CHAPTER 1

BRIEF GLOBAL ENERGY OVERVIEW: TRENDS/SCENARIOS AND THE NEW ROLE OF BIOFUELS

1.1. INTRODUCTION

The aim of this chapter is to provide a brief global overview of energy developments (trends and scenarios) in general, to help the reader to better understand potential future developments in Brazil. And the possible role of biofuels within the paradigm energy shift. In a globalized world with so much interconnected, any impact will resonate beyond national boarders, even in Brazil with its unique conditions for biofuel development.

A fundamental question we need to pose in this shifting scenario is, *what could be the future of biofuels in a new scenario in which no fuel will have the monopoly of oil and gas? How changes in the rest of the world will affect biofuels, particularly in Brazil?* A scenario that will be far more complex, mixed, volatile, and more geographically determined. Biofuels cannot operate on a vacuum, and hence what happen in other sectors, particularly oil, will shape their development. Take, for example, electric vehicles where in some parts of the world, as Europe, could relegate biofuels. In addition, there are two key drivers that will affect the outcome of the energy sector, and consequently biofuels: international response to climate change and environmental sustainability.

1.2. GENERAL BACKGROUND

The energy sector is facing a huge transformation catapulted by growing concern with climate change, global warming, decarbonization, environment, sustainability issues, and political volatility. This is further complicated by Russia's war in Ukraine whose final outcome is difficult to predict. Never before in history has there been so much social and political pressure to change.

The oil sector, and more specifically transport, has not been synonymous of rapid change in the past. In fact, for decades, hardly any significant change took place. For decades, the automobile industry and oil giants, have shared a marriage of convenience. However, the undergoing changes are unparalleled. There are many "unknowns" but undoubtedly such changes represent a paradigm shift with cataclysmic proportions. Huge economic, social, environmental and policy implications, with hundreds of billions of dollars at stage. Such changes represent both huge opportunities and also serious challenges and pitfalls. There is also huge uncertainty with regard to climate change whose enormous implications are difficult to predict; such outcome will have a major global impact, determining future directions and hence will be a key driver for change.

There will be a long energy transition, difficult to predict. But with the right policies, change can be like "a snowball" once started will be difficult to stop. It could work by its own inertia. Given the enormous resources potentially available, the world capacity for scientific and technological developments and innovations, such transition could be faster than predicted.[1] For example, climate warming has been ignored for far too long but now that the world community is beginning to take it more seriously, and social, and political pressures will increase to force change. Climate change is beginning to sink into the young population psychic, despite the fact that for large part of the world population it is a daily struggle for survival and is unwilling or unable to make the necessary sacrifices today for such changes, perceived as something that may happen in a long-distance future.

Within this context, what could be the potential role of biofuels in transport? Biofuels have been around for many decades, and in particular in Brazil and USA, and to a lesser extent in many other countries, hence they represent little technological challenge by comparison, as it is a well-known and proven technology and fuel. The pros and cons of biofuels have been heatedly debated, but on balance, if produced and used sustainably, the benefits far aweigh the negative impacts. Therefore, biofuels represent a considerable advantage over many other emerging alternatives in many parts of the world.

Biofuels have also been the object, as most renewables, of booms and busts. When such alternatives appeared to be economically viable, the price of oil came down dramatically e.g., early 1990s. This time would be different because pressure from climate warming and the environment. Hence, growing concern with climate change, environment, and sustainability, together with social and political pressures, means that this paradigm shift cannot be reversed. On the contrary, it is expected to be accelerated.

But biofuels also have also their negative side that limit their potential. The main one being land competition with food production and the requirement that biofuels need to be environmentally sustainable. The "food versus fuels" (FvF) dilemma has

1 The amount of data generated daily, and the speed in which new scientific data is generated, is such that it is impossible to keep pace except for very specific topics. This poses serious problems.

been the object of heated debate for decades. The debate (e.g., see ROSILLO-CALLE & JOHNSON, 2010; ROSILLO-CALLE, 2018) has been clouded by vested interest, bias, and lack of reliable scientific data. The "FvF" debate needs to consider the intertwined nature of biofuels, land use, food production, food waste, animal feed production, diets, social habits, food distribution systems, policy, and so forth. Advanced biofuels (G2 and G3) could avoid most these problems. It is generally accepted that food and biofuels production can be complementary and, in any case, food production will always prevail.

Biofuels have been around for decades and are an integral part of the fuel mix in the transportation systems. Currently this sector provides between 3-4% of fuel consumption in road transportation, with USA and Brazil as the main producers and consumers, and to a lesser scale in the EU, China, and India (see Figure 1.4). It is an unequal and uneven contribution on a global scale, representing a minuscule contribution in many countries, or none at all. This uneven distribution reflects resource endowment, cultural factors, know-how and policy options. The totality of biofuels is used blended with petrol and diesel in varying proportions, except in Brazil where about 50% is E100.

Another question we need to address is the extent to which the paradigm shift will enhance or inhibit their development, as oil is gradually replaced by other emerging alternatives, e.g., electricity, hydrogen, solar, etc. However, new technological developments such as G2 and G3, e.g., converting cellulose-based biomass to ethanol, will make available large additional amounts of feedstocks in many more countries, at competitive cost over time. Also, we need to ask: should biofuels be promoted as a vehicle fuel or should the focus be on new emerging markets e.g., aviation, maritime transport, or fine chemicals? Biofuels will not be the answer to oil, but they can play a much greater role than has been the case so far in the fuel mix and can make an important contribution to the solution.

During the oil crisis of the 1970s, Brazil showed a great vision by setting up a national ethanol fuel program (e.g., see ROTHMAN, GREENSHIELDS & ROSILLO-CALLE, 1983), a unique project at national level, that served as an international school and was, at the same time, the envy of many countries. This initiative put Brazil in a unique historical footage e.g., a considerable know-how on alternative fuel for transport, as well as technological, agricultural, economic, environmental, and social benefits. Thus, a key question we need to ask is: what will be the new role of biofuels in the emerging energy paradigm in Brazil? What lessons can be applied from its unique historical experience? What lessons are there for other countries? Such questions are addressed in the following chapters.

1.3. ENERGY/TECHNOLOGY TRENDS

Perhaps never in history has there been so much investment and research aimed at finding new alternatives to oil and gas, not only new fuels such as hydrogen, but also engine modifications (electric vehicles) and battery technology. Given the increasing amount of resources being allocated, technological innovations are growing spontaneously e.g., vehicle batteries, wind power, solar power, hydrogen, new feedstock, to name a few.

It can be stated that renewable energy (RE) in general is growing rapidly, though not necessarily at the pace of potential demand (this will require a fourfold increase), and very unequal around the world. There is a growing shift toward Asia (e.g., China and India), which could overtake the EU. Table 1.1 summarizes the main trends around the world in 2021.

Table 1.1 Summary of main global renewable energy (RE) indicators 2019-2020. Source: REN21 (2022).

Year		2019	2020
Investment on renewables (RE) (power & fuels	Billion $US	298.4	303.5
RE power capacity, including hydro	GW	2,581	2,838
RE capacity (excluding hydro)	GW	1,430	1,668
Hydropower capacity	GW	1,150	1,170
Solar PV capacity	GW	621	760
Wind power capacity	GW	650	743
Bio-power capacity	GW	137	145
Geothermal power capacity	GW	14.0	14.1
Concentrating solar thermal power	GW	6.1	6.2
Green power capacity	GW	0.5	0.5
Ethanol production (annual	Billion litres	115	105
FAME biodiesel production (annual)	Billion litres	41	39
HVO biodiesel production (annual)	Billion litres	6.5	7.5
Countries with biofuels blend mandates	–	65	65

Note: for further details and footnotes see source, page 13. *Please note there are some anomalies due to the Covid-19 pandemic.*

Among the indicators, it calls the attention the total investment going to RE, a firm indication of how investors are taking seriously RE. This trend is increasing rapidly due to recent political considerations such as growing concern with climate change and the Russia-Ukraine war. It demonstrates that RE is reaching maturity.

Annual demand for biofuels (bioethanol and biodiesel in particular) is expected to increase (see below) to around 190 billion litres (B/l) by 2023. Biofuel's production is (and will continue) to be very unequal around the world. Large programs are unlikely, with many small to medium side programs, scattered among many countries, and use primarily as blends. This panorama is unlikely to change fundamentally, with USA and Brazil continuing to dominate this market. It is difficult to predict how this new energy transition will be shaped, as policies are very fragmented around the world together with volatile geopolitics, reflecting national priorities, cultural and economic factors, resource endowment and know-how.

