RESOURCE USAGE, ZERO CARBON AND ZERO WASTE EMISSIONS David B. López Lluch Esther Sendra Nadal Leontina Lipan Key words: resource usage, natural, Hotelling, zero carbon, zero waste The first objective of this subchapter is to introduce readers to the different types of natural resources and the main way of using them in a sustainable way. Then it explores the concept of "zero carbon" including its three axes: zero material consumption; zero energy demand; and zero waste across the manufacturing system. Finally, "zero waste" concept is analysed looking at its global implications in an industry level. 1. Introduction Natural resources are central to human wellbeing. Human beings cannot live without clean air, without the plants that are the basis for our diet, and without good quality water. Natural resources are required for buildings, houses and premises, and for guaranteeing life conditions. So they are essential for survival and for people to thrive. The concept of natural resources refers to naturally occurring living and non-living elements of the Earth system, including plants, fish, and fungi, but also water, soil, and minerals. A useful way to think about natural resources is to look at them in terms of depletion risk: do they regenerate, and, if so, at what pace? Some resources, such as trees and plants, are renewable because they regenerate relatively 47 Resource usage, zero carbon and zero waste emissions quickly. Others, such as copper and oil, take much longer to form and are considered non-renewable. In this sense, pressure on natural resources and emerging environmental legislation are pushing society in general, and manufacturers, to adopt solutions that ensure their environmental impact is reduced, and thus to switch to a more sustainable producing paradigm, without losing competitiveness. One of the key concepts associated with environmental impact reduction is "zero carbon". Zero waste emissions, envisaging all the industrial inputs being used in final products or converted into value-added inputs for other industries or processes. In this way, industries are reorganized into clusters such that each industry's wastes / by-products are fully matched with the input requirements of another industry, and the integrated whole produces no waste of any kind.

2. Background 2.1. Resource usage Natural resources are resources that are drawn from nature and used by humans for satisfying their needs. This comprises sources with valued characteristics, such as industrial and commercial use, cultural value, aesthetic value, and scientific interest. On Earth, it includes sunlight, atmosphere, water, land, all minerals along with all vegetation, and wildlife. Natural-resource allocations can be at the centre of many economic and political confrontations both within and between countries. This is particularly true during periods of increasing scarcity and shortages (the depletion and overconsumption of resources). Resource extraction is also a major source of human rights violations and environmental damage. The Sustainable Development Goals and other international development agendas frequently focus on creating more sustainable resource extraction, with some scholars and researchers focused on creating economic models, such as the circular economy, that rely less on resource extraction, and more on reuse, recycling and renewable resources that can be sustainably managed. It is possible to classify natural resources according to origin: biotic and abiotic. Biotic resources originate from the biosphere, comprising 48 Introduction to sustainability all living beings that humans use (livestock, fisheries, flora, etc.) It also comprises fossils fuels (petroleum and coal, for example) as they are formed from organic materials. Abiotic resources originate from inorganic and non-living materials (land, water, metals, etc.). Natural resources can also be classified according to their stage of development. Potential resources are those that exist but cannot be employed yet. This can be due the lack of the required technology. Actual resources are those that are currently being used. Their use depends on technology and the feasibility level. Reserves are actual resources that can be used in the future in a profitable way. Stocks are resources that are known to exist but cannot be used due to technological constraints. Finally, natural resources can be classified looking at their degree of renewability/exhaustibility. Renewable resources are those resources that replenish naturally. Many of them (wind, air, solar energy, etc.) are always available

and their quantity does not depend on human use. Others (wood, land, water, etc.) do not recover so fast and are susceptible to depletion by over-use. So in this category a crucial issue is the rate of replenishment/recovery exceeding the rate of consumption. Non-renewable resources cannot be renewed quickly, as they have been formed over a long geological time period in the environment. This category includes minerals and the main fossil fuels. Their consumption rate exceeds their recovery rate. Some of these resources can be recycled (minerals) but others cannot (coal and petroleum). The main concerns about resources usage are focused on their renewability/exhaustibility. In this sense, Lord Lionel Robbins (1935) defined ECONOMICS as "the science which studies human behaviour as a relationship between ends and scarce means which have alternative uses". Following from this, NATURAL RESOURCE ECONOMICS is "the application of economics to manage naturally occurring resources for human needs/wants with efficiency as the primary goal". EFFICIENCY may be defined in market or nonmarket terms, focused on the short or long run, relative to current or future generations, local or global in scope. DECISION CHOICES include maintaining the status quo, altering the status quo, or doing nothing, with a focus on relevant institutions. EVALUATION always includes the costs & benefits of a decision & to whom those costs & benefits accrue. Therefore, RESOURCE USAGE requires NATURAL RESOURCE MANAGEMENT (NRM) that is defined as "the management of natural resources such as land, water, 49 Resource usage, zero carbon and zero waste emissions soil, plants and animals, with a particular focus on how management affects the quality of life for both present and future generations". Natural resources management involves identifying who has the right to use the resources, and who does not, for defining the boundaries of the resource. The resources may be managed by the users according to the rules governing when and how the resource is used, depending on local conditions, or the resources may be managed by a governmental organization or other central authority. Non-renewable resources are undoubtedly essential for the functioning of the productive system. For this reason, the debate on their depletion and possible consequences of their reduced abundance in the future is of special importance for the future possibilities of humanity. For this reason, in the following section we will try to develop some economic elements to answer the question of how dramatic the problem