Environment and a sustainable technologic growth

How technology may be a solution and not necessarily a problem

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ABSTRACT
This work concerns the relations existing between technology and the environment and has the aim to show how fundamental aspects of the nature of technology, studied by technology dynamics, make possible a sustainable technologic growth and environment protection at the same time. The study discusses the environmental critics to technology, the necessity of a scientific approach to public environmental controversies and limits of application of the precautional principle. The work considers then two approaches to form an environmental technological ecosystem: the circular industrial economy and the natural capitalism discussing the technological aspects in reaching their objectives, showing how the reaching of a full mature circular industrial economy is hardly feasible for thermodynamic reasons requiring enormous amount of energy for a full recycling. The study considers also how technology might supply solutions to the three major global environmental problems: pollution, depletion of resources and global warming. In particular, concerning global warming, the study critics the Kyoto Protocol for the approach, mainly political, instead of a technological approach representing actually the valid possible solution of global warming. That has led to a situation, after near thirty years from the convention of climate change, characterized by development of environmental technologies essentially only for a direct production of electrical energy from sun or wind. These technologies may contribute to the production of energy but appear unsuitable for a full substitution of conventional productions because of the discontinuous generation of electric energy necessitating important storage systems still under development. On the contrary, there has been a limited development effort on more efficient technologies in converting directly solar energy into chemical energy, as in photosynthesis, without these problems. Furthermore, global warming problems are dealt by industrialized countries promoting essentially policies with only local salutary effects, but not taking account of the possible future increase of energy demand in developing countries that might influence greatly the global warming, especially in absence of valid available environmental technologies for the satisfaction of their needs of energy.

KEYWORDS: technology transfer, literature overview, public research organization, qualitative studies, case studies, universities.

JEL CODES: O13, O14, O33, Q01, Q20, Q41, Q55, Q57, Q58

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1 INTRODUCTION

The knowledge of the basic processes and structures of technology, resulting from technology dynamics studies (Bonomi 2020), allows to deal, from a technological point of view, with the major questions concerning the relation existing between technology and the environment, with the objective to show how fundamental aspects of the nature of technology make possible a sustainable technologic growth forming an ecosystem in which technology and economy, would not find a compromise with environmental needs and protection, but supplying integrated solutions unifying these activities at all levels. It should be noted that there are many important environmental problems concerning aspects such as biodiversity, deforestation, conservation of land, etc., however we limit the study to technologies concerning mainly industrial activities, production of energy, transportation and domestic consumptions with their direct effects on the environment. Actually, this article is based not only on documentary studies, but also on field direct experience concerning environmental R&D projects for industries, carried out in the 70' at the Battelle Geneva Research Centre, with unpublished results with the exception of a work about solar thermal energy storage (Breda, Bonomi 1978), followed by a consulting activity concerning urban and industrial waste treatments and recycling with studies published mostly in the proceedings of the annual environmental meetings called RICICLA and after ECOMONDO (Bonomi 2000, 2001, 2002, 2003a, 2003b, 2005), including a study on technology for the elimination of lead pollution of drinking water (Bonomi, Riu 2004), and finally studies about management of environmental technologies (Bonomi 2004) and of R&D (Bonomi 2006), and relation of technology with the environmental problems (Bonomi 2012), showing that technology developments may be a solution and not necessarily a problem in environmental protection. However, it shall be noted that considerations and suggestions that may be derived from this study are coming from a technological point of view, and are not entering in social or political aspects leading to a specific environmental policy, but only giving a contribute concerning the technological factors and suggestions that have an impact and should be considered in the elaboration of an environmental policy. This work considers the existence of three major global problems related to the environment and consisting in: pollution, depletion of resources and global warming. Then it discusses, from the technological point of view, two approaches proposing an integrated solution to these problems taking account of both environmental and economic aspects. These approaches are the *Circular Economy* (Stahel 2019) and the *Natural Capitalism* (Hawken et al.1999) models, the first one raising a particular interest nowadays in Europe. These two approaches are examined in relation with their technological aspects involved in the realization of their objectives. The discussion on these models will after be useful to elaborate the possible contribution of technology to the solution of the global environmental problems cited previously.

This article is composed by six sections. After this introduction in the second section it is discussed the technological approach adopted in this study. In a third section is discussed the position of environmentalism about the deleterious effects of technology use, the contribution of science to the environmental controversies and the application of the precautional principle with its limits. In the fourth section we discuss the two approaches to environmental problems solutions constituted by the Circular Economy model and the Natural Capitalism model and comparing their potential efficiency in reaching their objectives from a technological point of view. In the fifth section we discuss possible solutions to the three cited environmental global problem and the condition with which technology may contribute to their solution. In the conclusive sixth section we present the major results of this study about a sustainability based on a technologic growth.

2 A TECHNOLOGICAL APPROACH TO THE ENVIRONMENTAL PROBLEMS

Environmental problems are largely studied in particular from a social and economic point of view. Technology is also of course considered in environmental studies, however that is done through two opposite views. The first one, typical of a certain environmentalism, considers technology the basic source of environmental problems and for these reasons shall be limited in the use without considering the possibility to develop alternative technologies free of environmental damages. The other one considering that it would be always a technological solution, being the necessary efforts in R&D made, however without entering in detail about limits and difficulties of finding the technological solutions, and that is a position existing for example in the Circular Economy model. These two positions, in a certain manner in contradiction, are in fact the result of a lack of knowledge of basic aspects of technology and its dynamics. Actually, in the study of technology, there is a gap between the field of studies concerning the development of specific technologies, intended as use of scientific results for this purpose, and the diffused studies generally limited to the effects of technology in the economic field, and how economy influence the technological change in facing environmental problems. In fact, the process generating genuine, original technology innovations is not well understood, and that hinders a valid estimation of technology potential and its limits in the solution of environmental problems. The covering of this gap of knowledge is the aim of studies on technology dynamics looking for the basic aspects of technology not necessarily limited by economic purposes as done in the major part of studies on technology effects (Bonomi 2020). In fact, the relation between environment and technology shall be considered taking into consideration the basic nature of technology and its potential in supplying technological solution to environmental problems in the frame of the existing natural physical limits. Technology dynamics considers technology a human activity to fulfill a human purpose (Arthur 2009). It shall be noted that technology dynamics studies do not enter into the nature and origin of the technological purposes, that depend on social, economic, etc. factors influencing technology evolution, but limits the study of technology to its materiality considering technology a process producing artefacts and their use. Technology innovations are considered the result of combination of preexistent technologies exploiting new phenomena discovered by science (Arthur 2009), but also only simple combinations of preexistent technologies in which phenomena discovered by science are possibly present only in the combined technologies (Bonomi 2020). All that leads to a scientific definition of technology as a set of physical, chemical and biological phenomena producing an effect that may be exploited to fulfill a human purpose not necessarily economic (Bonomi 2020). These definitions confirm also the neutral nature of technology, and in fact the positive or negative effects of use of a technology are due to the specific purpose of exploitation of its effects, and not by the existence of these effects. Actually, although generally a technology is developed for a specific purpose, that does not hinder the fact that it may be used for other completely different purposes showing its neutral nature, and the separation of technology from the purpose of its use (Bonomi 2020). The fact that it is not known another purpose for the use of a technology it does not mean that it is demonstrated its inexistence. A simple example of different purposes for the same technology is the bow and arrow that may be used to kill a prey assuring survival or to kill a man during a fight, but there are other examples: missile technology may be used for bombing during a war but also to put in orbit a useful satellite for meteorological applications or communication, the use of the atomic bomb in a war may destroy the humanity but it might be used also to vaporize an asteroid precipitating on the earth saving the humanity. The neutral nature of technology is often not considered by environmentalists, misleading a correct evaluation of the environmental problems and their possible solutions. Considering now potentiality and limits of technology for the solution of environmental problems, technology dynamics takes account of the combinatory of generation of new technologies that make available an enormous combinatory number of potential technologies, of course not necessarily all valid, but in which it is possible to find the right one. That is accompanied by a continuous progress of scientific knowledge that makes available an increasing number of phenomena exploitable for new technologies. Furthermore, technology dynamics shows that the innovation process, in particular R&D activities and the use of technology through the learning by doing, is generator of knowledge and innovative ideas. That may trigger an autocatalytic process in the generation of further new technologies if the necessary amount of innovation financing would be available (Bonomi 2020). The nature of technology and its potential in the generation of new technologies are then major factors to be considered for the solution of environmental problems although limited by scientific principles that shall be respected and, in particular in the case of the environment, by thermodynamic considerations.

