So, bioeconomy has to take care of the suffering environment to be able to survive. Indeed, although the needs of our environment are simple, their fulfillment is very difficult mainly because of the attitude of the first big babies: industrials and consumers. We purposely used the term of big babies to connote their lack of maturity, far-sightedness, and self-control, in addition to their reckless attitude all the way from exploiting fossil resources to the unsafe disposal of the generated wastes. More details about this crucial stage of transition are presented later in this chapter where the relation between bioeconomy, on the one hand, and agriculture, industry, and forestry, on the other hand, will be, respectively, analyzed.

2.3.3 Sustainable Profitability from Bioeconomy

To be adopted by entrepreneurs and implemented by industrialists, bioeconomy has to, primarily, generate profit. Sustainability is the major aim of bioeconomy. Thus, applying bioeconomy in the industrial sector means adopting sustainable production procedures, which will logically generate "sustainable profitability." How so?

2.3.3.1 From Maximizing Profitability to Sustaining It

All industries are designed and implemented to generate profits. Basically, the whole concept is to invest money, produce or manufacture products, and sell them to generate revenues. After a while (the shorter, the better), the project will compensate the initial investment and starts to generate net benefits. Maximizing those benefits is and will always be the main goal on any industrial activities, from the small artisan shop to the big multinational corporations.

Innovate, produce more, optimize your production process, hire highly skilled personnel, diversify your portfolio, and improve your brand value and reputation are among the adopted strategies to maximize profits and benefits. But, the main strategy to achieve this highly sought objective is and will remain cost reduction. Innovation needs an extensive R&D efforts which, on its turn, needs significant financing to find (or not) "good results." In order to produce more, you have to invest more, to secure a large and, more importantly, a continuous supply of raw materials. As well, to optimize and diversity you portfolio, you have to hire experienced executives, dedicated employees, and skilled workers. All those requirements, combined, are achievable only for big companies.

Most industries in the world endeavor to maximize their profits via the easiest and proven to be efficient strategy: cost reduction. The main targets in this context are raw material, energy, and labor. Thus, searching and using cheap fossil resources and nonrenewable energy supply led us to the previously discussed heavy dependency on fossil raw materials. The same strategy to cut costs in order to maximize benefits seriously affected the labor sector. Three worldwide phenomena are sufficient to illustrate the gravity of this inclination: low wages, outsourcing, and massive layoffs.

Overall, during the industries' quest to maximize profitability, two major factors were seriously affected, or at least neglected, namely, the social and environmental factors. Now, considering the disastrous legacy of this hunger for wealth (detailed in Chap. 1), it is no longer tolerable for an industry to generate profit without considering the impacts on both society and the environment. One of the results of such inevitable standpoint is the introduction of the notion of corporate social responsibility in the mid-1970s [16]. The idea is that companies will start to address and manage the impact of their industrial activities on the economic, environmental, and social levels, altogether. How so? Some rely on the companies' selfconscious, others on the inside pressure from some activist stakeholders, and many of restricting laws.

First of all, relying on big multinational corporations to become all of a sudden conscious about the environment and the well-being of societies is just idealistic. Even counting on activism pressures (few from inside or more from the outside) in order to "induce" this self-regulating sprit has no to little impact. Indeed, adopting this notion implies that companies are admitting their responsibilities for the great damages done to the environments and the society. More importantly, how is it possible to induce a change of this magnitude that will shake the core of the industry outside the strategic decision-making process. This is the real target to make any shift in policies and strategies.

To make a real and significant breakthrough in this very important matter, we have to think like entrepreneurs and industrials. How do big corporations perceive the notion of corporate social responsibility? They cannot neglect the urgent pressures calling for actions from the industries to seriously consider the social and environmental factors in their strategic planning. In most big corporations, this issue is dealt with, not by the executives or shareholders, but by the division of public affairs, and this alone summarizes how delicate is this subject of profitability.

In practice, the discussed subject is far removed for ideological opinions. It is a matter of balancing the social and environmental responsibilities of companies with their legitimate economic goal to generate benefit and maximize profit. The outcome is called sustainable profitability.

