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Abstract

Sustainability has become the emerging goal for countries, companies, and people. Sustainability usually refers to the need to develop models necessary for both human beings and our planet to survive. However, sustainability is not a short-term problem; it is above all a long-term issue, posing intergenerational equity problems. Moreover, sustainability needs efficiency. The efficient use of energy, natural, material, and informational resources is vital for sustainability and sustainable development, which should be the major goal of every country, as established in Rio in 1992, and reaffirmed at Rio+ 20 in 2012. But any strategy aiming at sustainability and efficient use of resources must focus on innovation and technological progress. Consequently, innovation is fundamental to making sustainability possible and improving efficiency. Yet, innovation for sustainability must be environmentally friendly (e.g., green technologies). The principle behind such a strategy is *better instead of more*. This paper aims at highlighting the key relationship among sustainability, innovation, and efficiency. First, it examines the concept of sustainability, looking at the neoclassical literature on sustainability and its relationship with innovation. Then, it analyzes different theoretical approaches and discusses the policy issues for sustainability where innovation, natural capital, human capital, population, and institutions are fundamental factors.

Keywords: Sustainability, Innovation, Efficiency, Sustainable Development Goals, Sustainable Development Policies

JEL Classification: Q32; Q38; Q50; Q55; Q56

Introduction.

This paper discusses the key relationship linking sustainability, innovation, and efficiency. On the one hand, sustainability has become the emerging goal for countries, companies, and people, the foundation for today's leading global framework for international cooperation—the 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs). On the other hand, innovation is a fundamental concept for prolonged and sustainable economic development, strictly related to economic and technical efficiency. Therefore, sustainability is a primary concept in this analysis. Today's view of sustainability is to keep the environment on a human scale, employ low-carbon technologies, obtain environmentally friendly products, limit the negative effects of climate change, and implement an approach of permanent recycling. All this means that sustainability requires eco-compatible innovations, as well as a population policy and adequate institutions. Moreover, sustainability requires efficiency. The efficient use of energy and of natural, material, and informational resources is vital for sustainability. Technological innovations that offer improved efficiency of technological processes should be used not just to provide a better standard of living for individuals while maintaining at the same initial level the rate of natural-resource consumption, but also to decrease the environmental degradation linked to the rate of natural- resource consumption, in order to reduce the pressure on the environment (Mayumi et al. 1998). However, without a substantial investment in innovation, the targets related to sustainability and sustainable development are not achievable. The environmental innovation capacity of a country must be increased, as well as that of its companies. That is why a policy for sustainability, innovation, and environment is necessary. This chapter aims to provide theoretical insights on the notion of sustainability and the relevance of its relationship with innovation and efficiency. The chapter looks at the neoclassical economics literature on sustainability and its relation to innovation. It also examines other theoretical approaches, focusing on the contributions of Partha Dasgupta because of his attention to the environment and the human condition and his evaluation of sustainability. Finally, the chapter discusses the policies for sustainability where innovation, natural capital, human capital, population, and institutions are fundamental factors.

1. Sustainability

2.1 The Concept

The concept of sustainability was introduced at the first United Nations (UN) Environment Conference in 1972, although only in 1987, with the publication of the report Our Common Future by the World Commission on Environment and Development (1987) (the so-called Brundtland Report),[1] was sustainability clearly related to the notion of development:

[1] The Brundtland Report (World Commission on Environment and Development 1987) follows an all-encompassing approach in which economic, social, and environmental objectives are placed on the same logical level. However, an increasingly common criticism of this approach is that it does not take sufficient account of the limits imposed by the ecosystem. In fact, in the Brundtland Report (and this is perhaps the key to its success) the natural environment does not constitute a limit for economic growth, while synergies are emphasized.

Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits—not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. (United Nations 2012, p. 15)

It is clear from the definition that the Brundtland Report took the object of interest to be human needs. Thus, in 1992, at The UN World's First Earth Summit, sustainability became the new paradigm of development itself. Essentially, sustainability takes into account how humans might live in harmony with the natural world, protecting it from damage and destruction. In this view (UNEP 1992), it is possible to identify three dimensions of sustainability: economic dimension (efficiency, growth); ecological dimension (reproducibility of resources); and social dimension (equity).

