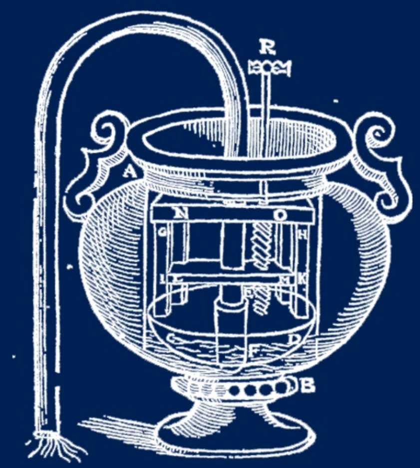
CNR-IRCrES Working Paper

Technology and Environmental Policies



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Technology and Environmental Policies

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ABSTRACT
This article explains how fundamental aspects of technology and technological innovation are involved in the environmental policies in terms of practicability and possibility of reaching their objectives. After a brief presentation of fundamentals of technology and its innovation, it discusses the limits of the precautional principle and its valid substitution with a risk analysis considering not only the dangers of using technology but also the dangers of not using technology. As regards problems of pollution and depletion of resources, this article describes the two environmental systems of natural capitalism and circular economy, while considering non-viable the objective of mature circular economy. As regards global warming, it discusses the available free carbon technologies and technologies under development in view of a global substitution of all conventional technologies. Environmental policies are criticized because the problem of global warming may be essentially solved by political agreements without taking account of technological implications. Scenarios of development of various green technologies are considered in the frame of various types of structural organization carrying out their development. Finally, this article observes the absence of a technological strategy considering the uncertainty about the time necessary for a full control of global warming, and the necessity to develop technologies able to mitigate its unavoidable dangerous effects.

KEYWORDS: technology dynamics, environmental policies, precautional principle, pollution, depletion of resources, global warming, natural capitalism, circular economy, Kyoto protocol, green technologies.

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1. INTRODUCTION

Technologies may contribute significantly to solve environmental problems such as pollution, depletion of resources and global warming. For this reason, they are involved in policies addressed to the solution of various social, economic and environmental problems. This article aims to consider how fundamental aspects of technology and technological innovation are necessarily involved in environmental policies and how they may impact these policies in terms of practicability and possibility of reaching their objectives, regardless of economic or social considerations. The aim of this article is neither to enter in a public debate about the social and economic aspects of environmental policies, nor to propose alternatives, but only to consider these policies in terms of a scientific vision of technology, observing how suitable models of technology and technology innovations may help to determine the possibilities and limits of environmental policies. In conclusion, the aim of this paper is to show that technology is not necessarily a problem but a solution, and a sustainable technological development is possible.

While environment is largely studied from a scientific, social and political point of view, technology does not have the same fundamental attention, and remains a quite undefined field characterized by a wide range of definitions that may be found in articles, books and encyclopedias, but are not necessarily coherent and indicative on what technology really is. In our opinion, for an effective discussion of relations between technology and the environment, it is necessary to consider technology from a scientific point of view, based on a general vision of its dynamics (Bonomi, 2020). That means to consider technology as an activity of exploitation of phenomena discovered by science for the development of new technologies, having a general structure with its own processes that should be taken in account in its relation with the environment. The scope of this article is to consider the involvement of technology in three main environmental problems: pollution, depletion of resources and global warming. That is preceded by a discussion on that precautionary principle, which is largely used in directives for the protection of the environment that are the limits of its practical application. Pollution and depletion of resources are considered in the frame of two environmental industrial models, the natural capitalism and the circular economy, discussing their possibility to reach their objectives from a technological point of view. Global warming is studied on the basis of the technological possibilities of the environmental technologies that are actually available or under development to arrest the greenhouse gas emissions, and the consequences of environmental policies deriving from the various agreements since the Kyoto protocol. As regards the impact of fundamental aspects of technology and technology innovation on the environmental policies, it is first necessary to explain briefly, in a preliminary section, the results of studies on the dynamics of technology, considering technology innovation as a result of the activity of structures organizing fluxes of knowledge and capitals (Bonomi 2020) that are useful for the innovation and management of technologies (Bonomi 2021a). That allows to understand the nature of the limits of technological objectives and of their time of realization.

After this introductory section, we will present some fundamental aspects of technology and technological innovations, the organizational structures in which these innovations are developed, the physical limits of technological objectives, and how technology dynamics influences the success and time of development of new technologies. In the third section, we will discuss the limits of use of the precautional principle and the possible valid substitution with a risk analysis.

In the fourth section, we will present the main environmental problems concerning technologies i.e. pollution, depletion of resources and global warming. In the fifth section, we will discuss the industrial models bringing solutions for environmental problems, i.e. the natural capitalism and the circular economy. In the sixth section, we will discuss the relation between technology and global warming, considering the available or under development carbon free technologies for production of energy, the technologies catching CO_2 and the relation between technology and environmental policies. In the seventh section, we will discuss the green technologies in terms of scenarios for their development. Finally, the eight section is dedicated to the conclusions of this study.

2. TECHNOLOGY AND TECHNOLOGY INNOVATION

In this section we present a scientific definition of technology, its structure in terms of technological operations and the derived model of technology (Bonomi 2020). Technology innovation is considered as the result of activities of structures organizing fluxes of knowledge and capitals (Bonomi 2020). This is followed by a discussion on the physical limits of technological objectives, and how technology dynamics influences the success and planned times for reaching these objectives. *The understanding of the general structures and processes of technology and its innovation is a key aspect to the understanding of the frame where green technologies may be developed with success, being the technological limits in their performance and time of realization.*

2.1. Definition of technology, structures and processes

A scientific vision of technology leads us to consider it as a set of physical, chemical and biological phenomena producing an effect that is exploitable for human purposes. The physical nature of technology determines its neutrality, and benefits or dangers of its use depend only on the human decision to exploit technology for a certain purpose, or not. Consequently, the same technology may result in a benefit or a danger following the purpose of its use. For example, arc and arrows may be used to kill a prey and ensure the survival, or kill a man during a fight. The enormous set of physical phenomena normally constituting a modern technology may be simplified and considered as a time-oriented set of technological operations constituting a graph (Bonomi, 2020). The structure of technology may be modelled and technology may be described mathematically in terms of technological space, presenting all possible uses of technology and of technological landscape, besides the efficiency of its processes and of the space of technology, which represents all the technologies pursuing the same purpose. The distance between technologies in the space of technology measures the technology's degree of radicality. A great distance between a new technology and a previous existing technology means that the new technology is radical, while a small distance means that the new technology is incremental (Bonomi, 2020). Meanwhile, the innovation process may be considered radical if this distance is great, or incremental if this distance is small. This indicator of radicality of technology or innovation is important as *it is linked to the probability of success in the development of a new technology and its economic, social and environmental impact*. This will be discussed in a further section about green technologies.

2.2. Organizational structures for technology innovations

The process of formation of innovative ideas for the development of new technologies is considered as the result of a combination of preexistent technologies (Bonomi 2020), possibly exploiting new or never used phenomena discovered by science (Arthur 2009). The model of technology considers an innovation as a change of the technology's structures and operations. Such change occurs in structures organizing fluxes of knowledge and capitals with the purpose of developing new technologies (Bonomi, 2021b). These organizational structures, which operate in a technology innovation system, are: the industrial R&D system, the startup-venture capital (SVC) system and the industrial platform system, and they are all involved in the development of green technologies. They are described as follows:

The industrial R&D system

The R&D activity consists in projects that are possibly financed by industries and by public aid, which is important in the development of green technologies. This activity produces new technologies and knowledge coming from either successful or abandoned projects. This knowledge, along with external scientific, technical or other knowledge, generates innovative ideas and proposals for new R&D projects. New technologies are introduced by availability of industrial capitals, generating returns of investments and new capitals for financing R&D. These capitals, which are possibly joined by public aid, finance selected proposals for R&D projects that will constitute the R&D activity, thus closing both cycles of knowledge and capitals.