3 ENVIRONMENTALISM AND TECHNOLOGY

3.1 Environmental critics to technology

A first critic of environmentalists to technology concerns the fact that humans undergo to natural laws and shall adapt themselves to the environment but, on the other side, humans are the only biological entity able to modify deeply the environment, not necessarily in the right way, in which they live. Human technology may then act negatively on two fronts, from one side it may pollute and deprive resources of the environment, on the other side the creation of a uniform and agreeable environment joined with progress of medicine decreases the selective pressure on natural biological evolution weakening genetically the population. It should be recognized that environmentalism has given an important contribution in signalling environmental problems and condemning certain uses of technology producing pollution, wastes, and depletion of resources, however, sometimes the neutral nature of technology has not been recognized, and technology assimilated to the problem not separated by the purposes of its use as discussed in the previous chapter. The consequence of this environmentalism, that may be called ideologic, has been the raising of a negative prejudice leading to consider as a solution of environmental problems just simply the elimination of the detrimental technology and not its substitution. Another typical criticism of environmentalists concerns the negative aspects of search of a continuous economic development, associated indirectly to technology development, that appears in contrast with a real growth of the welfare of the society and should be substituted by a new type of development taking account the environment, i.e. a *sustainable development*. The question in the reality does not concern directly technology, considering its neutral nature, but the responsibility of the objectives and the ways with which are used its effects in satisfying the various human purposes. All these considerations are object of public controversies of environmental nature, however not always based on a scientific approach, and with aspects that may be useful to discuss.

3.2 Environmental controversies

Before entering in our discussion on the nature and resolution of environmental controversies it is necessary to consider that in our discussions science and the scientific method represent the best means developed by humans to explain and make forecasting about natural phenomena with the highest allowed probability of success, in respect to any other approach based on simple considerations and ideas of various origins. Controversies appear not only about technologies associated to environmental problems but also in scientific fields, and it is useful to explain how they are solved through the application of the scientific method that has accompanied the development of the modern science. In the evolution of the scientific research there is often the appearance of controversies characterized by existence of opposed hypothesis for the explanation of a natural phenomenon that become polarized into two or plus conflicting positions constituting a controversy that evolves accompanied by studies and research. This activity is continued until the achievement of final results demonstrating the validity of one hypothesis of the controversy. This result is normally accepted by all or almost all the involved parts, and that is possible because all parts accept to examine the results following a common scientific method of evaluation. The validity of the result depends on its possibility to show definitely the validity of a hypothesis, and not by the number of studies made but that do not have given definitive results about the different hypothesis under study. An historical example of scientific controversy has been that about the spontaneous generation of simple forms of life apparently demonstrated by experiments of Béchamp on vegetal products. Pasteur contested this theory and succeeded in 1864 in rejecting the theory of spontaneous generation by boiling the material in a flask with a gooseneck, destroying bacteria but at the same time avoiding contamination from air. Actually, the solution of a controversy from a scientific point of view may last a long time waiting for the appearance of final decisive results. In the environmental field there is also the appearance of controversies that concern dangers for the human health or the nature, and the controversy concerns whether the use of a technology or its product is safety or not, and then the necessity to take a decision on its use or not use. Often in an environmental controversy, that is of public domain, there is the appearance of two positions, one resulting sometimes by an ideological environmental view that considers technology always as a problem for the environment and that it is necessary to avoid any risk by limiting its use. The other one takes account that the use of certain technologies may be a problem for the environment but that other technologies may be developed in alternative without damages for the environment. As a technology, or its products, is the effect of a set of physical, chemical and biological phenomena used for a certain purpose, the scientific aspects of a technology or of its products have a great importance in the solution of an environmental controversy that is conditioned in fact by the acceptation of the scientific method of evaluation. Actually, ideological environmentalists often consider as definitive the results of studies carried out in a controversy just because these results agree with their ideology before they may have a true scientific demonstration following the scientific method. Sometimes, in their articles and books, this type of environmentalists sustains arguments in clear violation of scientific principles because they disagree with their ideology. An example is that about the environmental role of entropy in the earth system (Rifkin 1980), misinterpreting the nature of this thermodynamic function, and rejecting the results of Ylia Prigogine, a Belgian chemist of Russian origin, Nobel Prize in chemistry for his studies in this field. Environmental positions are sustained often by presenting the dangers of use of a technology but not considering the problems raised by the not-use of the technology that in fact may be difficult to estimate but not necessarily not existing and negligible. Actually, this type of ideological environmentalism is fundamentally antiscientific forgetting the fact that science and technology, although not always in measure to give an answer, are nevertheless the better way to make explanations and forecasting of what it happens, assuring at the same time, by a correct use of technology, the survival and improvement of the conditions of human life. An important difference between the scientific controversies and environmental ones is the fact that often it is necessary to take a decision about the use or not use of a technology or its product before that this decision would be supported by scientific results. In this case a decision may be taken considering what it is called the *precautional principle* that has however quite complex conditions of application explained in the next paragraph.