2.3.3.2 Ensuring a Sustainable Profitability

Basically, industrial complexes are assembled to manufacture products with economic value in the marketplace. The major aim of each industry is to maximize its profit gain by producing more (quantity) and/or better (quality), at the lowest possible cost. With this strategy, profitability can only be maximized if the industry is constantly able to adjust the produced amount of each product with the ever fluctuating raw materials cost, on the one hand, and the equally fluctuating costumers' demand, on the other hand [17].

Now, what if industries rely on a renewable, thus continuous, flow of feedstock and energy supply (instead of the current reliance on fossil resources), such shift would have two major repercussions:

1. Maximizing the production value by minimizing the costs of raw material and energy since their sources under this scheme are stable (i.e., less fluctuation considering the renewable character of those resources which will block the path to the damaging monopoly and speculation activities).
2. Sustaining the generated profitability on the long run. Indeed, profitability from renewable resources will exceed than that from nonrenewable resources when the cost related to the exploration and exploitation of fossil resources becomes

higher than the cost related for the industrial conversion of renewable resources into the desired products.

Let us take the case of a petroleum-extracting company. The process will start with a heavy exploration cost, added to the high initial investment (heavy equipment, large sites, and highly skilled staff). Once it starts to extract and sell crude oil, it will have to manage low variable costs (maintenance, wages, emergency management, etc.), as long as the supply flow is constant (or appearing so). With time, however, the amount of extracted crude oil will start to decrease, thus gradually increasing the related variable costs until the extraction costs become too high and the company starts to lose money.

On the other hand, in the same energy sector, the production of fuel from renewable resources (bioethanol for instance) will need larger initial investments as the technology is not yet mature for large-scale worldwide production systems and the workforce is less skilled (for now) compared with that involved in the field of fossil fuels. These costs are mainly related to building biorefineries, buying equipments, acquiring renewable raw materials and managing the co-products.

Nonetheless, it is precisely the renewable character of the raw material which will give the profitability its sustainable dimension. Indeed, under this scheme, the feedstock flow will be continuous and the production procedure will be optimized, so that the output will remain constant and could even be increased as some variable costs are expected to decline with each technological breakthrough.

Currently, during the exploitation phase, the "well established" nonrenewable system requires less investment, compared with the "still developing" system based on renewable resources. Then, during the production phase, the nonrenewable system is able to generate profit quicker and higher than the competing renewable system, but for a certain period of time. However, on the long run, the fossil resources will gradually start to deplete, thus increasing the exploitation cost until the whole nonrenewable system becomes unprofitable (even before the complete depletion of the resource). On the other hand, the system based of the exploitation of renewable resources, although having a slow start, will sustain profitability almost indefinitely (pending an exploitation rate lower than the bioresources' regeneration rate).

In addition, as an emerging exploitation and production system, bioeconomy possesses a very important asset compared to the still highly performing fossil-based economy: a wide margin for progress. Thus, each R&D breakthrough and each technological innovation will considerably impact the profitability of bioeconomy in terms of decreasing the initial investment, quickening the profit generation phase, and stabilizing the profitability for long-lasting period of time [18].

Now, in practice, how to change the exploitation, production, and conversion systems from using nonrenewable resources to using renewable ones? In other terms, how to make the shift to bioeconomy financially profitable? Well, two major strategies could be implemented.

1. Industries which are able to financially support the slow and costly implementation of sustainable production units until becoming productive and thus

profitable. Those high initial investment will permit installing highly efficient operational units from the start, which will lead, on the medium to long term, to decrease the costs and increase the production yields, therefore increasing the profitably and stabilizing it when the production process reaches “maturity.” This strategy could be adopted and implemented by big corporations, whether committed to bioeconomy and sustainable development or just planning to invest in sustainability in order to diversify their portfolio, thus enhancing the returns, as well as lowering the risks and overall volatility.

2. Most industries committed to the transition to bioeconomy will adopt a gradual approach. Basically, this strategy deals with already operational units for which small and gradual changes are applied to the established conversion and production procedures. Such approach will avoid the high initial investment, thus bringing about substantial cost savings, which could be channeled to afford costly, but more efficient, technologies and skilled workforce. Combined, both the technological and the human factors will enable a more efficient exploitation, conversion, and production of renewable raw materials, thus generating a gradual increase in profitability, on the short and medium run, and stable returns, on the long run. For instance, already functional industrial complexes like fossil-fuel power plants, petroleum refineries, and wood-based industries could be “upgraded” to the sustainability concept, thus benefiting from their proven efficiency to ease and quicken the transition to bioeconomy.