The SVC system

This system is composed by companies called startups, which are financed by venture capital (VC). Differently from industrial capital, VC finances the development of new technologies for their sale and not for their exploitation. The objective of a startup is to reach an exit consisting in selling the technology or in transforming itself in an industrial company. The activity of a startup does not only consist in R&D projects for the development of a new technology, but also in the development of suitable business models for the developed technology. The activity of VC necessitates to close positively their financial cycle. In this case the returns of the exits shall cover the investments in successful or abandoned startups, with a surplus that is partly retained by VC and the rest, which is reinvested in new startups.

The industrial platform system

This system represents a new way to generate new technologies based on an increased availability of knowledge. It is composed by the owners of the platform and their partners, who are in relation with peer producers such as companies, startups, research laboratories, etc. that supply services and new technologies to the platform. Peer consumers obtain new technologies from the platform and exchange knowledge about the use of the technologies favorizing improvements and generation of further new technologies with the platform. A platform does not generate directly new technologies, which are in fact the task of R&D projects and startups active in the structure of the platform.

The experience has shown that the SVC system is particularly suitable for the development of radical technologies, which, make the SVC financial cycle positive thanks to their high returns. On the other side, the industrial R&D system is suitable for more incremental technologies with lower returns but also with a lower risk of failure. The industrial platform system is not based on specific financial strategies but on an increase of knowledge availability useful for the generation of new technologies.

2.3. Physical limits to technological objectives

When determining technological objectives it is important to consider the existence of scientific principles, physical constants and magnitude of natural data, which limit the performance of a specific technology. As regards environmental technologies, the laws of thermodynamics, physical constants and magnitude of natural data are highly significant. For example, the amount of photovoltaic production of electric energy is limited by the natural magnitude of solar irradiation of photovoltaic cells and by the theoretical maximum efficiency of its production by the photovoltaic material, which transforms solar energy into electric energy. The second law of thermodynamics limits the efficiency in the transformation of thermal energy into mechanical or electric energy, while the concept of entropy derived by these laws limits, for example, the possibility of recycling waste in a circular economy, because the need for energy required for recycling increases greatly with the dispersion or dilution of materials that should be recovered and transformed in usable virgin products.

2.4. Technological success and development times of new technologies

Technology dynamics considers that the probability of success in the development of a new technology decreases with the increase of its radicality. On the other side, the probable impacts and returns of a new technology increase with its radicality. On the contrary, the development of incremental technologies has a higher probability of success but a lower probability to have great returns and impacts. This behaviour is a consequence of the fact that a radical innovation is characterized by large modifications of the structure and operations of a previous technology, and that it is accompanied by a higher uncertainness in the results. Furthermore, it should be considered that the chance of success in the development of a new technology also depends on the phase of its development (Bonomi, 2020), and that the initial feasibility phase or the last industrialization phase have higher probability of success than the intermediate phase of development. This one concerns the study of the performance and the economy of technology, which play a key role in the success of a new technology. Consequently, if we consider, for example, the development of a radical environmental technology, it is necessary to finance various R&D feasibility projects having different ideas but the same purpose in order to increase the probability to obtain a successful technology. Furthermore, it should be taken into account that the possible scientific and technical criteria to select the initial projects for radical innovations are of scarce importance. This is due to the high uncertainness characterizing the possible results of these projects. *In the case of radical green technologies, criteria based on a high environmental potential may be considered more important than those of a presumed technological success*. As regards the estimation of development times, it should be considered that the development of a new technology is composed by a sequence of R&D projects concerning the feasibility and development phases. At the end of each project, the results are evaluated to choose whether to continue or arrest the development. Furthermore, it should be considered that it is not really possible to plan and estimate accurately the duration of the next projects without knowing the results of the previous projects. This limits the estimation of the possible duration of development and the existence of a great uncertainness especially in the case of the development of radical technologies. Another aspect concerns the possibility to reduce the development time by increasing the availability of financing. However, project cost management shows that this action generally increases also the cost of development, and that the possible reduction of duration is limited by the necessary sequence of projects that should be made for the development.

3. THE PRECAUTIONAL PRINCIPLE AND THE QUESTION OF RISK

The precautional principle has been largely adopted in environmental policies concerning the non-use of a new technology for which future dangers cannot be excluded. The Rio Declaration on Environment and Development of 1992 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 the German philosopher Hans Jonas (Jonas, 1979). He contested the utopian belief in a technology able to solve any problem, which is typical of the modern Western civilization. He considered that it is not correct to look only at the past or present consequences of our actions, but that it is necessary to consider also the consequences in the far future, which are outside of any possibility of reparation. Technology and science, with the uncertainness of their consequences in the far future, pose questions of ethics for humanity. In fact, if it is not possible to know the consequences of our actions on nature and mankind in the far future, it is necessary to face the unknown with another form of anticipation, such as the precautional principle. Nevertheless, the attitude of Hans Jonas does not contain 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 suitable technical effort (Bourg, 1993). Although being a very reasonable principle, it does not contain any real indication about the conditions to which it could be applied in practice, so it becomes the source of various different interpretations. On the other side, this principle could be overturned with the same type of arguments affirming that the *non-use of technology* might lead to serious consequences in the far future beyond any possibility of repairing because of the aleatory behaviour of nature, which generates infrequent but extremely dangerous events such as the recent COVID19 pandemic, for which a specific technology would had been able to supply a solution. As previously noted, technology dynamics has shown, in fact, that new technologies are the result of the combination of preexistent technologies. Consequently, the development and use of a new technology able to face a dangerous event might be impossible if preexistent technologies that are necessary for the combination did not have the necessary development and use because of application of the precautional principle. In fact, all technologies are part of an ecosystem in which, by the effect of the combinatory nature of innovation, the appearance or disappearance of a specific technology may influence the availability or unavailability of future technologies.

The problem of interpretation and use of the precautional principle is present in many directives derived by the Rio declaration in 1992. That is the case of the EU directive of 1998, which considers 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*, specifying later that the principle *presumes 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 directive may be criticized from a methodological point of view, as it leaves 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, in principle, science cannot demonstrate the complete absence of effects but only their presence. The presumed dangers of microwaves used for smartphones well illustrate the problems of identification of technology’s potential risks in the application of the principle. Microwaves are electromagnetic waves, and their behaviour is well known in physics. All electromagnetic waves are formed by a certain number of packets of energy called photons, and the levels of energy increase with the frequency of the wave. The interaction of electromagnetic waves with the matter is possible only if the energy of photons is high enough to provoke the interaction, otherwise they will go through the matter without any effect, independently of their number. For example, gamma, X and UV waves, with their high frequencies, can break molecular bonds making damages. Infrared waves have lower frequencies, and they can only interact with molecular movements resulting in a heating effect. Microwaves frequencies are lower than infrared and they have only a weak heating effect, which decreases with their frequency. That means that microwaves dangerous effects on human body will be possible only if there is a low energy molecular process that may be activated by microwaves producing damage. Science cannot advance any process of this type, nor it can demonstrate its inexistence, leaving the application of the directives cited previously uncertain. In this case, a verification of the effects might be done through correlations in statistical epidemiologic studies which, are not equivalent to highly controllable laboratory experiments, however. In fact, the correlated effect might be the result of other causes or even unknown factors, and only a scientific knowledge of the process at the origin of the correlation enables to consider epidemiological results as a scientific demonstration. Some statistical studies on microwave effects have shown the possible existence of a very low number of caused fatalities. However, this number of fatalities is not scientifically proven to be caused by microwaves: in fact, it is much lower than the number of saved lives by smartphones and their alerting possibilities. In conclusion, it may be argued if *a realistic alternative of application of the precautional principle might be a risk evaluation that takes into account not only the possible dangers of use of a specific technology, but also the possible dangers of its non-use*. In more recent times, the difficulty of application of the precautional principle has been recognized for its rigidity, which generates a paralyzing effect. In 2017, the UNO has elaborated a resolution about “Objectives for a Sustainable Development” without citing the precautional principle and using a risk-based approach or probability-based approach, which is an alternative to the precautional principle. The advantages of this approach concern a more equilibrated evaluation of risks and dangers considering not only the use but also the nonuse of a specific technology. Such risk-based approach will be used in the next section, which will consider the production of energy by nuclear fission vs. solar energy in the frame of global warming.

4. TECHNOLOGY AND ENVIRONMENTAL PROBLEMS

There are three main environmental problems linked to technology : pollution, depletion of resources and global warming. The next sections will describe their historical development and their current characteristics.