Afterward, at the Rio+20 UN Conference in 2012, which acknowledged the insufficient progress in sustainable development, new global goals for sustainable development were defined, including the Millennium Development Goals, to be framed within the post-2015 agenda. Furthermore, a ten-year policy framework was adopted by sustainable production and consumption models.

The conference focused in particular on two major themes (United Nations 2012): first, "a green economy in the context of sustainable development and poverty eradication," to be understood as a transition to a green economy, representing a new paradigm that seeks to alleviate global threats such as climate change, loss of biodiversity, desertification, and depletion of natural resources, and at the same time to promote social and economic well-being. The second theme was an "institutional framework for sustainable development," to be understood as a reference to the global governance system for sustainable development, including institutions responsible for developing, monitoring, and implementing policies for sustainable development through its three pillars: economy, society, and environment.

Moreover, according to the United Nations (2012), technology and technological innovation play an important role in sustainability. The access, development, transfer, and diffusion of environmentally sound technologies and corresponding know-how to developing countries is of great importance.

An implication of the approach to sustainability put forward by the United Nations (2012) is that sustainability and efficiency can go hand in hand. Enterprises that embrace the concept can effectively realize competitive advantages: more efficient processes, improvements in productivity, lower costs of compliance, and new strategic market opportunities.

Furthermore, the European Commission in January 2014 launched the 2030 climate and energy framework,[2] where technological innovation and industrial competitiveness are key aspects of EU climate and energy policies. The goals concern moving toward a low-carbon economy.

1.2 The Neoclassical View

Neoclassical economics developed an analysis of the environment and of the notion of sustainability in relation to economic growth. The important points of this analysis are the environmental externalities, the optimal intergenerational allocation of non-renewable resources, and the substitutability of natural capital with other capital factors, thanks to innovation. However, a key

[2] European Commission (2014).

aspect concerns the substitutability between human-made capital and non-renewable resources, and whether non-renewable resources are essential.

In his seminal paper, "The Economics of Exhaustible Economics," Hotelling (1931) had already pointed out the possibility that growth may collapse with the depletion of non-renewable resources. However, in historical experience, a continuous flow of technological innovations has improved human capacities to constantly exploit new natural resources, continually loosening the effectiveness of their absolute scarcity. This historical evidence suggests a profound link between investment in technical capital, technological progress, and the ability to find solutions to absolute scarcity. The neoclassical growth model offered the theoretical underpinning to such empirical evidence. In particular, a Cobb–Douglas production function with neutral technical progress, as in the Solow model (Schilirò 2017), provides the needed theoretical assumptions. Solow's well-known neoclassical approach to growth is based on the notion of production function and (almost unlimited) trust in the substitutability of factors and technological progress.

Solow dealt with the problem of scarcity and exhaustion of resources, and the problem of sustainability, in various writings.[3] Particularly in his Ely Lecture, "The Economics of Resources or the Resources of Economics" (1974a), Solow presented an optimistic view of the exploitation of scarce natural resources, observing that

the seriousness of the resource-exhaustion problem depends in an important way on two aspects of technology: first, the likelihood of technical progress, especially natural-resource-saving technical progress, and, second, the ease with which other factors of production, especially labor and reproducible capital, can be substituted for exhaustible resources in production. (p. 10)

He cited Nordhaus' "backstop technology"[4] to highlight the possibility of inexhaustible supplies, thanks to technological progress. Further on, Solow, arguing on substitutability, states:

As you would expect, the degree of substitutability is also a key factor. If it is easy to substitute other factors for natural resources, then there is in principle no "problem". The world can, in effect, get along without natural resources, so exhaustion is just an event, not a catastrophe. […] at some finite cost, production can be freed of dependence on exhaustible resource altogether. If, on the other hand, real output per unit of resources is effectively bounded–cannot exceed some upper limit of productivity which is in turn not too far from where we are now–then catastrophe is unavoidable. In-between there is a wide range of cases in which the problem is real, interesting, and not foreclosed. (p. 11)

Although the last sentence indicates that Solow was quite optimistic about technology at that time, he certainly did not make the assertion that we do not need natural resources at all. At the same time, he was aware of the importance of technical progress to relieve "the drag on economic welfare

[3] Solow (1973, 1974a, b, 1976, 1986, 1992, 1993, 2009).