From this analysis, the availability and renewability of the biological resources will attract both governmental and private investment capitals. In addition, the “green” processes involved in biomass conversion will generate less pollution and less carbon footprint than the processes involved during the extraction and transformation of fossil resources. In this context, environmental taxation policies are expected to become more severe [19] which will make investment in renewable resources more profitable. As well, bioeconomy will become more attractive for entrepreneurs and industrialist as the technologically advanced exploitation and conversion procedures of renewable resources will decrease the initial investment, hasten the profit generation, and increase the net profitably.

2.3.4 Leading Role of Science and Technology in the Transition

Bioeconomy is a knowledge-based concept developed to generate sustainable growth and to bring better life conditions for mankind and safer conditions for the environment. Many of us promoting sustainable bioeconomy are “selling” it as a vision for the future. But even so, we have to agree that in order to build a better future we have to start now.

2.3.4.1 A Multidisciplinary Effort

Research and Development (R&D) are among the main drivers of growth for bioeconomy [20, 21]. Indeed inventions and innovations are the only way to enhance productivity, induce economic growth, and justify big conceptual and structural changes. R&D should and will enable the expansion of sustainable bioeconomy, guarantee its efficiency and competitiveness, and later ensure its worldwide implementation. Therefore, in order to reach the objective of worldwide implementation of sustainable bioeconomy, we should promote R&D efforts with all its multidisciplinary dimension. Indeed, integrating high-level scientific expertise from various scientific disciplines is a key requirement to set up the knowledge-based bioeconomy.

If bioeconomy is the ship that will carry us safely to the shores of "sustainable world," R&D is the engine of that ship. However, to make this engine work and propel the ship to the desired destination we need fuel, and money is the fuel of that engine. Indeed, with money you can acquire the two indispensable factors to ensure reliable and efficient R&D efforts: high-tech equipment and highly skilled researchers.

To achieve the transition towards a sustainable, low carbon, resource-efficient bioeconomy, we need to invest more in science and technology (S&T). Proper investment, good management of those financial resources, and a multidisciplinary R&D effort will quicken the process of building an efficient, robust, and viable economic paradigm. Indeed, the commitment of the S&T community, as a whole, in this major human endeavor is crucial to quickly attain the goal.

The involvement of scientists and researchers from fields as diverse as chemistry, biology, biochemistry, economics, agronomics, engineering, medical, and social studies (to name a few) is a prerequisite for success, since the issues related to the concept of sustainable bioeconomy are not defined by specific disciplines but rather by complex problems that need to be dealt with and solved in an multidimensional manner. It starts with debates and interactions among scientists, development and/or optimization of procedures and technologies, and later assessing their impacts on human society and the environment. The amount and quality of the produced knowledge will be decisive to properly (i.e., quickly and efficiently) address urgent problems of sustainability, economic development, and environmental preservation.

One of the most visible illustrations of this cooperation is the growing collaboration between academia and industry, especially when the latter started to recognize the importance of the free thinking spirit embodied by universities. Such collaboration is and will remain delicate to manage as conflicts of interest could easily erupt because academia need the money from the industry to boost its R&D potential, and the industry needs brains from academia to optimize what is working and fix what is not.

The Energy Biosciences Institute (EBI) is a good example of this kind of cooperation. This self-proclaimed "largest public–private partnership of its kind in the world" involves a consortium made of the University of California at Berkeley, Lawrence Berkeley National Laboratory, the University of Illinois at Urbana-Champaign, and the energy company British Petroleum (BP). This interesting, yet delicate, cooperation was based on a couple of important guiding principles including that inventions made during the research investigations conducted by EBI are owned by the involved academic institutions according to U.S. patent law. The private partner BP will receive an automatic, but nonexclusive, license in return for its research funding. As well, all four partners have representation in the EBI's governing board of directors, with none having a majority or veto power, thus encouraging consensus in all decisions [22].

Overall, the model of university research backed by industry will open the door for new innovations and therefore will be a major strategy for the development of sustainable bioeconomy.

2.3.4.2 Managing the Transition to Sustainability

Basically, the transition management is a coordinated transdisciplinary effort aiming to ease and speed up large-scale changes based on the concept of sustainable development. This vital transitory phase will help breaking up with conventional way of thinking and doing, thus opening more windows for visionary thinking, which is the key to invent and innovate.