4.1. Pollution

The problem of pollution has accompanied the industrial development of all countries, but the first environmental actions implemented to face this problem may be dated to 1962, with the publication of the book *Silent Spring* written by Rachel 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 pollution concerns not only industry and the production of energy, but also other activities such as agriculture, transportation and domestic activities for heating and use of appliances. In transportation, we assist to the shift from combustion motors to electric motors, which implies a reduction of pollution but an increase in need of electrical energy in substitution of gasoline, and also the question of using a technology that respects the environment and avoids greenhouse gas emissions. A certain support to the solution of pollution problems may be found in environmental industrial systems such as the natural capitalism and the circular economy, which will be treated further in the frame of the environmental industrial models.

4.2. Depletion of resources

The problem of depletion of resources has been put to international attention in 1972, through the report of the Club of Rome, *The Limits of Growth*, (Meadows et al., 1972). This book presented a scenario derived from a global model of development concerning the consequences of depletion of resources on growth. Written by a group of experts, this report signalled the danger of the excessive consumption of resources. Although the authors claimed that calculations were made to consider the knowledge about the estimated amounts of resources at that time, and those which might be further discovered in the future, the book was sometimes perceived as a lugubrious prophecy or forecasting, but it was actually only a possible scenario. In the economic and political milieu there was a refusal to consider the problem of depletion of resources. One of the main problems raised by the book was linked to the production of energy, which is presently removed by the discovery of new great deposits of combustibles such as coal, shale oil and natural gas, but their use is associated to problems of global warming. The problem of depletion of resources persists in other numerous cases in which niche materials are necessary for new technologies, such as rare earths for electronic applications, cobalt for high performant magnetic materials, lithium for automotive batteries and several others. Such problems might be solved reducing consumptions, finding alternative technologies to these materials, or looking to their extraction from very low concentrated ore or waste requiring high consumption of energy. In fact, both approaches of natural capitalism and circular economy discussed forward about environmental industrial models, offering solutions to decrease sensibly without eliminating completely the depletion of resources.

4.3. Global warming

The complex question of global warming had caught general attention since 1992, when UNO organized the Earth Summit in Rio de Janeiro, with an international environmental treaty called United Nations Framework Convention on Climate Change (UNFCCC) and followed by the Kyoto Protocol, an agreement of 1997 that established policies to limit the emissions of greenhouse gases in the atmosphere. This protocol was signed by the 36 countries participating at the first summit. The problem of global warming is linked to the existence of a natural cycle based on the carbon element. Its reduced form of carbon compounds (combustibles) may be oxidized (burned), producing energy including that (glucose) used by living species for their vital activity. All that produces essentially carbon dioxide (CO_2), which is transformed in reduced carbon compounds again, exploiting solar energy by natural photosynthesis, thus closing the cycle. Photosynthesis is assured by the existence of plants, algae and cyanobacteria on the earth. Presently, the anthropic activity of energy production is in a great measure assured by the use of fossil carbon in form of coal, oil and natural gas, and by the exploitation of the chemical energy accumulated in form of fossil carbon when the photosynthesis process was boosted by high temperature and great availability of CO_2. The CO_2 of anthropic origin, added to the 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 global warming. Although we do not know with exactitude the irregular amount of CO_2 emitted by volcanic activities, the amount of anthropic emission cumulated since the beginning of industrial activities is considered as the origin of the rapid increase of CO_2 concentration in the atmosphere. However, when discussing the consequent global warming, it is necessary to consider the whole evolution of temperature on the earth over billions of years, since it has varied greatly: in fact, the earth was completely covered with ice for millions of years, followed by periods in which ice was not present. In these periods, cycles of minor variations of temperature have been observed, leading to the conclusion that we are in a heating phase of the cycle. However, what has been observed at the present is a rapid increase of temperature, which is much higher than that observed in the past cycles and which may be attributed to the increase of anthropic activity since the last century, with great emission of CO_2 by conventional processes of energy and transport production. Nowadays, the rapid increase of temperature causes a lot of problems in ecosystems unlike the past, when changes were slow and it was relatively easy for nature to adapt to these changes. The rapid global warming may produce, for example, highly energetic atmospheric phenomena such as the melting of ice in polar region, as well as a rapid increase of the sea level and salt water intrusion in coastal areas. The problem of global warming will be discussed further considering the various environmental technologies producing energy, and their technological implications with environmental policies.

5. INDUSTRIAL ENVIRONMENTAL MODELS

It is recognized that the use of technologies may be the cause of environmental damages and diseconomies of various nature, which have been described for example in a discussion about the decreasing returns of technology (Giarini & Loubergé, 1978). However, from a technological point of view, it should be noted that conventional technologies could not be substituted by environmental technologies that are not necessarily more expensive, because they might reduce energy and raw material consumption and waste production, as well as avoid the costs of pollution control and elimination. The formation of what may be called *environmental technology ecosystem*, in which environmental technologies substitute conventional technologies and interact in a synergic way, would be even economically favorable. In fact, in this ecosystem, each technology is influenced by other technologies and externalities of economic and physical nature. 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 having a synergistic relationship with other environmental technologies, and in which input-output analysis of the processes of production are economically 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 *Natural Capitalism* (Hawken et al., 1999), proposes that natural resources should be considered as a capital analogous to other types of capitals involved in the economic activity, and it gives suggestions about the changes that might be made to optimize the use of the natural capital, thus contributing to solve environmental problems such as pollution, depletion of resources and global warming. The second one, called *Circular Economy* (Stahel, 2019), considers the potentiality of a new industrial system that integrates production, products and their recycling to increase the duration of products, their possible substitution with services and an effective recycling of waste in order to obtain as much virgin material as possible, which can be reused for productions eliminating the depletion of resources. These two environmental industrial models are presented in detail as follows.

5.1. Natural capitalism

The natural capitalism approach to environmental problems and their economic impact has its origin in the USA, and it is presented in detail in *Natural Capitalism* (Hawken et al. 1999). The authors would show that valid technological solutions, some of which are 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, the book considers that the economic-productive system may survive only within the limits of the global ecosystem. The authors think that considering the environment, economy and social policies in competition is a prejudice, and the best solution is not a compromise that assures an improbable equilibrium among them, but an integrated solution in which these factors are unified at all levels. Various types of capitals are considered in this book: the human capital, which is constituted by labor, intellectual property, culture and organization; the financial capital, which is constituted by money, investments and monetary instruments; the asset capital, which is constituted by equipment and buildings; the natural capital, which is constituted by raw materials and living systems. In fact, natural capital is the result of a complex activity of many living ecosystems that interact with natural phenomena. Its substitution with other types of capital is possible through technology, but it has some limits linked to factors that self-regulate atmospheric conditions, oceans, photosynthesis, the cycle of water, and that of natural or anthropic wastes, and the protection from cosmic rays, all that making life possible on 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 quality of life. The history of the continuous increase of population indicates that there was first an abundance of natural capital in terms of energy, raw materials, etc. and a scarcity of human resources, while now there is a scarcity of natural capital and abundance of human resources. Using the same economic logic of the industrial system, a compensation is necessary to make resources more productive and improve an efficient use of natural capital. In fact, the environment represents the shell that contains, provides, and sustains the whole economic and industrial system, and production technologies should take in consideration all types of capitals including the natural one. There are four strategies suggested by natural capitalism:

- radical increase of the productivity of resources;
- bio-imitation in the production processes;
- an economy of fluxes and services based on quality, usefulness and performance rather than on goods and purchase, changing the mentality of buying as a measure of affluence and wellness;
- making investments in natural capital enabling as much services and resources as possible.

The increase of the productivity of resources means the obtention of a product with less material and energy, indirectly improving the quality of life and 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, which is 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 being purchased, is offered as a service optimizing its use and maintenance and entering in a more efficient flux for recycling, in a strategy similar to that of the circular economy that will be discussed further. Investments in natural capital are necessary to maintain a constant and suitable supply of services to a population in constant increase, and they should be accompanied by technological developments necessary for the efficient use of 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 non-existent pollution and toxicity, and finally longer life cycles of products. In Fig. 1 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 of production might present many economic advantages such as lower energy consumption, lower raw material consumption, less waste production and treatment, elimination or reduction of gaseous emissions and effluents to be treated, and costs of the necessary pollution controls.