3.3 The precautional principle application

For a definition of the precautional principle it is possible to consider the Rio Declaration on Environment and Development of 1992 that formulates the principle in this way: *in order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.* The precautional principle has been originally proposed by Hans Jonas, a German philosopher (Jonas 1979), scholar of Martin Heidegger, finding a great diffusion among the nascent environmental movements. Hans Jonas with this principle contested the utopic believing, typical of the modern Western civilization, in a technology able to solve all the problems it creates. He considered that it is not correct to look only at the past or present consequences of our actions, but it is necessary also to consider the consequences in a far future that are outside of a possibility of reparation. The technology, undissociated from science, with the uncertainness of its consequences in the far future, poses questions of ethics for the humanity. In fact, if it is not possible to know the far future of our actions on the nature and the mankind, it is necessary to face this unknown by another form of anticipation such as a precautional principle. It is interesting to note that this principle could be overturned with the same type of arguments affirming that the *not-use of technologies* might leave consequence in the far future, outside the possibility of reparation because of the aleatory behaviour of the nature generating not frequent but extremely dangerous events, such as the recent pandemic diffusion of COVID19, for which technology instead might supply a solution. Nevertheless, the attitude of Hans Jonas however, differently from the position of many ideological environmentalists, does not contain in fact any disapproval to science and technology, as it would not be possible to build up a system more respectful to the environment without a scientific and a suitable technical effort (Bourg 1993). From the scientific point of view the precautional principle presents a certain number of interrogatives. Although being a very reasonable principle, it does not contain any real indication about the conditions it could be applied in practice becoming consequently the source of various interpretations that, in the case of ideologic environmentalism, would lead practically to the arrest of any technological development to comply the absolute absence of any technological risk. This problem is present also in some governmental regulation, for example in the 1998 a directive of the European Union establishes the principle as *a decisional norm that may be applied in situations of scientific uncertainty having the necessity to carry out actions facing a serious potential risk without waiting for results of scientific research.* This norm was specified later affirming that the recourse to the principle *presume the identification of potentially negative effects derived by a phenomenon, a product or a procedure, as well as a scientific evaluation of risk.* Actually, this norm, as other norms on the precautional principle, may be criticized from a methodological point of view as they leave undetermined the degree of scientific evidences necessary for a sanitary or environmental risk to be declared identified, and how much scientific evidence should lack to consider that a phenomenon or a human activity could be declared harmless, taking account that science cannot by principle demonstrate the complete absence of effects but only their presence. Actually, certain interpretations of the precautional principle are based on results of statistical correlations assuming the existence of a relation cause-effect derived by epidemiologic studies that would show some deleterious consequences by the use of a technology or a product. However, from a scientific point of view, an epidemiological study in the determination of a relation cause-effect is not equivalent to a laboratory experiment in which the conditions are highly controlled. On the contrary in the epidemiological studies it cannot be excluded the presence of unknown or undetermined factors that may influence the results, that is particularly valid when the correlation is statistically weak. For these reasons, from a strict scientific point of view, the existence of a relation cause-effects indicated in an epidemiologic study may be really confirmed only if the process involved in this relation is known. Then the existence of a statistical correlation cause-effects may be considered just an indication that, dependently on the statistical importance of the correlation, suggests or not studies on the process that is at the origin of the effect. In fact, following the previous considerations, the precautional principle opens controversial situations in which opinions without any scientific base may be raised to justify the application of the principle, that in disagreement with a reality in which science, although with certain limitations, remains the best way for the humanity to explain and make forecasting on the behaviour of the nature. Actually, the strict generalized application of the precautional principle, outside the guide of a scientific view, would lead to a triggered cycle of events concerning technology innovation in which this activity would be continuously hindered until its arrest with a nefarious influence on exploitation of future utility of technologies. In order to explain in practice an example of the paralyzing effect of a strict application of the precautional principle we describe the case of supposed deleterious effect of microwaves in communication for which the opponents require a moratorium of their use waiting for that science could demonstrate their harmless. For a full explication of this example, showing the limits of the precautional principle, it is necessary to enter into details on physics of microwaves that may be fully appreciated by readers with a scientific and technical education. From the scientific point of view the interaction of electromagnetic waves with matter is described by quantum physics that considers these waves having a double nature of oscillation of an electromagnetic field at a certain frequency, and at the same time the nature of discrete packets of energy called photons. The energy of each photon increases with the frequency of the wave and an interaction with matter is possible only if the energy of each photon is high enough to produce a physical or molecular interaction. That means that the interaction with matter is possible only if the frequency of the wave is sufficiently high, and in this case the effects will increase with the intensity of the wave and then with the number of photons that reach the matter. If the energy of the photon is lower to produces an effect, the interaction cannot occur independently of the intensity of the wave or the number of photons reaching the matter. Actually, considering the molecular composition of living matter, only electromagnetic waves with high frequency such UV, X rays and gamma rays can disrupt molecular bonds making damages. Electromagnetic waves of lower frequency, such as infrared waves, may only tune with vibration of chemical bonds or rotation of molecules provoking a heating effect. Microwaves have a frequency lower than infrared waves and have only a weak heating effect that decreases with the decrease of their frequency. In order to have an effect of microwaves on living matter it is necessary to have a low energy molecular phenomenon that tunes with the frequency of micro-waves generating an effect potentially dangerous. Actually, science cannot advance at the moment any realistic hypothesis about the type of molecular phenomenon able to tune with microwaves, nor demonstrate absolutely its inexistence. Consequently, science cannot plan any experiment showing the existence or not existence of such phenomenon giving an answer to the questions raised by opponents to microwaves invoking the precautional principle. It may appear a paradox that matter may be crossed by a large number of photons with a relatively great total amount of energy without effects, but that is an apparent paradox typical of quantum physics opposed to common feelings (Albert 1992). This example shows well the impasse of application of the precautional principle when it is not clear what is the possible provoked process of damage of a technology. This situation is different from the case of technologies or products that have known methods for the determination of their dangers, and it is then reasonable to wait for the results before the use of the technology or the product. Furthermore, it would be useful in every case to consider not only the potential hypothetical damage of the technology but also the negative effects of the not-use of the technology, sometimes more difficult to identify but also possibly much more important. Finally, this discussion of the precautional principle put in evidence that its application cannot be considered without taking account of scientific knowledge and application of the scientific method. On the other side, although in accord with Hans Jonas consideration that technology is not always able to solve the problems it creates, nevertheless the humanity does not have available any other realistic alternative to technological innovations with their intrinsic risks, taking account that also the arrest of technology innovations presents intrinsic risks, and taking risks in a certain measure has been an unavoidable consequence of the survival activity and improvement of conditions of life of the humanity.

4 THE ENVIRONMENTAL TECHNOLOGY ECOSYSTEM

It is recognized that use of technologies may be the cause of environmental damages and diseconomies of various nature and that have been already described for example in a discussion about the decreasing returns of technology (Giarini, Loubergé 1978). However, it should be noted that, from the technological point of view, there are not limitations that conventional technologies, having dangerous effects on the environment, could not be substituted by environmental technologies that are not necessarily more expensive because they might reduce energy consumption and waste production as well as avoiding at the same time costs of control and elimination of pollution. That would be even economically more favorable if there is the formation of what it may be called an entire *environmental technology ecosystem* in which environmental technologies, substituting conventional technologies, interact in a synergic way. In fact, technologies operate in an ecosystem in which each technology is influenced by externalities, also of economic nature, linked to raw materials, semi-products used for the production and possibly products and by-products use, etc. that depend on other technologies. That means that an environmental technology included in a conventional technological ecosystem may presents diseconomies that could disappear with the formation of an environmental technological ecosystem with synergic relations in which economy of input and output of the production process are economically and environmentally more favorable. The possibility of a technological evolution compatible with both economic and environmental aspects may be discussed considering two types of approaches. The first one, called Circular Economy (Stahel 2019), considers the potentiality of recycling in industrial activities and use of products that would result in a decrease of pollution, nearly elimination of depletion of resources and indirectly decreasing the global warming effect. Furthermore, it indicates a future evolution in which production, use of products and waste recycling are completely integrated in a single cycle practically eliminating depletion of resources. The second one, called Natural Capitalism (Hawken et al.1999), considers that natural resources shall be considered a capital analogous to other types of capitals involved in the economic activity, and giving suggestions about the changes that might be made to optimize the use of the natural capital contributing in this way to the solution of environmental problems such as pollution, depletion of resources and global warming. Such approaches are detailed as follows.