This coordinated effort of scientists led to concrete transdisciplinary interactions, best illustrated by the emergence of the field of sustainable science. The founding principle of this science is visibly sustainability. As for the objectives, Kates et al. [23], in their paper in Science magazine, defined three major targets:

1. Understanding the fundamental interactions between nature and society
2. Guiding these interactions along sustainable trajectories
3. Promoting the social learning necessary to navigate the transition to sustainability

Nowadays, after more than two decades of research, development and innovation, sustainability science has emerged as a vibrant field of study. Today, it is profoundly contributing in the transition phase towards bioeconomy based on the increasing numbers of involvement of research centers and laboratories from various scientific backgrounds and, equally important, based on the increasing number of universities committed to teaching sustainable science [24].

The generated theoretical and practical results from extensive studies and debates on how to manage this transition phase paved the path for promoting sustainable development. The whole process was developed by large network of scientists, in collaboration with industrialists and decision makers. Nonetheless, some researchers are urging for more progress down this path of sustainability as they think that socio-technical change remains underappreciated and relatively unexplored in sustainability research, which is key for society and its institutions to articulate visions of sustainability [25].

At this point, it has to be noticed that neither top-down government policies nor bottom-up market forces or scientific findings can alone support the heavy weight of introducing changes in various strategic sectors, not only related to the well-being of mankind, but even with its survival. Such major changes have to be managed, especially during the transition phase, through combinations of R&D efforts, government policies, market forces, and constructive initiatives from civil society [26].

In short, sustainability science should set up a new research agenda for scientists from different backgrounds and convert all the resulting R&D effort towards the single most important objective for decades ahead: reforming mankind–nature interactions.

2.4 Bioeconomy and Agriculture

Agriculture will always be the pillar of any economic model. Its place is even vital in the bioeconomy concept. As an efficient biomass-producing system, agriculture should have a privileged position in bioeconomy. As for the dilemma of using agriculture to produce food and feed or fuel and chemicals, the response is quite simple. This is a rich world dilemma. The question itself is an aberration in the poor world, which happens to constitute most of the inhabitants of planet earth.

Thus, as a global economic model, bioeconomy should focus on agriculture to secure the food requirements of the still growing seven billion people. Agriculture in bioeconomy should have a clear directive: fill the stomach first, then the fuel tank.

2.4.1 Why Sustainable Agriculture

Basically, sustainability in agriculture means satisfying mankind's needs for food, feed, fibers, and fuel, while enhancing (or at least maintaining) the quality of environment and conserving natural resources for the next generations to fulfill their needs.

For the previous and current economic systems, the objective is very clear: use all the available resources (land, water, and energy) to feed the growing population. Such approach led to the expansion of unsustainable agricultural practices, which deteriorated the quality and quantity of the exploited natural resources. The main repercussions are the increasing shortage in arable land, soil, and water pollution with herbicides and pesticides, deforestation, and soil erosion. Such conditions are not only seriously affecting the environment but started to seriously threaten the viability of future agricultural production activities.

In this gloomy context, sustainable agriculture was founded in order to meet three major objectives:

1. Reform our "unsustainable" practices by carefully managing our natural resources, while ensuring a highly efficient production system.
2. Connect sustainability and profitability
3. Reconsider the social dimension, intrinsically related to agriculture

2.4.2 How to Make Agriculture Sustainable

The supply of agricultural commodities is vital to human existence. The big dilemma is how can sustainable agriculture reconcile the needs of mankind and that of the environment? In other terms, how can we demand more from Nature while trying to preserve it?

The agricultural practices carried out during the last decades have greatly increased global food supply. For instance, the worldwide cereal production has doubled in the past 40 years to meet the need of 7 billion people. This remarkable achievement was mainly due to the increased yields resulting from the exploitation of more lands, greater inputs of fertilizers, water, pesticides, new crop strains, and other technologies of the so-called "Green Revolution" [27].

Now that scientists are looking back into the unsustainable practices used in modern agriculture to increase the crop yields; they are concluding that agriculture is pushing itself towards stagnation with severe damage to ecosystems. The best illustration is the unbalanced cycles of nitrogen and phosphorus and the subsequent nutrients deficiencies which seriously affected the food production and contributed to land degradation in some parts of the world [28].

