Mika Sillanpää · Chaker Ncibi

A Sustainable Bioeconomy

The Green Industrial Revolution

Springer

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Preface

Nowadays, the sustainable production of food, energy, chemicals, and materials is the major challenge facing modern societies and future generations, after decades of reliance on fossil resources which, on the one hand, did generate economic growth and prosperity but, on the other hand, has left heavy environmental, geopolitical, and social legacies. In this alarming context, the concept of bioeconomy has been developed and promoted as a new sustainable and knowledge-based economic model centered on the use of renewable biomass and derived agro-industrial and municipal wastes using various supply chains and pretreatment, conversion, separation, and purification procedures and technologies. Thus, as a multidimensional concept, bioeconomy has the delicate task to replace the declining fossil-based economic model and manage its global and complicated legacy, while facing its own set of challenges, especially during the delicate transition phase toward the full-scale implementation of a biomass-based economy.

Throughout this book, the authors presented, analyzed, and discussed the concept of bioeconomy from various angles in order to provide basic and advanced knowledge about bioeconomy for students, researchers, industrialists, decision makers, and the general public by showing opportunities, discussing R&D findings, analyzing strategies, assessing the impacts and challenges, showcasing industrial achievements, criticizing policies, and proposing solutions. The task was indeed challenging for one book, and we sincerely hope that we were able to accomplish it.

Hence, this book, which is divided into nine chapters, started in Chap. 1 by analyzing the current situation resulting from the petroleum-based economy, showing its deficiencies and disastrous legacy, which is one of the major driving forces toward the shift to a new model: biomass-based economy. Chapter 2 analyzed the concept of bioeconomy and its sustainable dimension by discussing the proposed definitions and key issues related to the current transition phase such as raw material change and sustainable profitability. The expected role and impact of sustainable bioeconomy on the two main economic pillars, agriculture and industry, are also presented.

In Chap. 3, renewable biomass was discussed, as the core element in the bioeconomy concept, in order to provide the readers with information about its definition, classification (woody, herbaceous, and aquatic biomass, along with derived wastes), composition (cellulose, hemicelluose, lignin, proteins, lipids, etc.), as well as the various opportunities for their industrial valorization into strategic and added-value products.

Then, the opportunities to produce a multitude of bioproducts from biomass were showcased and thoroughly discussed in three consecutive chapters: Chap. 4 for biofuels and bioenergy, Chap. 5 for biochemicals, and Chap. 6 for the production of biomaterials. In each one of those chapters, a theoretical background was presented, followed by a detailed analysis of the various mechanical, thermochemical, and biological conversion procedures applied to transform raw biomass into value-added end products including bioethanol, biodiesel, biogas, organic acids, food and fuel additives, biocosmetics, biopesticides, as well as pulp and paper, bioplastics, biochars, and activated carbons.

One of the main challenges facing bioeconomy is to develop viable and efficient industrial-scale production schemes. Thus, Chap. 7 was devoted to analyze the industrial dimension of the bio-based economic model and its sustainable and integrated biorefining activities. In this chapter, the implementation of bioeconomy on the ground was examined by illustrating the various designs of biorefineries, the obstacles facing the implementation scenarios, as well as some study cases of green biorefining technologies. The knowledge and experiences of key countries in the field of bioeconomy were detailed and discussed in Chap. 8. The objective was to provide readers from different backgrounds with the strategic visions of the USA, many Eastern European countries, and China toward adopting bioeconomy and its various sustainable industrial-scale production processes and technologies. As well, the available bioresources, opportunities, and challenges in the studied countries were also investigated, along with some interesting industrial study cases. A special focus was made on the industrial achievements and prospects in Finland.

In Chap. 9, the various impacts of bioeconomy and the prospects of its worldwide implementation were thoroughly discussed from a multidimensional outlook including industrial, environmental, social, and geopolitical perspectives. This includes reflections on the need for a continuous monitoring of the sustainability of bioproducts and biorefineries via various indicators, as well as the assessment of key environmental and social factors such as greenhouse gas emissions, land-use change, biodiversity, employment, and food security.

Finally, we sincerely hope that our contribution to promote sustainable bioeconomy in this book will benefit researchers, industrialists, decision makers, professionals, and students around the world and thus create a momentum behind biomass-based economy and sustainable development. The authors thank Springer International Publishing for supporting our book from the preparation phase until its final publication.

Mikkeli, Finland

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Contents

Chapter 1
Legacy of Petroleum-Based Economy

Abstract During the industrial revolution of the nineteenth century, the use of coal as fuel set the "train" of progress in motion, which definitely induced a significant improvement in the living standards. After several discoveries, inventions, and innovations, the use of crude oil, the so-called black gold, enabled humanity to reach a higher level of prosperity, especially so between the end of the second World War and the oil embargo crisis. Currently, crude oil is the most traded commodity in the world market and is the main feedstock to produce a wide range of fuels and products such as plastics, textile fibers, dyes, etc.

The heavy reliance on petroleum and other fossil fuels for decades caused many environmental disasters around the world and major geopolitical tensions especially in oil-producing countries. In this chapter, the environmental (water, soil, and air) and geopolitical legacy of the petroleum era as well as its impact of human society are thoroughly discussed in order to highlight seriousness of those issues and the necessity for an alternative sustainable economic model for the future.

1.1 Introduction

Different economic systems were and are being implemented worldwide depending on the degree of governmental involvement, on the one hand, and the manufacturers and consumers freedom to decide what, when, and how much to produce, on the other. Nonetheless, although Humanity developed different economic systems from ancient history until our current era, the straightforward objective was always the same: GENERATE and GROW WEALTH.

Basically, economic systems are founded on four major activities: (1) resources exploitation, (2) commodities production, (3) trading (resources or commodities), and (4) consumption. It is indeed amazing how the Human history could be summarized into those four activities. First, men exploited the natural resources for consumption. Then, they used those resources as feedstock to produce commodities for themselves. Later, they were able to exploit more resources thus increasing and diversifying their products. At this point, they started selling those products gradually for other tribes, other provinces, and other countries. After centuries of inventions and industrial revolutions, men are now able to exploit, produce, and sell products in every corner of this earth.

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This tremendous industrial progress was based on two main factors, invention and energy supply. It all started with wood for which the discovery of fire enabled Humans to exploit the energy stored in biomass. The invention of the wheel helped exploiting another form of energy, animal traction, as well as the sail which exploited the wind and enabled travels and commerce through vast seas. Then came the industrial revolution and the exploitation of coal along with invention of the steam engine by James Watt (1781) and steam turbine which opened the door for a new era of industrial progress and economic growth in the nineteenth century. The twentieth century was the age of petroleum. Innovations were abundant and mainly related to its extraction (various drilling techniques), refining (atmospheric and vacuum towers, cracking techniques. . .), and utilization (petrol engine).