Two new candidates seem to be particularly strong, i) electrification and ii) hydrogen. None of them are really new as they have been around for a long time (see below). What is new is the huge amount of resources and R&D going into these sectors. Electrification of transport is a real challenge and poses serious problems e.g., how to ensure electricity is generated from RE, and problems posed by such large demand for batteries. In fact, there is a serious danger of creating a monopoly, as with oil, in some countries by relaying too much on electricity. Given the nature and control of rare material by just a few countries, pursuing this option is problematic. There are, therefore, serious economic, political, and environmental unsolved and unanswered problems.

Costs of these alternatives are coming down quite considerably and becoming competitive with conventional fuels, at least in the medium term. Despite the promise of such alternatives, it seems conventional RE (hydro, solar, geothermal and biofuels) will continue to grow rapidly and being a major alternative (IEA, 2021a).

1.4. ENERGY SCENARIOS

There have been many energy scenario predictions but hardly any of them have turned out to be correct. There are a multitude of possible scenarios, but despite improvement of data, energy uncertainly remains an integral part of the world's volatile geopolitics, and a multitude of changing political and economic factors.

One thing seems certain, the automobile of the future will be very different, in which decarbonization, environment and sustainable fuels will play a key role. Such changes represent an enormous challenge to both the automobile and oil industries e.g., technological, environmental, economic, and social. While oil is not going away any time soon it will, progressively, be phased out over time. And many candidates are emerging e.g., electricity, hydrogen, solar, modern biofuels (bioethanol, biodiesel). The future will be dominated by a mixture of fuels with none of them playing a dominant role as oil.

Figure 1.1 shows the changing nature of energy markets, 1900 to 2050. As can be appreciated all RE experience a rapid increase from 2020 and become the main source of energy, with nearly 60%, while fossil fuels declined considerably in the Accelerated Scenario (see below). Decarbonization plays a major role in the increase of RE and a sharp decline of fossil fuels.

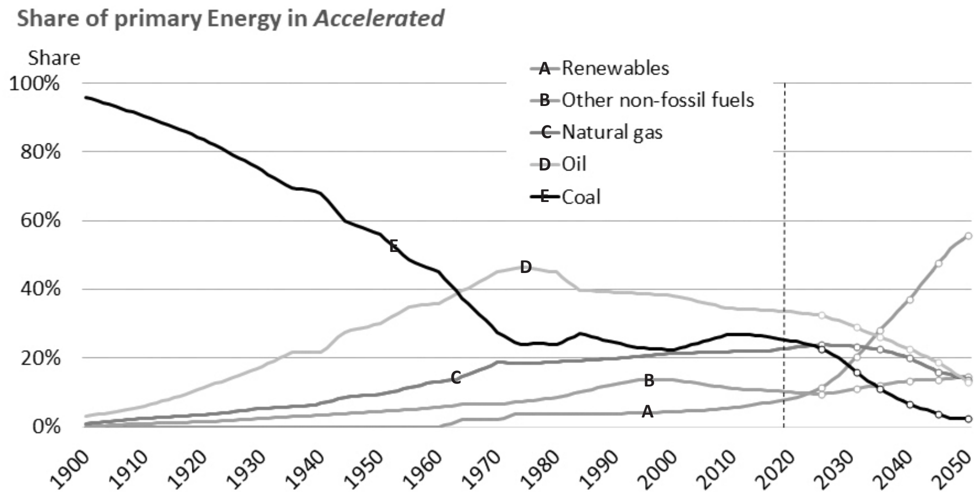

Figure 1.1 Changing nature of global markets: more diverse energy mix, increased competition, and greater customer choice. Source: BP (2022).

The following figure (Figure 1.2) shows in more specific details the role of modern bioenergy according to BP three scenarios: Accelerated, Net Zero and New Momentum, from 2019 to 2050.

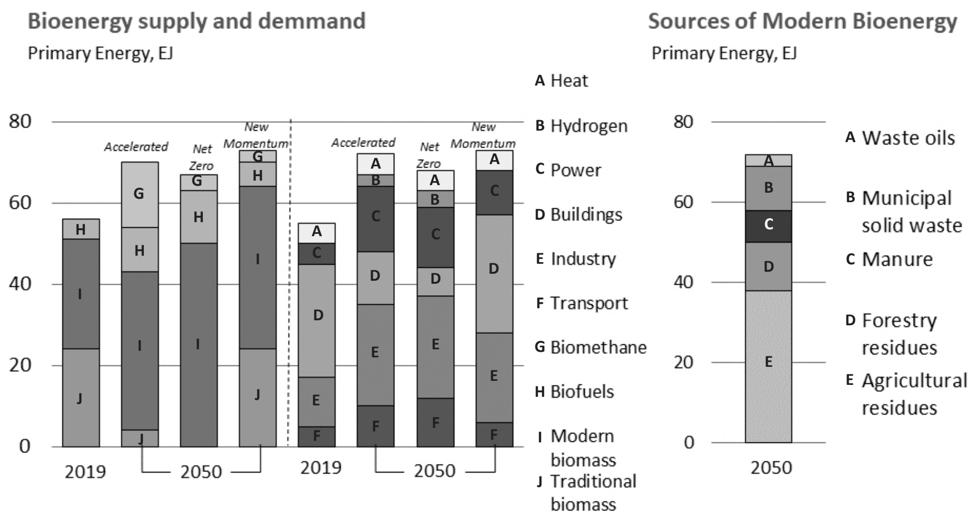

Figure 1.2 Modern bioenergy increases sharply, supporting the transition to a low-carbon energy system. Source: BP (2022).

BP has developed three main energy scenarios: *Accelerated Scenario, Net Zero and New Momentum*.[2] The first two are broadly in line with the Paris Agreement (UN

2 For a detailed assessment of the three energy scenarios, please see BP (2022) Energy Outlook 2022 Edition (www.bp.com/energy/global)

COP25). This requires maintaining temperature below 2°C. Global energy demand measured at the final point of use (total final consumption - TFC) peaks in all scenarios as gains in energy efficiency accelerates. TFC peaks in the early 2020s in the Net Zero, around 2030 in the Accelerated and in mid-2040 in the New Momentum (BP, 2022, p. 17).

Total final energy consumption across all emerging economies growth by about 35% and 5% in the New Momentum and Accelerated and falls by 20% in the Net Zero. In the developed world, contrary, the TFC falls by 25-50% in all three scenarios by 2050s. The share of fossil fuels in TFC declines from around 65% in 2019 to 30-50% in all three scenarios, with the greatest fall corresponding to coal (BP, 2022, p. 39).

It is important to keep in mind that scenarios are largely a function of the level of decarbonization and a multitude of other factors. For details of world energy consumption and projections see also the International Energy Agency (IEA) e.g., IEA (2021a); IEA (2021b); IEA (2021c). There are many others excellent reports and databases on energy e.g. (https://ourworldindata.org/energy-key-charts) where you will find a wealth of excellent energy data.[3]

1.5. BIOFUEL SCENARIOS {CONVENTIONAL AND ADVANCED (G2 AND G3) BIOFUELS}

Figure 1.3 summarizes final use of biofuels demand, based on the IEA (2017) data. The main striking point is the rapid growth of advanced biodiesel and biojet. It is important to state that it is one of many scenarios and hence should be seen as just a *potential outcome*. Scenarios are just potential projections, but despite the discrepancies, all of them point to the same direction: a rapid increase in RE and a steady decline of fossil fuels.

The reason why this Figure 1.3 has been chosen is because data for the latest few years have been distorted by the Covid-19 pandemic. There are three new factors not fully recognized in this figure: i) the rapid growth of electricity and hydrogen, ii) much greater concern with climate change, and iii) growing energy uncertainly and volitivity. This new political reality (caused by Russia's war on Ukraine, among others) could potentially speed up the development of all RE considerably or, contrary, delate it implementation. For example, India is increasing the blending of ethanol with gasoline, primarily to save oil imports due to rising oil prices.[4] And in Europe, which is highly dependent on Russia fossil fuels, politicians are struggling to reduce such dependency with a multitude of options under consideration. Time will tell.