4.1 Circular economy

The circular economy approach had origin in Europe at the beginning of 80', in particular with the publication made in 1982 by the European Commission of a report entitled "The Potential for Substituting Manpower for Energy" written by Walter Stahel and Genevieve Reday. The basic ideas of circular economy have been now condensed and updated in a recent book (Stahel 2019) considered for this study. A preliminary observation is that the book treats in large measure the policies, social aspects and industrial strategies of the circular economy and only in limited generic way its technological implications. For these reasons, being the object of this article only the relation between technology and the environment, we do not enter in discussion about the policies, social and industrial strategies of circular economy limiting our discussions to the feasibility of its objectives from the technological point of view. The root context of a circular economy is a guiding principle of nature and existing also in primitive and less developed living of the man. The aim is to maintain the value and manage stocks of assets from natural, cultural, human manufactured stocks to financial stocks. Following the circular economy model presently it exists a linear industrial economy that is linked to a circular economy through the point of sale of products or services. In the model the linear industrial economy is represented by industries involved in extraction and exploitation of resources, manufacturing and reaching the point of sale for products and services. The circular industrial economy starts from the point of sale and involves the use of products, repairing, return to the producer for repairing or upgrading for reusing and recycling of waste materials recovering materials at the highest quality, pure as virgin materials that may be used anew for manufacturing. Both the schematic views of the linear industrial economy connected with the circular industrial economy is reported in Fig. 1. The objective of circular economy is the development of circular conditions in such extended manner to incorporate the linear industrial economy into the circular economy, and exploiting in this way all its full economic, social and environmental advantages as reported also in Fig. 1. In the book are used the terms *atoms and molecules* in the recovering of wastes. Actually, the use of terms of atoms and molecules in this context is from the strict chemical point of view inaccurate and misleading. In fact, from the chemical point of view, atoms and molecules are aggregated in different ways and very rarely existing as simple separated atoms or molecules in wastes as it might perhaps appear from the text, and the use of these terms does not give a real idea of the chemical aspects and technological reality existing in carrying out the wastes recycling. For these reasons we have substituted discussing the book the terms of atoms and molecules with the terms of *waste or recovered materials* in the frame of a process transforming wastes into recovered materials in their highest utility and value form. It should be noted that circular industrial economy renounces for example to look into the rapid expanding of bio-economy. Bio-economy in facts focuses on a more efficient use of natural capital but its characteristics resemble more the linear than the circular industrial economy. Circular industrial economy differs from linear industrial economy because its objective is to maintain value not to create added value. The circular economy employs local small-scale processes operated by craftsmen and availability of do-it-yourself and repairing centres in order to extend the service-life of manufactured objects as well of regional industrial remanufacturing workshops and factories to achieve the same objectives. Sustainability and circular industrial economy are two faces of the same coin, in fact it is:

- Sustainable because maintains existing resources investments to fulfill market needs instead of relying on new materials and energy resources
- Manages manufactured stocks by the use of human, manufactured, natural and financial assets
- Decouples wealth and welfare creation from resources consumption
- Promotes service-life extension activities

By extending the service life of goods circular industrial economy employs labor-intensive activities replacing the production of new goods substituting manpower for energy, considering that human capital is not only a renewable resource but also improvable through education and training. A mature circular industrial economy will integrate the linear industrial economy into the single loop with the use-value replacing the exchange-value as central economic value substantially decreasing the greenhouse effect and increasing the number of jobs. It is possible to distinguish two eras of development of the circular industrial economy in term of key innovations from R&D:

- The era of R reuse and service-life extension of goods
- The era of D recovering of waste as pure virgin materials

Within the industrial circular economy there are differences in tasks in the two eras:

- The era of R is controlled by owners-users and it can appear inhomogeneous because the stock of goods in use are dispersed geographically and of high diversity and R activities may be local for tailor made objects or regional for manufactured of mass-produced goods
- The era of D is controlled by economic actors for end of service-life objects and needs material and technology innovation to sort high volume and low value of waste materials and turn it in recyclable goods

In a mature circular industrial economy, solutions of era of R should be preferred over solutions of era of D. The era of R aims to maintain infrastructures, buildings, equipment, vehicles, goods and other manufactured objects at the highest utility and use value at all times. Do not discard what it is not broken, do not remanufacture somethings that can be repaired, do not recycle a product that can be remanufactured. The era of D needs actions to recover materials at the highest quality, pure as virgin and includes for example technologies that:

- De-polymerize
- De-alloy
- De-laminate
- De-vulcanize
- De-coat materials
- De-construct building and infrastructures

noting however that these technologies are not still available and require R&D efforts. In a modern circular industrial economy production become segment of the loop producing innovative components and it is recognized that the sector of circular industrial economy with the biggest potential of technical innovation and research is in the era of D, and concerning recycling of waste materials in the highest utility and value, and opening new fields in the development of reusable manufactured materials and easy to be recycled.

4.2 Natural capitalism

The natural capitalism approach to environmental problems and their economic impact, had its origin in USA, and presented in detail in a book written by Paul Hawken and other two co-authors entitled "Natural Capitalism" (Hawken et al. 1999). This book would show that valid technological solutions, some of those already existent, may defend and valorize the environment with an increase of natural resources and not with their destruction. The objective of natural capitalism is a transformation of the actual socio-economic system into a system compatible with the environment. In fact, it considers that the economic-productive system may survive only within the limits of the global ecosystem. The authors think that considering the environment, economy, social policies in competition is a prejudice, and the best solution shall not be found in a compromise that assures an improbable equilibrium among them, but by an integrated solution unifying these factors at all levels. In the book are considered various types of capitals, not only the human capital constituted by labor, intellectual property, culture and organization, financial capital constituted by money, investments and monetary instruments and asset capital constituted by equipment and buildings, but also a natural capital constituted by raw materials and living systems. The natural capital is in fact the result of a complex activity of many living ecosystems that interact with natural phenomena. The substitution of natural capital with other types of capital is possible through technology but has its limits linked to factors that auto-regulate the conditions of the atmosphere, oceans, the cycle of waters, photosynthesis, cycle of natural or anthropic wastes, protection from cosmic rays, all that making possible the life on the earth. The present industrial and economic system uses the first three types of capitals for the transformation of natural capital into economic and social goods. In the traditional capitalism it is accepted to consider the environment but this attention is equilibrated by the necessity of an economic growth and the maintaining of high standard of life. The history of the continuous increase of population indicates that at the beginning there was an abundance of natural capital in term of energy, raw materials, etc. and scarcity of human resources, now, on the contrary, we have a scarcity of natural capital and abundance of human resources. Using the same economic logic of the industrial system it is necessary a compensation by making resources more productive improving the efficiency with which the natural capital is used. In fact, the environment represents the shell that contains, provides and sustains the whole economic and industrial system, and production technologies shall take in consideration all types of capitals including the natural one. There are four strategies suggested by natural capitalism:

- The radical increase of productivity of resources
- Bio-imitation in the production processes

- An economy of fluxes and services based, instead on goods and purchase, on quality, usefulness and performance changing a mentality of buying as measure of affluence and wellness.
- Investments in natural capital enabling as much as possible services and resources.