All those historical developments led to the increased dependency of countries on energy resources. The production systems were almost entirely run on nonrenewable supplies of energy (petroleum as well as coal and natural gas). Overall, the generated economic growth seemed to have blinded Humanity for “a while” (a century and a half or so) about the obvious fact that we were feeding our infinite hunger for wealth from a limited provision.

1.2 Fast Facts About Fossil Fuels

Fossil fuels are the hydrocarbon-based matter formed through the anaerobic decomposition of living organisms (plants and animals) buried under thick layers of sediments. Over millions of years, the combined effect of pressure and heat is believed to induce the transformation of the formed organic matter in sedimentary rocks into liquid (petroleum), solid (coal), and gaseous (natural gas) hydrocarbons via catagenesis [1].

Fossils fuels have been the world’s primary energy supply for deceases. According to the International Energy Agency (IEA) 2014 statistics [2], petroleum, coal, and natural gas accounted for more than 80% of the energy supply for the last 30 years (1972–2012). Overall, a slight decrease occurred during the last three decades (86.7% in 1972) and (81.7% in 2012), mainly related to the decrease in the petroleum share from 46.1 to 31.4%. However, the shares of the two other fossil fuels were increased (from 24.6 to 29% for coal and from 16 to 21.3% for natural gas).

Another important remark has to be made from those historical statistics. During the last three decades, the share of biofuels in the total energy supply decreased (10.5–10%). It is a slight decrease one might say, but considering the numerous breakthroughs made in the R&D field of biofuels, the increased awareness about the environmental risks of fossil fuels, the momentum behind global warming, and more importantly the involvement of countries and international bodies, we should have expected an increase in the share of biofuels in the world’s primary energy source over the last 30 years. But no, it decreased. What happened then? Where did all this effort go? More importantly, if governments are involved in developing the biofuels sector, so the real question is who (or what) is more powerful than governments so that he (or it) could oppose the increase in biofuels share in the total energy supply or at least stagnate it for the last three decades? We shall address those important questions and many others later in this chapter and in Chap. 2.

1.3 Petroleum: The Fossil Fuel that Changed the World

1.3.1 Petroleum Composition and Classification

Petroleum, or crude oil, is a viscous, dark-colored liquid trapped in deep reservoirs in the crust of the earth formed by porous or fractured rock formations [3]. Petroleum is composed of a mixture of various types of hydrocarbons, organic compounds, and trace metals. Nonetheless, hydrocarbons remain the primary component of petroleum (largely alkanes and aromatics). They can be classified into four groups:

1. *Paraffins*: entirely made of straight or branched alkanes chains with a carbon-to-hydrogen ratio of 1:2. They can make up 15–60% of crude oil [4] and the shorter the paraffins are, the lighter the petroleum is.
2. *Naphthenes*: cyclic hydrocarbons with a carbon-to-hydrogen ratio of 1:2. They could make up 30–60% of the petroleum composition. These cycloparaffins (if $C > 20$) are more dense and more viscous than equivalent paraffins.
3. *Aromatics*: They can make up 3–30% of crude oil. Aromatic rings are formed by alternating double and single bonds between carbon atoms. Aromatic hydrocarbons can be monocyclic (MAH) or polycyclic (PAH). Compared with paraffins, aromatics possess much less hydrogen to carbon. Their incomplete combustion generates soot, impure carbon particle believed to be one of the causes for global warming.

Petroleum is commonly classified based on its density (light to heavy) and sulfur content (sweet to sour).

Density is classified by the American Petroleum Institute (API) [5]. API gravity is defined based on density at a temperature of 15.6 °C. The higher the API gravity is, the lighter the crude is. Light crude generally has an API gravity $\geq 31.1°$ and heavy crude an API gravity of 22.3° or less. Crude with an API gravity between 22.3° and 31.1° is generally referred as medium crude.

Sweet crude is commonly defined as oil with a sulfur content of less than 0.5%, while sour crude has a sulfur content of greater than 0.5%. Since sulfur is corrosive, Sweet crude is easier to refine and safer to extract and transport than sour crude. Like light crude, sweet crude causes less damage during the refining process, thus resulting in lower maintenance costs. Regarding the sour crude, in addition to the higher sulfur content, the possible formation of high levels of hydrogen sulfide can pose serious health problems, hence the need to remove it before the transportation of sour crude oil.

Benchmarks are crude oils from various regions used as pricing references for petroleum trading. As the most actively traded commodity, petroleum is bought and sold in contracts usually in units of 1000 barrels of oil. Thus, benchmarks help to determine the price of an oil barrel in a contract. There are three major benchmarks upon which is based the pricing of most crudes, namely: Brent, West Texas Intermediate (WTI), and Dubai–Oman.

1. *Brent Blend*: This waterborne crude is used in Europe and in OPEC market basket, making it the most widely used marker (almost two-thirds of all crude contracts around the world). This benchmark is a mix of crude oil from 15 different fields in the North Sea including Brent, Forties, and Oseberg. Crudes from those fields and others are light (API Gravity of 38.3°) and sweet (about 0.45% sulfur), therefore ideal for refining gasoline and diesel fuel, along with other high-added value products.
2. *WTI or US crude:* It refers to oil extracted from fields in the United States and sent via pipeline to Cushing, Oklahoma, the price settlement point for this crude. This oil is also light (API Gravity of 38.7°) and sweet (around 0.45% sulfur). Those properties make this crude ideal for gasoline refining.
3. *Dubai–Oman:* This Middle Eastern crude is a useful reference for oil of a lower grade than WTI or Brent (i.e., slightly heavier and sourer). Originally, this basket consisted of crude from Dubai (around 31 API and 2.13% Sulfur). Then, when its production plummeted to less than 100,000 barrels per day, crude from Oman was added. Starting from June 2007, the Dubai–Oman crude oil became the pricing benchmark for the Middle Eastern oil in the Asian market.

1.3.2 Worldwide Production and Consumption

The worldwide production and consumption statistics of crude oil, reported in Fig. 1.1, reveals how much the present economic systems are dependent on so-called black gold.

Indeed, the reported data is showing a steady increase (almost linear) in both production and consumption between 1983 and 2013. Thus, for the last three decades, the petroleum production was increased by 13.7 (1983–1993), 15.7% (1993–2003), and 12.4% (2003–2013). The consumption also increased during the same period by 13.1, 15.6, and 12.2%, respectively.

