ENERGY FUTURES AND CLIMATE CHANGE MITIGATION: A QUALITATIVE AND QUANTITATIVE ASSESSMENT IN THE SUSTAINABLE DEVELOPMENT GOALS PERSPECTIVE

FUTUROS ENERGÉTICOS E MITIGAÇÃO DAS MUDANÇAS CLIMÁTICAS: UMA AVALIAÇÃO QUALITATIVA E QUANTITATIVA NA PERSPECTIVA DOS OBJETIVOS DE DESENVOLVIMENTO SUSTENTÁVEL

Isabella Alloisio

Dr Isabella Alloisio, Adviser, Florence School of Regulation Energy and Climate,
European University Institute, Florence, Italy,
E-mail: isabella.alloisio@eui.eu

Andrea Zucca

Mr Andrea Zucca, Project Manager, Fondazione Giangiacomo Feltrinelli, Milan, Italy.
E-mail: andrea.zucca@fondazionefeltrinelli.it

Samuel Carrara

Dr. Samuel Carrara, Researcher and Marie Skłodowska-Curie Fellow,
Fondazione Eni Enrico Mattei (FEEM), Milan, Italy,
E-mail: samuel.carrara@feem.it

Convidados

ABSTRACT: The 2030 Agenda – with its seventeen Sustainable Development Goals (SDGs) – and the Paris Agreement represent a turning point for Sustainable Development. For the first time, world leaders have developed an integrated sustainable agenda and ratified a global agreement to reduce greenhouse gas emissions, recognizing that the current development model is not sustainable from an economic, social, and environmental standpoint. Sustainable energy, being the driver of social and economic growth, will play a crucial role in the achievement of the 2030 Agenda objectives and for closing the gap to the mitigation targets of 2°C and 1.5°C defined by the Paris Agreement.
This paper aims at showing that SDG 7 – the SDG dedicated to energy – can be considered as an enabling factor for the implementation of the other SDGs, and in particular of SDG 13, the goal on climate action. This relation is bidirectional, meaning that climate change mitigation is positively driven by the deployment of sustainable energy services and that the integration of climate change mitigation strategies into national policies positively contributes to the deployment of sustainable energy solutions. The paper also shows that future energy scenarios, compatible with the abovementioned ambitious mitigation targets, are in line with the SDG 7 targets that can benefit from the strong technology innovation that those scenarios will require.

Keywords: Sustainable Development Goals. Technology innovation. Sustainable finance. Climate change mitigation. Low carbon energy. Electricity.

RESUMO: A Agenda 2030 – com seus dezessete Objetivos de Desenvolvimento Sustentável (ODS) – e o Acordo de Paris representam um ponto de virada para o Desenvolvimento Sustentável. Pela primeira vez, os líderes mundiais desenvolveram uma agenda sustentável integrada e ratificaram um acordo global para reduzir as emissões de gases de efeito estufa, reconhecendo que o atual modelo de desenvolvimento não é sustentável do ponto de vista econômico, social e ambiental. A energia sustentável, sendo o motor do crescimento social e econômico, desempenhará um papel crucial na consecução dos objetivos da Agenda 2030 e para fechar a lacuna em relação às metas de mitigação de 2°C e 1,5°C definidas pelo Acordo de Paris.
Este artigo tem como objetivo mostrar que o ODS 7 – o ODS dedicado à energia – pode ser considerado um fator facilitador para a implementação dos demais ODS e, em particular, do ODS 13, a meta de ação climática. Essa relação é bidirecional, o que significa que a mitigação das mudanças climáticas é impulsionada positivamente pela implantação de serviços de energia sustentável e que a integração das estratégias de mitigação das mudanças climáticas nas políticas nacionais contribui positivamente para a implantação de soluções de energia sustentável. O documento também mostra que os cenários energéticos futuros, compatíveis com as ambiciosas metas de mitigação acima mencionadas, estão alinhados com as metas do ODS 7 que podem se beneficiar da forte inovação tecnológica que esses cenários exigirão.

Keywords: Metas de desenvolvimento sustentável. Inovação tecnológica. Finanças sustentáveis. Mitigação das mudanças climáticas. Energia de baixo carbono. Eletricidade.

INTRODUÇÃO

2015 can be considered as the “Year of Sustainable Development” (Sachs, 2015).

In September, during the 70th General Assembly held in New York, the Secretary-General of the United Nations Ban Ki-moon launched the 2030 Agenda and the related seventeen Sustainable Development Goals (SDGs) (UN, 2015) with the aim of tackling the global economic, social, and environmental challenges and eradicating the extreme poverty around the world over the next fifteen years. These Goals, covering a much broader range of issues than their predecessors, the Millennium Development Goals (MDGs) (UN, 2000), aspire to be universal and therefore to be addressed to all countries and not only to the developing ones.