[4] Solow (1974a, p. 4) pointed out that a backstop technology is "a technology capable of producing or substituting for a mineral resource at relatively high cost, but on an effectively inexhaustible resource base."

The concept of backstop technology was developed by Nordhaus (1973) and was very influential in energy economics; in fact, it is a technology for mobilizing energy that is not based on an exhaustible resource. Backstop technology, according to Nordhaus, is an ultimate technology resting on a very abundant resource base. This technology allows for a substitute process with an infinite resource base. See also Nordhaus (1993).

exercised by natural-resource scarcity" (Solow 1974a, p. 11). He was also aware that only under standard assumptions is efficiency (as well as social optimality) guaranteed, since the Hotelling rule (considering the fundamental principle of natural-resource economics) becomes the necessary condition for it.[5] But Solow warned against the possible failures in the functioning of competitive markets (e.g., because of the presence of externalities, and also because the choice of a social discount rate is a policy decision about the intergenerational distribution). Therefore, he stressed the need for and the difficulty of implementing a policy on intergenerational distribution.

In brief, the neoclassical theory of non-renewable resources (Solow 1974a; Dasgupta and Heal 1974; Hartwick 1977; Stiglitz 1974) basically states that (a) non-renewable resources represent a challenge for growth and even for sustainability; and (b) there is not an obvious answer to the question of whether future economic development will be sustainable. But to try to answer this question, the typical neoclassical model of non- renewable resources contains two important elasticities: the elasticity of substitution between human-made capital and the non-renewable resource, and the elasticity of resource efficiency with respect to the resource price.

The major criticism of this approach is that natural and human-made (or artificial) capital may not be as substitutable as assumed in this kind of model.[6] This is especially true when referring in particular to ecosystem services such as natural floodplains and oxygen cycle (Perman et al. 2003).

Later, Solow (1992) points out the relevance of sustainability in discussions of long-run economic policy. Solow's central point is that sustainability is at its core about leaving sufficient capital for future generations. Today's decisions about how much we consume versus how much we invest are the key drivers of sustainability (Solow 1992). Then he defines sustainability as the societal outcomes that allow future generations to be at least as well off as people are today, stressing that the questions connected with sustainability are very complex. "Sustainability is a [moral] obligation to conduct ourselves so that we leave to the future the option or the capacity to be as well off as we are" (Solow 1992, p. 181). Since the future is unknown, Solow emphasizes the vagueness but not the meaninglessness of that concept. Moreover, Solow points out that the definition of sustainability tells us that goods and services can be substituted for one another, suggesting that we do not owe to the future any particular thing. Solow believed that the principle of non-specificity applies also to nature.

In Solow's (1992) view, sustainability is about distributional equity: "It is about the sharing of well-being between present people and future people" (p. 182). Furthermore, as a matter of distributional equity between present and future, sustainability becomes a problem about saving and investment. Thus, "there is a conflict between present and future and the demand to satisfy needs" (p. 187).

Hartwick's (1978) analytical result is recalled by Solow (1992).[7] Hartwick studied an economy that takes rentals, the pure return to a non- renewable resource, and invests in those rentals.

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[5] Hotelling's rule states that the most socially and economically profitable extraction path of a non-renewable resource is one along which the price of the resource, determined by the marginal net revenue from the sale of the resource, increases at the rate of interest.

[6] A limitation on the substitutability between natural capital and artificial capital is that natural capital has the feature of multi-functionality (all life-support functions); a similar feature is not shared by artificial capital (Pearce and Turner 1990).