Let us now analyze the production and consumption of petroleum by country. For this, we will compare the 2013 statistics [6] of two main groups: the 12 OPEC countries (Organization of the Petroleum Exporting Countries), on the one hand, and the top 12 countries having the largest economies (GDP-based ranking).

The related results are depicted in Fig. 1.2.

As shown, OPEC is responsible for almost 40% of the world production. Saudi Arabia is by far the highest producing country with 11.73 million barrels per day.

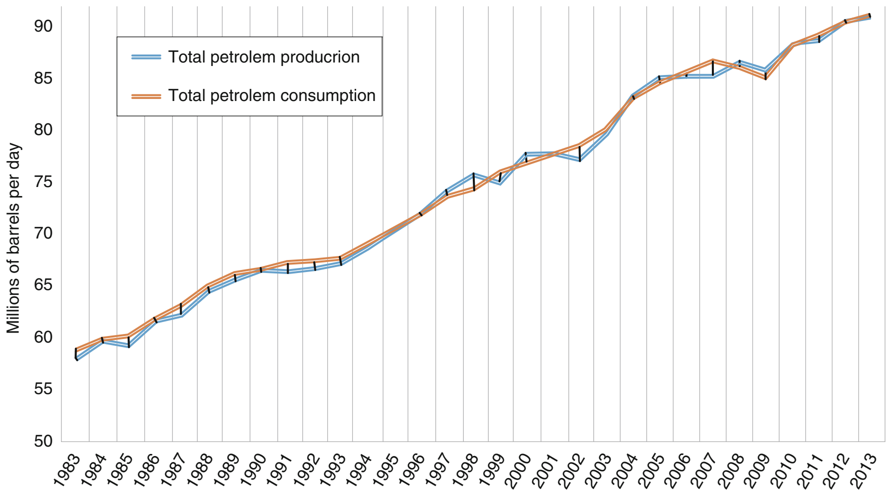


Fig. 1.1 Worldwide petroleum production and consumption between 1983 and 2013 (Data source [6])

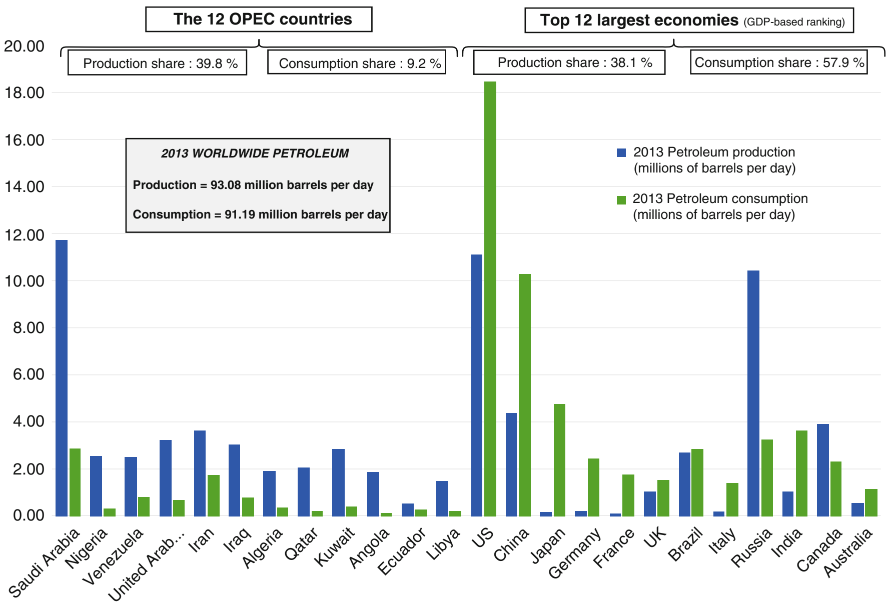


Fig. 1.2 Petroleum production and consumption: OPEC versus largest economies (Data source [6])

Among the largest economies in the world, the United States and Russia are the highest producing countries with 11.11 and 10.40 million barrel of petroleum per day, respectively. Thus, the crude oil world production share of the 12 members of

OPEC is slightly higher than the one for the 12 countries having the largest economies (39.8 and 38.1%, respectively). However, when it comes to consumption, the share of the 12 largest economies is 57.9%, six times more than the consumption share of 12 OPEC members (only 9.2%). Thus, we have two distinct models: countries producing petroleum to generate wealth and countries consuming petroleum to generate wealth. Is one of those models better? What are their respective repercussions on societies and the environment? We shall address this important issue later in this chapter.

1.3.3 Petroleum Refining Processes

As we have seen in the previous section, petroleum is composed of a mixture of hydrocarbons (paraffins, naphthenes, and aromatics) in varying proportions depending on the location of the extraction field. Other elements are also present in the crude oil including sulfur, nitrogen, oxygen, trace metals, and salts. The straightforward objective of a refinery is to purify petroleum, remove the impurities, and fractionate its hydrocarbons content to marketable products (gasoline, diesel, jet fuel, etc.). Further processing could be included to produce specialty end products such as lubricants, asphalt, wax, and other petrochemicals feedstock.

The refining process is based on the three major stages: distillation, cracking, and reforming/isomerization:

1.3.3.1 Distillation

After purification, the petroleum is preheated at 343–399 °C in pipe furnaces and transformed from liquid to gaseous phase (evaporation rate approximating 80%) [7]. The resulting hot gas is fed into the bottom of a distillation tower. As the heated gases move up the column, the temperature decreases and the various hydrocarbons gradually start to condensate based on their respective boiling points and molecular weights, hence the designation fractional distillation. As a result, three different categories of distillates are produced. The light distillates include liquefied petroleum gas (LPG), gasoline and naphtha, the middle distillates (kerosene, diesel), and heavy distillates and residuals (heavy fuel oil, lubricating oils, wax, and asphalt). The characteristics of each distillate (carbon content and boiling points) are presented in Fig. 1.3. In practice, atmospheric distillation columns are configured to stop at this level. More advanced vacuum distillation columns further refine the heavier fractions into lighter products in order to increase the production of high-value petroleum products.