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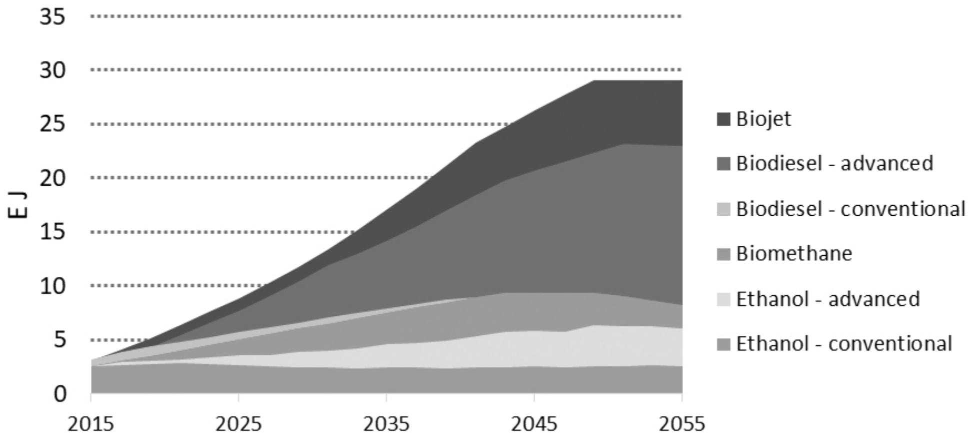
3 See also IEA (2021) Key World Energy Statistics (www.iea.org), IEA (2021) World Energy Statistics and Balances 2021 (www.iea.org)

4 See for example The Times of India, 19th May 2022. India to launch20% ethanol-mixed gasoline (…) (www.thetimesofindia.com)

The evolution of such fuels is strongly dependent on environmental, and climate change and political considerations. If concern with climate warming accelerates significantly, then such scenarios could be quite realistic. Huge resources are being channelled towards this end.

The main biofuels (conventional and modern) continue to be bioethanol and biodiesel. The expected growing role of biojet is somehow a bit controversial as other models give a much lower potential contribution. Much depends on growing demand of such sectors such as aviation and maritime transport. (IEA, 2017). See Section 10.



Notes: Conventional biodiesel referes to crop based FAME biodiesel; Advanced biodiesel refers to a range of advanced biofuels suitable for use in the diesel pool.

Figure 1.3 Biofuels final transport energy demand by fuel type in the IEA 2DS, 2060.
Source: IEA (2017).

As for the type of fuel and geographical distribution, the USA and Brazil continue to dominate biofuel production and consumption, with Europe remaining more or less stable and small increases in Asian markets. A notable increase is advanced biodiesel and biojet fuel. Indonesia is set to be an important player on biodiesel, although it is environmentally controversial because such expansion is based on palm oil plantations (see Figure 1.6).

1.6. ETHANOL FUEL

The following figure (Figure 1.4) shows the geographical distribution of ethanol fuel, and global production in 2021. As can be appreciated, the USA and Brazil are the key players, followed by the EU and some Asian countries (China, India, Thailand). The rest of the world represent a very small market, and in many none at all.

Ethanol was the first candidate as vehicle fuel rather than gasoline. And in Brazil as early as 1925 there was a Federal Law that made compulsory blending ethanol with gasoline (e.g., see ROTHMAN, GREENSHIELDS & ROSILLO-CALLE, 1983); see also Chapter 6).

Ethanol has been the king as transport fuel around the world. It has been growing steadily, except for 2020 due to the Covid-19 pandemic. It is not expected to expand exponentially as a few countries have the capacity to increase production in large scale and even in Brazil there are questions as its future expansion (see Chapter 5). Total world production of ethanol fuel in 2021 was estimated at 102.2 B/l.

Figure 1.4 Global Fuel Ethanol Production in 2021. Source: RFA (2022).

Note: One USA gallon = 3.785 litres

The USA is the world largest ethanol producer and consumer, representing 55%, followed by Brazil with 27%. Figure 1.5 shows the historical production of ethanol in the USA, rising from almost zero in 1981 to about 56.70 B/l (c.15 B/gal) in 2021. Despite this impressive achievement, current policy indicates the USA does not plan to increase ethanol production in any significant scale in the near future. Unlike USA, Brazil has considerable potential to increase both production and consumption significantly, depending on governmental policy, as discussed in detail in the following chapters.

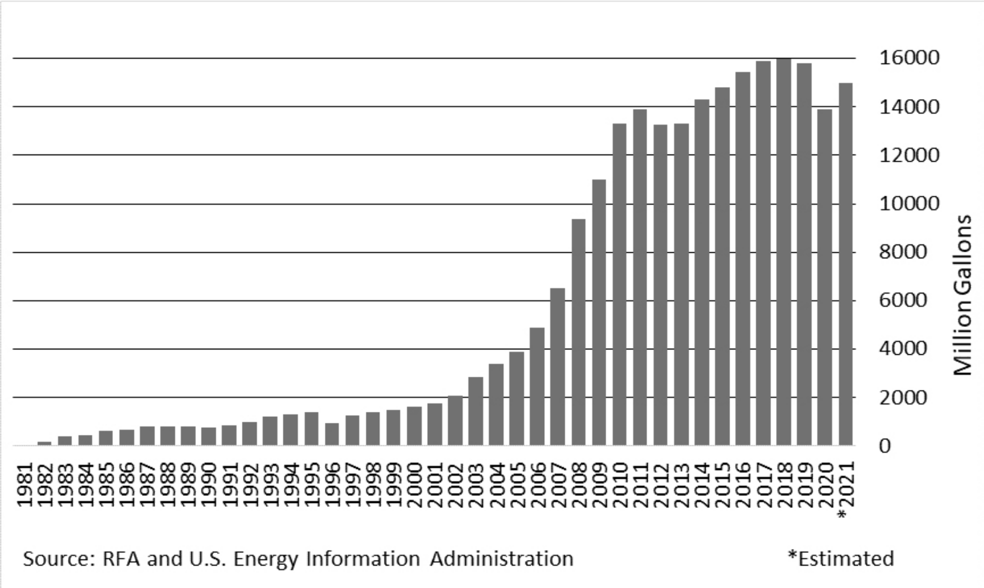


Figure 1.5 Historical U.S. fuel ethanol production. U.S. Energy Information Administration. Source: RFA (2022).

As it has been explained, biofuels are globally unequally produced and used. Many countries are unlikely to produce any at all. A good example is Africa (Sub-Saharan countries), where despite of having a significant potential, there is little prospects in the near future for a combination of political, social, cultural factor, in addition to lack of capital, know-how, etc, as illustrated in Box 1.1.

BOX 1.1: THE ROLE OF BIOETHANOL IN MOZAMBIQUE´S ENERGY TRANSITION BY RUI DA MAIA[5]

The Republic of Mozambique is a country with a vast territory of about 800 000 km2, colonized by the Portuguese, as Brazil, and with a population of around 30 million. Although, there are fundamental differences between the two countries, both can be considered medium-to-low income, where commodities are responsible for a significant share of exports.

Imports consist of fuels, machinery, and agricultural products, representing about 50% of country´s imports. South Africa, China, Emirates, and The Netherlands are

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the most important partners.[6] The country exports fuels and metals represent nearly 73%, and India, South Africa, and The Netherlands are the most important trade partners. It can be added that South Africa and India are Mozambique´s traditional partners, while China is gradually increasing its importance.

In the energy area, Mozambique has large oil reserves and petroleum plays an important part in its economy. The country has four oil refineries: S&S Refinery, CPF, South Oil, and Southern Refineries (Maëva). Although with important oil reserves and refineries, the country suffers energy supply difficulties particularly in the rural areas due to lack of electricity and other transport fuels.

As for agricultural, the country has a great potential, with fertile land and abundant water, although the country still needs to import basic products. The main reason for the food insecurity of Mozambique relies in the precarious agrarian system where land tenure is the main issue. The present agrarian system can be considered a major obstacle to a more organize and modern agricultural production system, either for food or biofuels production. On top of difficulties associated with land, there is chronic lack of capital, and skills.

The Civil War that followed the Mozambican independence destroyed much of the country´s agriculture and rural infrastructure. The colonial period had its negative consequences, associated with the problems related with Civil War. Although the country has had relatively high growth rates after 1994, this was not sufficient to compensate and rebuilt what was destroyed.