5.2. Circular economy

The circular economy approach has its origin in Europe in the early 1980s, when the European Commission published the report *The Potential for Substituting Manpower for Energy*, written by Walter Stahel and Genevieve Ready (1982). The basic ideas of circular economy have been condensed and updated in a recent book (Stahel 2019) that has been considered for this article. A preliminary observation is that the book mainly deals with policies, social aspects, and industrial strategies of the circular economy, and it considers in a very generic way its technological implications, which will be object of discussion in this article. Following the circular economy model, presently there is a linear industrial economy linked to a circular economy through the point of sale for products and services. In this 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 using, repairing, upgrading and recycling materials for reusing or manufacturing. *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*, thus exploiting all its economic, social and environmental advantages, and forming what is called a *mature circular economy*. Both the schematic views of the linear industrial economy, which are connected with the circular industrial economy and the transformation into a mature circular economy, are reported in Fig. 2. Circular industrial economy differs from linear industrial economy because its objective is not to create added value, but to maintain value. Circular economy employs local small-scale processes operated by craftsmen, availability of "Do-It-Yourself" and repairing centres to extend the service life of manufactured objects, as well as 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, they maintain existing resources to fulfill market needs instead of relying on new materials and energy resources. By extending the service life of goods, circular industrial economy employs labor-intensive activities that replace the production of new goods and substitute 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: the era of R, reusing and service-life extension of goods, and the era of D, recovering of waste as pure virgin materials. The era of R is controlled by owners-users, and it can appear inhomogeneous because the stock of goods in use are dispersed geographically with a high diversity; R activities may be local for tailor-made objects or regional for manufactured or mass-produced goods. The era of D is controlled by economic actors for the end of service life objects and needs material and technology innovation to sort high volume and low value of waste materials and turn them in recyclable goods. In a mature circular industrial economy, the era of R solutions should be preferred over the era of D solutions. The era of R aims to maintain infrastructures, buildings, equipment, vehicles, goods, and other manufactured objects at the highest utility and always use value. The era of D needs actions to recover materials at the highest quality and pure as virgin materials, and includes for example technologies such as depolymerization, dealloying, devulcanizing, etc. However, it should be noted that these technologies are still not available and require R&D efforts. In a modern circular industrial economy, production becomes a segment of the loop producing innovative components. 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 concerns recycling of waste materials in the highest utility and value and opening of new fields in the development of reusable manufactured materials easy to be recycled.

5.3. Comparison between the two industrial environmental approaches

Ideas about circular economy emerged more than 15 years before those about natural capitalism, which has not received much attention. These ideas have recently become part of environmental policies especially in the EU. Present circular economy policies concern mainly social aspects and circular industrial strategies, while technologies, although being an essential part of the industrial system, are generally considered assuming that they are available for the purposes of the system or may be obtained simply by making sufficient R&D efforts. This last consideration constitutes in fact a questionable aspect following the knowledge of technology dynamics. On the contrary, natural capitalism enters fully in the relation between technology and the environment, giving specific directives about the environmental technologies that should be developed. Similarly, it includes many aspects that are considered in the circular economy and that are favorable to the environment, but not the full recycling considered in the case of a mature circular economy. Both environmental industrial systems have scientific and technological limits in reaching their objectives, and that will be discussed as follows.

Limits to natural capitalism

The interest and originality of the natural capitalism approach lie in its search for the integration of technologies in the environment, and not simply in a compromise between economic aspects of technologies and environmental exigences, while looking for technologies that are both more economic and respectful of the environment. The major limitation of this approach is the ambitious objective to substitute all conventional technologies with really valid environmental technologies, possibly building up an entire environmental technological ecosystem. Consequently, important efforts in R&D are necessary, but they are accompanied by uncertainty of the duration of efforts and the achievement of the objectives. Another limitation that may be considered has a thermodynamic nature, and corresponds to the minimum but necessary need of energy to maintain the environmental technology ecosystem viable. This amount of energy consumptions may be a limit for some considered advanced objectives. However, comparing with circular industrial economy, the objectives of natural capitalism seem to be easier to attain than those of a full realization of a mature circular industrial economy, although natural capitalism cannot assure the complete elimination of depletion of resources but only its reduction.

Limits to the circular industrial economy

First of all, it should be noted that circular industrial economy represents a real novel approach to industrial production: it supports integration in making and using products, and it values recycling waste to obtain virgin materials that may be used a new for manufacturing. All that fosters reduction of pollution and elimination of depletion of resources. The major limitation of this model principally involves the full inclusion of linear industrial economy into the industrial circular economy, which is transformed in a part of the cycle. That requires full recycling of wastes, which are transformed in virgin materials during the manufacturing step, eliminating practically the consumption of resources. There are two main critics to this objective. The first is of thermodynamic nature and concerns the need for energy to collect and transform waste in virgin materials and which, for entropic reasons, becomes very high as the dispersion and dilution of materials to be recovered increase. These thermodynamic limits have been in fact already cited in previous studies on circular economy (Korhonen et al., 2017). On the other side, it is doubtful that some reasonable technologies are able to separate virgin components. For example, alloys or plastics are usable for the fabrication of the same products as considered in a mature circular economy. Furthermore, there are other two limits of circular economy that influence indirectly but negatively the technological efforts necessary to face economic and environmental problems. The first limit concerns the fact that circular economy does not have any real management strategy for innovations of radical nature that rapidly make existent products and their recycling obsolete, implicitly leading to the paradox of hindering radical innovations and their benefits in order to conserve circular economy. In fact, radical innovations will generate a great quantity of obsolete products and equipment for repairing, reusing and recycling, worsening the operability of circular economy. The second limit concerns the fact that circular economy is focused on R&D efforts to change production processes in terms of reusing and recycling of products without transforming conventional production processes into environmental processes and generating an environmental technological ecosystem, as considered in the natural capitalism system. For example, circular economy tends to renounce to biotechnologies, which are considered in natural capitalism, because of their linear nature not integrable in a mature cycle (Stahel, 2019). In fact, that may influence negatively influence solutions of the problems caused by industrial pollution and global warming.

From the above observations, it appears that the most efficient industrial environmental model could be a combination of two systems in which the transformation of conventional processes into environmental processes is accompanied by the development of a circular economy, not necessarily searching a full transformation into its mature version, and accepting new radical technologies even if they interfere with the recyclability of products. Finally, it should be noted that neither natural capitalism nor circular economy enter into specific discussions about the necessary technological transformation of conventional into environmental production of energy for a solution to global warming. This point will be discussed in the next chapter, which is about the relation between technology and the problem of global warming.

6. Technology and the problem of global warming

Nowadays, greenhouse gas emissions are especially important e for industrial and agricultural activities, followed by transportation and domestic emissions. The changes in the technologies that produce energy are essential for solving the problem of global warming, but it is necessary to elaborate environmental policies suitable to favorize the reduction and elimination of greenhouse gas emissions. In this section, we describe the environmental technologies for the production of energy, considering either those that are already available or under development, and considering also those that are able to catch CO_2 and store it in a concentrated form. These technologies will be discussed from the point of view of the possibility of reaching their technological objectives. Afterwards, there is a discussion on the environmental policies elaborated since the Kyoto protocol in 1997 until the recent Glasgow international meeting COP26 in 2021 from a technological point of view.

6.1. Environmental technologies available for energy production

The main available technologies producing energy without greenhouse gas emissions are: nuclear fission, hydroelectric, biomass, wind and photovoltaic technologies. Nuclear fission technology might be called environmental because of its implication in radioactive waste production, and past Chernobyl and Fukushima nuclear plants disasters. However, nuclear fission is a free carbon technology that produces energy as the other environmental technologies. From a technological point of view, it should be assessed also taking account of possible technological improvements and reduction of risks in comparison with the other environmental technologies.