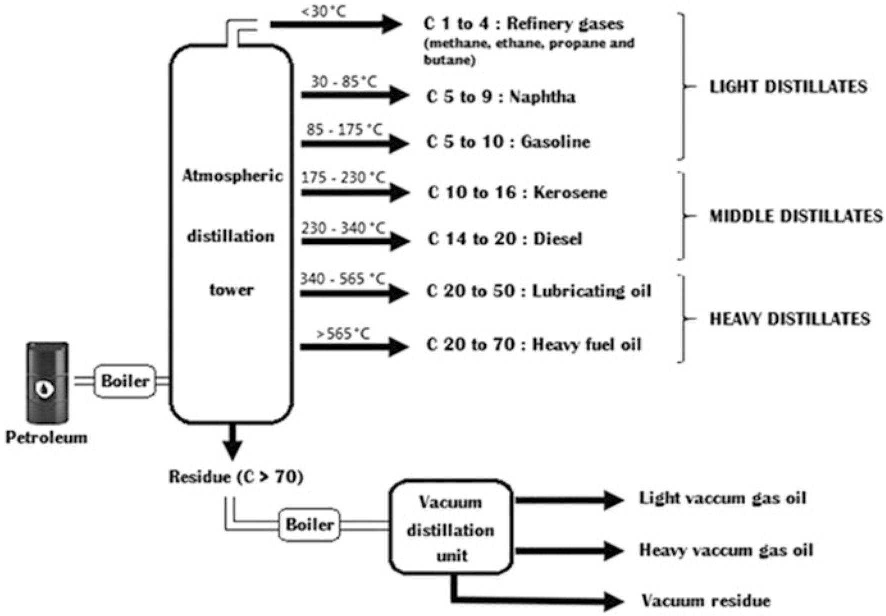


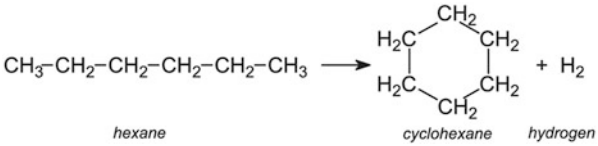
Fig. 1.3 Fractional distillation unit and related petroleum-derived distillates

1.3.3.2 Cracking

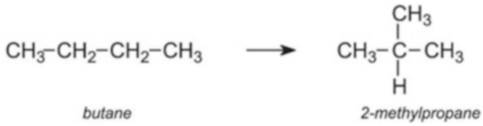
Among all petroleum-distilled products, the greatest demand is for gasoline. One barrel of crude petroleum contains only 30–47% gasoline. Transportation demands require that over 50% of the crude oil be transformed into gasoline [8]. To meet this demand, some petroleum fractions must be converted to gasoline. This may be done by cracking, i.e., breaking down large molecules of heavy hydrocarbons into smaller thus lighter hydrocarbons. Cracking is accomplished using high pressures and temperatures without a catalyst (thermal and stream cracking) or lower temperatures and pressures in the presence of a catalyst (fluid catalytic and hydrocracking). In practice, fluid catalytic cracking produces a high yield of gasoline and liquid petroleum gases, while hydrocracking is a major source of jet fuel, diesel fuel, and naphtha.

1.3.3.3 Reforming/Isomerization

Those procedures are basically applied to generate more useful hydrocarbons. Reforming is set to rearrange hydrocarbon molecules into other molecules, usually with the loss of hydrogen. An example is the conversion of an alkane molecule into a cycloalkane or an aromatic hydrocarbon, for instance hexane to cyclohexane.



As for isomerization, it is the mechanism with which the same hydrocarbon molecule is rearranged into a more useful isomer (i.e., same chemical formula but different structure). For instance, this process is particularly useful in enhancing the octane rating of gasoline, as branched alkanes burn more efficiently in a car engine than straight-chain alkanes. A related example is the isomerization of butane to 2-methylpropane (isobutane).



1.3.4 *Petroleum-Based Products*

1.3.4.1 Products from the Refining Industry

As illustrated in Fig. 1.3, the refining process produces various commodities such as refinery gases (*aka*. liquefied petroleum gas, mainly propane and butane), gasoline, diesel, kerosene, jet fuel and fuel oils. The amount and quality of refined petroleum products is mainly related to the type of crude oil used as feedstock as well as the configuration of the refinery. In general, lighter and sweeter crude oils are more expensive but generate greater yields of higher value refined petroleum products including gasoline, kerosene, and other jet fuels. Heavier and sourer crude oils are less expensive and generate greater yields of lower value petroleum products, such as diesel and fuel oils.

In average, a single barrel of petroleum could produce 25–50% gasoline, 10–25% diesel, 10–40% fuel oil, 7–12% jet fuel, and 6–8% gases. Figure 1.4 represents the breakdown of a barrel of US oil (42 gallons $\approx$ 159 liters) into various refining products.

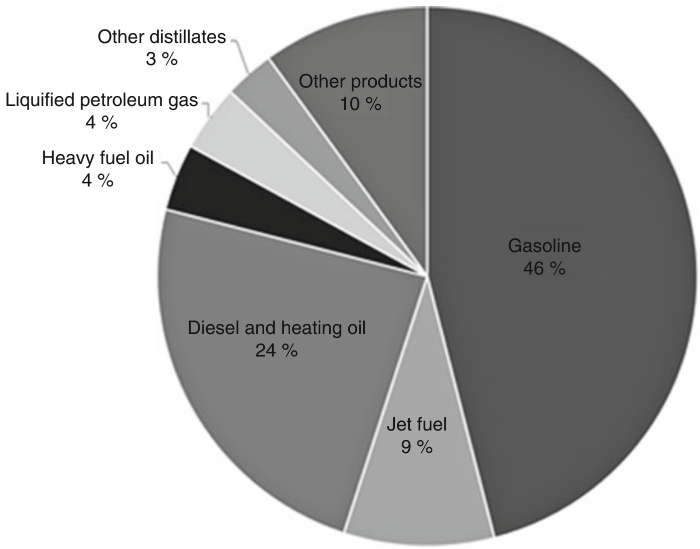


Fig. 1.4 A breakdown of barrel of crude oil into various products (Data source [9, 10])

1.3.4.2 Products from the Petrochemical Industry

The petrochemical industry uses a fast array of hydrocarbons as feedstock, belonging to two major groups: olefins and aromatics.

(i) *Olefins*: are unsaturated aliphatic hydrocarbons containing one or more carbon–carbon double bonds (alkenes), mainly produced from steam cracking and catalytic reforming. It includes ethylene (C_2H_4, the smallest olefin), propylene (C_3H_6), and butadinene (C_4H_6)
(ii) *Aromatics*: are unsaturated cyclic hydrocarbons containing one or more rings mainly produced by catalytic reforming processes. This group includes benzene, toluene, and xylene isomers.

Both olefins and aromatics are feedstocks for a multitude of chemical products and commodities. The flow diagram (Fig. 1.5) gives an overview on those petrochemicals.

Regarding the industrial applications, petrochemicals are the building blocks for the production of diverse products, thus providing end markets and consumers with various commodities throughout the world. The extent of utilization of petroleum-derived products is just staggering as it affects every aspect in our today's life.

The illustration in Fig. 1.6 gives a clear assessment on the degree of dependency individuals and societies alike have on petroleum, a nonrenewable depleting supply.