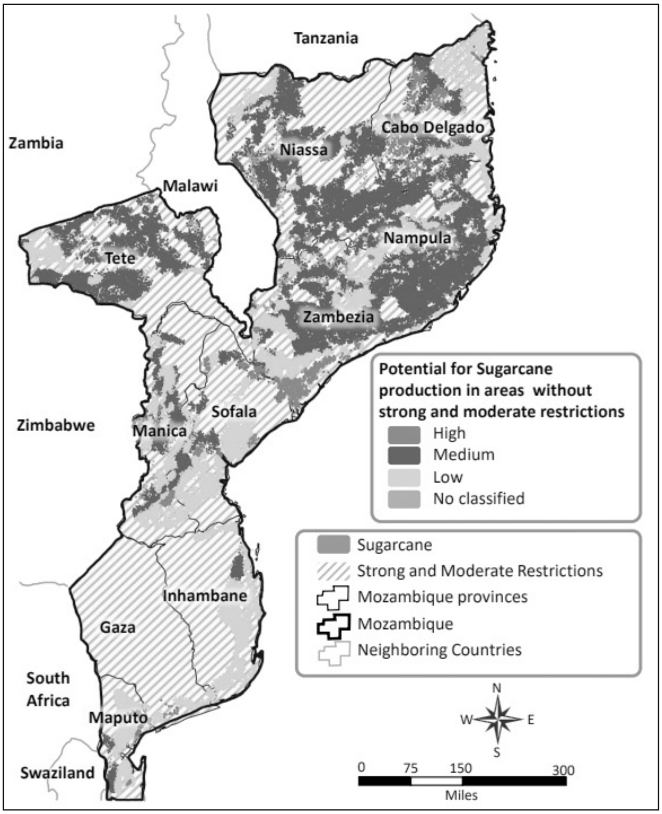
Also, when government authorities considered a biofuel program in the 2000s, crops such as Jatrofa Curcas were considered. As it will be discussed later in this book, the adoption of a non-energy crop for biofuel production is not recommended. Mozambique has experience with sugarcane and should try to use it in any biofuel program.

Sugarcane sector in Mozambique is quite large and organized. The annual sugarcane production is around 3 million tons of cane/year.[7] The Mozambique Sugar Producers Association (APAMO) counts with 4 mills producing around 530,000 tons of sugar and an estimated area of 57,900 ha, directly employing more than 140,000 people.[8] These mills are owned by South African companies.

6 http://portalcomercioexterno.gov.mz/pt/trade-data#:~:text=Os%20principais%20grupos%20de%20bens%20importados%20foram%20os%20Combust%C3%ADveis%20Minerais,USD%20872.6%20milh%C3%B5es%20(12.2%25).

7 FAO (2018)

8 https://i-enterpriser.com/2022/02/27/governo-investe-no-fomento-da-producao-de-cana-de-acucar/



Source: Moreira et al. (2019)

Regarding fuel sugarcane ethanol production, in 2009 it attracted attention from Brazilian investors (UNICA). Basically, three projects were considered, one in the south (120 million litres/year), one in the central region – Manica (100 million litres/year), and one in the North (300 million litres/year). Investments in sugar and ethanol are considered strategic in Mozambique because former colonies are allowed to export to European countries without import taxes.[9] A study conducted by MOREIRA et al. (2019) estimates that 33 Mha are suitable for sugarcane cultivation in Mozambique with medium and high potentials, mostly in the North part of the country (figure below: Source: Moreira et al. (2019)).

Naturally, the role of ethanol production in Mozambique would be more oriented to achieve socio-economic goals, such as increasing exports, population income, and jobs. Therefore, the GHG emissions could be considered a secondary achievement. Another important role of biofuels production would be the introduction of a new

9 https://www2.senado.leg.br/bdsf/bitstream/handle/id/448956/noticia.htm?sequence=1

agrarian system, in which the most important stakeholders could be included. It can be said that, without including the traditional landowners in the negotiation, hardly any one of these goals would be achieved. Therefore, sugarcane ethanol could play an important role in the energy transition in Mozambique.

Food versus biofuels is indeed very sensitive and an important consideration in Mozambique. This may explain, at least partially, FAO doubts in supporting biofuels production and hence its recommendation to use crops that do not compete directly with food production. FAO was probably more concerned with food security than with energy security or jobs, and probably thinks that non-food crops are a safer option when biofuels production is considered.

Mozambique is a country where, despite its considerable biofuel potential, is a good example in which biofuels would not have any future in the short term (5-10 years). This is due to a combination of factors e.g., lack of investment, skill, and political will. Since the social and political situation in most of Sub-Saharan countries are quite similar, one could conclude that this Continent offers little prospects for biofuels in the short term, at least in any significant scale.

Mozambique, as other middle- and low-income economies, doesn´t have means to absorb rapidly the electric mobility. High vehicle prices and lack of necessary infrastructure are the main drawbacks. This transition will probably take several decades. In the meantime, several technologies/fuels will coexist, creating additional pressure in infrastructure and services. Most likely, multinational corporations from China or Europe will start to introduce electric vehicles coexisting with internal combustion engines.

REFERENCES

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Table 1.2 summarizes the major feedstocks used in the production of conventional biofuels. For ethanol, the dominant sources are sugarcane in Brazil and maize in the USA. For biodiesel are mainly soybean (Brazil and USA) But feedstocks are becoming more diversified and with the advance of biofuels (G2 and G3) using woody biomass, and oil-bearing plants will be of much greater importance.

Table 1.2 Biofuel production ranking and key feedstocks. Source: OECD/FAO (2019), "OECD-FAO Agricultural Outlook", OECD Agriculture statistics (database)[10]

Production ranking (base period)			Major feedstocks	
	Ethanol	**Biodiesel**	**Ethanol**	**Biodiesel**
United States	1(50%)	2(19%)	Maize	Soybean oil/diverse other oils
European Union	4(5%)	1(36%)	Maize/wheat/sugar beet	Rapeseed oil/wastes oils
Brazil	2(24%)	3(12%)	Sugarcane	Soybean oil
China	3(8%)	8(3%)	Maize	Wastes oils
India	5(2%)	15(0.5%)	Molasses	Palm oil
Canada	6(1.6%)	10(1.4%)	Maize	Wastes oils
Indonesia	23(0.2%)	4(10%)	Molasses	Palm oil
Argentina	9(1%)	5(7%)	Maize/sugarcane	Soybean oil
Thailand	7(1.5%)	6(4%)	Molasses/cassava	Palm oil
Colombia	13(0.4%)	9(1.5%)	Sugarcane	Palm oil
Paraguay	15(0.3%)	19(0.03%)	Maize/sugarcane	Soybean oil

Note: Percentage numbers refers to the production share of countries in the base period.

1.7. BIODIESEL

Large scale biodiesel production has been limited by the cost of feedstocks (e.g., soybean, palm oil) because, contrary to sugarcane and corn, productivity is much lower and costs much higher e.g., feedstock can represent 70-80% of the total costs. The markets are also quite different and fragmented. None of the major ethanol producers and consumers (Brazil and USA) have been at the forefront of the biodiesel market, partly for limitations of the feedstock. The most important market has been the EU where, contrary to ethanol, biodiesel has received greater priority. Figure 1.6 summarizes the main producers of biodiesel. The EU remains the main player followed by the USA, Indonesia, and Brazil. As can be appreciated, this market is not expected to growth globally in any large scale. USA and Indonesia are expected to grow faster, but much will depend on anergy policy developments, and the availability of large-scale sustainable feedstocks.

As said, and contrary to ethanol, biodiesel production in the USA may increase significantly. In January 2021, the county produced 2.4 B/gal (just over 9 B/l), in 75 biodiesel plants (www.eia.todayinenergy/details) (EIA, 2022), which is still small in comparison to fuel ethanol.

10 http://dx.doi.org/10,1787/agr-out-data-en

Biodiesel is, and will remain, a much smaller market than bioethanol for transportation for reasons stated above. There are currently six major global markets for biodiesel, EU, USA, Indonesia, Brazil, and Argentina and to a lesser extent, Colombia. No major changes in any these markets are expected except, perhaps, in Brazil where production could increase significantly, and Colombia that has already a growing and dynamic market, be still in a small scale. There are other fuels, e.g., biogas and biomethane, which are also a growing rapidly. Brazil, in particular, has considerable potential e.g., by use of stillage from ethanol sector (see Chapter 4).