Nuclear fission production

This technology was developed after the 2nd World War, exploiting also technologies developed in the frame of the Manhattan Project (Rhodes 1986), and it is widely used in particular for great plants around or above 1000 MW of power. The two major accidents caused by this technology are relate to Chernobyl and Fukushima nuclear plants: the first accident was due to human error and safety design deficiency, whereas the second accident was due to the design of a plant that was unable to resist to major environmental events such as a tsunami. From a technological point of view, it is possible to design nuclear plants with a higher level of safety, or even make a completely new design: for example, a radically new design is under development in China, and it consists of a molten salt nuclear reactor based on thorium instead of uranium. However, new accidents cannot be completely excluded although they are less probable than in the past. An important safety problem related to this technology involves the treatment of nuclear and exhausted combustibles, and the storage of radioactive waste, which also needs technological improvements. The advantage of Nuclear fission plants consists in their great power without the need for great surfaces, and their stable continuous production of energy. One of their limitations is related to the long time periods necessary to build up the nuclear plants instead, for example, of wind or photovoltaic plants.

Hydroelectric production

This technology produces electric energy and has spread since the beginning of the XX century. It is considered a safe, environmental, and economic technology to produce energy that, however, cannot always have the great power of nuclear plants. One of its advantages is the rapidity in producing energy, being ideal to cover peaks of energy demand at any time. Although this technology has many advantages, it cannot be considered as an extended substitution of fossil fuels because it can be utilized only in favourable specific locations in which it is possible to build hydroelectric basins on mountains or dams on great rivers.

Biomass production

Biomass production of energy not only means the use of wood or other vegetal products to generate thermic energy but also the production of fuels, such as ethanol, which is an alternative to the use of gasoline of fossil origin for transportation. Ethanol may be obtained by fermentation of suitable cultivated plants, and productivity might be improved by development of a suitable GMO plant. However, biomass energy cannot be considered as an extended substitution of fossil fuels. In fact, the natural photosynthetic process is slow, and cannot follow the entire demand of a continuous large need for energy.

Wind energy production

The wind electric energy is obtained by using modern wind propeller plants. The level of obtainable power is limited by the dimension of blades that cannot be extended beyond certain lengths for mechanical reasons. A certain number of wind propellers are often grouped in a favourable location to have reasonable production powers. Wind energy, differently from solar thermal or photovoltaic production, can also be produced during the night, although depending on the variability of wind intensity. Wind plants normally produce electric energy without high levels of power, although some of them are planned in suitable windy locations with great available surfaces. This technology is generally not considered as the main substitute of fossil energy as in the case of photovoltaic technology, but only a contribution. In industrialized countries, wind plants sometimes find the opposition of environmentalists because they change the landscape and are a source of noise.

Solar thermal production

Solar thermal energy production consists in a field composed by numerous suitable mirrors that concentrate solar energy on a central receptor that normally produces steam used for producing electric energy in a turbine. Although there are several operated plants, the large surface necessary for the mirrors in order to produce sufficient steam for the turbine makes this technology efficient only in locations with elevated solar irradiation, and cannot be considered valid for an extended substitution of conventional energy producing technologies. It should be noted that solar thermal power plants for the production of hot water were widely diffused in the past, but now the domestic production of photovoltaic electric energy is preferred.

Photovoltaic production

This technology is considered as a possible global substitute of conventional technologies, and it is based on the property of certain materials, such as silicon, to transform solar energy into electric energy. Energy is normally produced by using suitable panels with a surface of silicon. The power depends on their surface extension and intensity of solar irradiation in the geographical location. The advantage of this technology is the production of electric energy in a simple and static way, with levels of power proportional to the panels surface. However, it cannot produce energy during the night, and production is limited in case of cloudy weather. This technology has been widely used to produce electric energy for houses and buildings, and in a certain measure also for feeding distribution networks. The obtention of high power in photovoltaic plants may be considered in countries with large free surfaces. In China, for example, five plants are in operation or under construction, with a power ranging from a maximum of 2200 MW to a minimum of 850 MW. However, such plants may be difficult to plan in industrialized countries. In fact, considering an average power production of 70 W/m^2 (Rebaudengo, 2021), it may be estimated that a 1000 MW plant needs about 15 km^2 of panels surface: a similar power plant cannot be located where there are already the present conventional plants, and that needs also the restructuration of the energy distribution network. In industrialized countries with a relatively high density of population, a generalized production of energy with photovoltaic plants necessarily involves also the existence of peaks of demand of energy that does not correspond to the peak of energy production, and the consumption of energy in industrial plants during the night, in which photovoltaic production is absent. That needs an efficient storage of the electric energy produced for peaks and night consumptions. Nowadays, the problem of an efficient storage of a large quantity of electric energy has not been completely solved. An efficient system consists in pumping water to a basin on a mountain during the peaks of production, generating hydroelectric energy by discharging the pumped water into a lake. However, the use of such system is limited by the availability of suitable locations. Another possibility is the use of batteries necessary for the storage of high powers and great amounts of electric energy, and that currently exist only at the level of pilot plants. However, such system is conditioned by loss of efficiency for thermodynamic reasons due to the transformation of electric energy into chemical energy and its necessary retransformation into electric energy. The photovoltaic production of electric energy is included in many policies for major reductions of greenhouse gas emissions and the arrest of global warming. However, it might be argued that if these reductions are planned within 10 to 30 years, they would not be affected by great uncertainty, considering the limits suggested by technology dynamics, which have been previously discussed. On the other side, even if objectives could be reached, that does not mean that the arrest of global warming will be obtained, as often indicated when presenting these policies. That is because the total arrest of greenhouse gas emissions cannot be satisfied only by the industrialized countries, but depends also on the energy policies of developing countries and their increasing needs for energy.

6.2. Environmental technologies under development for the production of energy

The main technologies under development that produce energy without greenhouse gas emissions are the nuclear fusion, the production of combustibles by solar thermal energy or the artificial photosynthesis, using water and atmospheric CO_2. Another possibility is the use of the hydrogen cycle to produce energy, since hydrogen is obtained through environmental technologies and without greenhouse gas emissions.

Nuclear fusion production

This technology uses extremely high temperatures for the nuclear fusion of hydrogen isotopes that are obtained from water. However, the types of hydrogen isotopes that should feed the nuclear fusion are still not completely defined and might involve also an indirect consumption of lithium. The very high temperatures are normally obtained in a ring of plasma gas, which is maintained suspended and heated in a toroidal magnetic system in which the fusion takes place. Its main difficulty is the generation of the amount of energy necessary to reach and keep the necessary very high temperatures for the fusion, while having an excess of exploitable energy at the same time. These conditions have never been reached for the moment. A nuclear fusion plant of great dimension is currently under construction: that would be able to obtain the excess of energy necessary for the production. This plant is part of the ITER project, which is internationally financed by various industrialized countries. This technology has less problems of radioactivity than nuclear fission, and lower probabilities of possible major accidents. However, it appears exploitable only for a very big production of electric energy, in which it is necessary to have probably more than 10 GW of power in a plant to obtain a GW of exploitable energy to produce electricity. A completely different nuclear fusion technology under development involves the heating of small quantities of fusion material with a high-power laser. Recent results have shown the possibility of producing 80% of the energy necessary to make the fusion with this system. Such technology, if successful, might be suitable also for plants with minor power dimensions. Fusion technology appears to be an ideal substitute of conventional fossil technologies, as it does not necessitate very large surfaces and allows for a continuous production without limits in the location. However, these technologies are expected to present long-term development and diffusion in the frame of a substitution of conventional technologies.