[7] Hartwick (1977, 1978), following Solow (1974b), showed in a number of models that keeping investment equal to the rents (really profits from the flow of depletion) from exhaustible resources under competitive pricing yields a path of constant consumption. Thus, altogether this is known as the Solow–Hartwick sustainability model (Solow–Hartwick sustainability was defined as "weak sustainability").

Hartwick's rule is synthetized by Solow (2009)[8]: "The investment of all (competitive) resource rents along an efficient path leads to just enough capital accumulation to maintain a constant level of consumption" (p. 3). According to Solow (1986), directing the rents on non-renewable resources into investment is a good rule of thumb, and in a simple economy, it will guarantee a perpetually constant capacity to consume.

Among the policy proposals contained in Solow (1992) particular attention is paid to investment, especially in relation to current environmental protection, since it is more important to limit consumption than investment.[9] In addition, Solow suggests that the natural first-order concern about sustainability is population. Thus, in his view, "control of population growth would probably be the best available policy on behalf of sustainability" (p. 186).

Solow (1993) recognizes the importance and the strong influence of technological progress, while investment decisions are key to guaranteeing sustainability. In Solow's view (1993), preserving sustainability amounts to maintaining society's capital intact. This means that each generation

should replace the used-up resources with other assets of equal value, or equal shadow value. How much is that? The shadow value of resource depletion is exactly the aggregate of Hotelling rents.[10] It is exactly the quantity that should be deducted from conventional net national product to give a truer NNP that takes account of the depletion of resources. ... This is sometimes known as Hartwick's rule: a society that invests aggregate resource rents in reproducible capital is preserving its capacity to sustain a constant level of consumption. (p. 170)[11]

Of course, technological progress makes things easier. Consequently, a concern for sustainability implies a bias toward investment. It means just enough investment to maintain the broad stock of capital intact. In policy terms, "a commitment to sustainability is translated into a commitment to a specifiable amount of productive investment" (Solow 1993, p. 171).

Solow (1993) also claims that the same approach can be applied to environmental assets. However, the environmental case is more complex, because even a stylized model of environmental degradation and rehabilitation is more complex than a model of resource depletion.

Finally, in "An Amateur Among Professionals," using a general equilibrium analytical framework, Solow (2009)[12] puts forward the idea that the organization and development of backstop technologies is "the way a growing economy typically evades the sustainability problem" (p. 12). This is because "Societies typically do not conserve scarce nonrenewable resources; instead, societies typically work around them, either by shifting to technologies based on more abundant resources or, in the limit, by reducing use of scarce resources to a minimum" (p. 12).

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[8] The Hartwick's rule consists in continuously zero net investment in human-made capital and natural resources, and it guarantees sustainability in the form of constant utility. Without disutility from degradation, the rule results in constant consumption as well as constant utility. The Hartwick's rule has been extensively developed since its first appearance in Hartwick (1977).

[9] Solow was aware that the concrete translation of sustainability into a policy is problematic, for example the deep uncertainty about environmental benefits and costs.

[10] It is well known that the Hotelling rent or scarcity rent is the maximum rent that could be obtained while emptying the stock resource (Hotelling 1931).

[11] Solow is arguing for comprehensive green national accounts that would allow some approximation to the volume of net investment in reproducible capital required for sustainability of national consumption (2009).

[12] In the Appendix (Solow 2009, pp. 5–14).

In conclusion, Solow shows strong confidence in technology and technical progress, together with the capacity for substitutability of productive factors (of natural capital, i.e., non-productive resources in particular) to solve the problem of long-term growth and, therefore, of sustainability. At the same time, Solow stresses the role of externalities, population growth, the limits of market mechanisms, the uncertainty of the future, and the complexity of an environmental policy to warn us about the difficulty of solving the sustainability issue.