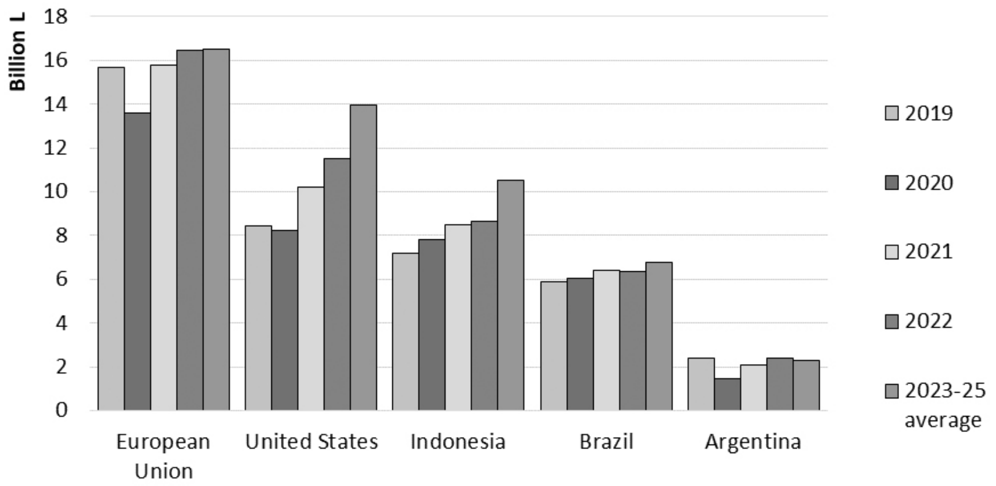

Figure 1.6 Biodiesel and HVO Production and Key Markets, 2019 – 2025. Source: IEA (2021c).

1.8. ADVANCED BIOFUELS (G2 AND G3)

There is a huge expectation as to the future potential of advance biofuels. Up to now, there have been far more failures than successes. The main challenge is reducing costs and the sustainability of the feedstocks in large scale. There is an astonishing array of feedstocks, and end-products under consideration. Unfortunately, few will succeed. The future of bioethanol and biodiesel are strongly linked to such advances, together with environmental considerations. But because environmental and energy security considerations, the expectations are high e.g., some estimates put the market growth of about 46% annually and be worth close to $50 billion within this decade (www.technavio.com).

Figure 1.7 shows global operational capacity of advanced biofuels, up to 2025. As can be appreciated, hydrotreatment of feedstocks is the most important alternative under consideration. Brazil is one of the countries with the largest potential (see Chapter 5).

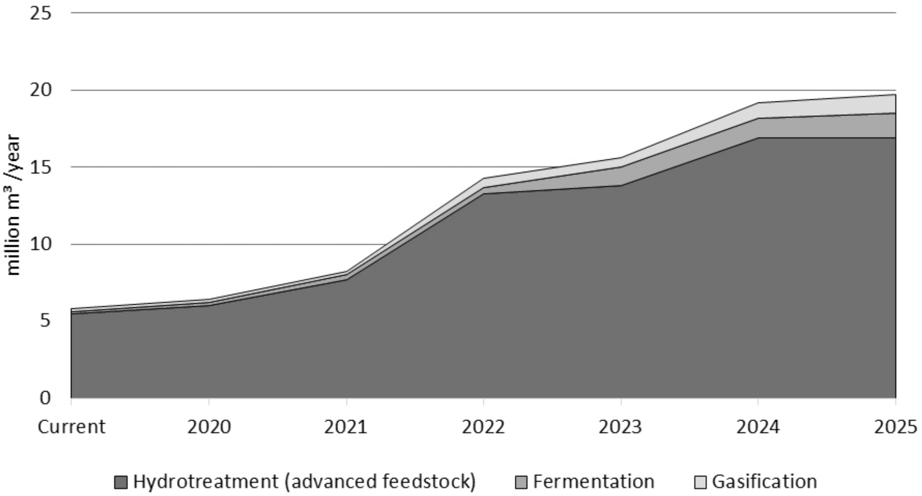

Figure 1.7 Global production capacity of advanced biofuels (operational). Source: CIT (2020).

The potential contribution and expectations on advanced biofuels vary considerably around the world. Take for example Southern Africa, as illustrated in Box 1.2, which examine the pros and cons of such potential developments. According to Gorgens, the expansion of G2 and G3 biofuels in Southern Africa would only be possible in combination with the development other RE.

BOX 1.2: EMERGING OPPORTUNITIES AND APPROACHES FOR THE PRODUCTION OF ADVANCED BIOFUELS IN SOUTHERN AFRICA BY JOHANN GÖRGENS[11]

INTRODUCTION

The industrial production of biofuels for transportation in the southern Africa context remains in its infancy, both for first-generation biofuels and more advanced options. Although approximately 400 million litres of bioethanol are produced in the region annually, the majority of it is used as potable or beverage grade products (Deenanath et al., 2012). The local biodiesel industry also remains small, and largely constrained by superior prices for waste vegetable oils, offered by European importers (Chiaramonti and Goumas, 2019). Considering the limitations on local government support for the implementation of biofuels production, the drivers for these remain as the ambitious climate change and carbon neutrality targets of the private sector, where biofuels have to compete against other renewable alternatives, and the export markets. The reduced attractiveness

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of crop-based biofuels to the export markets is driving a movement towards waste-based biofuels (Doumax-Tagliavini and Sarasa,2018), where industrial technologies remain to be demonstrated. In the context of both ambitious climate change targets and export markets, future opportunities for development of the biofuels sector in southern Africa seem to be focussed on second- and third-generation feedstocks and processing technologies, which offer more attractive opportunities in both regards.

SECOND- AND THIRD-GENERATION FEEDSTOCKS FOR BIOFUELS (G2 AND G3)

One of the primary examples of waste-based lignocelluloses potential available for conversion to advanced biofuels are various types of harvesting and bioprocessing residues, such as corn stover, forestry residues, sugarcane harvesting residues [SAEON, 2022]. There are, however, limitations to what portion of these lignocelluloses can be applied as feedstocks for conversion, as excess removal from the land may reduce soil fertility and productivity [Cherubin et al., 2019; Rocha et al., 2018).

Residues from industrial biomass processing such as paper waste sludges and various types of food processing wastes, which are presently landfilled, may offer the most attractive G2 resources, also considering substantial environmental and financial benefits with the avoided disposal to landfill of high-moisture organic wastes. Conversion methods such as anaerobic digestion (biogas product upgraded to compressed or liquefied methane) (Tratzi et al., 2022), fermentation (to ethanol) (Mahmoodi et al., 2018) and gasification (to produce syngas) (Chan et al., 2019) may be applied to organic wastes destined for landfilling, offering substantial environmental and economic benefits.

Several of the agroprocessing residues such as sugarcane bagasse are utilised in industrial facilities as energy feedstocks; liberating a portion of these for further valorisation can be achieved by substantial investments to increase energy efficiency in these facilities (Birru et al., 2019). Conversion of sugarcane lignocelluloses such as bagasse into alcohols through integrated first- and second-generation biorefineries, in so-called 1G2G facilities, holds substantial potential to reduce the costs of lignocelluloses conversion, through process integration and economies of scale benefits (Gnansounou et al., 2015). The 1G-portion of the resulting 1G2G biofuel would thus be classified as crop-based, while the 2G-portion would be waste-based.

Invasive alien plants (IAPs) and bush encroachment represent two largely underutilised biomass feedstocks in the region (Vera et al., 2022). Regular clearing activities are required to manage and eradicate these biomasses, often with spill-over benefits in groundwater flows and supplies to dams. Although some programs for their clearing/eradication may seem to offer access to low-cost feedstocks for valorisation, the reality is not much higher investments in these activities are required, which ultimately must be paid for by the biofuels production facility. This results in these feedstocks being as costly as other types of lignocelluloses available for processing.

Advances in the development and commercialisation of CO-gas fermentation to ethanol have availed new opportunities for third-generation biofuels production from industrial offgasses (Petersen et al., 2021). Several of the minerals processing smelters in the South African mining industry produce CO-rich offgasses, which have substantial climate change impacts. Capturing, compression and fermentation of these gasses results in the production of ethanol.