of depletion of non-renewable resources is. The first position, which we can describe as pessimistic, emphasizes the imminence of the physical depletion of known resource reserves. Here, scarcity is measured by the time remaining until the extinction of a specific resource. This is a relatively easy measure to construct if we know the reserves of the material and the amount that is extracted from it at a given moment. To illustrate this reasoning, let us briefly look at the Club of Rome report on the limits of growth, in which the problem of the depletion of non-renewable resources is dramatically posed. The basic data on which this pessimistic vision of the future is based are those found in Table 1. Thus, for example, according to statistics from the United States Bureau of Mines, in 1970 the known copper reserves were around 310 million tons, and given that world copper consumption reached the figure of 8.5 million tonnes that same year, we can conclude that, if copper demand had remained stable, the reserves available in 1970 would have been completely exhausted after 36 years. Although this conclusion was worrying, some authors considered it too optimistic. Indeed, according to the Club of Rome, copper demand was not likely to remain stable; on the contrary, it was more reasonable to think that in the future this demand would continue to grow at the rate observed in the last 70 years (that is, at 4.6 percent per year), which would have reduced the expected life of copper from 36 to 21 years. (Table 1). Of the 19 non-renewable resources listed in Table 1, using the exponential scarcity rate, only coal could have been expected to exist for more than 100 years. 50 Introduction to sustainability Among the most dramatic cases, there is a long list of resources that, according to this type of forecast, would have been exhausted before the year 2000, including, apart from copper, gold, lead, mercury, natural gas, oil, silver, tin and zinc. Fortunately, none of the pessimistic forecasts of the 1970s have come to pass. However, our interest in this part of the subchapter is not simply to show that the Club of Rome report made serious miscalculations that can be corrected in the light of new information. Rather, what we want to demonstrate is that the reasoning implicit in the scarcity measures is wrong. Basically, the mistake lies in conceiving scarcity as a physical phenomenon, when it is, as we will see, an economic and social phenomenon. This fact will help us to advance in the discussion of the criteria that should guide the management of non-renewable resources.

2.1.1. What is scarcity? The above analysis highlights the possibility of non-renewable resource depletion. Many of the confusion and forecasting errors can be avoided if we carefully distinguish between two interrelated concepts: available resources and known reserves. Reserves are defined as deposits with known quantities and qualities, of which, given available technology and political and economic conditions, it is profitable to extract minerals. For their part, the resources are potential sources of minerals that can be used in the future if changes in technology and economic, political and legal conditions allow it. Since economics, technology and politics are essential parts of this definition, mineral reserves can increase or decrease significantly without changing the amount available in the Earth's crust. For example, due to legal restrictions, while the treaty that reserves the territory of Antarctica for research purposes is in force, the existing mineral resources there cannot be counted as reserves. Obviously, the greater the extraction of a mineral, the lower its future availability. However, the importance that this has for us and for future generations does not depend only on the amount of unexploited resources, but also on at least three additional factors whose nature is eminently social and historical. These factors are: ● firstly, our degree of knowledge about the quantity and physical quality of the resources and the reserves available, ● secondly, the technological capacity that we have to use such reserves productively, ● finally, thirdly, the value that such reserves have for the economic system. Let's look at the three elements separately to illustrate their importance. The information available First of all, although we know more and more about the geology of the planet, our information about the available reserves is 52 Introduction to sustainability incomplete. Even today, there is a significant degree of uncertainty about the quantity and quality of the remaining resources on the planet. For example, we do not know with certainty the amount of oil that exists under the seabed. In other cases, we know of the existence of some material deposits, for example in Antarctica, but until exhaustive exploration is carried out, we will not know their quantity and quality. In other areas, given the geological characteristics of the environment, we can deduce the probability that there are significant reserves, and we have the possibility of reducing such uncertainty through, for example, the study of magnetic fields or the drilling of exploratory wells. Therefore, apart from an exclusively physical measurement, reserves must be measured based on our degree of knowledge of their quantity and quality. Actually, at the most general level, our certainties boil down to a global estimate of the total amount of each mineral existing in the Earth's crust. Thus, for example, from the composition of the Earth's crust, we can deduce that there are still 11,000 billion tonnes of unexploited copper left on Earth (11x1017 tonnes), which, if we were able to exploit them, would allow us to satisfy any foreseeable demand for several million years. This is a measure of the resource, or potential reserves. However, physical abundance has little to do with economic abundance. By contrast, highly concentrated copper deposits are extremely scarce, and according to 1992 data, copper reserves reached 550 million tons, indicating that with current prices and with our technological knowledge, we can only obtain one in every 22 million of the existing copper particles on the planet. Figure 1 illustrates our knowledge about available reserves. The upper axis presents some useful concepts to define our degree of knowledge about the resources of a hypothetical mineral. It is therefore important to establish a clear distinction between the proven reserves of a mineral, the probable or inferred reserves, and those not yet discovered. The important thing is that, although the available resources are fixed, the boundary between proven, probable and inferred reserves changes over time, moving to the right in the diagram, with each new exploration discovery. 53 Resource usage, zero carbon and zero waste emissions DEGREE OF UNCER