1.3 A Different Theoretical Approach to Sustainability

A different approach to sustainability is offered by Partha Dasgupta, who has made major contributions to the theory of sustainable development, as well as providing measures for evaluating sustainability by tracking intergenerational well-being.[13] To Dasgupta, sustainable development means "sustained social well-being … not just current well-being, but well-being across generations. … An economy would enjoy sustainable development if and only if, relative to its population, inclusive investment is not negative" (Dasgupta 2007, p. 3).[14] He also warns that the sustainability criteria (i.e., relative to population, inclusive investment is not negative) must be kept over time and continue in the future. However, Dasgupta argues that the market system is unable to provide the solutions to the environmental problems, and unfortunately there is a large collection of them.[15] Thus, he says, without a policy that orients the economy toward not destroying the planet's resources, there is the danger of not saving ourselves. Particularly in discussing the need for an index consistent with sustainable development, he criticizes the use of gross domestic product (GDP) per capita and the Human Development Index (HDI) of the United Nations Development Programme (UNDP) to judge the performance of economies. In particular, GDP ignores the depreciation of capital assets. Thus, he adopts a capital-assets perspective on the determinants of sustainability (including natural capital, manufactured capital, human capital, social capital, and knowledge capital).[16]Dasgupta (2007, 2010, 2014) claims that GDP and HDI are inadequate as indices of sustainable development, because they are not a correct measure of a country's productive base. The productive base comprises capital assets (produced capital, human capital, natural capital) and enabling assets (institutions, knowledge, social capital, exogenous technological change) (Dasgupta 2014, 2016). A country's productive base and wealth per capita can decline even as its GDP per head and HDI increase.[17] As indicators of the long-run performance of a country, GDP and HDI can be misleading (Dasgupta 2007, 2010, 2014).
In addition, Dasgupta is not fully convinced of the effectiveness and possibility of substitutability of natural capital with other types of capital. This becomes particularly critical when the scale of the economy (measured by GDP) is relevant to maintaining the inclusive wealth and, therefore, sustainable.

As an economy's scale increases, natural capital (e.g. ecosystems) becomes more scarce relative to the size of the economy. Consequently, the amount of other types of capital needed to substitute for

[13] Although Dasgupta is labeled a neoclassical economist (e.g., the Dasgupta-Heal model, 1974), he continued to work for a much wider economic science than classical or neoclassical theories.
[14] This definition corresponds, de facto, to the Brundtland Commission report's definition of sustainable development.
[15] Dasgupta (2001, 2010, 2016).
[16] Natural capital includes aquifers, ocean fisheries, tropical forests, estuaries, the atmosphere as a carbon sink—that is, ecosystems generally (Dasgupta 2010, p. 5).
[17] An economy's productive base will shrink if its stock of capital assets depreciates and its institutions are not able to improve sufficiently to compensate for that depreciation.

natural capital may rise ... There can even come to a point where no amount of feasible investment in manufactured capital or human capital can offset further declines in natural capital. (Dasgupta 2007, p. 5)

Therefore, according to Dasgupta, the replacement of natural capital with artificial capital is not an acceptable response to environmental problems. Thus, the accumulation of reproducible capital, growth in human capital, and improvements in the economy's institutions cannot overcome diminutions in natural capital (Dasgupta 2010). The idea of keeping natural capital unchanged is desirable, but unfortunately is difficult to apply. A major obstacle in this regard is related to the possibility of monetary quantification of environmental goods.

Furthermore, Dasgupta believes that institutions are an important key to understanding and assessing sustainable development, especially in poor countries, since when they deteriorate, assets are used even more inefficiently.[18] For instance, an important aspect of institutions concerns property rights to natural capital, frequently unprotected or ill-specified.

This situation typically leads to their overexploitation, and, therefore, to waste and inequity (Dasgupta 2010). Consequently, in his view, the creation of better institutions is necessary. The fundamental idea of a comprehensive measure of wealth—one that accounts for natural capital and human capital as well as reproducible capital—is also present in a contribution by Dasgupta with Arrow et al. (2012). These authors provide a consistent theoretical framework of growth accounting that incorporates population growth, technological change, human capital, and environmental quality. They develop and apply the model for determining whether a given nation satisfies a reasonable criterion for sustainability.[19] Arrow et al. (2012) define sustainability in terms of the capacity to provide well-being to future generations. The indicator of this capacity is a comprehensive measure of wealth—one that includes both marketed and non-marketed assets. The sustainability criterion is satisfied if this comprehensive wealth measure is increasing on a per capita basis. The main result of their investigation is that significant increases in human capital regarding its two key components, that is, education and health,[20] enable comprehensive wealth to be maintained and sustainability to be achieved, despite significant reductions in the natural-resource base. Therefore, human capital is critical for sustainable growth.