Combustible production

Solar energy may be basically exploited to produce a combustible through reactions at high temperature between water and CO_2 present in the atmosphere. The combustible may be obtained through a thermal catalytic process, concentrating solar energy in a reactor. This technology is object of the R&D activity, and even of pilot plants. An alternative, which is now under study, might be an artificial photosynthetic process that is possibly more rapid than the natural photosynthesis used for the previously discussed biomass production. The artificial photosynthetic process appears more favourable but also more challenging. However, there are no chemical or thermodynamic reasons that hinder the realization of such process, but the necessity of large research efforts that have not been made until now. These processes are less developed than nuclear fusion and it is difficult to forecast their ability of substitution of conventional technologies

The production of energy with the hydrogen cycle

Solar energy may be basically exploited by using a cycle that is different from the carbon cycle involving CO_2, and that is based on hydrogen. In this case, water should be split in separated hydrogen and oxygen gas, this last being conserved or liberated into the air. Hydrogen may be used as combustible, burning it with air, or as fuel in combustion motors in alternative to gasoline, returning in form of water. Otherwise, conserving oxygen, both gases may be used to feed a fuel cell producing electric energy. Hydrogen and air may be used also to feed fuel cells producing electricity for motors of electric vehicles. The key point of this technology is the splitting of water by solar energy. Presently, the only available environmental technology that can be widespread is the photovoltaic production of electric energy, followed by electrolysis of water producing hydrogen and oxygen separately. This process may be considered also as a possibility to chemically store the discontinuous production of photovoltaic electric energy as hydrogen gas. However, this technology of hydrogen production, or storage of photovoltaic energy production, presents some efficiency limits. In fact, it involves a series of processes such as: the transformation of solar energy into electric energy, the electrolysis of water and storage of hydrogen, and finally its possible transformation anew in electric energy in fuel cells. A favorable aspect of the hydrogen cycle might be the possibility of using a distribution network of hydrogen exploiting the present natural gas network.

6.3. Technologies catching carbon dioxide

The process of capturing CO_2 from the atmosphere or from emissions of industrial plants is being studied in order to contribute to the elimination of this gas and to the arrest of global warming,, and there are more than sixty plants in the phase of demonstration, planning or under development. This technology is based essentially on a suitable solid or liquid material adsorbing CO_2, which is then liberated by heating and stored in various ways, for example by mixing it with water and pumping the mixture deeply in suitable rocks. This process might be useful to capture the CO_2 emissions from industrial plants at a relatively high concentration, but it is doubtful that it can be used to catch the amount of CO_2 in the atmosphere, really reducing its concentration and arresting global warming. In fact, there are two great difficulties in reaching this objective. The first one concerns the fact that CO_2 is extremely diluted in the atmosphere, and that its transformation in a concentrated form suitable for its storage needs a great amount of energy, with its environmental implications, for thermodynamic reasons. The second one concerns the fact that there are thousands of billions of tons of CO_2 to be eliminated, which might require the use of an enormous number of plants operating for long time to reach the objective.

6.4. Environmental policies and technology

Considering the environmental policies elaborated since 1997 Kyoto protocol until the recent Glasgow meeting COP26 in 2021, there are two main critical aspects that should be examined from a technological point of view. The first one concerns the availability of a suitable technology for an environmental energy production in the frame of an increasing demand of energy, especially in the case of developing countries. The second one concerns the existence of valid technological strategies able to reach an effective global arrest of greenhouse gas emissions and subsequently of global warming. All these critical points are accompanied by technological questions about the choice of the suitable free carbon technologies able to substitute completely the fossil carbon production of energy, and the choice to use or not to use nuclear fission technology in combination with solar energy production, in particular with photovoltaic technology, in order to completely arrest greenhouse gas emissions and subsequently of global warming.

The impact of the increasing energy demand in developing countries

The substitution of fossil production of energy with free carbon productions occurs in the frame of an increasing energy demand. In industrialized countries it is expected, for example, that the complete transition of transportation technologies based on energy from carbon fuels to electric vehicles will increase electric energy consumption. This increase is not necessarily compensated by greater efficiency and saving of other electric energy consumptions. Much more important is the expected increase of energy demand in developing countries and the problem of substitution of their fossil energy production. It should be considered that important countries under development, such as India and China, will increase their energy demand: presently, India produces electrical energy entirely by coal, and China uses coal for a great part of its energy production. These two countries represent about 40% of world population, and the arrest of greenhouses gas emissions and global warming is not possible without their contribution in changing their technologies of energy production. The problem of the increase of energy consumption in developing countries was not sufficiently considered: since India and China were not among the 36 countries signing 1997 Kyoto protocol. These countries, thanks to their development, became two of the biggest greenhouse gas emitters. Even during COP26 there was a difficulty to reach an agreement about the degree of reduction of emissions and planned times with these two countries. The problem of developing countries and their use of environmental technologies to produce energy was taken in consideration just few years after the signature of the Kyoto protocol, notably in a study on modelling of technical change and energy - environment outcomes (Grubb & Koehler, 2002). In this study, technical change was considered an important factor in addressing major environmental issues, particularly large-scale long-term problems like climate change. The focus of the cited study was not on the importance of technology development, which seems beyond question, but on how technology development occurs and is represented in models, and the nature of the economic and policy conclusions that flow from this. The authors developed a model following the rules of the Kyoto protocol, according to which carbon emission reduction in developing countries depended on the choice of environmental technologies instead of conventional technologies. The result of this model showed that, only in the case of a high spillover of environmental technologies, carbon emission does not reach much higher values in developing countries compared to industrialized countries. Otherwise, these values might be even about ten times the emission of the industrialized countries following the rules of the Kyoto protocol. In conclusion, it may be observed that many of the actual environmental policies elaborated in industrialized countries are presented as solutions to global warming, but in fact they provide directives concerning only industrialized countries, without taking account of the different problematic situations existing in developing countries. Consequently, they may not actually be considered alone as a real effective solution for global warming.

Environmental policies and technological strategies

After thirty years from the Rio de Janeiro UNO Earth Summit and twenty-five years after the Kyoto protocol, there is a continuous increase of CO_2 concentration in the atmosphere and a consequent global warming, despite of the application of various environmental policies. It might be argued whether these policies are ineffective because of their limited application, or if a new environmental strategy would be necessary. From a technological point of view, there could be some criticisms about the fact that the agreements taken under the Kyoto protocol until the COP26 meeting consider the establishment of suitable environmental policies as an essentially political solution to global warming. In fact, these policies consider essentially that free carbon technologies for the production of energy are already available and just need to be spread, while useful new technologies may be simply obtained by an adequate R&D effort. However, this article indicates that, for a global substitution of conventional technologies, the only carbon free production of energy fully available and experienced is the nuclear fission technology, even if it is contested because of the dangers involved. The other technologies, which are based on solar energy, have still some development problems in view of their possible global substitution of conventional technologies. These problems concern the need for great surfaces and the storage of electric energy, especially for their use in industrialized countries. That does not mean that these solar technologies cannot find a solution to their problematic diffusion, but *whether these solutions will be available before the increase of concentration of greenhouse gases with a high level of global warming, they will manifest in a great measure their deleterious effects.* On the other side, the development of new technologies for the environmental production of electric energy, from the technological point of view and the experience in technology innovations, cannot be considered successful only by making an adequate R&D effort and it is improbable that they will be able to reduce the time necessary to globally arrest greenhouse gas emissions. All that raises the question if it will be necessary to combine the available nuclear fission technology with solar technology. The uncertainty in the time it takes to arrest greenhouse gas emissions has recently become very important: for example, the EU has included nuclear fission technology and natural gas as acceptable technologies for the reduction of carbon emissions, despite of the fact that burning natural gas is not free of carbon emission, but only a reduced emission in respect to coal or oil burning. Nuclear fission technology is contested for its dangers, especially in industrialized countries such as Italy, where the nuclear energy production has been abandoned since many years, and Germany and Switzerland, where it has been decided not to build new nuclear plants. Other countries have made different choices: for example, France has always considered nuclear energy production as a valid substitution of fossil production, while China considers to substitute its energy production based on coal with a mix of nuclear and solar technologies. All these positions are now under discussion to decide whether nuclear energy production must be used in combination with solar energy or not. This question may be seen also from a technological point of view, considering the possible risks and two main scenarios, without considering the precautional principle and its limits previously discussed : in the first scenario, conventional technologies are globally substituted by solar energy only; in the second scenario, conventional technologies are substituted by both solar energy and nuclear energy. It should be considered that nuclear technology may be improved in terms of decrease in risk of major accidents, taking account of Chernobyl and Fukushima disasters, although it is impossible to automatically exclude a disaster of another type. On the other side, solar energy production may be affected by great problems, too. That is the case of a possible great volcanic activity, with a fine dust in the atmosphere reducing sensibly the available solar energy for several years. Such accident cannot be considered more improbable than a major accident caused by a nuclear plant with improved safety. The damages of these two cases are different, and nuclear damages might be considered less desirable than the loss of energy production. However, it should be considered that nuclear accidents have large but relatively local effects, while great volcanic activities have global effects and a decrease of energy production in the entire world. In the context of risks analysis, it appears that a scenario in which nuclear and solar energy are both used might urgently arrest greenhouse gas emissions and lower damages due to global warming in respect to a scenario in which only solar energy is involved. Ultimately, there is an important uncertainty about the time it takes to completely arrest greenhouse emissions, and which would be the level of dangerous effects at that time. As a result, from a technological point of view, there are necessarily much more studies and efforts on the development and diffusion of technologies mitigating directly the global warming effects.