The technology Apart from the information available, in the definition of reserves it is also important to take into account the technological capacity that we have to produce well-being from non-renewable resources. Such capacity essentially depends on the technology available to exploit, use and recycle the materials we obtain from the Earth's crust. Innovations, driven by scarcity and the price increases that this entails, gradually increase the available reserves. Technical progress can take multiple forms, depending essentially on the point in the life cycle of minerals at which technological innovations occur. Thus, technology can improve in the phase of exploration, extraction, transportation, production, consumption, or recycling of materials. Let's see some examples of each case. First, our knowledge of how mineral deposits form has strongly affected the way we search for them. If we go back to the old explorer with his mule and his punt, we can gain some perspective on how far we've come. To a large extent, these fortune seekers, with their limited knowledge of geology or mineralogy, were looking for an environment favourable to mineralization, pursuing a certain type of stone or colour. Modern exploration does the same thing, but in a more sophisticated way. Recent advances in scientific knowledge about how and where mineral deposits form have given geologists intellectual tools their predecessors lacked. Theoretical and technical advances 54 Introduction to sustainability in geochemistry and geophysics have made it possible to delimit and focus search tasks. As important as they are to the well-being and improvement of modern societies, mineral deposits occupy less than one percent of the Earth's surface. Since these are found only where the vagaries of geological processes have deposited them, the benefits of the new information obtained from exploration must be weighed against the costs of resources and alternative uses of land assigned to mining. Secondly, scarcity, and the increase in prices that it entails, produces the necessary incentives to research and develop mineral extraction technologies. By way of example, it can be mentioned that the minimum concentration required for the profitable exploitation of a copper ore deposit fell from 3 percent in 1880 to 0.5 percent in 1960, and to 0.1 in 1985. In the same way, only twenty years ago the recovery factor of oil fields, that is, the amount that can be extracted profitably from a well, was 30 percent; today the average is around 45 percent and is likely to continue to increase in the coming years. All this has resulted in an effective increase in copper and oil reserves. Thirdly, scarcity is also related to the processing technologies for materials obtained from nature. Most of the minerals and energy resources are only raw materials for the elaboration of more complex materials that are used for consumption or for the production of other goods. Thus, iron is used in the production of steel, and crude oil to obtain gasoline. In this secondary treatment process there are also important possibilities for technical progress and, consequently, for the conservation of the remaining resources. As an example, we can once again use the oil industry. Crude oil, which is obtained directly from the subsoil, is a heterogeneous mixture of different hydrocarbons (that is, chains of different lengths from carbon to hydrogen atoms). The short chains, of up to four carbon atoms, are gases, those of intermediate length are liquids; the more viscous, the greater their length, from the shortest, such as gasoline, to the longest, such as waxes. Petroleum refining basically consists of the meticulous separation of hydrocarbons of the same length, forming homogeneous gases or liquids. This is how gasoline, kerosene, diesel oil, lubricants, etc. are obtained. The mix, and what can be obtained from it, is basically determined by the quality of the crude found in the reservoir, which poses a major economic problem. Gasoline, for example, is the product with the highest market value; but what to do 55 Resource usage, zero carbon and zero waste emissions with the other by-products? The desire to increase the proportion obtained from the most valuable components of petroleum has served to produce important technological advances in the recent history of the sector. Thus, to avoid unwanted surpluses, the long chains are broken to form shorter chains that allow, at the same time, more gasoline to be obtained and by-product surpluses to be reduced through techniques known as catalytic cracking. In addition to this, it is not only possible to increase the amount of gasoline obtained from a barrel of oil, but also to increase its power; this is achieved through the so-called hydrocarbon molecule reforming techniques, which, through chemical processing using heat and catalytic agents, manage to reform the C8 hydrocarbon, called octane, into isoctane that burns more efficiently and reduces gasoline consumption in automobiles. None of these techniques make oil more abundant in nature, but they do make it less scarce for society; in other words, they increase the level of well-being that we can get from the same amount of crude oil. Finally, in the definition of what we consider scarce or abundant, one must not lose sight of the fact that, at least in modern market societies, the production and commercialization of raw materials ultimately depends on the supply and demand of goods for whose elaboration these are used. Thus, for example, oil only became a commodity with economic value in the 19th century; precisely at a time when the whaling industry was beginning to be unable to provide enough oil to light the lamps of the world. In August 1859 Edwin Drake in Pennsylvania inaugurated a new era by digging the first oil well and a few years later the invention of the internal combustion engine made gasoline a vital element for transportation, and this demand has not stopped increasing ever since. Today, 70 million barrels are consumed daily in the world. However, as the demand grows, so does the technology of their use, with more efficient motors and lighter materials used in their construction. For all these reasons, with the exception of the 1970s, economically exploitable oil reserves have not stopped increasing, guided by exploration, the discovery of new technologies, and the substitution of materials. Exploitation costs and market prices In short, both the available information and the technological possibilities of exploiting and using the reserves must be reflected in the production costs and in the prices of the different resources. 