Therefore, urgent calls for action are being made by the scientific community regarding the need to apply more sustainable agricultural methods. The main target is to ensure the continuous production of sufficient amount of good quality food, with minimum harm to the environment.

In practice, and in order to become sustainable, agriculture has to deal with those key aspects: soil, water, energy, and cultivation practices.

2.4.2.1 Sustainable Land Use

Sustainable land management is primarily based on maintaining and restoring (if necessary) the soil fertility in order to allow the production of food supplies and other renewable natural resources on a long-term basis. This implies that the natural ecosystems should be managed in such a way that the nutrients cycles and energy fluxes among soil, water, and atmosphere are preserved [29].

In agriculture, soil fertility is the main characteristic to enable high crop yields, a very crucial feature to meet the needs of an increasing world population, as well as the limitations in terms of availability of new arable lands. The sustainable dimension in agriculture aims at preserving soil fertility for improved production yields with less harm to the environment [30].

In this regard, scientists are advising that improving soil fertility should not only consider enhancing crops yields but also maintaining the balance between nutrients requirement on the one hand and nutrients supplies on the other [31]. The reason is that either excessive or deficient nutrients in soils have harmful repercussions not only on agricultural productivity but also the living organism, especially microbes, which are the key players in various nutrients cycles in soil [32]. Studies showed that excessive nitrogen amendments to the soil during fertilization could lead to serious consequences on the agricultural ecosystem and the climate, respectively, through nitrate (NO_3^-) leaching and the emissions of nitrous oxide (N_2O), a greenhouse gas [33, 34].

In the same context, another study revealed that N_2O emissions from agriculture are responsible for more than 75% of total anthropogenic emissions [35], which constitute 40% of the global N_2O emissions (natural and anthropogenic sources combined) [36].

Considering all the previously mentioned facts, soil "health" is definitely one of the most important constituents of efficient agricultural ecosystems. Overall, healthy soil means vigorous crops and dynamic microbes. If the soil is subjected to unsustainable practices, it will require frequent fertilization campaigns. Then, to increase the production yields, highly productive, but often vulnerable, crop varieties will be cultivated. Thus, more pesticides and herbicides have to be used to protect the crops. Overall, a "sick soil" will induce more chemical contamination, thus further sickening the soil and polluting water resources and the atmosphere. To face those environmental threats, sustainable agriculture has to work on two different fronts regarding soil quality:

1. Maintain the fertility of healthy soils.
2. And enhance the fertility of « sick » soils.

Another important point regarding sustainable agriculture regards its interaction with its immediate environment. A symbiotic relationship between agriculture and the ecosystem could benefit both. The productivity could be improved while preserving the integrity of the natural habitat and biodiversity of the region where the exploitation is occurring. This is the essence of sustainable agriculture. For instance, local crops are more in harmony with the ecosystem as they have adapted themselves to its pedoclimatic conditions. As well, maintaining the biodiversity of local wildlife can help increase the production yields via enhanced pollination through bees or quick and efficient pest management through natural predators.

2.4.2.2 Sustainable Water Management

Although irrigation consumes approximately 70% of the world's freshwater supply per year [37], the demands for water from the strategic agricultural sector are increasing, but the amount and quality of the water supply is decreasing. Numerous factors intervene in this decrease including the urban use from an increasing world population and the competition from the industrial sector. As well, the pollution of surface and groundwater resources further limits the availability of water for agricultural use, in addition to the public health and environmental contamination issues. To reclaim those contaminated waters, costly treatment procedures had to be applied which contributes in increasing the cost of clean water.

Currently, new kinds of pressures on water resources are coming from the repercussions of climate change, which are likely to alter both water availability and agricultural water demands. Therefore, scientists are warning that the agricultural sector is particularly vulnerable to climate change as it affects both water resources and land [38]. Indeed, even minor changes in average temperatures, precipitation patterns, or the frequency of extreme weather conditions will cause serious damages to the agricultural activities [39].

Considering all those threats, sustainable management of water resources is a key endeavor in sustainable agriculture by maintaining good water quality and sufficient supply. Thus, pollution prevention will help keeping harmful contaminants such as pesticides and chemicals fertilizers away from surface and groundwater reserves, as well as preserving soils from contamination and therefore ensuring a continuous and sustainable exploitation of valuable arable lands.