7. Technological innovation and green technologies

In the context of the study of relations between technology and environmental policies, it is useful to consider the innovative possibilities concerning not only the previously discussed technologies of energy production, but also those necessary for other problems involved in the realization of an environmental technological ecosystem, as suggested by the natural capitalism and circular economy systems. These possibilities and the consequent technological strategies to be adopted may be discussed taking account of the specific characteristics of the organizational structures for innovation, in which green technologies may be developed, i.e. the industrial R&D, the SVC and the industrial platform systems described previously. Before discussing the role of these organizational structures, it is useful to summarize the various involved technologies and in particular their degree of radicality, which determines their probability of success, and the financial strategies that should be considered. The various technologies may be divided following the type of environmental problem they try to solve, i.e. pollution, depletion of resources and global warming.

Technologies against pollution

These green technologies are particularly involved in the industrial system based on the natural capitalism view, and have the aim to form an environmental technological ecosystem, with synergic relations among the technologies. That may be obtained transforming conventional technologies of production into environmental technologies, as indicated in Fig. 1. These new technologies aim at reducing energy consumption and raw materials, and at eliminating or reducing pollution and solid waste, and they may be of both incremental or radical type. For these purposes, technologies of incremental type concern improvements obtained for example by process digitalization, while technologies of radical type are able to substitute conventional production processes with environmental processes.

Technologies against depletion of resources

These technologies are involved especially in the circular economy approach, and they concern the improvement of the duration of the products and their reuse after being repaired, upgraded and recycled. Most of these technologies are of incremental nature, but radical technologies may be involved especially for a more effective recycling.

Technologies against global warming

These technologies concern the carbon free production of energy. Some technologies such as nuclear fission, photovoltaic and wind technologies are already available and mainly involved in incremental innovations. However, in the case of nuclear fission technologies, radical changes with new reactor designs and new types of nuclear fuels are also possible. Concerning technologies under development such as nuclear fusion, the production of fuels by thermal solar energy or artificial photosynthesis and the realization of the hydrogen cycle for energy production are all of radical nature.

The development of green technologies occurs in structures organizing fluxes of knowledge and capitals, following technology dynamics. In these organizations, technology innovation is obtained through processes that are independent of the type of institutional or industrial organization in which development is carried out. That means that for example an R&D activity is carried out through the same organizational process in a university research laboratory, a research center, or an industrial R&D laboratory. The independence of organizational structures from institutional or industrial organizations allows a generalization of the innovation process defining it on the base of its degree of radicality. As previously said, this degree determines the probability of success of the development of a new technology and its impact. A high value of radicality decreases the probability of success of development, but at the same time it increases the possibility of a positive future impact of economic, social and environmental nature on the developed innovation. On the contrary, a low value increases the probability of success of development but, at the same time, it decreases the possibility of a positive future impact of economic, social and environmental nature on the developed innovation. This indicator may then be used to explain the actual and future scenarios of the development of several green technologies, according to the value and the type of organization in which development is carried out.

The industrial R&D system and green technologies

The industrial R&D activity has been shown to be particularly suitable for the development of technologies with a relatively low radical degree and higher probability of success. This system is typically followed by industry and well appropriated for the improvement of production and products. This system may be then considered suitable for the incremental development of green technologies involved in the environmental industrial system, as well as for the improvement of available technologies for carbon free production of energy. However, the important relation between the degree of radicality of technology and the organizational structure suitable for its development, has not been taken in consideration in the established policies since the Kyoto protocol. In fact, the task of technology development has been left essentially to the industrial R&D system possibly with public aids. Consequently, R&D was oriented towards well-known technologies such as solar thermal, photovoltaic, and wind technologies with a low degree of radicality and lower risk of failure, instead of orienting major efforts towards more radical technologies, such as solar thermal or artificial photosynthesis for the production of fuels or hydrogen. Technologies with higher risk of failure are also possibly much more suitable for a global substitution of conventional technologies. If there was a political agreement, since the Kyoto protocol, promoting a great international project for the development and coordination of various radical technologies free of carbon emissions, this would be similar to the Manhattan Project complexity (Rhodes 1986), this time not endangering but saving mankind. Now, after almost thirty years of development, we would probably have an available set of these new radical technologies for a strong reduction of carbon emissions. That would have also a consequent favorable spillover for the energetic needs of developing countries, and a possibly more rapid arrest of global emissions of greenhouse gases. In fact, a cooperation of this kind has been done only in the case of the ITER project concerning nuclear fusion, a too limited action to face the various complex situations existing for the global substitution of conventional energy productions.

The SVC system and green technologies

The SVC system is known to be suitable for the development of radical technologies, and VC invests in this kind of technologies with the aim to sell the developed technology and obtain high returns. In fact, VC is known to invest in green technologies with a certain high degree of radicality and with possible high returns. However, certain new radical technologies, especially those of energy production, do not fit well with the normal financing strategies for VC, mainly because of the necessary length of development and political involvement in the diffusion of this type of technologies. For this reason, the SVC system cannot be considered as a full solution for the development of radical green technologies and, again, public financing and international cooperation are necessary to accompany the SVC activity in green technologies, as in the case of the industrial R&D system.

The industrial platform system and green technologies

The industrial platform system is not involved directly in the development of technologies and green technologies. These ones may be developed by the R&D and startup activities present in the structure of the platform. In fact, the function of the platform is to increase the available knowledge, boosting improvement and development of new technologies through the relations among the various actors of the platform. However, the possible evolution of this system towards the formation of an industrial platform network (Bonomi 2020), with platforms supplying basic green technologies to industrial companies, would be particularly favorable for the development of an environmental industrial ecosystem based on natural capitalism and circular economy.

8. CONCLUSIONS

In this article we have explained the importance of knowledge of technology fundamentals and innovation through a discussion of the relation between technology and environmental policies. Above all, we have discussed the limits of use of the precautional principle in environmental policies, and its valid substitution with a risk analysis able to consider not only the dangers of using technology, but also those of non-using it. As regards the environmental problems concerning pollution and depletion of resources, we have described and compared two types of environmental industrial systems, natural capitalism and circular economy, in view of the development of a technological industrial ecosystem based on them, and considering that the objective of obtention of a mature circular economy is not viable. As regards the problem of global warming, we have discussed the limits of the available free carbon technologies and those under development, for a global substitution of conventional technologies. Consequently, we have raised criticisms to the environmental policies elaborated since the Kyoto protocol, which are based on the idea that global warming may be essentially solved by political agreements without taking account of all technological implications. These policies have not favorized the formation of an effective international cooperation and coordination of the development of environmental radical technologies to produce energy, which is necessary for an effective and rapid arrest of global warming. Finally, we have considered the scenarios of development of the various green technologies following their degree of radicality and the suitability of the different structural organizations in which they may be developed. In conclusion, we have underlined the lacking of a technological strategy that takes account of the uncertainty about the time necessary for a full and global substitution of conventional technologies of energy production, and then we have also considered the necessity of development of technologies that are able to mitigate the unavoidable dangerous effects of global warming.