In December, in the 21st Conference of the Parties (COP21) held in Paris, 195 States reached the Climate Agreement by committing to holding the increase in the global average temperature in 2100 well below 2°C above the pre-industrial levels and to pursuing efforts to limit the temperature increase to 1.5°C above the pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change (UNFCCC, 2015).

Climate change mitigation is one of the challenges taken into account by the 2030 Agenda, and in particular by SDG 13 (“Take urgent action to combat climate change and its impacts”). The Paris Agreement and SDG 13 represent the international strategic guidelines to struggle against climate change and its impacts. SDG 7 ("Ensure access to affordable, reliable, sustainable and modern energy for all") is closely related to SDG 13, as the fulfilment of the SDG 7 targets, especially as far as renewable energies and energy efficiency measures are concerned, contributes to the achievement of SDG 13 and to the promotion of a sustainable growth.

In this perspective, this paper focuses on SDG 7 with a twofold objective. First, we aim at showing that SDG 7 can be considered as an enabling factor for the achievement of the other SDGs. Second, we discuss how technology innovation (which is fundamental in the SDG 7 perspective, especially in the electricity sector) can promote the achievement of a low-carbon energy system.

The paper is structured as follows. Section 2 describes the SDG 7 targets and analyzes the existing interactions between SDG 7 and the other SDGs by using a framework developed by the International Council for Science (Nilsson et al., 2016). Following the key findings of the analysis, as well as the relationships existing between SDG 7 and SDG 13 and vice versa, Section 3 focuses on the role of technology innovation in relation to the SDG 7 targets as a key means of implementation to decarbonize the electricity sector. Section 4 reports the final discussion and conclusions.

1 MAPPING THE INTERACTIONS BETWEEN SDG 7 AND THE OTHER SDGS

1.1 SDG 7 and its targets

The analysis aims at understanding how each target of SDG 7 impacts on the targets of the other SDGs, with a special focus on the relationships existing between SDG 7 and SDG 13.

SDG 7 is structured in the following three main targets, all having the year 2030 as a time horizon:

- 7.1: Ensure universal access to affordable, reliable and modern energy services
- 7.2: Increase substantially the share of renewable energy in the global energy mix
- 7.3: Double the global rate of improvement in energy efficiency

SDG 7 calls for the access to "affordable, reliable, sustainable, and modern energy". The three adjectives affordable, reliable, and modern are explicitly included in Target 7.1, whereas the remaining adjective sustainable is indirectly comprised in Target 7.2 and Target 7.3, as we will explain in the next paragraphs.

1.1.1 Target 7.1

Access to energy is key for the development of a society. Energy is an input to support the delivery of fundamental services such as education, health, and other social services (Bonan et al., 2017). The Industrial Revolution was made possible, among other factors, by the availability of relatively high quantities of energy at relatively low prices (Stern and Kander, 2012). The clear and unequivocal link between energy availability and development is summarized in Figure 1, which shows the relationship between the Human Development Index (HDI) and the energy use (Karekezi et al., 2012). The relationship is not linear: at low levels of HDI, a small increase in energy availability results in a significant growth in development, which is why energy availability is fundamental especially in developing countries.