Furthermore, managing water consumption is an equally important endeavor in sustainable agriculture, especially in arid climates were high evaporation rates and frequent droughts could significantly decrease the water reserves, if coupled with unsustainable irrigation practices. Thus, in order to sustain their agricultural activities with respect to water consumption, farmers working in arid regions or with limited access to water resources should manage well the available supply of water by adopting water-saving technologies such as micro-irrigation or drip systems, in addition to cultivating drought-tolerant crops.

2.4.2.3 Sustainable Cultivation Practices

The great challenge facing modern agriculture is to increase food and feed production in a sustainable manner without overexploiting natural ecosystems and compromising public health. This has to be echoed not only in the management of land and water but also on the cultivation techniques. Indeed, sustainable agricultural practices are developed and applied in order to limit and replace chemical-based agriculture by minimizing the systematic recourse to pesticides and chemical fertilizers. If efficient in terms of productivity, sustainable agriculture would both save money and reduce the impact on the environment to tolerable levels.

Most of the sustainable practices in agriculture aim to preserve the quality of soil and avoid erosion and enhance the efficiency of natural pest and weed control. In practice, those objectives could be reached via different old and innovative methods such as:

– *The use of cover crops* which are plants grown between two cropping periods (instead of leaving the land uncultivated), mainly to restore fertility to the exploited soil, to prevent erosion [40], and to control invasive weeds [41]. As well, using nitrogen-fixing cover crops help reducing the leaching of nitrogen from cultivated fields [42], thus reducing the threat of groundwater contamination.

– *Amendments of biochars* is currently being promoted by researchers in order to improve soil health. Indeed, numerous studies reported several agronomic and environmental benefits for the addition of biochars into soils including enhancing soil fertility [43], improving carbon sequestration (thus mitigating climate change), and reducing the bioavailability and leachability of heavy metals and organic pollutants in soils [44].
– *Adopting an eco-friendly pest management approach* through the use of natural predators, natural biopesticides [45] (instead of chemical pesticides), and natural bioherbicides to protect crops from invasive weeds [46]. Two strategies could be adopted in this context. The first relies exclusively on biological measures like in organic farming. The second adopts the integrated pest management approach where the initial interventions are biological, with the possibility to use chemical pesticides as a last resort solution.
– *Crop rotation* is an ancient method still being practiced in order to maintain the fertility of soil. It is based on alternating different crops so that the nutrients absorbed by this year's crop would be replenished by cultivating another species next year. For instance, research studies proved that including grain legumes in the rotation helped increasing cereal crop yield and improving soil fertility without adding nitrogen fertilizers [47], as leguminous plants are able to fix nitrous oxide and biological nitrogen [48].
– *Recycling* is also a common practice in sustainable farming. It consists of collecting and reusing crop wastes or animal manure as biological fertilizers. As well, leaving crop residues in the field after harvest or composting them could also be an organic source for nutrients to replace chemical fertilizers. Reclamation and utilization of treated wastewater or the collection of rainwater for irrigation are other examples of sustainable recycling practices.

2.4.3 Bioeconomy and Food Security

Unfortunately, despite the worldwide dimension of bioeconomy, most countries lean towards implementing it individually. Thus, each country will adapt bioeconomy and its agricultural activities to feed its population and livestock. As a consequence, the rich and developed countries will easily reach this strategic goal of food security and also end up with a production surplus which will be put on the world market or used to produce fuel and chemicals. For the poor and even the developing countries, they will struggle securing the food requirements of their populations, let alone reserving bits of arable land to produce energy crops.

Thus, implementing bioeconomy independently will for sure benefit developed and industrialized countries, for a while, but it will be an epic mistake since mankind will miss a rare (may be the last) opportunity to join forces to combat world hunger and poverty (among many other challenges facing bioeconomy, notably climate change).

Let us consider this fact. Agriculture is and will remain the major source for food. If there is not enough food, hunger will occur. According to the “Hunger Statistics” [49] from the World Food Programme, the vast majority of the world’s hungry people live in developing countries. Asia is the continent with the highest count of hungry people (two-thirds of the total), and Sub-Saharan Africa is the region with the highest prevalence of hunger. Why is that? Because 20% of the world’s wealthiest population is consuming 76.6% of the natural resources, while 80% of humanity gets the remainder [50].