2. Policies for Sustainability: A discussion

Our analysis highlights that sustainability refers to the need to develop models necessary for both human beings and our planet to survive. The economic literature on sustainability and environment, as in the case of the contributions by Dasgupta, has shown that old models of consumption and industrialization are not able to sustain the world's growing population and to prevent the exhaustion of non-renewable resources and the negative effects of climate change on the environment. Humans will have to re-examine their policies on environmental protection, social responsibility, and economic practice to make the world sustainable, as affirmed at the Rio+20 UN Conference (United

[18] However, other than institutions, Dasgupta has expressed concern about population growth especially in poor countries (Dasgupta 1995).

[19] The authors apply the framework to five countries that differ significantly in stages of development and resource bases: United States, China, Brazil, India, and Venezuela.

[20] Dasgupta (2016).

Nations 2012) and indicated in the 2030 Agenda for Sustainable Development.[21] But, as Rennings (2000) claims, a fundamental point in implementing policies for sustainability is to define sustainable development operationally. For this reason Rennings and other environmental economists have made important contributions to providing a regulatory framework for the problem of innovation and environment, in order to make the policies operational (Hemmelskamp et al. 2000; Beise and Rennings 2003; Rennings and Rammer 2011). At the same time, Dasgupta (Dasgupta 2007, 2010, 2014, 2016; Arrow et al. 2012) has provided measures for evaluating sustainability by properly defining capital assets and tracking intergenerational well-being.

In addition, today more than ever, climate change has become a major threat to the environment and the economy, endangering human well- being. Dasgupta et al. (2015) emphasize the importance and urgency of taking concrete actions that entail "the shift from fossil fuels to zero- carbon and low carbon sources and technologies, coupled with a reversal of deforestation, land degradation, and air pollution" (p. 1). An important step in this direction, albeit insufficient, is the agreement reached in Paris at the UN 21st Conference of the Parties (COP21) on global warming on December 12, 2015, signed by 195 countries.[22] The COP21 agreement aims to limit the temperature increase to well below 2 °C relative to the pre-industrial level, with efforts to limit it to 1.5 °C in order to significantly reduce the risks and effects of climate change. The "2030 climate and energy framework" launched by the European Commission in January 2014,[23] a framework for EU climate and energy policies in the 2020–2030 period, represents another important piece of climate change and environment policy. The 2030 framework proposes new targets and measures to make the EU's economy and energy system more competitive, secure, and sustainable. It includes targets for reducing greenhouse-gas emissions and increasing use of renewable energies, and proposes a new governance system and performance indicators.[24] In addition, on December 2, 2015, the European Commission put forward a package to support the EU's transition to a Circular Economy, where the value of products and materials is maintained for as long as possible, and waste and resource use are minimized. This action plan is an essential contribution to the EU's efforts to develop a sustainable, low-carbon, resource-efficient, and competitive economy.[25] As a matter of fact, the Circular Economy is receiving increasing attention worldwide as a way to overcome the current production and consumption model which is based on continuous growth and increasing resource throughput. By promoting the adoption of closing-the-loop production patterns within an economic system, the Circular Economy aims to increase the efficiency of resource use, with special focus on urban and industrial waste, to achieve a better balance among the economy, environment, and society. The ultimate goal of promoting the Circular Economy is the decoupling of environmental pressure from economic growth (Ghisellini et al. 2016).

However, despite the efforts and the policy actions taken, in 2018 the United Nations Intergovernmental Panel on Climate Change (IPCC) reported a very high concentration of CO2 in

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[21] The Agenda is an action program for people, the planet, and prosperity signed in September 2015 by the governments of the 193 member countries of the UN. It includes 17 Sustainable Development Goals (SDGs).