The increase of productivity of resources means the obtention of a product with less materials and energy, improving indirectly the quality of life, showing that environment and business are not in contrast or even in conflict but on the contrary compatible in a more efficient system. Bio-imitation means a logic of production similar to that of biological systems substituting heavy structures and combustions with minimal inputs, lower process temperatures and pressures and reactions of enzymatic type (new catalysts). New fluxes and services mean that a product with a certain function, instead of be purchased, is offered as service optimizing its use and maintenance entering in a more efficient flux for recycling in a strategy similar to that of the circular economy. Investments in natural capital are necessary to maintain a constant and suitable supply of services to a population in constant increase, and shall be accompanied by technological developments necessary to use efficiently such capital. All that leads to a dematerialization of products and production systems, a decrease of consumption of energy for the production, an increased productivity of resources, an efficient closure of the cycle of resources, limited or even eliminated pollution and toxicity and finally longer life cycles of products. In Fig. 2 we have schematically reported how natural capitalism considers the transformation of a conventional process of production into an environmental process of production following the suggested strategies. It may be observed how the transformation of a conventional process of production into an environmental process might present many economic advantages such as lower energy consumptions, lower raw material consumption, less waste production and treatment, elimination or reduction of gaseous emissions and effluents to be treated and cost of necessary pollution controls.

4.3 Critics of the two environmental approaches

Before entering in a discussion about the critics of the two environmental models of circular industrial economy and natural capitalism, it is useful, for a full understanding, to make some thermodynamic considerations that establish physical limitations to the objectives of these models. It might be surprising that thermodynamics science is implied in economic activities determining possibilities and limits. In fact, economic activities depend more or less on technological activities that are a set of physical, chemical and biological phenomena in action that respect the laws of thermodynamics. Economic activities are then in an indirect relation with thermodynamics and that may become important when economy is considered in terms of a global activity interesting the entire earth system as it is the case of circular economy or natural capitalism approaches. It is then useful to present some aspects of thermodynamics in order to discuss from this point of view the critics of the two considered global models. This science is based on two principles, the first principle concerns the conservation of matter and energy in any transformation of a system, the second principle establishes that it is impossible to realize a transformation in a system in which the unique result will be the transfer of heat, seen as a form of energy, from a system at a given temperature to another system at higher temperature. This second principle is of great importance in discussing the links between economy and thermodynamics and explanations demand the use of a physical magnitude derived from the second principle called *entropy*. The concept of entropy is quite difficult to fully understand as it is implied in many very different systems from steam engines to information science. For our purposes we may simplify the meaning of this magnitude considering it simply a measure of the molecular disorder of a system, higher a system is disordered higher is its entropy and vice versa, in fact entropy increases or decreases following the temperature of a system. Another important aspect of entropy is that a closed system, defined as a system without exchange of matter or energy with the environment, tends naturally to an equilibrium characterized by reaching a maximum of entropy or of disorder and, if we want to maintain a system far from the equilibrium conserving order, it is necessary to supply continuously energy. That is the case of earth that it is maintained far from the equilibrium, with the presence for example of living organisms as a form of order, by a continuous supply of energy from the sun. In conclusion, the reduction of entropy (or temperature), seen as disorder, may be obtained only by supplying energy and that explains the fact that it is necessary to supply energy for the cooling in a refrigerator. These facts are of great importance considering the recycling in the circular industrial economy in which this operation will need, independently of its technological feasibility, an amount of energy increasing with the amount of reduction of disorder involved in the operation of recycling. On the other side natural capitalism shall take account of the existence of a minimum need of energy to maintain order in a system with the aim to minimize such need of energy in order to avoid its transformation in a dead disordered system.

4.3.1 Critics to the circular industrial economy

It should be noted, before all, that the circular industrial economy proposes modifications in the use of products concerning maintenance, repairing, return to producer for repairing or upgrading for reusing, as well as transforming use of products in term of services and not of buying. Furthermore, it proposes treatments of waste for the recycling of materials that may be used anew for manufacturing. All that represents certainly a useful strategy to solve many environmental problems concerning, pollution, depletion of resources and contrasting indirectly the global warming. However, it should be noted that the descriptions made for the circular industrial economy concerns mainly policies, social aspects and industrial strategies and only in limited generic way its technological implications. Although some examples of needed technology innovations are cited, there is none about details and realization difficulties for these new technologies. In fact, it seems that in circular industrial economy technology is considered such as “manna from heaven” and that there would be always a technological solution, being the necessary efforts in R&D be made, for all needs of the objective of integrating linear industrial economy into the circular industrial economy. In circular economy it is recognized that technological radical jumps, will have as effect an avalanche of used material becoming obsolete and to be necessarily recycled, but that, following the circular economy, would be foreseeable and be less abrupt to industry that considers on time the development of radical innovations. In fact, that may be doubtful as many technologies, as for example ICT or future applications of artificial intelligence, evolve in a rapid sequence of radical innovations in specific technological fields. Actually, the circular economy does not have a management strategy for innovations of radical nature that makes rapidly obsolete existent products and their recycling, leading implicitly to the paradox to hinder radical innovations with their benefits in order to conserve the circularity of the economy. In fact, radical innovations will generate a great quantity, not only of obsolete products, but also obsolete equipment for repairing, reusing and recycling worsening the operability of the circularity. Actually, the major critic that may be raised to this model involves principally its objective that concerns the full inclusion of the linear industrial economy into the industrial circular economy transformed simply as a part of the cycle. That requires the full recycling of wastes, transformed in virgin products, usable by the manufacturing step, eliminating practically the consumption of resources. A critic to circular economy objectives is based consequently on the enormous amounts of energy that would be required for a full recycling because of thermodynamic reasons. This fact has been already observed in previous studies (Korhonen et al. 2017). In fact, for example, some recycling operations considered in circular economy, such as de-alloying separating pure metals, may appear quite difficult, independently of the technological feasibility of the considered recycling operation because there are thermodynamic implications, concerning consumption of energy, that limit strongly these operations. Recycling then is not a free lunch, but a typical operation in which, a high disorder, i.e. a high level of entropy existing for wastes, is transformed in a lower disorder, i.e. lower level of entropy in virgin materials usable for manufacturing, that, following the laws of thermodynamics cited previously, will require an adequate consumption of energy. Considering the full closure of the circular economy cycle it is very probable that some recycling operations, independently of their technological feasibility, will require enormous quantities of energy. That is the case, for example, of de-alloying in recovering the pure metals, de-vulcanizing of rubber in tyres recovering monomers for further rubber production and recovering of metals in the oxidized and diluted form dissolved or dispersed in liquid or solid waste materials. These recoveries need, independently of their technical feasibility, the inclusion in the cycle of enormous productions of energy implying problems of costs, pollution, avoidable only by future use of valid environmental technologies, otherwise we would assist to a consequent increase of the greenhouse gas emissions. For these reasons the possibility of a full integration of the linear industrial economy in the circular industrial economy appears quite doubtful.