56 Introduction to sustainability As companies are forced to mine for lower concentration materials further from the surface, or in more hostile environments, the effects of resource depletion will be felt in rising extraction costs and higher prices. However, as we have seen, these effects can be offset by other positive factors. Mining companies will add exploration and discovery efforts, and technological advances will make such materials usable (through more sophisticated mining techniques or new processing methods that increase the economic quality of the materials). Additionally, the market will react to price increases by searching for and developing substitute goods (new materials, or new uses for available materials), more efficient use of resources, or recycling activities. In general, the higher the market price, the greater the volume of reserves. For example, most of the oil fields currently in exploitation are between 900 and 5,000 meters deep; however, today it is possible to pump oil from 8 kilometres under the ground or the sea surface, as long as the better crude oil quality offsets higher pumping costs. All these ideas can be summarized in Figure 1, which presents the basic elements of the economic theory of scarcity that we have developed in this section. The diagram is adapted from the so-called McKelvey Box, used to clarify the distinction between reserves and resources. If the resources are a physical measure of the potential remaining reserves, the reserves are a social measure that depends on our degree of knowledge (represented by the upper arrow) and the economic viability of exploitation of the different deposits (represented by the vertical arrow). The basic purpose of McKelvey's system is to order all the necessary elements for long-term planning of the use of non-renewable resources, taking into account the evolution of prices, the probabilities of new discoveries, etc. Thus, both reserves and resources are continually underestimated in light of new geological evidence, technological progress, reserve extraction, and economic and political circumstances. All of the interior divisions of the McKelvey box are mobile and their dynamics must be explained in light of changing economic and political conditions. An overview In this section we have moved from a pessimistic point of view, which we illustrated with some of the conclusions of the Club of Rome, to another that can justify a certain optimism. However, it is necessary to mention some reasons for caution that should warn us against the 57 Resource usage, zero carbon and zero waste emissions danger of taking the optimism of our analysis scheme too far. McKelvey's box orders the available information, makes it possible to analyze with a certain logic what has happened in the past, and gives some clues about what will happen in the future. However, this scheme has limited claims to forecast the future. The relative success of the past is not a guarantee for the future. We cannot assume that technical progress in the future will occur at the same rate as in the past, or that all the problems of scarcity and the responses of society will be articulated in the years to come so harmoniously that there will be no shortage of materials and energy or severe environmental problems. 2.1.2. An analysis model The important question in the economics of non-renewable resources is: at what rate should they be exploited? That is to say: what amount must be extracted each year for current uses? Or how much should remain in the subsoil as a reserve for future uses? This question leads to another, equivalent one: what is the price at which units of each resource should be sold and how should this price vary over time? These issues are clearly normative; what interests us is knowing how resources should be used, and once we have a clear answer to this question, we will be able to judge the behavior of the market economy and assess the problems caused by the different property rights structures. Below we will first explore the basic model of natural resource management using the concepts of static and dynamic efficiency. Some basic principles Unlike other productive sectors, in the extraction of minerals the production at a given moment is not independent of the production in the past or of what will be done in the future. For many reasons, in decisions to extract minerals or non-renewable energy resources, it is necessary to take into account the close interrelationship between past decisions, present decisions and the possibilities that we leave open for the future. The cost of extracting a unit at present depends not only on the use of production factors, such as labour and energy, and on their prices, but also on the extractions carried out in the past and their impact on the current profitability of the products. 58 Introduction to sustainability Similarly, current extraction decisions depend on those made in the past, as well as expectations about future costs and prices. The current extraction rate will affect the amount that can be obtained in the future, and not only because the remaining reserves in each deposit will depend on it, but also because the current rate of decline in reserves may be an incentive to increase exploration and the development of activities that may lead to an increase in the future level of reserves. Furthermore, for a given level of currently known reserves, the decision to mine the deposits with lower extraction costs will leave only deposits with higher extraction costs for the future. Similarly, the reduction of the content of large ore deposits, and the tendency to concentrate exploration in the most accessible places, and where the richest deposits are most likely to be found, will lead to an increase in exploration costs in the future. The basic analysis model for the management of non-renewable resources that we develop below aims to account for these complex intertemporal relationships, in order to resolve the basic question of the rate at which the reserves of a non-renewable resource should be used. To do this, we will concentrate the analysis on a specific resource, of which we know the reserves currently available and their uses by the productive system. Thus, our problem is reduced to finding out, at each moment in time, how much must be withdrawn and, consequently, how much must be reserved for future periods. These decisions depend, first of all, on the existing demand in the economy for the resource in question. Non-renewable resources are basically productive inputs for the manufacture of other goods. Thus, iron ore is required to produce steel, which is then used for the manufacture of different machines and utensils. Crude oil is an input used to refine gasoline which, in turn, is required by others to meet the transportation needs of society. Consequently, the demand for non-renewable resources will depend on the value of the final consumer goods and the services that can be obtained from them. Given the technology of steel production, for example, it can be said that the iron and steel industry is more inclined to procure a larger quantity of minerals when the acquisition price is lower. We can then admit that the mineral demand function can be defined as a decreasing relationship between the market price and the quantity that firms are willing to buy. In addition to the usual reasons to justify the decreasing form 59 Resource usage, zero carbon and zero waste emissions of the demand function, in the case of minerals there is an additional reason: the fact that as the price increases, the recycling processes become profitable and, consequently, the used material gradually becomes a profitable substitute for the original raw material. The demand function allows us to explain why, at a certain moment, it is useful to extract minerals from the ground, but it does not tell us anything about the value of the reserves that remain buried, nor about the reasons that lead their