[22] UNCC (2016). https://unfccc.int/documents/9097.

[23] The European Council agreed on the 2030 climate and energy framework on October 23, 2014.

[24] Among the actions proposed, there is a commitment to continue reducing greenhousegas emissions, setting a reduction target of 40% by 2030 relative to 1990 levels. There is also a renewable energy target of at least 27% of energy consumption, with flexibility for member states to set national targets (European Commission 2014). https://www.consilium.europa. eu/en/policies/climate-change/2030-climate-and-energy-framework/.

[25] European Commission (2015).

the atmosphere, never before reached to date, and CO2 is considered a main cause of global warming and climate change.[26] One of the key messages that comes out very strongly from this report is that we are already seeing the consequences of 1 °C of global warming through more extreme weather, rising sea levels, and diminishing Arctic sea ice, among other changes. Consequently, it is necessary to avoid the irreversible negative effects of climate change, but also to preserve the environment and guarantee sustainability. The policy solution is to move toward a green economy and low-carbon world, through the creation and diffusion of low-carbon technologies, as highlighted in Carfì and Schilirò (2012a). Limiting at the global level the amount of carbon that gets into the earth's atmosphere is critical to keeping climate change within acceptable boundaries. Carfì and Schilirò (2012b) suggest an environmentally sustainable model at a global level, which aims to maintain natural capital, and to invest in green technologies in order to reduce emissions of CO2. Such a model, which applies game theory and is based on the notion of co-petition, suggests appropriate strategies to provide win–win solutions for countries and companies,[27] as long as they cooperate with each other and adopt innovative eco- sustainable technologies. Moreover, any technological solution that limits CO2 emissions is an improvement in energy efficiency and favors sustainability. Incentives and taxes represent policy tools that can promote the adoption of eco-innovative technologies. According to the Organization for Economic Co-operation and Development (OECD),[28] which considers pricing and carbon emission through taxes and emission trading (i.e., using trade schemes, including state and local schemes) of 42 OECD and G20 governments, accounting for around 80% of global emissions, only a few of these countries (around 15%) are pricing carbon high enough to meet climate targets. The report finds that today's carbon prices, while slowly rising, are still too low to have a significant impact on curbing climate change. Among the strategies that businesses can follow are initiatives such as setting a science-based target, putting an internal price on carbon,[29] reducing energy use, switching to renewable forms of power, and working with partners to lower emissions across value chains. All of these efforts support the goals of the Paris Agreement. But, in any case, more investment is necessary, as well as inventiveness in finding new innovative solutions. Emerging from this analysis is the affirmation of innovation as key for both the environment and sustainability. The neoclassical theory and other theoretical approaches share this view. However, in this context, innovation should be understood as eco-innovation (Rennings 2000), which is related not only to technological innovation,[30] but also to social, institutional, and financial innovation. Yet, as Dasgupta shows, other factors are also important, such as natural capital, human capital, population, and institutions. The analysis carried out on sustainability and the related notion of sustainable development has shown some fundamental characteristics. First, natural resources are limited; there are limits regarding non-renewable resources. Moreover, there are environmental problems related to climate change, which also set limits. There are balances that can be irreparably altered by inadequate models of production and consumption and by an incorrect environmental policy. Second, each model of development is the result of a choice between different options for which we are responsible to our generation and future generations. Thus, the principle of responsibility applies. Third, choices must

[26] IPCC (2018).

[27] Companies must rely on synthesis rather than separation to contain tensions between them, following a sort of contextual integration.

[28] OECD (2018), Effective Carbon Rates 2018. http://www.oecd.org/tax/effectivecarbon-rates-2018-9789264305304-en.htm

[29] There are several problems with carbon pricing. However, more companies are using internal carbon pricing to drive their business decisions.