LIGNOCELLULOSES PROCESSING VIA GASIFICATION-SYNTHESIS

The processing of lignocellulosic biomass through gasification-synthesis processes is an attractive opportunity for local implementation, due to South Africa being a world-leader in commercial implementation of gasification and Fischer-Tropsch (FT) synthesis technologies, for the production of gasoline, diesel, jetfuel and a range of chemicals from coal (Gupta et al., 2020). These industrial facilities offer opportunities to reduce greenhouse gas emissions by partial or complete replacement of coal with natural gas and/or lignocellulosic biomass. Existing industrial facilities may contribute to biomass-conversion into biofuels through either co-gasification of biomass with coal in existing gasifiers (Quintero-Coronel et al., 2022), or by erecting biomass-only gasifiers and co-feeding the resulting gas product with syngas derived from coal or natural gas. Unique technical and economic opportunities also exist for co-processing/reforming of natural gas with biomass-derived syngas (Gardezi et al., 2013), which may be explored further in future. Both of these approaches will rely on the allocation of the renewable carbons, co-fed into synthesis steps with fossil-derived carbon, to specific products of interest, through the so-called mass-balance approach (Rosenfeld et al., 2020). This will allow for the recovery of the increased cost of biomass compared to fossil fuels from specific products that are able to attract premium prices in the market.

Alternatively, biomass conversion through gasification-synthesis may be pursued through dedicated, greenfields, biomass-only processing facilities, which may either be decentralised or centralised, depending on the locations of biomass resources. Such facilities will require that all products (gasoline, diesel, chemicals, jetfuel) be sold at premium prices, to recover the costs of biomass procurement (Petersen et al. 2022). Recent developments in FT-synthesis have therefore targeted new catalysts able to increase the proportion of sustainable aviation fuel (SAF) produced from such facilities, to maximise the commercial potential of these facilities.

ENVIRONMENTAL CONSIDERATIONS FOR SECOND- AND THIRD-GENERATION BIOFUELS

The implementation of second- and third-generation biofuels production is largely driven by expected environmental benefits, either for local industries or the export markets. In this regard the allocation of environmental burdens to a range of products typically obtained from biomass-processing facilities, warrant careful consideration. Together with the "greening" of utilities for processing/conversion of biomasses, these two factors have substantial impacts on the environmental credits attributed to final biofuel products.

As a first example, sugarcane mills that produce biofuels should preferably continue to co-produce sugar with biofuels. This will allow a substantial portion of the environmental burdens associated with sugarcane cultivation, harvesting and processing to be allocated to the sugar product (Maga et al., 2019), which often faces fewer market-acceptance hurdles due to environmental impacts such as greenhouse gas emissions. This situation may well change in future where food markets are gradually becoming more sensitive to the climate impacts of food products.

On the other hand, the processing of industrial, CO-rich offgasses into bioethanol through gas fermentation, requires substantial amounts of electrical energy for gas compression (Petersen et al., 2021). Such electricity should be provided from renewable energy sources such as wind or solar, rather than being produced from a portion of the available CO-gas, so as to increase the amount of ethanol produced per unit of CO-feed and benefit from the resulting economies of scale.

Gasification-synthesis processes require both renewable electricity and green hydrogen obtained from substantial solar and wind resources, as co-feeds with biomass, to maximise the yields of biofuels on available biomasses, and benefit from economies of scale (Dossow et al., 2021). Whether co-feeding of these types of renewable energy feedstocks will provide immediate economic benefits, depends on their production costs, where solar and wind-based electricity is often cheaper *than biomass-derived. In it clear that in future scenarios the supply of renewable and sustainable biomass not only for biofuels production, but also for a wide range of other biomass-derived products, will be a limited resource, further justifying the use of solar and wind resources to provide "green" utilities for biomass conversion.*

FUTURE PERSPECTIVES

The potential expansion of biofuels production in the southern Africa context should be viewed together with simultaneous development of substantial solar and wind electricity resources, and the associated green hydrogen options, as well as electrification of transportation systems. Large investments in renewable electricity supply remain to be ramped up substantially, to provide grid-based charging options for electric vehicles, which are still substantially more expensive than internal combustion vehicles, while solar and wind-based hydrogen remains largely unaffordable to local markets. Biofuels produced from low-cost or negative cost feedstocks (such as organic wastes destined for landfilling) may offer meaningful investment opportunities for local implementation in the short-term, while in a longer horizon there will be increasing competition from other potential applications of the limited supply of renewable carbon that the region can offer.

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1.9. HYDROGEN

The utilization of hydrogen as fuel is not new. In fact, it has been used for over a century but in small and specific applications, with booms and busts. In recent years, however, it has received an enormous interest and huge amount of investment is being pouring into hydrogen, especially green hydrogen. Hydrogen is very versatile fuel that can be produced from a verity of energy sources e.g., coal, oil, natural gas, biomass, other RE, nuclear, etc., through a wide variety of technologies (reforming, gasification, electrolysis, water splitting etc. (IEA, 2021e).

Global hydrogen demand in 2020 was 90 Mt, almost entirely from fossil fuels (see Figure 1.8). Seventy-nine percent was produced from dedicated hydrogen production plants (IEA, 2021e).

Green Hydrogen, produced from RE, is currently booming catapulted by concern with environment and climate change. For many analysts, this option represents the future fuel for transport. There are, however, a lot of unanswered questions since this will require huge investment, infrastructure, and natural renewable resources…. For example, if vehicle batteries were to use green electricity, the demand will be enormous.

If present projections on electric vehicles materialize, this will represent a huge change in the automobile industry. According to the IEA (IEA, 2021f), at the end of 2020 there were 10 million electric cars in the road worldwide. Europe leads with about 1.6 million, followed closely by China with 1.5 million and USA far behind with c300.000 units, which could change dramatically. All major vehicle manufactures have ambitious electrification plans. In 2020 consumers expending in electric cars reached $120 billion, and governments around the world were expending around $14 billion supporting electric car sales, in 2019 alone. If present trends continue, this market could reach 230 million vehicles in 2030 (IEA, 2021f).

This market is in constant a flux as technological advances cut costs and pressure to decarbonizes increases to cut pollution. This will have major consequences worldwide for biofuels. For example, in Europe with such focus on electric cars, it is unlikely that bioethanol will be a priority, unlike biodiesel which has a much brighter future. In this scenario, Brazil is a privileged position, it will have the flexibility of using bioethanol, biodiesel, and electricity, given its enormous hydro power potential (see Chapter 5). The country is already the world's largest contributor of RE in the national energy matrix.

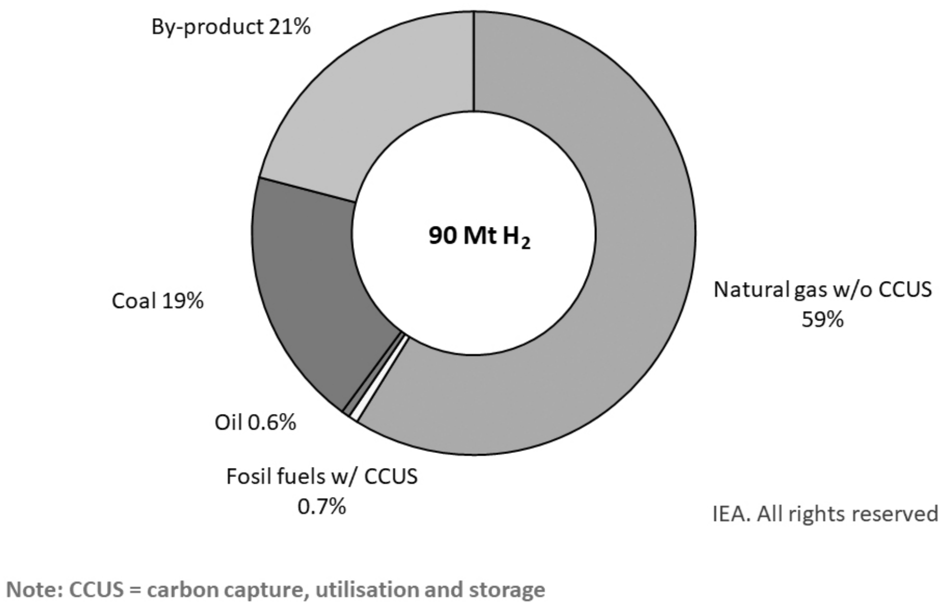

Figure 1.8 Sources of hydrogen production, 2020. Source: IEA (2021e).