owners to keep them. Natural resource economics treats "the resources in the soil" as capital assets for society. Society as a whole has reasons to preserve much of the resources to meet future demands. However, in a market society, where most mineral deposits are privately owned, these conservation decisions depend on the individual owners of each vein or each deposit. If the reserves in the ground do not produce any return, the owners of the same would prefer to extract them in the shortest possible time to make a profit that can be invested in a more profitable activity. However, things do not happen this way; for businessmen, and for society as a whole, waiting before running out of resources in the shortest possible time is a desirable and profitable solution. The reasons and incentives that exist to wait are the central argument of the basic model of the management of non-renewable resources. Let's look at these reasons assuming that, as is usually the case, the resource in question is privately owned. For its owner, a well, a vein, or a deposit is an investment, an asset, that provides benefits, and, from their point of view, it is comparable to other investments that provide financial returns in the economy. However, unlike a machine, or other assets, the resources that remain buried do not produce any income until they are extracted and offered for sale. In a market economy, there is only one reasonable reason for the owner of a mineral deposit to decide to hold it, and that is for the asset to increase in value over time. The only reason to keep most of the reserves of non-renewable resources unexploited is that the financial return that can be obtained from them in the future is higher than the one that can be obtained at present. The Basic Model To keep things simple, let us assume that mineral reserves can be extracted at no cost and that no new reserves are to be discovered, nor is change in future mineral demand to be expected. In this case, the 60 Introduction to sustainability only reason to save reserves for the future is the expectation that the sale price of the mineral will increase. The amount that business people decide to extract will depend on their expectations regarding the increase in prices. But such expectations are far from being something immutable and, at all times, they must be reviewed and corrected based on the decisions that other business people are taking and, in short, on the evolution of the mineral market. For example, suppose that business people expect the price of mineral to rise very little, or not at all, over the next few years. In this case, it is logical that many of them will choose to extract and sell all their reserves as soon as possible, in order to transfer their capital to a more promising alternative. However, this reasonable decision will only create a situation in which everyone will be forced to modify their expectations and present decisions. The increase in production will create an excess supply in the market, which will momentarily decrease the sale prices of the ore, but will also make a shortage of minerals foreseeable in the following years, making a future increase in prices plausible. These effects, the decrease in current prices, the result of overproduction, and the expected increase in future prices, the result of greater scarcity, restore the incentives to conserve a greater quantity of minerals in the soil and will serve to adjust the patterns of production. In general terms, we can say that the above situation will be what happens when business people expect the price of minerals to grow at a lower rate than the interest rate in the economy. We can also think of a completely opposite example to the previous one. Suppose that business people expect that, due to past depletion of known deposits, prices in the future will be much higher than today. If so, the logical decision for them would be to wait, keeping the unexploited minerals to sell in the future at a higher profit margin. However, as in the previous case, these decisions will not be stable and the market itself will be in charge of forcing companies to review them. If many reserves are left for the future it will not be reasonable to expect very high prices in subsequent years; on the other hand, the current market will be depressed and, consequently, the current price of minerals will increase. By increasing the current price and reducing the expectation of very high prices in the future, new incentives will be created to extract more resources in the present moment. This situation will be the one that occurs when business people initially 61 Resource usage, zero carbon and zero waste emissions expect the price of minerals to grow at a higher rate than the interest rate in the economy. Between the two extreme cases, there is an intermediate situation that can be maintained over time, extracting a sufficient quantity each year so that mineral prices grow at the same rate as the interest rate in the economy. This is the central idea of the so-called Hotelling'S Rule: according to this rule, the optimal pattern of exploitation of a natural resource is characterized by the fact that, over time, the marginal benefit that can be obtained with the extraction and sale of the resource must grow at the same rate as the interest rate. In our simple model, since the extraction costs are zero, the profit is equal to the sale price. To clarify the meaning of Hotelling's rule, we can see some of its more general consequences with the help of Figure 2. According to the demand curve, the only way to increase the price of the mineral is by decreasing the amount that is extracted year after year. For this reason, Hotelling's rule also means that, with our restrictive assumptions that we will clarify later, the amount of the mineral that is extracted each year is less than that of the previous year. This is illustrated in Figure 2, in which three fundamental elements are related to understand the pattern of exploitation of a non-renewable resource in a market economy: ● firstly, the demand for the resource, shown in panel (a); ● secondly, the price growth pattern, according to Hotelling's rule, in panel (b) and, ● thirdly, the two previous elements are related in panel (c) where the price pattern is represented, decreasing extraction over time. In short, in the optimal pattern of resource extraction, as price increases, the quantity demanded gradually decreases, and with it decreases the amount of material removed from the soil. Let us now complete the basic model with two important elements, the possibility that in the future we can do without a specific non-renewable resource and the total volume of reserves that we can exploit from it. Regarding the first, the technological knowledge that we have makes it possible to think that, if the market price is high enough, some of the resources that today seem essential for the normal functioning of the economy could no longer be so. This is because there 62 Introduction to sustainability are technologies that would make it possible to satisfy the demands of society in a more adequate way using some alternative resource.