This list of end products is far from extensive. In the public mind, when the word petroleum is heard, most people will think of gasoline, diesel, plastics, and some textile fibers and dyes. The current situation is far from being restricted to fuel our

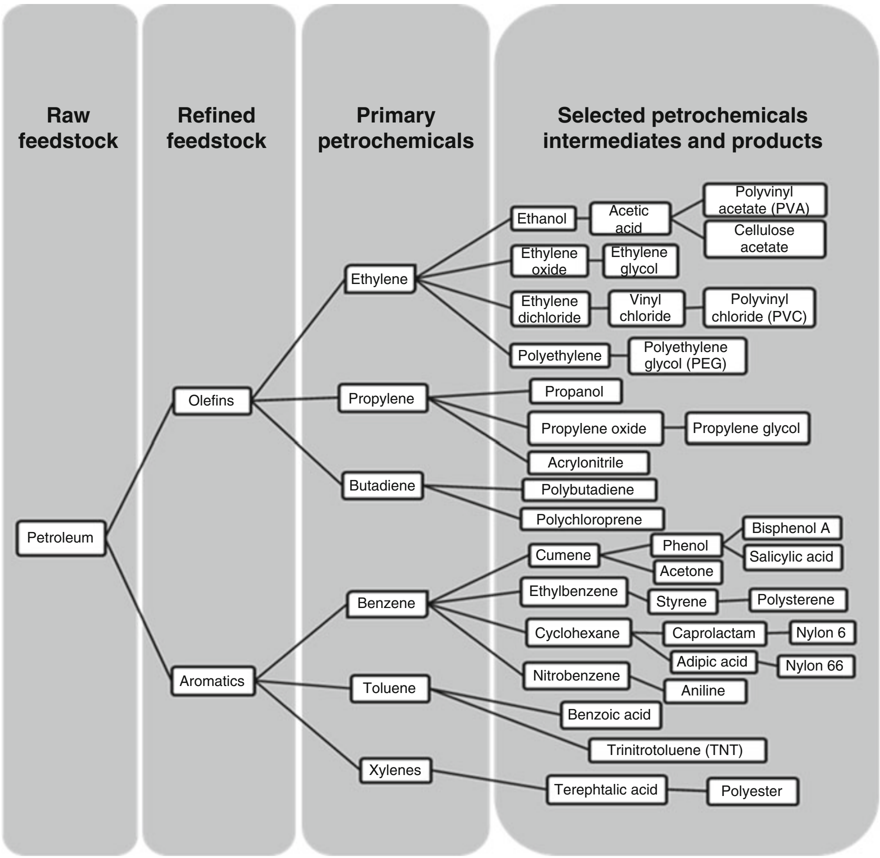


Fig. 1.5 From raw feedstock to petrochemicals: a flow-diagram illustration

cars, make our clothes, and produce some plastic bags out of petroleum derivatives. Indeed, as shown in the previous figure, we use petroleum to protect our crops, to take care of ourselves, and even to medicate ourselves with petroleum-derived pharmaceuticals.

But, the dependency does not end there. Ironically, we depend on nonrenewable petroleum to produce renewable energies. Indeed, in the petrochemical products related to the energy sector in Fig. 1.6, we have purposely mentioned two specific products: protective films and lubricants. The first, protective front and back sheet films are used in the solar panel industry as the outermost layer of the photovoltaic module to protect the inner components from weathering and also act as electric insulators [11]. Those films are mainly made from ethylene-tetrafluoroethylene (ETFE), polyvinyl fluoride (PVF), or polyethylene terephthalate (PET), petroleum-derived thermoplastic polymers. In addition, solar cells contain layers of encapsulants made from the copolymer ethylene-vinyl acetate (EVA), polyvinyl butyral (PVB), or thermoplastic polyurethanes, all petrochemical compounds [12].

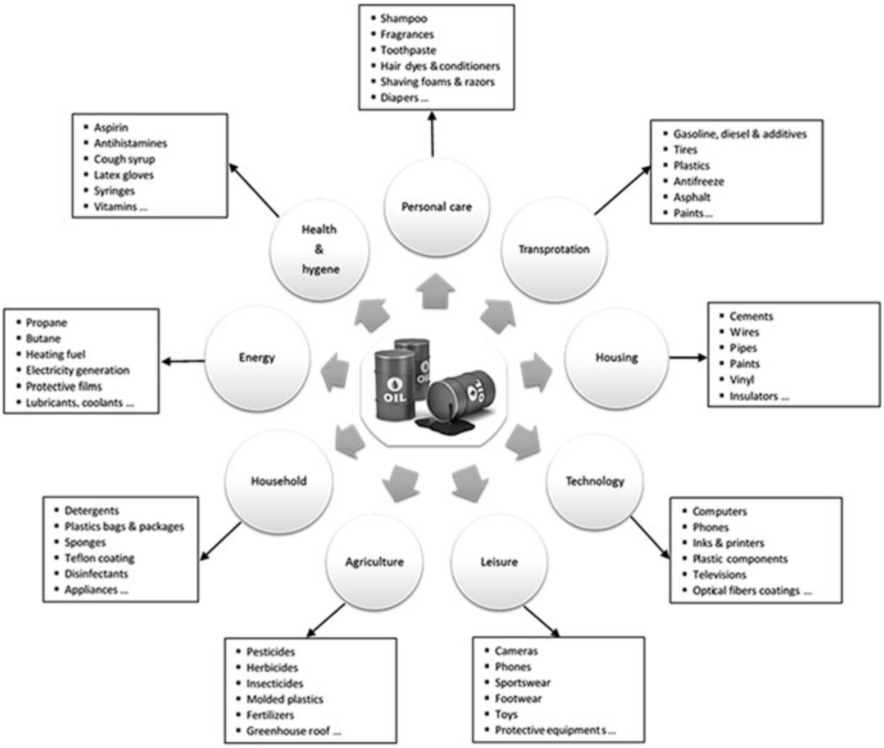


Fig. 1.6 Petroleum-derived end products and markets

On the other hand, petroleum-derived lubricants (oils and greases) and coolants have a very important impact on the wind energy sector. Indeed, wind turbines are very expensive machines generally installed in remote areas; thus, the use of lubricants and coolants (for gearboxes and blades) will help maintaining peak conversion performances and reducing the costly and time-consuming maintenance interventions.

Thus, petroleum is much more deep-rooted in our everyday life than most of us think. This situation has to be seriously taken into account when proposing bioeconomy as an alternative model. To "compete" with petroleum, the sustainability factor alone is not enough. The focus should be on establishing *equally* versatile and efficient production systems. At this stage, and this stage alone, that sustainability will intervene as a decisive factor.