4.3.2 Critics to the natural capitalism

The interest and originality of the natural capitalism approach is in its search of an integration of technologies and environment and not simply a compromise between economic aspects of technologies and environmental exigences, and that looking for technologies that at the same time are more economic and respectful of the environment. On the other side the natural capitalism approach includes many suggested industrial strategies existing also in the circular industrial economy but without looking for a complete integration of linear industrial economy into the circular one. For example, natural capitalism favorizes bio-economy that in circular industrial economy is considered an obstacle to a full integration in the cycle of the linear industrial economy. A limit that may be raised to natural capitalism is that it shall take account of the existence, from the thermodynamic point of view, of a minimum need of energy that it is necessary to maintain order in the environmental technology ecosystem, and that may rise limits in minimizing such need of energy considered for some of its advanced objectives. Another limiting aspect concerns surely the necessary great effort in R&D to find new technologies that are fully integrated with the environment and not just for an economic compromise. Comparing with circular industrial economy, the objectives of natural capitalism seem however to be easier to attain, compared with the full realization of a circular industrial economy with their thermodynamic limits explained previously, although natural capitalism cannot of course assure the complete elimination of depletion of resources but only its reduction.

5 Environmental global problems

There are three global environmental problems we consider in this study that are: pollution, depletion of resources and global warming. The problem of pollution has accompanied in fact all the industrial development of countries but the awakening of environmental actions concerning this problem may be dated back with the publication of a book of Rachel Carson in 1962 entitled "Silent Spring" (Carson 1962) documenting the adverse environmental effects caused by the indiscriminate use of pesticides, and accusing the chemical industry of spreading disinformation. The problem of depletion of resources has been put to an international attention by publication in 1972 of a report of the Club of Rome entitled "The Limits of Growth" (Meadows et al. 1972). In this book it was presented a scenario, derived from a global model, about the consequences of depletion of resources on growth. The complex question of global warming had found a general attention since the Earth Summit, organized by UNO at Rio de Janeiro in 1992, with the creation of an international environmental treaty called United Nations Framework Convention on Climate Change (UNFCCC), followed by an agreement in 1997, called the Kyoto Protocol, establishing policies for limiting emission of greenhouse gas in the atmosphere, and signed by the 36 countries participating at this first committing.

5.1 Pollution

The problem of pollution of the environment concerns not only industry, and in particular the production of energy, but also other activities, such as transportation and domestic activities such as for example heating and use of appliances. Concerning the contribute of technology to the solution of pollution problems, this has been discussed previously in the description of the circular economy and natural capitalism and their possibility to develop environmental processes of production, and the increase of life and recycling of products. In transportation we assist to the shift of combustion motors to electric motors and that implies an increased production of electrical energy in substitution of gasoline use, and then the question to have a technology respecting the environment and avoiding global warming for a mass production of electric energy. A solution of pollution problems may be found also if an efficient environmental system of production of hydrogen would be available. In this case the fossil carbon cycle polluting and producing greenhouse gas might be substituted by a pollution-free hydrogen cycle.

5.2 Depletion of resources

The problem of depletion of resources was raised, as we have cited previously, well before the problem of global warming, at the beginning of 70' of the past century with the publication of the book entitled "The Limits to Growth" (Meadows et al. 1972). Written by a group of experts sponsored by the Club of Rome, and using the results of a global model of development signaling the danger of an excessive consumption of resources. Although the authors wrote that calculations were made considering the knowledge at that time about the estimated amounts of resources, that might be discovered greater in the future, the book was perceived sometimes as a lugubrious prophecy considering as a forecasting what in the reality was only a possible scenario. That diffused in the economic and political milieu a refusal to consider the problem of depletion of resources. Actually, the main problem raised by the book was linked to the production of energy and, being presently removed apparently by the discovery of new great deposits of combustibles such as coal, shale oil and natural gas, combustibles that however their use is deleterious favorizing the global warming. In fact, the problem of depletion of resources, beside the questions on combustibles with a possible substitution for example with solar or nuclear energy, persists in minor part, but in numerous cases, for niche materials necessary for new technologies. That is the case for example of rare earths for electronic applications, cobalt for high performant magnetic materials, lithium for automotive batteries and many others. Such problems might be solved by reducing consumptions, finding alternative technologies not using such materials, or looking to extraction of these materials from very low concentrated ore or waste requiring however very high consumptions of energy. In fact, both approaches of circular economy and natural capitalism, discussed previously, offer solutions to decrease sensibly the depletion of resources, however the doubtful possibility to close completely the cycles of material with the elimination of the linear industrial economy, as suggested by the circular economy model discussed previously, shows that a complete elimination of depletion of resources appears unattainable and that only a sensible reduction is possible.