These production processes, which make it possible to produce without a natural resource are known as replacement technologies. Many of them are known and have passed the test studies necessary for their development. Several renewable energies fall into this category, and other similar options have already been adopted by society in the past, such as the substitution of synthetic fibres for rubber, or of natural fertilizers for chemical fertilizers. In the simple model of analysis, the replacement technology can be represented through a price, sufficiently high, which would make the demand for the mineral in question zero, as represented in panel (a) of Figure 2. This price, in practical terms, represents a threshold, beyond which the mineral deposit ceases to have value for its owner. Once replacement technology is activated and becomes widespread, resources that have not been exploited will become worthless. This allows us to qualify the first result of Hotelling's rule: mineral prices should grow at the rate set by the interest rate, and should approach the price of the replacement technology as the remaining reserves approach zero. 63 Resource usage, zero carbon and zero waste emissions The Hotelling model aims to show us the optimal pattern for the extraction of a natural resource throughout its useful life. That is, during the entire period of time in which such a resource is used by the economy. The duration of that period of time will be determined, apart from the demand and the exploitation technology, by the amount of available reserves. These reserves will be equal to the sum of all the amounts that are extracted from the present moment until the moment in which the company can dispense with the resource, which is represented by the shaded area in panel (c) of Figure 2. We already have the analysis model for the economic management of natural resources completed. If we had all the necessary information, we could say that as a non-renewable resource is used, prices must rise at the rate of discount, reflecting the increasing scarcity. At the same time, the rate of extraction must decrease as the resource is depleted and its price converges to that which allows a smooth transition to a new technology that makes it possible to do without it. To develop our basic model we have made some restrictive and unrealistic assumptions, especially in an analysis period as long as the time it will take humanity to extract the last particle of iron or burn the last barrel of oil. We have assumed, first, that mining costs are zero, that current and future mineral demand can be represented by a stable curve over time, and that the interest rate, or discount rate, is stable. Second, we have implicitly assumed that there is a perfectly competitive market, which excludes monopolies and any other barriers to trade. Finally, we have also assumed that we have all the information on the amount of reserves available, and on the technologies of exploitation, use, and replacement of the non-renewable resource. All the aforementioned assumptions allowed us to obtain a relatively simple answer to the question of how fast we should deplete a non-renewable resource and, in particular, the assumption of complete information, allowed us to deduce how much should be consumed each year and at what price it should be sold. It would be naive not to recognize that these assumptions are wrong. However, the usefulness of our model is not that it faithfully represents the reality in which we live, but rather that it provides us with a basic analysis tool that, while offering us simple answers, we can expand in many directions by introducing all the complications that we have mentioned and for which there are answers in the most advanced texts on the subject. 64 Introduction to sustainability The answer that our society can give to the problem of the depletion of natural resources will necessarily depend on the information that we currently have. This also means that our forecasts on the path of depletion of a non-renewable resource must be constantly revised whenever this information changes. For this reason, the efficiency path that we have defined is surprisingly vulnerable to any change in the starting conditions, for example, in the volume of known reserves, in the demand for minerals, or in replacement technologies. By way of illustration let us see what happens in the third of the mentioned cases. Let's suppose there is a new discovery that makes it possible to find a way to replace gasoline as fuel for automobiles and that, although it is more expensive than the current market price of gasoline, it is cheaper than obtaining the same fuel with known coal liquefaction techniques. In other words, it will no longer be necessary for the price of a barrel of oil to reach the substitution price for us to decide on a massive change of fuel. What consequences will this circumstance have on oil reserves and extraction? The first consequence is that, although the physical quantity of oil in the subsoil is the same as before, oil will now be a less scarce resource than before; the effective possibilities of maintaining our well-being without oil are now greater than before. This will necessarily have consequences that will affect the prices of a barrel of oil. If the current growth in prices continues, the time will soon be reached when we will not require oil to produce gasoline and, at that time, untapped reserves will be left in the ground that will be worthless to the owners of the oil wells. For that reason all forecasts will have to be revised, it will be necessary to speed up the rate of extraction, which will lead to a revision of current and future prices, and probably also reduce the useful life of the oil. The example is only intended to illustrate a characteristic of Hotelling's rule: the path of exploitation of a non-renewable resource changes with each new circumstance and must be revised with each discovery of new reserves, of new technologies, or with each change in total demand. 