In Europe, the wealthiest continent in the world, the perception of food is completely different. While other continents are suffering from hunger, European experts in their white paper “*En Route to the Knowledge-Based Bio-Economy*” are expecting that food will be designed for special consumer groups. One priority is the development of foods for groups with defined risk factors or diseases like diabetes, obesity, and cardiovascular problems [51]. Paradoxically, all these diseases are caused or accentuated by the overconsumption of food. In this context, a Canadian study showed that, on a population-wide level, wars, economic crises, and the widespread food shortages are “the only interventions that have dramatically reduced the prevalence of obesity and cardiovascular disease in modern times” [52].

During the previous century or so, we have lost many battles during the fossil-based economy, especially in the environmental and social fronts. As well, international inequalities were accentuated, which fueled more animosity to the already tense relationships between poor developing countries and rich developed one (military invasions, economic sanctions, illegal immigration, etc.).

If bioeconomy could narrow this gap between countries, at least for the most basic human needs of water and food, we would have learned valuable lesson from our previous lost battles and then alone we could stand together to win the war on hunger and poverty with the sustainable economic model.

2.5 Bioeconomy and Industry

The main concern of industrialists is to secure a continuous flow of feedstock to their production units at the lowest cost possible. They could be flexible about the production procedure itself, and even about the end products, but the raw material is another matter. Let us now reflect on how industrials think about this important matter of raw material. It is a very important analysis because industry is the pillar for bioeconomy implementation on the ground, and a healthy transition towards using renewable raw materials is a keystone in building bioeconomy and preparing for a sustainable future.

2.5.1 Bioeconomy and the Energy Industry

For an industrialist, fossil fuels (petroleum, coal, and natural gas) are the backbone for many industries as feedstocks for many lucrative industrial products including fuels, heating oils, and fine chemicals. Nowadays, despite the shortage in fossil supplies, the reliance on those nonrenewable resources will continue until the alternative renewable supplies become affordable and available for large-scale exploitation.

Based on the current consumption pattern, on the one hand, and the amount of proven reserves on the other, petroleum is likely to be exploited and depleted first. What to do next? With all the disastrous legacy of petroleum-based economy, one should look for a new type of raw material, a renewable and eco-friendly one. But, as long as there is enough petroleum cheaper than the closest alternatives, the reliance will continue to be on the former. The infrastructure is already there; the know-how was acquired over decades of extraction and refining.

Thus, in order to have the strategic energy sector "onboard," sustainable bioeconomy has to provide reliable alternative fuel supplies. In this context, several aspects have to be considered and carefully planned. A detailed description and discussion on the role and implication of the energy industry in the development and implementation of sustainable bioeconomy will be presented in the coming Chaps. 4, 7, and 8.

2.5.2 Bioeconomy and the Chemical Industry

In the chemical industry, a gradual replacement of fossil resources by renewable raw materials is expected in the future but definitely not before long. Thus, crude oil will remain the dominant raw material in the chemical industry in the foreseeable future, at least as long as the extraction and transportation of fossil fuels remains cost effective.

The transition towards sustainable industries needs to move forward as fast as possible in order to reduce the time for this transitory phase and quicken the full implementation of bioeconomy and benefit (economically, socially, and environmentally) from its sustainable exploitation, conversion, production, and recycling procedures.

Such crucial objective could be attained mainly through (1) enhanced R&D efforts, (2) bold initiatives from the industry especially in terms of investments, and (3) legislations promoting and easing this transition from parliaments and governments. As this process is advancing, renewable raw materials will gradually become more economically attractive for the production of various chemicals compounds, mainly the ones produced via improved large-scale conversion technologies. As well, in the event of a significant shift in the price ratio of fossil fuels to renewable sources, an increase in the share of renewable raw materials in the production of basic chemicals is conceivable [53].

2.5.3 Bioeconomy and the Forest Industry

Compared with the other biomass-producing ecosystems, forestry has a tremendous advantage to become one of the pillars of bioeconomy. Three major assets could be pointed out:

1. Forests have large biomass production potential.
2. They do not compete with the strategic agricultural sector.
3. They contribute in climate change mitigation through carbon capture and sequestration.