5.3 Global warming

The problem of global warming is much more complex of that of pollution and depletion of resources, as it implies important technological, economical and natural factors, and merits then a more extended discussion. This problem is linked to the existence in nature of an important cycle based on the carbon element. In its reduced form of carbon compounds (combustibles), it may be oxidized (burned) producing energy including that (glucose) used by living species for their vital activity. All that occurs producing essentially carbon dioxide (CO_2). This last compound is transformed anew in reduced carbon compounds exploiting solar energy by photosynthesis, closing in this way the cycle. Photosynthesis is assured on the earth in particular by existence of plants. algae and cyanobacteria. Presently, the anthropic activity of production of energy is in a great measure assured by the use of fossil carbon in form of coal, oil and natural gas, and then by exploiting the chemical energy accumulated in the past in form of fossil carbon in period in which photosynthesis process was boosted by high temperature and great availability of CO_2. The present emitted CO_2 of anthropic origin, added to natural CO_2 emitted by volcanic activities, increases the concentration of this gas in the atmosphere. In this way the equilibrium of the carbon cycle is broken cumulating an excess of CO_2 that is the cause of the greenhouse effect and then of a global warming. Although we do not know with exactitude the amount of CO_2 emitted by volcanic activities, the amount of anthropic emission, cumulated since the beginning of industrial activities, is considered comparable and at the origin of the observed rapid increase of CO_2 concentration in the atmosphere. Discussing the consequent global warming it is necessary to consider the whole evolution of temperature on the earth in the billions of years of its existence. Research, made especially on history of ice in the Antarctic continent, has shown that the temperature of earth has varied greatly forming periods of millions of years in which it was completely covered with ice to periods in which ice was not present on earth. It seems that presently we are in a heating phase of the earth, however, during this period, there are cycling phases of limited increase or decrease of temperature that have been observed in historical times and confirmed also by archeological research. Concluding it seems that we are now in a period of natural global warming but with a rapid increase of temperature probably as effect of the anthropic activity. This rapid increase of temperature, differently in the past when changes were slow and it was easy for the nature the adapting to these changes, now the rapid increase of temperature may raise a lot of problems in the ecosystems, and a rapid global warming may for example produce highly energetic atmospheric phenomena and melting of ice in the polar regions with rapid increase of the sea level and invasion with water of coastal cities. As we have previously cited, the awareness of the dangers of global warming, followed by the Earth Summit at Rio de Janeiro in 1992 and creation of UNFCCC had the result to obtain in 1997 an agreement, called the Kyoto Protocol, about efforts that should be made by the various nations to limit the emission of greenhouse gas in order to control the global warming. Further international meetings, organized by UNFCCC, were made periodically until nowadays to implement new agreements. Looking to these efforts made for the reduction of global warming, there are two types of criticisms concerning the real possibility to reach an effective control of global warming. The key point is that global warming may be stopped only by existence of environmental technologies assuring a near global, and not only a partial, elimination of greenhouse gas emissions. That is at the base of the first criticism because of the exclusion of countries in the Kyoto Protocol as in the case of China that, with its development and absence of valid environmental technologies, has contributed to an important not considered emissions of greenhouse gas. The second criticism is linked to the previous one and raises the question whether the policies, essentially adopted in industrial countries, and efforts made to develop new environmental technologies for the production of energy, are really effective. Actually, about more than twenty years after the Kyoto Protocol, concentration of greenhouse gas and temperature are still increasing. The question concerns the development of environmental technologies for energy production based actually on photovoltaic, solar thermal, and Aeolian technologies, and whether these technologies may be fully suitable for the global technological substitution necessary to arrest the global warming. Actually, there are a certain number of limitations of these technologies that could put doubts about the reaching of this objective. The first is that they necessitate enormous surfaces or a very high number of propellers to reach the same generation power of a conventional nuclear or thermal plant. The second is that they produce electric energy discontinuously with peaks of production that do not correspond to the peaks of consumptions necessitating then the storage of the produced electric energy. Actually, the available systems of mass storage of electric energy are at the moment the hydroelectric systems pumping water, but limited in number because of scarce availability of suitable sites, and the use of great batteries systems or other systems but that have still to demonstrate their suitability for a massive storage of electric energy. In conclusion it seems that these technologies might give only a minor contribution to an environmental global production of energy, although photovoltaic technology may give an important contribution especially by limiting consumption of energy in buildings. On the other side little attention has been paid on development of technologies of use of solar energy for a direct conversion into chemical energy, like in the natural photosynthesis, and able to produce for example hydrogen from water, allowing an environmental energy cycle alternative to the carbon cycle, based on water and not only on the CO_2 of the atmosphere. Another advantage of combustibles generated by solar energy is that they have an easy and much higher density of energy for storage, in respect to any other storage system of electric energy. Considering the previous questions, we might ask whether interventions on rules, trade exchange of carbon emissions, taxes and simple promotion and financial aid of environmental technological developments, considered in industrialized countries, that are surely useful to decrease local pollution, energy consumptions, etc. would be really effective to arrest the global warming. In conclusion we may ask whether the real solution of global warming would be in fact technological and not political as it is considered in the Kyoto and subsequent protocols. The critics raised previously about the possible inefficiency of an approach mainly political and not sufficiently technological to global warming problems have been raised in fact indirectly by studies carried out just few years after the signature of the Kyoto Protocol, and in particular in a study on modelling technical change and energy - environment outcomes (Grubb, Koehler 2002), presented in a workshop organized in Paris by OECD in 2001. In this study technical change was considered to be an important factor in addressing major environmental issues, particularly large-scale, long-term problems like climate change. In fact, rapid development of efficient clean energy technology can reduce risks facing uncertain long-term environmental threats. However, in modelling of policy questions in this area, relatively little attention was paid to how technical change occurs and how it diffuses at a global level. The focus of the cited study was not on whether technology development is important, which seems beyond question, but on how technology development occurs, how it is represented in models, and the nature of the economic and policy conclusions that flow from this. Actually, the process generating genuine, original innovations is not well understood, however, viable commercial technologies do not appear as "manna from heaven", they require considerable developmental effort, much of it by industry, as well as by laboratories that carry out basic research, in agreement with results of technology dynamics studies on the process of technology innovation (Bonomi 2020). Furthermore, studies on emerging energy technologies, that seem likely to have significant market impact, reflect primarily a process of demand pull rather than supply push (Grubb, Walker 1992). The authors then reviewed about twenty models about technical change on large scale, most of them of macroeconomic type but some taking account also of learning by doing activity as source of technical change, this last in fact in accord with results of technology dynamics studies on the generation of new technologies (Bonomi 2020). Concluding discussion about models, the authors supported the argument that technology policy, including support for R&D and the provision of incentives for investment in innovative technologies, should be a *key component of climate change policie*s. Therefore, policies should be directed at encouraging the development of many different technologies and providing an economic environment in which R&D is promoted. However, the authors observed that no global models yet exist that could credibly quantify directly the process of global diffusion of induced technological change. In the absence of more specific models, the authors considered their developed model in which emissions intensity, defined as the ratio of CO_2 emissions to economic output, as a proxy indicator of technology choice and international diffusion, as well as other potential international linkages. In this way it was possible to compare the carbon emission of industrialized countries, assuming 1% reduction of emission per year following the rules of the Kyoto Protocol, and increase of emission of developing countries as a function of the spillover degree of environmental technologies, i.e. the fact that these countries, in the frame of their development, make a choice of environmental technologies instead of conventional technologies at a more or less extent. The results of such model showed that only with a high spillover of environmental technologies the carbon emission of developing countries does not reach much higher values, in respect to industrialized countries, otherwise these values might be even about ten times the emission of industrialized countries. Looking now, after about twenty years the date of the publication of this study, the present situation of technological change and the still continuous observed increase of global temperature, it appears that in fact the present environmental technologies seem not still competitive, for the reasons cited previously, in the realization of the necessary high spillover covering the energy needs in developing countries. That would mean that policies of industrialized countries, simply promoting environmental technologies and favoring research in various interested industries, fail to reach the objectives of the Kyoto Protocol in term of arrest of global warming. Beside these considerations there are however no reasons that hinder the development of valid environmental energy production technologies covering this objective if there are enough high number of innovative ideas, adequate important R&D effort and available financing. That would make possible important studies also for example on synthetic photosynthesis, and synthetic fuel or hydrogen production using directly solar energy, that have found until now little attention. Considering that the real solution able to stop the global warming would be in fact technological and not political, it may be noted that the Kyoto Protocol, if it would have had an agreement, not only of political nature, but also of promotion of a great international project for the development of various technologies free of carbon emissions, now, after near thirty years of development, we would have probably available a set of new economic technologies for a strong reduction of carbon emission with a favorable spillover for the energetic needs of the developing countries. What it would had be necessary to propose at that time, from a technological point of view, was the realization of a great coordinated international project, analogous and even larger of the Manhattan Project, this time not putting in danger but saving the humanity. A consequence of the absence of an international coordinated and financed project has been the orientation of private and public R&D toward basically known technologies, such as solar thermal, photovoltaic and Aeolian technologies, with a low degree of radicality and lower risk of failure, instead of paying attention to more radical technologies, based on production of chemical and not electric energy, more suitable but with a higher risk of failure. However, such risk would be sensibly reduced if the R&D activity overcomes certain critical limits of development efforts, as it has been demonstrated in the study of technology dynamics (Bonomi 2020), and that would be possible in fact by an international cooperation project, similar but larger than the ITER project for nuclear fusion, was operative. Finally, we shall consider the existence of technologies producing energy neither using fossil combustibles nor solar energy, but nuclear energy through fissile or fusion processes. Fissile nuclear technology is already well developed, however its diffusion in use is limited by possible enormous dangerous accidents in production and in mass handling of exhausted nuclear combustibles. Fusion nuclear energy has much less problems of this type, but it is still only under development. Actually, these types of technologies are of interest because alternative to solar source of energy. In fact, a complete dependence of solar energy in the production of energy is not suitable in the long term. That because of possible reduction of its availability, even for several years, in the case of not frequent but occurring strong volcanic activities, and a mix of nuclear energy, possibly by fusion, with solar energy exploitation might be a possible optimal solution. Concluding, from a technological point of view, it does not seem probable that present environmental policies, applied in fact only in a certain number of industrialized countries, would be able to arrest the future global warming described in the scenarios developed in the frame of the UNFCCC activities. Consequently, it would be important now also to look for interventions and development of technologies apt to face the unavoidable rapid global increment of temperature.