65 Resource usage, zero carbon and zero waste emissions 2.2. Zero carbon Carbon neutrality, zero carbon footprint, net zero or climate neutrality refers to achieving zero net carbon dioxide emissions by balancing the amount of carbon dioxide released into the atmosphere with an equivalent amount removed from the atmosphere, or fixed by plants, or by purchasing enough carbon credits. The term “carbon neutral” is used in the context of processes associated with the emission of carbon dioxide, such as transportation or energy production using fossil fuels (coal, oil or natural gas). It should be clarified that in the context of climate change, energy, atmosphere, etc., when you say “carbon”, you are generally talking about carbon dioxide ($CO_2$ ), a chemical compound, gaseous at room temperature; while in other contexts (biology, organic chemistry), when one says “carbon”, one alludes to a chemical element, the sixth in the periodic table, with the symbol C, and with properties totally different from those of $CO_2$ . The concept of carbon neutrality can be extended to include other greenhouse gases (GHGs) measured in terms of their equivalence to carbon dioxide ($CO_2$ e) – the impact that a GHG has on the atmosphere expressed in the equivalent amount of $CO_2$. For example, methane produces a greenhouse effect 21 times greater than $CO_2$. Therefore, if some emissions consist of one tonne of $CO_2$ and one tonne of methane, they will add up to 22 tonnes of carbon dioxide equivalent ($CO_2$ e). The term climate neutral reflects the inclusion of other GHGs. Although $CO_2$ is the most abundant, other GHGs regulated by the Kyoto Protocol are methane ($CH_4$ ), nitrogen oxide ($N_2O$), hydrofluorocarbons (HFCs), fluorocarbons (PFCs), and sulphur hexafluoride ($SF_6$ ). Best practice for organizations and individuals seeking to become carbon neutral involves first reducing or avoiding as many GHG emissions as possible, so that afterwards they only need to offset unavoidable emissions. Neutrality is generally achieved in two ways: ● Using only renewable energy, which does not produce carbon dioxide (this is also called a low-carbon economy, a decarbonized economy, or a post-carbon economy). ● Carbon offsetting – paying others to capture and store 100% of the carbon dioxide emitted into the atmosphere (for example by planting trees) or financing carbon projects that should lead to preventing future emissions, or buying 66 Introduction to sustainability carbon credits, which, in practice, are rights to emit GHGs, and there are a limited number of them in the emissions market. If someone buys them, and does not emit those GHGs, the amount of GHGs emitted will be reduced by that amount. The practice of these offsets has received some criticism. The term carbon neutrality was the 2006 word of the year for the New Oxford American Dictionary. Carbon neutrality is typically achieved by the following steps (although they may vary depending on whether they are taken by individuals, businesses, organizations, cities, regions, or countries): Commitment For individuals the decision is likely to be straightforward, but for more complex ensembles it usually requires political leadership at the highest level and broad popular agreement on the validity of the effort. Computation and analysis Quantifying and analyzing the emissions that must be eliminated, and the options to do so, is the crucial step in the process, because it allows setting priorities for action – from the products that are purchased (some have a larger carbon footprint than others) to the energy production, use and transport – and beginning to measure progress. This can be achieved through a GHG inventory that answers questions such as: ● What operations, activities and units should be included? ● What sources should be included? ● Who is responsible for what emissions? ● What gases should be included? For individuals, carbon calculators can make it easy for them to compile an inventory of their emissions. They typically measure electricity consumption in kWh, the amount and type of fuel used for heating and hot water, and how many miles the individual drives, flies, and rides in other vehicles. Individuals can also set various boundaries on the system where they move, e.g. personal GHG emissions, emissions from home, or what company they work for. Many carbon calculators are available on the Internet, which vary significantly in their usefulness and the parameters they measure. Some only take 67 Resource usage, zero carbon and zero waste emissions into account cars, planes and household energy. Others also cover household waste and leisure. In some circumstances, a goal is set to go beyond carbon neutrality (usually after a certain amount of time to achieve it) and begin to reduce carbon dioxide in the atmosphere, rather than just not increasing it. Although some individuals, companies or countries have reduced their emissions, even considerably, the concentration of carbon dioxide in the atmosphere continues to grow. Action To start moving towards climate neutrality, companies and local governments can use an environmental or sustainability management system (EMS) established by the international standard ISO 14001 (developed by the International Organization for Standardization, ISO). Another EMS framework is EMAS, the European Eco-Management and Audit Scheme, used by many EU companies. Many local authorities apply EMS to certain sectors of their administration, or even certify (i.e. they have all their operations examined by an independent auditor) against one of these standards. Reduction One of the strongest arguments for reducing GHG emissions is that it saves money. When energy prices engage in one of their frequent upward cycles (often fuelled by rising oil prices), it becomes more expensive to travel, heat and light homes and workplaces, and run a modern economy. So, it is both common sense and climate wise to use energy as sparingly as possible. Examples of actions to reduce GHG emissions are: ● Limit energy consumption and emissions from transport (using – instead of a private vehicle – bicycles, public transport or your own feet, avoiding plane journeys, using low-consumption vehicles), as well as from buildings, equipment, animals and processes. ● Get electricity and other energy from a renewable energy source (for example, a solar thermal installation), either directly by the end user of the energy (such as installing photovoltaic panels on the roof of your house), or by selecting a certified green energy supplier. Another proposed