There are, of course many different scenarios and considerable uncertainties. For example, in the analysis carried out by IRENA (2022), hydrogen could play a similar role to oil in transportation. Perhaps this view is too optimistic and the energy scenario will be far more mixed (see Figure 1.9)

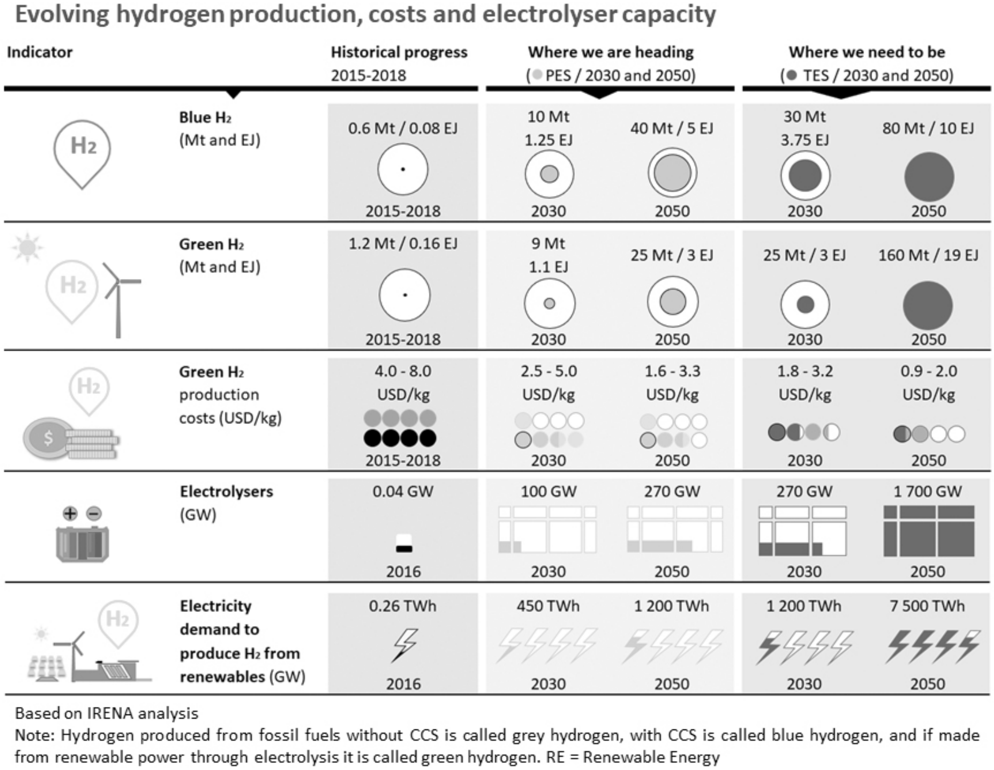

Figure 1.9 Hydrogen: A key part of future energy systems. Source: IRENA (2020).

1.10. EMERGING MARKETS FOR BIOFUELS (COMPETITION VERSUS COMPLEMENTARITY)

There are a large and diversified potential markets for biofuels beyond road transport. Some alternatives will be competing directly as fuel but in most cases, this will open up new opportunities, and be complementary to biofuels. This section will briefly consider cases where Brazil will have a competitive advantage: air transport, maritime transport, and fine chemicals (see following chapters).

1.10.1. BIOFUELS FOR AVIATION

About a decade or so ago, the academic community and a few of the major airlines began to show strong interest in "sustainable aviation fuels (SAF)" partly because the monopolistic structure of kerosene, rather than for environmental reasons. It was a wake up to a very tricky situation. In 2012 under the auspices of the IEA Task 40, a report was prepared (see ROSILLO-CALLE et al 2012) to investigate the potential use of biofuels in aviation. The main conclusions of the report ranged from an overall demand of 9EJ/yr. in 2010 to 16 EJ/yr. by 2050 (between 375 to 575 Mt). Assuming a 10% the potential use of biojet fuel, the demand was estimated at between 36.8 and 57.5 Mt (1.6 to 2.5EJ).

It turned out that the report largely underestimated these projections. Considerable amount of water has gone under bridge since then! Currently all major airlines are scrambling to find SAF, driven primarily by environmental considerations, but constrained by costs. Both IATA (2021) and ICAO (2022) have introduced specific policies to reduce emissions. In a few years, the vision and attitudes of air travel have shifted significantly in favour of achieving carbon neutrality. For example, IATA (2021) Annual Report indicates that SAF has the capability to reduce emissions by 80% in certain conditions. Despite high costs, SAF is increasing dramatically e.g., in 2021 production and use was estimated between 100 to 150 million litres (m/l), a 50% increase over the previous year. By 2025 about 5 B/l of SAF could be available, capable to meet 2% of global demand, and the 2030 projections are to cover at least 5% of global demand (IATA, 2021).

This trend is accelerating, with strong support from both IATA and ICAO. For example, ICAO in its 41st Assembly in October 2022, adopted a Long-Term Aspirational Goal (TAG) to achieve net zero CO_2 emissions by 2050 (ICAO, 2022a).

The interest on SAF has increased dramatically. Undoubtedly, this is a major potential market for biofuels and consequently requires clear and supporting policies on R&DD. Brazil was the first country in the world to have a policy on the use of biofuels in aviation (see BOEING/EMBRAER/FAPESP, 2013). Various studies have demonstrated the validly of biomass-based alternatives, particularly in Brazil e.g., see Walter et al (2021). There is a long way to go since aviation requires a very high-quality fuel. (See also Chapter 5).

1.10.2. BIOFUELS AND MARITIME TRANSPORT

This is perhaps one of the most promising emerging opportunity for biofuels in transport for various reasons: i) marine transport lags behind other sectors when it comes to pollution, ii) unlike aviation, the quality of the fuel is far lower and less stringent, iii) various studies have demonstrated it is possible to use agroforestry residues at competitive price e.g., Walter et al (2021) have carried out a study covering Brazil, Europe, South Africa and USA which demonstrates its viability. And in the case of Brazil, the study identified a potential of 196.5 PJ with costs ranging from \$1.4 to \$0.80GJ (WALTER et al, 2021). iv) this sector is under enormous pressure to cut pollution and catch up with other transportation sectors, with regards to the environment.

This is a growing sector, fundamental to world trade. It is estimated that four-fifths of trade (8 billion tons, out 9.84 billion) is transported by sea (UNCTAD, 2015). Other studies (CORTEZ et al, 2021; CARVALHO et al, 2021) have also shown the potential of using cellulose-based biofuels in maritime transport in Brazil (see Chapter 5).

1.10.3. BIOFUELS AND FINE CHEMISTRY (ETHANOL CHEMISTRY)

As most industrial sectors, the chemistry industry is moving away from fossil fuel-based chemical products and the focus is on renewable sources as much as possible. There are already many chemicals obtained from biomass e.g., fatty acids, lactic acid, pyrolytic biooil, specialty chemicals, butanol, bioplastics, glycerine etc. (e.g., see IEA, 2020).

Brazil used to have a small but flourishing ethanol-based fine chemical industry in the 1970s and 1980s (e.g., see ROSILLO-CALLE, 1986). This industry witnessed a gradual decline due to a number of factors, including i) direct competition from USA and Japan who had the market and know how, ii) lack of know-how in Brazil for this specialty sector; and iii) the growing petrochemical industry in Brazil.

Fine chemicals are a great emerging opportunity for the ethanol sector in the country because the feedstock can be produced at competitive cost and be available in sufficient quantities (see Chapter 5).

1.11. FOOD AND FUEL AND LAND USE

As stated previously, biofuels versus land use have been the subject of heating debate for decades. The “food versus fuel” debate needs to consider the intertwined nature of biofuels, land use, food production, food waste, animal feed production, diets, social habits, food distribution systems, policy, etc, as already stated. In fact, this controversy is being discredited, as explained in chapter 6. A more fundamental problem is unsustainable food production and lack of clear policy and debate on how to prioritize food systems.

It is almost unbelievable that agriculture is so low down in most government political priorities. Industrialization has received much greater investment. A study by the Global Alliance for the Future of Food (https://futureoffood.org) has put it very plainly, we need a radical change of how we produce food to save the planet.

Not only we produce food unsustainably, but we also waste a huge amount of it! About 17% of total food production is wasted (more than 900 Mt/year). And in some countries where refrigeration in transport is not available, as much as 75% of vegetables are wasted. A report by the Natural Research Defence Council says Americans throw away food worth $165 billion annually. It is an unbelievable waste so that the UN has started a strong campaign to reduce so much waste (see www.un.org/en/observances-end-food-waste).