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10. FIGURES

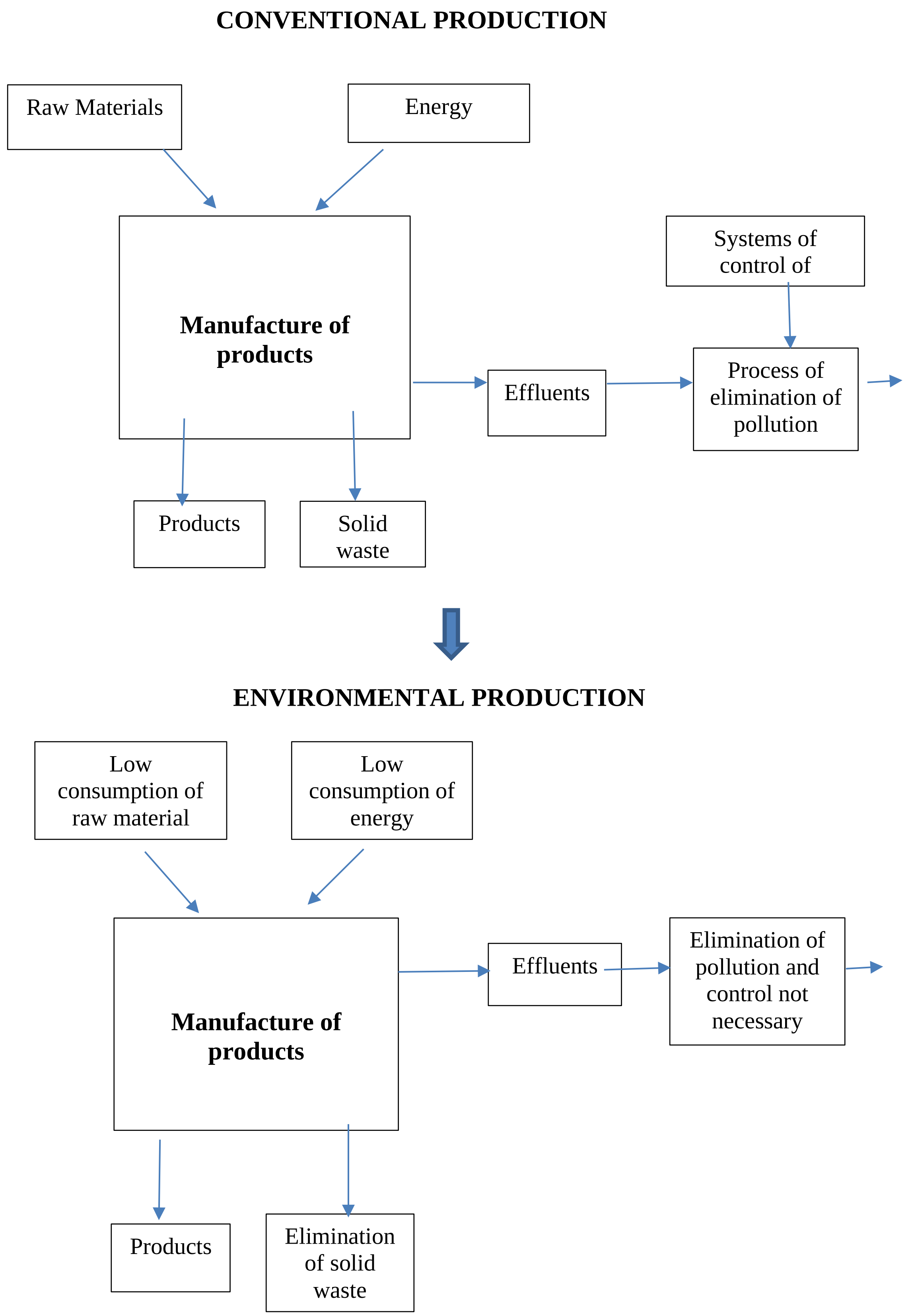

Figure 1. Conventional production process to environmental production process (See also Bonomi, 2004).

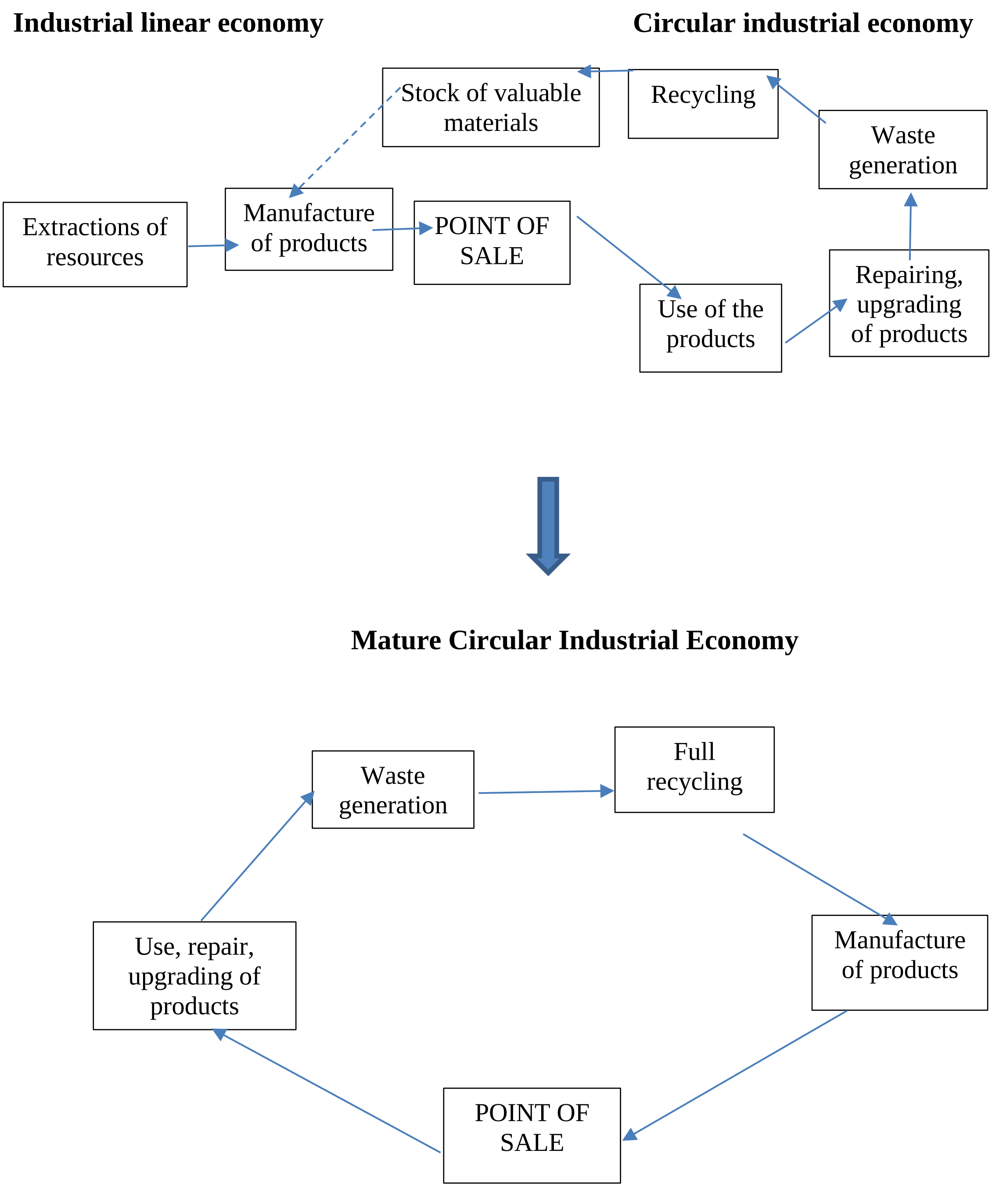

Figure 2. Industrial linear economy to mature circular industrial economy (See also Stahel, 2019).

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Numeri precedenti/Previous issues

This article explains how fundamental aspects of technology and technological innovation are involved in the environmental policies in terms of practicability and possibility of reaching their objectives. After a brief presentation of fundamentals of technology and its innovation, it discusses the limits of the precautional principle and its valid substitution with a risk analysis considering not only the dangers of using technology but also the dangers of not using technology. As regards problems of pollution and depletion of resources, this article describes the two environmental systems of natural capitalism and circular economy, while considering non-viable the objective of mature circular economy. As regards global warming, it discusses the available free carbon technologies and technologies under development in view of a global substitution of all conventional technologies. Environmental policies are criticized because the problem of global warming may be essentially solved by political agreements without taking account of technological implications. Scenarios of development of various green technologies are considered in the frame of various types of structural organization carrying out their development. Finally, this article observes the absence of a technological strategy considering the uncertainty about the time necessary for a full control of global warming, and the necessity to develop technologies able to mitigate its unavoidable dangerous effects.

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