method is to use alternative low-emission fuels, such as sustainable 68 Introduction to sustainability biofuels, but these are controversial because they can result in a net increase in emissions, as well as increased food prices and deforestation. Compensation The use of carbon offsets is intended to neutralize a certain volume of GHG emissions by financing projects–such as planting trees–that should result in lower emissions elsewhere. Under the "first reduce what you can, then offset the rest" premise, offsetting can be achieved by supporting a responsible carbon project, or by purchasing carbon offsets or carbon credits. Carbon offsetting is also a tool for various local authorities around the world. Compensation is sometimes seen as a contentious and biased issue (whoever talks about it belongs to a certain faction). For example, James Hansen describes the offset as "modern indulgences, sold to an increasingly emissions-conscious public to absolve its climate sins". Indulgences are a mechanism of the Catholic Church to exempt recipients from the temporal penalties that sins entail. Its highly criticized abuse gave rise, along with other factors, to the Protestant schism. Evaluation and repetition This phase includes evaluating the results and compiling a list of proposed improvements, with the results documented and reported, so that experience of what works (and what does not) is shared with those who can put it to good use. Finally, with everything completed, the carbon neutrality process begins again, this time incorporating the lessons learned. Science and technology advance, regulations (for example, on emissions) become stricter and the standards demanded by the population rise. So, the second cycle will go further than the first, and the process will continue, each successive phase building on and improving on the previous one. 2.3. Zero waste emissions Zero waste refers to the principles that encourage the reuse of products so that they do not return to nature in the form of waste or garbage. 69 Resource usage, zero carbon and zero waste emissions In this paradigm, the life cycle of objects would be lengthened by recycling, and it requires including in their composition as many biodegradable materials as possible that do not harm the planet. This is a very different model from that in which most products are wrapped in or made of plastic (which takes between one and four centuries to degrade) and other polluting substances. According to the Zero Waste International Alliance (ZWIA), it is about achieving "the conservation of all resources through the responsible production, consumption, reuse and recovery of all products, packaging and materials, without burning them and without dumping them on the ground, water or air so that they do not threaten the environment or human health". For ZWIA, achieving that goal calls on producers and manufacturers when they decide whether or not to follow these principles, but it is also in the hands of each consumer, with regard to the commitments favourable to that cause. The change in habits and priorities calls for the whole of society to act, and institutions and governments play a key role in applying regulations related to zero waste, as well as tax incentives and support for less polluting activities. The model is summarized in these concepts: ● Reject what is not needed. ● Reduce what is needed. ● Reuse all kinds of materials, packaging and containers (with the recommendation of consuming second-hand products). ● Recycle everything that cannot be rejected or reduced. ● “Rot”– the action of decomposing or composting organic matter to obtain natural fertilizer. The problem is that, despite these initiatives, waste is increasing at a worrying rate. According to the World Bank, cities alone generated 2,010 million tonnes of solid waste in 2016 (0.74 kilos per person per day). If a global zero waste policy is not successfully promoted, that number would reach 3.4 billion tonnes by 2050. 2.4. Plastic recycling How is plastic recycled and what is its purpose? This material poses a threat to ecosystems, especially to marine life. It is in the seas and oceans where the bulk of this type of waste is deposited, sometimes on the seabed in the form of microplastics. Reducing the consumption 70 Introduction to sustainability of packaging, using recyclable bags, and recycling plastic is key to helping the planet. What measures are being taken? For example, charging for plastic bags in stores and supermarkets to reduce their use, since they are among the objects that pollute the oceans the most, along with cigarette butts, food wrappers and plastic bottles, according to the Ocean Conservancy. Reducing the use of bags is also the goal of a European Parliament directive (from 2015) that includes industrial incentives to develop less polluting alternatives and the collection of 90% of plastic beverage containers (those for single use) by 2025. Some countries legislate with the same objective. For example, Spain plans to ban “the use, marketing, import and export of utensils such as plates, glasses, cups, cutlery and disposable straws, designed to be removed after a single use, entirely made of any variety of plastic ”. These utensils would have to be made with at least 50% biodegradable materials. Information and the circular economy Conservation associations such as EcologistasenAcción call for improving product labelling so that consumers are aware of the environmental impact, including waste, of what they buy, and they warn that materials that are advertised as biodegradable turn out not to be so. For example, biodegradable plastics have emerged, made from organic products such as cassava, corn or wheat, but the United Nations Environment Program (UNEP) has pointed out secondary effects, such as the difficulty of their degradation in the sea or the increase in the cultivation area necessary to cover the demand. Therefore, in addition to the five R’s in consumption, there should be a paradigm shift towards the circular economy: “The model of production and consumption that involves sharing, renting, reusing, repairing, renewing and recycling existing materials and products as many times as possible to create added value and extend the product life cycle”, as defined by the European Commission.