In Europe, for instance, forests cover about 40% of the total land area (equivalent to 157 million ha), and those areas have increased by about 3 million ha in the last 10 years. Production wise, the total amount of wood is estimated at 24.1 billion m^3, corresponding to an increase of 4.9 billion m^3 over the past 20 years. In addition, the European forest sector involves around 3.5 million workers, mainly located in rural areas. All those considerations give a strategic importance to forestry within the bioeconomy model as it is already dealing with the industrial, environmental, and societal challenges.

Currently, with the technological developments in biomass conversion procedures, on the one hand, and the decreasing demand for paper, on the other, the role of the forest industry and its contribution in strengthening the sustainable dimension of bioeconomy are increasing [54]. Indeed, for many decades, when spoken of the forest industry, two main products come in mind: pulp and paper and timber. With the various R&D breakthroughs in the field of biomass valorization, especially lignocellulosic wood, modern forest industry became a high-tech industry providing world markets with value-added bioproducts including biofuels, biopolymers, and chemicals.

In addition, the serious challenges facing humanity regarding energy supply and climate change are putting a great deal of pressure on researchers and policymakers to find sustainable solutions which create new incentives for bioenergy and biofuel production. In this context, using wood from sustainable forest or industrial residues such as wood chips and sawdust to produce biofuels and bioenergy provides an option that provides increasing profits along with tightening energy and fossil fuel policies [55].

Equally important is the fact that the contribution of forests in the bioeconomic model is not restricted to its biomass (wood) production. Indeed, sustainability-managed forests play a very important role in three major environmental issues: (1) biodiversity conservation, (2) water and soil protection, and (3) climate change mitigation and adaptation. Although those “services” by forests are important to the well-being of our environment, they remain not properly appreciated. Indeed, scientists are confirming that this forest contribution (wood production aside) are excluded from the market, and they are suggesting that introducing payments for them would encourage private landowners to manage their forests sustainably [56].

2.6 Challenges Facing the Transition to Bioeconomy

During the transition phase, and in order to replace the current fossil fuels-based economy, bioeconomy will face various obstacles, especially that the expectations from this new economic model are very high, both quantitatively and qualitatively. Indeed, bioeconomy is expected to replace old industries, products, and practices by new eco-friendly industries, bioproducts, and procedures, thus enhancing the sustainable dimension in the production and consumption processes, and meeting market feedstock demand and price [57].

Another major expectation from bioeconomy is ensuring a continuous supply of feedstock for the various industrial sectors (food/feed, energy, chemicals, pharmaceuticals, construction, etc.) while mitigating climate change and preventing further degradation of clean water supply and biodiversity [58].

Overall, the big challenge facing bioeconomy is ensuring an economic growth using renewable resources without harming the environment and responding to the global issues of energy and food security, climate change, poverty, and the ever increasing shortages of clean water supply and productive land.

Now, to give more insights about possible barriers for the transition to sustainable bioeconomy, the Technical University of Denmark conducted an interesting survey on behalf of the International Energy Agency (IEA Bioenergy—Task 42 Biorefinery), in which diverse factors affecting this transition to bioeconomy were analyzed [53]. The involved countries were Australia, Austria, Canada, Denmark, Italy, Japan, the Netherlands, New Zealand, and the United States. Overall, the participants to this survey were from the industrial sector (64%), academia (16%), governmental institutions (12%), and public organization (8%).

The main finding reported in this study is that profitability is the most important obstacle for the transition to bioeconomy. The second limiting factor was governmental policies, followed by finding suitable markets for the bioproducts, in addition to securing the supply of biomass resources.

Another very important point regarding this transition phase is how should we proceed? Unfortunately, despite the worldwide dimension of bioeconomy, countries are implementing it individually. For instance, each country will adapt bioeconomy and its agricultural sector to feed its population. As a consequence, the rich and developed countries will easily reach this strategic goal of food security and also end up with a production surplus which will be put on the world market or used to produce fuel and chemicals. For most of the developing countries, they will struggle securing the food requirements of their growing populations, let alone reserving bits of arable land to produce energy crops.

After studying the legacy of the petroleum-based economy in the first chapter and the transition to the sustainable bioeconomy in the second chapter, let us now start analyzing bioeconomy, study its various constituents, and discuss the impact of this sustainable economic model on both mankind and the environment, as a green industrial revolution. In the next chapter, we will start with the most important sustainable pillar of bioeconomy: BIOMASS.

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