1.4 Prosperity from Black Gold, to Whom and at What Price

1.4.1 Petroleum and Economic Prosperity: Producers Versus Consumers

During the industrial revolution of the nineteenth century, the use of coal as fuel set the "train" of progress in motion, which definitely induced a significant improvement in the living standards. After several discoveries, inventions, and innovations, the use of crude oil, the other so-called black gold, enabled humanity to reach a higher level of prosperity, especially so between the end of the second World War (1945) and the 1973 oil embargo crisis.

Crude oil is the most traded commodity in the world market. In Fig. 1.2, a comparative analysis was carried out based on the production/consumption data for two groups of countries: (1) the 12 members of the organization of petroleum exporting countries (OPEC) and (2) the 12 best performing economies in the world (based on the 2013 GDP statistics [13]). The main findings were that, for the 12 OPEC members, the petroleum production far exceeds the consumption, leading the straightforward strategy of petroleum exportation. As for the 12 strongest economies, the consumption exceeds the national production, except for Russia and to a lesser extent Canada.

Now, in order to better understand the situation, a simplified yet straightforward assessment of the petroleum impact on economies is presented via analyzing the relationship between one important economic indicator, gross domestic products (GDP), and the statistics data about crude oil (production and consumption). Basically, the comparison is between petroleum producing/exporting countries and consuming/importing ones.

First, the analysis of the GDP on the one hand and petroleum production on the other (Fig. 1.7) clearly shows that economic prosperity is not linked to the produced amount of crude oil. For instance, the combined GDP of all OPEC members almost equals that of Germany alone, although they are producing petroleum 218 times more.

It is therefore obvious that mono-product export-orientating economic model adopted by most OPEC members is not only vulnerable but also inefficient in generating national wealth. As for the countries with strong "mixed" economies, petroleum production seems to play a promoting role in the economy via boosting the diverse production activities in countries like the United States and China. Other countries with highly performing economies do not even produce significant amount of petroleum including Japan, Germany, and France. This means that petroleum production is not an affecting factor, so what about its consumption?

To answer this question, let us analyze the correlation between the GDP and the petroleum consumption data depicted in Fig. 1.8.

Contrary to its correlation with production, the GDP had a good fit with petroleum consumption. Therefore, for the selected countries, economic growth is

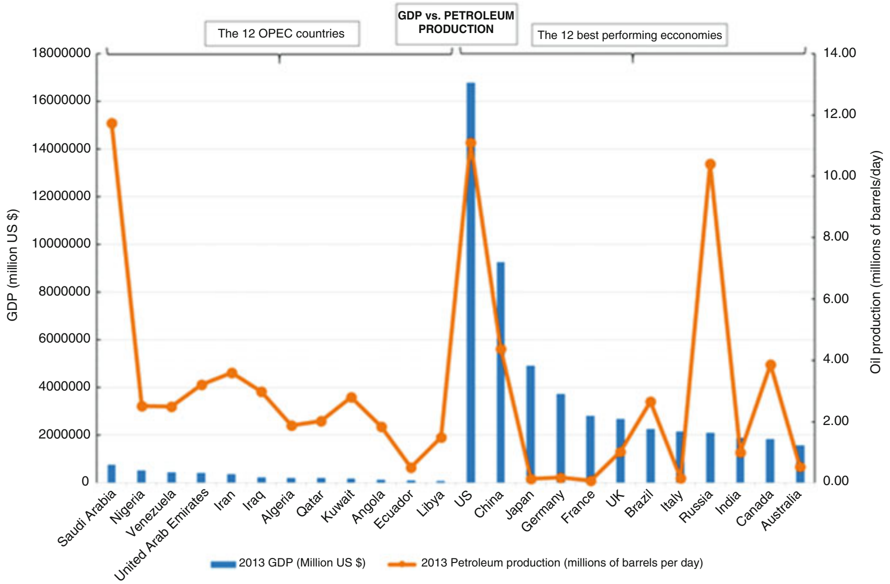


Fig. 1.7 Correlation between petroleum production (Data source [6]) and GDP (Data source [13])

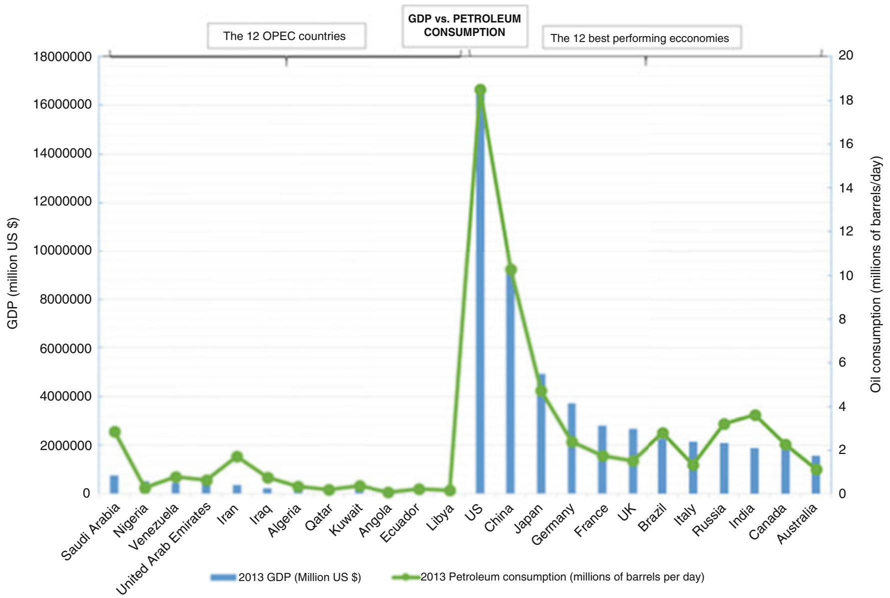


Fig. 1.8 Correlation between petroleum consumption (Data source [6]) and GDP (Data source [13])

linked to petroleum consumption and, as the most traded commodity in the world, induces economic prosperity for the consumers but not for the producers.

The question now is whether the petroleum consumption generates growth or the economic growth increases petroleum consumption. Several investigations were carried out on this matter to find out the causality relationship between oil consumption and GDP. Most economic analysts used the Granger causality model [14, 15] or the modified Toda and Yamamoto version [16]. It was found that this relationship is more prevalent in the developed OECD (Organization for Economic Co-operation and Development) countries compared to the developing non-OECD countries [17].