In addition, according to UFOP (2022) most of grain production is used an animal feed rather than for direct human consumption, as illustrated in Figure 1.10. As can be appreciated, in 2021/22 harvest grain production was 2 333 Mt, of which 1 045 Mt were for animal feed (45%), food 749Mt (33%), and biofuels 168Mt or a mere 7%. The following figure (Figure 1.11) shows that about 81.6 Mha, or 7% of total cropland is dedicated to biofuels production. This does not consider the by-products obtained in biofuel production (e.g., animal feed, energy (from bagasse), yeast etc.).

In Brazil FvF has never been a real issue given the large land area (850 Mha) and abundance of uncultivated and underutilized land.

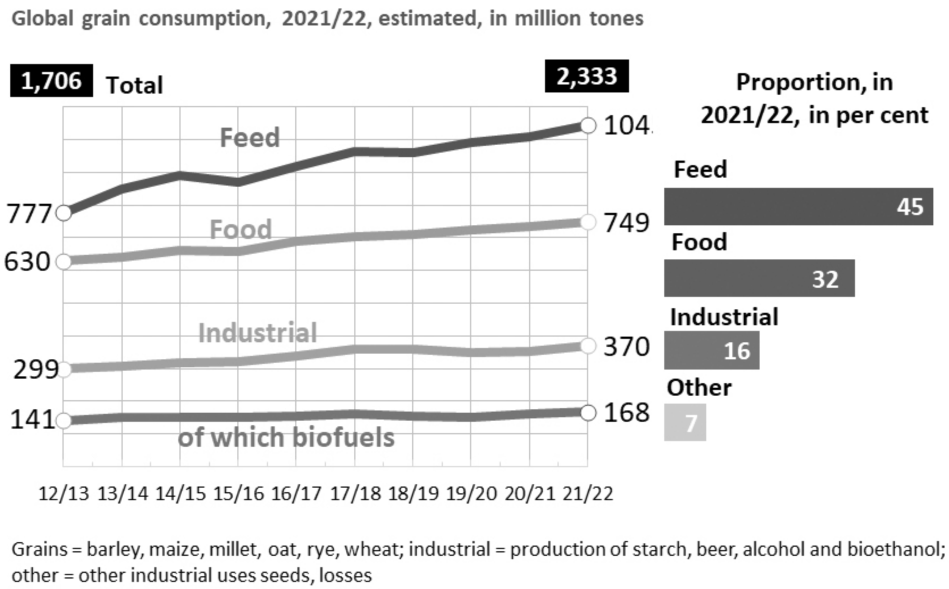

Figure 1.10 Grain is mainly used for feed production. Source: UFOP (2022).

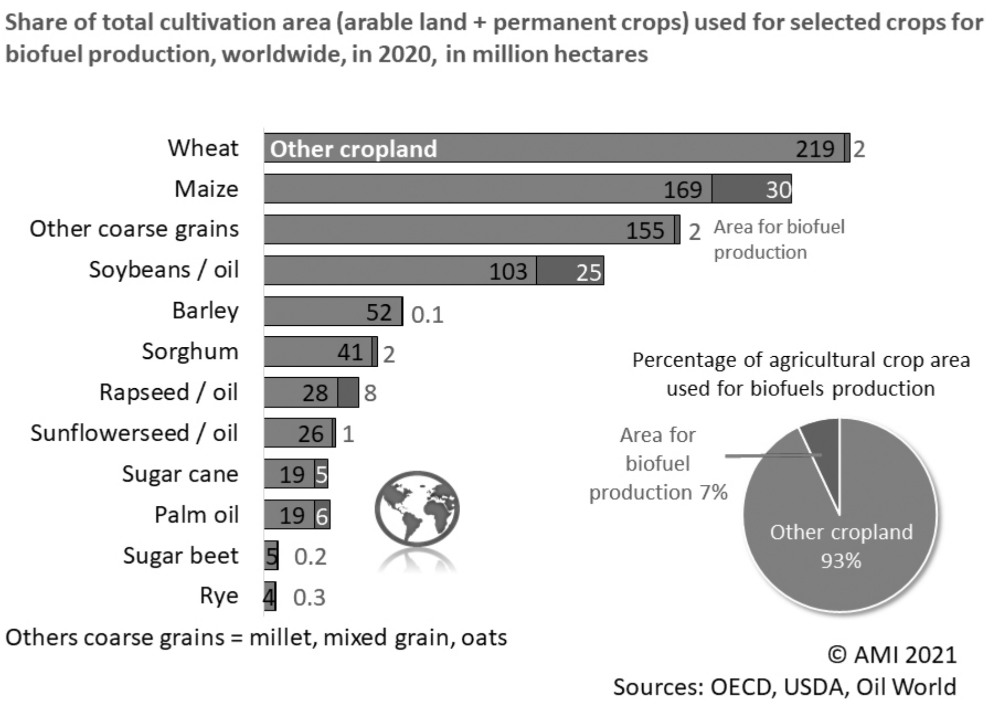

Figure 1.11 Biofuels take up little space. Source: UFOP (2022).

1.12. ENVIRONMENTAL ISSUES

Environmental sustainability and climate change will be key drivers of any future energy scenario. This requires international agreement or some consensus. An overly complex issue which we cannot do justice here given the complicity of issues involved (political, economic, social, technical etc). The implementation of biofuels, either nationally or in a global scale, thus depends on how such issues move forwards. Some countries will have greater autonomy than others. There is also the issue of the great unbalance among countries as to the amount of CO_2 emitted, as illustrated in Figure 1.12. While some rich countries as USA emits 15 tCO_2/person, in Brazil is a mere 1.9. This puts a lot of strain in poorer countries (see MME, 2021).

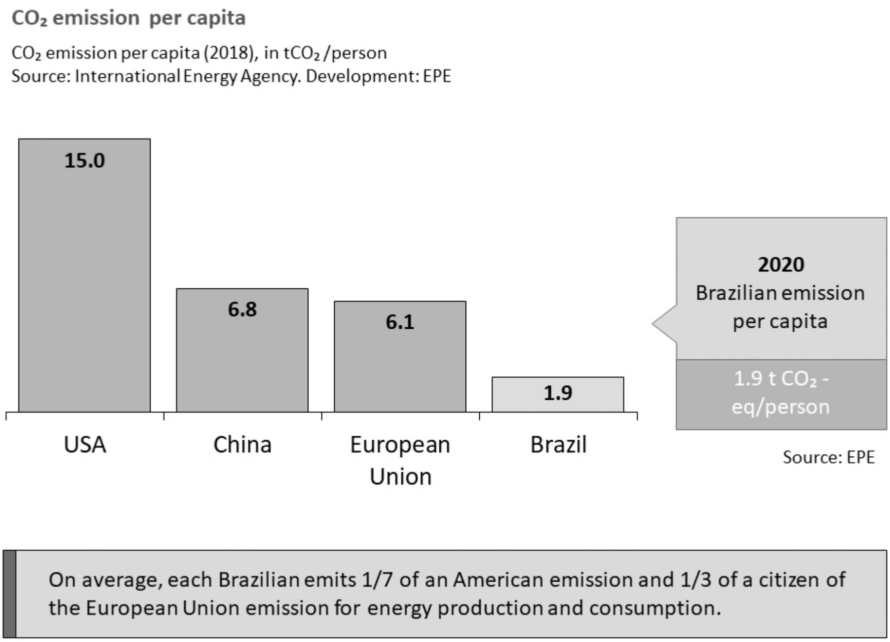

Figure 1.12 Brazilians per capita CO_2 emissions. Source: MME (2021).

FINAL REMARKS

This chapter has presented a brief summary of global energy scenarios, and potential implications. A shifting energy paradigm with huge potential impacts and ramifications, and the potential role of biofuels within this emerging reality. This overview will help the reader to better understand present energy trends and the implications for Brazil.

No country is an island and hence what happens around the world will impact directly or indirectly in an individual country and its policies. Even in Brazil with its unique position and historical experience and natural advantages, biofuels will not be immune to developments outside its borders.

Environment and climate change will be key drivers in any future anergy scenario as already emphasized. This requires international agreement or some kind of consensus. But environmentalism is clouded with conflicting and contradictory vested interests. Thus, the future development of biofuels will be partly shaped by external factors. And the question is *will Brazil use these advantages to promote biofuels in the future? Have biofuels a future in Brazil?* (see also Chapter 6).

The main challenge for Brazil seems political rather than technological, social, or economic, since the country has the technological know-how, natural and human resources, and research capability to deal successfully with any possible energy future scenarios.

This is what the following chapters try to answer.

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