[30] For instance, technological innovation plays a key role in curbing CO2 emissions.

be made considering their effects in a complexity of interrelated areas. Climate change, any way one sees it, is a major issue in the field of sustainability. Debates on its impact continue to dictate government policies, corporate decisions, and individual actions. Thus, in order to achieve sustainable development, it is necessary to design the political instruments to take appropriate action, choosing certain models of development at the expense of others. Innovation and sustainability are also inextricably linked for companies, since innovation is a core capability for sustainable companies. The success of innovation depends on several factors, such as access to finance, infrastructure, skilled labor, and good managerial and organizational practices. In the absence of these factors, returns from investing in the development of new ideas and capabilities are likely to be low. Thus, businesses are looking for a new paradigm to face the problem of sustainability, environment, and innovation. They should create long-term practices that do more to respect the environment, the well-being of employees, and the prospects of future generations. Nidumolu et al. (2009) underline that sustainability in itself has become a major determinant of organizational and technological innovations that yield returns. In order for sustainability to impact innovation, companies look at changing their existing business model or creating a new one. Sustainability-driven innovation goes beyond designing green products. It entails improving business operations and processes to become more efficient, with a goal of dramatically reducing costs and waste. Sustainability- driven innovation can include finding new applications for current services and products, changing existing business processes, developing new products and services, using or creating new technologies, and changing management techniques, all the while ensuring that these result in environmental and social benefits as well as financial ones. It is also about insulating a business from the risk of resource price shocks and shortages. Taken together, these enhancements can deliver business benefits and improve the overall carbon footprint. This view has been reaffirmed by Luqmani et al. (2017). "Sustainability-oriented innovation concerns the production, assimilation or exploitation of a product, process, service, method, structure or social institution that is novel in its application, and which improves economic, environmental and social outcomes throughout the life cycle of the application, compared to relevant alternatives" (p. 95). It becomes the cornerstone of a company's strategy and involves continuous research to find new solutions, respecting the environment and the communities in which a company operates. In this context, "efficiency" does not simply mean optimizing the economic output of each human being, but also that the quantity of goods must be replaced by quality of life, namely, better instead of more. In addition, companies can undertake corporate sustainability, which refers to the efforts a company makes related to conducting business in a socially and environmentally responsible manner. It contains elements that include sustainable development, corporate social responsibility (CSR), stakeholder concerns, and corporate accountability (Tascioglu 2015). Therefore, companies are asked to provide a new governance model to generate sustainable innovation. This can be done through an ecosystem approach, a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way, as described by the COP21. Following this approach, public institutions and public policy can be relevant in supporting a governance model that generates sustainable innovation. Thus, it is very difficult to identify general rules concerning the precise form of policy for sustainability. The analysis shows that the relationship with innovation and efficiency is very important and can lead to positive results, but companies, institutions, and governments must face a complex interaction in order to balance the positive spillovers of innovation and efficiency with the limits set by the environment, as well as by society.

3. Conclusions

This paper highlights the topic of sustainability and the key relationship with innovation and efficiency. According to Solow (1992), sustainability is essentially an intergenerational and long-term issue, since it is an obligation to leave to the future the capacity to be as well off as we are. Innovation is key to sustainability, but innovation must be interpreted as eco- innovation that preserves the environment, preventing the negative effects of climate change. Moreover, Dasgupta points out that institutions and human capital are important factors influencing sustainability. Furthermore, in his view, inclusion and equity are embedded in the notion of sustainability. Therefore, a sustainable society is founded on equal access to health care, nutrition, clean water, shelter, education, energy, economic opportunities, and employment. Innovation, environment, and climate change are also keys in the analysis of sustainability. In this context, efficiency does not simply mean optimizing the economic output of each human being, but also that the quantity of goods must be replaced by quality of life, namely, better instead of more. Although it is impossible to specify general rules concerning the precise form of intervention, policies for sustainability must consider a positive and virtuous relationship with innovation and efficiency, where companies, institutions, and governments must interact by considering both market failure and government failure. Moreover, it is necessary to balance the positive spillovers of innovation and efficiency with possible negative externalities on the environment and society. To conclude, drawing from Dasgupta et al. (2015): "Over and above institutional reforms, policy changes and technological innovations for affordable access to renewable energy sources, there is a fundamental need to reorient our attitude toward nature and, thereby, toward ourselves" (p. 8).

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