For the BRICS countries (Brazil, Russia, India, China, and South Africa), the analysis showed that oil consumption and economic growth are not sensitive to each other for the studied panel. However, for the distinct study case of China, a bidirectional causality was proposed [18], as energy supply is needed to "fuel" the industries, but rapid growing industrial activities will put pressure on energy demand thus increasing the oil consumption as well as coal and natural gas. Thus, although the industrial output of China only accounted for about 40% of GDP, the industrial energy consumption accounted for almost 70% of the energy consumption [19].

1.4.2 *Prosperity from Petroleum: The Other Side of the Story*

In the previous section, the simplified analysis showed that petroleum is more profitable for consumers than producers. Indeed, most exporting countries produce and sell crude oil to generate wealth, contrary to the industrialized countries, which import petroleum and use it to generate wealth. The common, but misleading, question asked regarding the most important raw materials on earth is: Do you have petroleum? The real question though is: what are you going to do with it?

In most nations, economic strategies and foreign relations policies are planed based on their reply to this question. Overall, countries could be divided into two main groups: the exporting producers and the importing consumers. "We are planning to sell petroleum and generate prosperity and economic growth from its revenues," replied the first group. The reply of the second group would be: "we are going to buy petroleum and use it as a feedstock to produce various kinds of value-added commodities. The commercialization of those products will generate wealth from various sources, thus generating economic growth and sustaining it."

Let us now analyze the situation for representatives of those two groups: the OPEC 12 members for the first group and the 12 best economies in the world for the second one. The relationship between those two entities has been suspicious most of the time and even nervous some of the time. The price fluctuations of crude oil throughout the last decades say it all. Both groups know very well the importance of the raw material being traded, the so-called black gold.

For OPEC, most of its members rely heavily on petroleum export. According to the organization statistics, the contribution of crude oil in the total export revenues could reach very high levels as it is the case for Saudi Arabia (85%); Nigeria (90%); and Venezuela, Kuwait, and Libya (95%). Thus, petroleum is the backbone of OPEC members' economies since its export is the primary income for member countries to generate revenues (average of 75% of total export revenues) [20]. To name a few, the revenues are being used for decades to build and maintain roads and bridges; construct and equip housing complexes, schools, and hospitals; and import many commodities, most of them derivatives from the refining and petrochemical industries. So, the diagnosis in this case is a "chronic" dependency on depleting fossil resources.

For the industrialized countries, petroleum plays another role yet equally important. It is the backbone of many industrial activities as a feedstock for the production of many value-added products or as the major energy supply for strategic sectors like transportation (cf. Fig. 1.6). For this group, the dependency on petroleum was gradual and discrete (but not for the big oil companies). With the development of the lucrative petrochemical industry, the dependency became chronic.

The actual relationship between petroleum exporting producers and importing consumers is a *mutual dependency*. The first group needs the second to buy the supply. The second needs the first to provide him with these resources to "feed" its large industrial complexes, always hungry for energy. Thus, instead of tense and nervous relationship between OPEC and the industrialized countries, the situation should be analyzed in a wise manner because the current situation is both precarious and escalating, especially considering the geographical distribution of petroleum reserves in the world (politically unstable regions) on the one hand, and with the orientation towards the exploitation of more fossil resources like oil shale and tar sands.

To give a very simple metaphor portraying relationship between OPEC and industrialized countries, let us tell you the story of two farmers, one with a cow (OPEC) and the other with a fruit orchard (industrialized countries). The first has a very productive cow giving him far more milk than his needs for his family. The second has a highly productive orchard with many kinds of fruits giving him decent revenues. In the beginning, the farmer with the cow did not know that it has milk but the second farmer knew that. So, he helped his neighbor to extract milk from the cow with the condition to sell him a daily amount at a "special" price in addition to some fruits from his orchard. The deal went on for decades.

The family of the farmer with the orchard liked milk very much, especially that they were able to produce delicious butter, cheese, and yoghurt out of it. Those products become a staple in their daily diet and they did not seem to get enough of it. The farmer with the cow, now aware of the importance of milk, started taking care of his cow to produce more and more. Overall, both farmers benefited from the precious milk. The first was satisfied with the revenues from his cow and took care of his entire family from the milk revenues only. The second farmer become too dependent on the delicious milk to a point that he is not taking care of his orchard anymore and started to think “why buying milk if I could get the cow or, at least, I can give its custody to a friend.” From this point, the relationship between two farmers became very tense and all the neighborhood became anxious and fearful.

One day, a wise veterinary came to see the troublesome farmers. He told the first farmer (OPEC): “open your eyes, the cow is suffering and it has only couple of more years to life.” Then, he turned to the second farmer (industrialized countries) and said: “if you like milk this much, I’ve heard of another farmer producing Soy milk, it’s similar to the conventional milk and made from renewable resources.” The two farmers looked to the vet, the meager cow and the deserted orchard. Then, they looked to each other for seconds and the first (OPEC) said to the second (industrialized countries): “Still want your usual dose of milk?,” and the latter replied: “of course my friend,” and the story goes on.

1.4.3 The Petroleum Paradox

The dangerous facet of the story is that both groups (exporting and importing countries) are establishing strategies for entire nations and given hopes for entire populations, based on a precious yet depleting resource. Every one of them is trying to ensure an ever increasing prosperity for their countries and well-being for their citizens (a quite selective as we shall see later). The goal in itself is worthwhile but the adopted strategy is short-sighted, hasty, and unwise.

Normally, strategists, policy makers, and decisions makers are wise and insightful men and women, the best a nation can give. So, why we ended up with unwise strategies leading to excessive dependency on a nonrenewable resource like petroleum?

For decades, political economists and experts analyzing the petroleum production, consumption, and trading proposed several concepts to explain the abnormality that oil-rich countries have weak economies, namely, the “petroleum curse” [21] and the “Dutch disease” [22].

The constant flow of petroleum to markets throughout the entire world, its “affordable” price range (most of the time), in addition to its huge revenues, gave the sense that it is unlimited resource. This illusion led to the gradual surge in dependency, and it is not only affecting the known oil exporting countries where the apparent abundance of petroleum strangely led to a weak industrial manufacturing and agricultural activities (the so-called Dutch disease) but also developed nations. Indeed, the largest concentration of refining capacity is not in the Middle East, the largest producing arrear and where most of the reserves are, but in North America and Europe. The Unites States alone accounts around one-quarter of the crude oil distillation capacity of the world [23].