6 CONCLUSIONS

This study has shown various aspects of the relation between technology and the environment. In particular it has shown the necessity of a scientific approach to environmental controversies and the necessity to consider the scientific point of view on environmental problems. Furthermore, it has shown limits on the precautional principle that, in its application, it is necessary to consider not only the danger of use of a technology but also the negative effects of its non-use. It has been discussed then the two possible approaches to the realization of an environmental technology ecosystem: the circular industrial economy and the natural capitalism approach, showing how are important the technology developments to attain the objectives of these models. It has been shown that natural capitalism model has objectives easier to reach instead of circular industrial economy model in which a full circular recycling is probably unattainable because of its enormous need of energy. Considering then the problem of global warming the study shows that this problem could not be dealt only from a political point of view by establishing policies about greenhouse gas emissions and minor aid to R&D, but it would need a technological approach within a global coordinated project of development of environmental technologies for the production of energy suitable for a global substitution of conventional technologies. Furthermore, it should be considered that the arrest of global warming does not depend only by policies of industrialized countries but also on the availability of environmental technologies of production of energy, competitive with conventional technologies, for countries under development. Actually, the lack of effective environmental technologies globally effective, raises doubts on the possibility to control the global warming, and it is then the time to look for technologies contrasting the effects of a fatal increase of global temperatures. Finally, this study underlines, in accord with technology dynamics studies, that there are key factors in technology developments that may assure technological solutions to environmental problems. These factors are represented by the combinatory nature of formation of new technologies, and the continuous development of new exploitable scientific knowledge. All that makes the substitution of conventional technologies with environmental technologies a possible objective, realizing a technologic growth in the frame of a sustainable economic growth and environment protection. That would of course be possible if there is an adequate promotion of innovative ideas and availability of investments in technology innovation.

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Fig. 1. Industrial linear economy to mature circular industrial economy

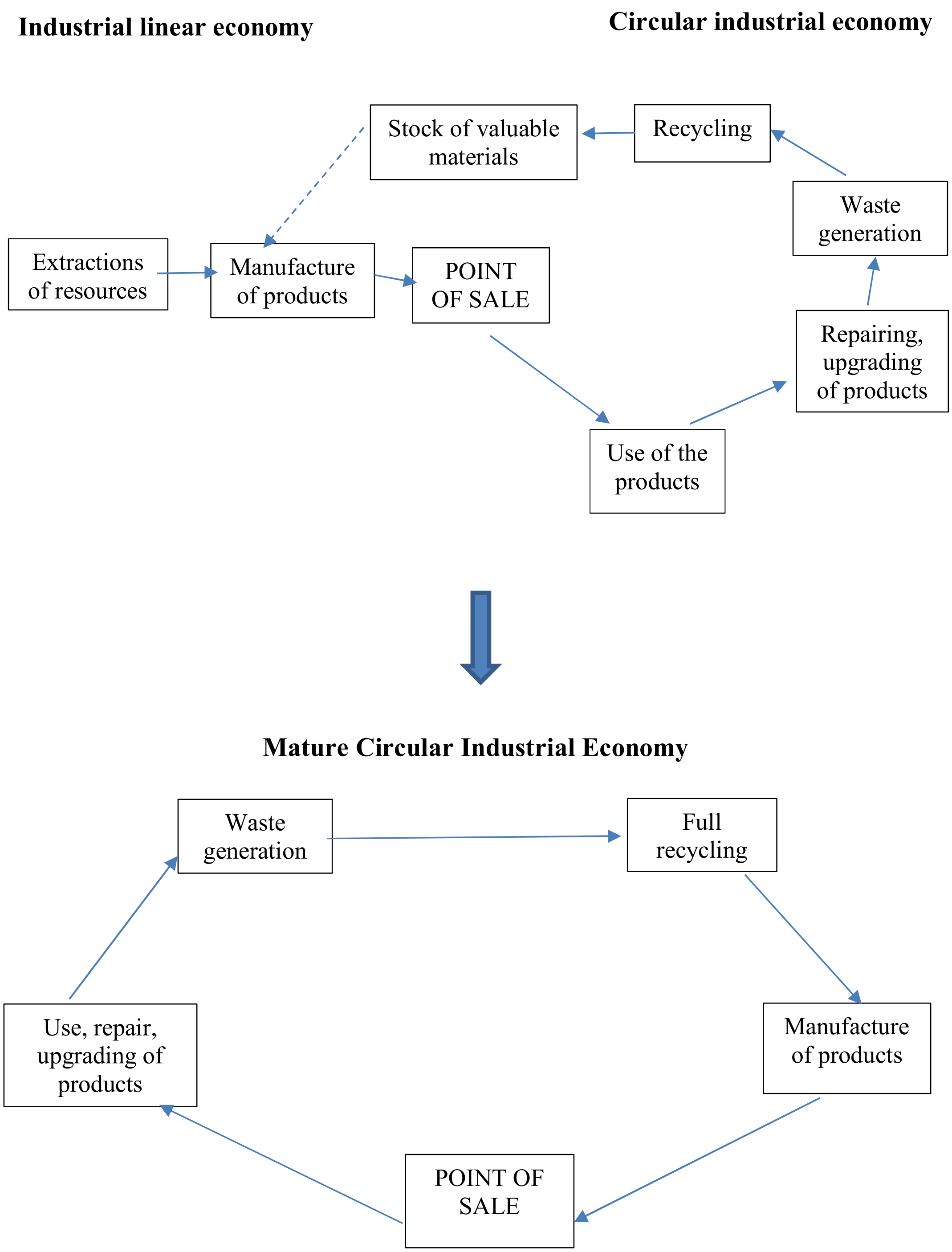

Fig.2. Conventional production process to environmental production process