A comparative example from the European Nordic region gives a clear illustration of this syndrome also affecting developed nations. The discovery of petroleum in the North Sea in late 1969 transformed the core of the Norwegian economy. Norway is among the top ten largest oil exporter, and petroleum accounts for 30%

of the country's revenues [24]. Since the so-called 1970's boom, those revenues were channeled to cover the high spending in wages and welfare benefits to unsustainable levels, making Norway one of the world's most generous welfare model, second only to Sweden [25]. Thus, the Norwegian economy gradually became highly dependent on its fossil resources and the economic growth highly susceptible to currency evaluation, pricing, and demand fluctuations. During the early stages of the oil boom, little governmental initiatives were instigated to develop the established industries and encourage new enterprises in the private sector. In the meantime, neighboring Finland, with no petroleum resources, managed to build a vibrant and highly industrialized economy involving various sectors such as electronics, machinery, mining, forest products, and chemicals [26].

So, the paradox is undeniable and valid for most oil-rich countries, mainly in developing nations (most OPEC members) but also, and to a lesser extent, developed countries (UK, Netherlands, Norway. . .). The general tendency is that, once a country discovers petroleum, it will become visible on the world map (even if too tiny), the economic growth will go up rapidly, the manufacturing and agricultural activities (if any) start to go down, and the whole country, if not the entire region, becomes vulnerable, unstable, and insecure. Some call it a disease, others a curse.

Either way, the fundamental question is: who brought the disease or spelled the curse on those countries? We shall address this important issue in an unbiased manner in the last section of this chapter and we shall point to the source of the problem directly. A straightforward and frank diagnosis is half the cure, and it is about time to begin the healing process.

1.5 End of an Area: Environmental Disasters and Geopolitical Instability

Petroleum is the cause of many environmental disasters and major geopolitical developments in the world. Many will agree and some will disagree, depending on the impact of this highly addictive commodity on one's life. Yet, petroleum is just the superficial cause. It's merely taking the place, for a determined lapse of time, of many other precious commodities before it such as gold, ivory, cotton, and minerals. The real and deeply rooted problem is in the mind of men, greedy and corrupt men.

This is not to diminish the role of petroleum exploitation in the current disastrous state of the planet. Rather, it is crucial to make a proper diagnosis and know the real source of the problem. If not, proposing bioeconomy as new sustainable model of exploitation and production, under the same circumstances, will be futile. We have to break up this cycle of bloody and costly struggle over resource. It has to end, too much is at stake. The global situation is not just precarious for next generations, it is already so for the current generation. The earth is suffering, soil, air, and water alike, and humanity too.

Thus, analyzing the legacy of the petroleum era would be a very important endeavor to draw lessons for the future and be a constant reminder for those of us with short memories.

1.5.1 Serious Environmental Degradation

Environmental pollution caused by petroleum extraction and refining, along with its derived products manufacturing, utilization and disposal, has led (and still do) to major ecological disasters. The impact is not restricted to industrialized countries where the bulk of the refining, transformation, and utilization occurs, but also in less developed countries where petroleum is extracted and in even less developed countries where most of the petroleumderivative wastes, among many other contaminants, are dumped. Thus, during the last decades, the only feature that equals the worldwide importance of petroleum in human societies is its worldwide mess in human environment.

1.5.1.1 Toxicity of Petroleum and Derived Products

Public Health Risk

Petroleum and its derived intermediates and products constitute one of the most widespread sources of environmental degradation in the world due to their wide and extensive extraction, storage, transportation, and use. Intrinsically, petroleum has various toxicity levels as it is a complex mixture of hydrocarbons, in addition to trace amounts of sulfur and nitrogen compounds, some of which are toxic, poisonous, and carcinogenic.

Petroleum products are persistent and highly mobile contaminants making them difficult to remove from soils and groundwater. Besides, several petrochemicals are known or suspected carcinogens or mutagens which can pose serious human health risks (e.g., cancer, birth defects, and other chronic conditions) at 10 ppb and below in groundwater resources [27]. Inhalation of high concentrations of crude oil may cause central nervous system effects, and a prolonged or repeated skin contact may cause dermatitis.

The major concern is about the potential carcinogenicity of some polycyclic aromatic hydrocarbon (PAHs) [28]. Benzo(a)pyrene is considered one of the most potent carcinogenic PAH. Along with benz(a)anthracene, they are classified as probable human carcinogens inducing skin tumor development [29]. At relatively high levels, the volatile organic compounds benzene, toluene, ethylbenzene, and xylene (BTEX), commonly found in petroleum derivatives, can be associated with serious neurotoxic [30, 31] and hepatotoxic complications [32].

Soil and Ground Water Contamination

Soil and ground water contamination by petroleum and its derivatives is related to two main pollution source: point and nonpoint sources [33]. The first could be caused by spills and leaks from petroleum wells, pipelines, and underground storage tanks. It could also be generated in landfills and industrial waste disposal sites. Either way, the leaking can seriously contaminate large areas of soil, deteriorating their fertility and even making them nonexploitable and source of serious health risk from organisms living in them or feeding from them. For instance, 25% of the content of underground petroleum storage tanks is estimated to be leaked into the ground [34]. If the treatment of soils contaminated by petroleum is not both quick and efficient, toxic hydrocarbons can leach into the groundwater and contaminate vital water resources, particularly if the aquifer is shallow and not sealed by an overlying layer of low permeability material like clay.

The second source is related to the commonly used petroleum products. For instance, the agricultural sector is highly affected by any deterioration of the quality of both soils and water resources. Thus, the various petrochemicals used in agriculture including fertilizers, pesticides, and herbicides constitute a nonpoint source of pollution especially considering their worldwide extensive applications.

Air Pollution

During the petroleum refining process, several toxic gaseous compounds are emitted into the atmosphere. As well, the utilization of petroleum distillates and derivatives in the transportation, industrial, and agricultural sectors is partly responsible for the worldwide degradation of the air quality.

The U.S. Environmental Protection Agency (EPA) designates six criteria pollutants for determining air quality including carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), ground-level ozone (O_3), and particulate matter (soot, dust, pesticides, and metals) [35]. In addition, petroleum-fueled vehicles and industrial machinery running on fossil fuel directly produce considerable amounts of toxic CO, NO_x, and volatile organic compounds (VOCs) in the atmosphere. The combination of VOCs and NO_x in sunlight create O_3, well known for blocking ultraviolet rays in the upper atmosphere, but could cause human health problems when present in the lower atmosphere (tropospheric ozone) [36].

Sulfur dioxide is a trace component of petroleum. When released into the air with the refineries emissions, it could cause acid rains [37]. Indeed, SO_2 and NO_x react with the water molecules in the atmosphere to form corrosive acid rain which could be harmful to exposed living organisms and even buildings and other infrastructure.

Incomplete combustion of petroleum occurring on a burning oil rig or when an oil spill catches fire generates smoke plumes containing a mixture of toxic gases (CO, CO_2, NO_x. . .) and particulates matter (soot and acidic aerosols). The particulate matter is also constantly being emitted by vehicle exhausts along with other