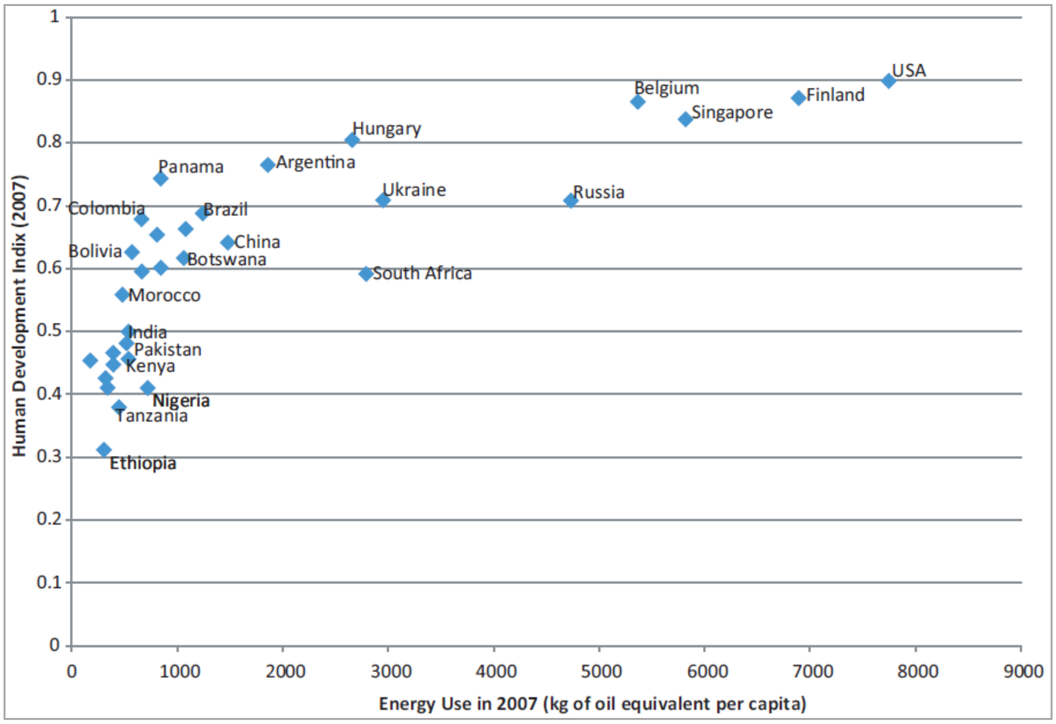

Figure 1 – Relationship between the Human Development Index and energy (Source: Karekezi et al., 2012).

Two indicators can be considered relevant to evaluate access to energy (Karekezi et al., 2012): the first is access to electricity, the second is referred to the use of solid fuels for household applications (essentially heating and cooking).

Electricity is indeed the most valuable form of energy: it is clean, it can be converted into other forms of energy with virtually 100%-efficiency, and it can be delivered over long distances, among other advantages. Therefore, electricity is key in showing the level of development of a country. Figure 2 reports the relation between the HDI and electricity use (IAC, 2007). As one can see, the graph is very similar to Figure 1.

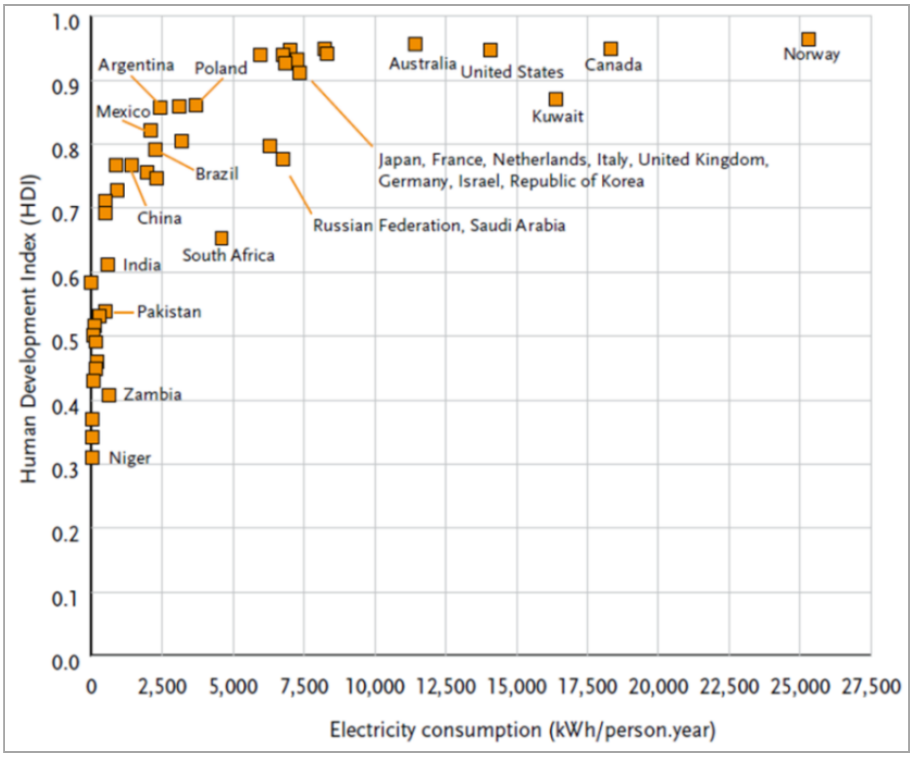

Figure 2 – Relationship between the Human Development Index and electricity use (Source: IAC, 2007).

The second indicator is relevant because populations which have no or low access to modern forms of energies normally use solid fuels (biomass or charcoal) for heating and cooking purposes. These fuels are burnt in open devices inside houses, which is very inefficient from an energy point of view and, above all, is highly impacting from a health point of view, as the untreated emissions cause serious diseases at the breathing apparatus of the occupants (Smith et al., 2004, Dherani et al., 2008, Martin et al., 2011). Naturally, this does not happen in developed countries where gas or electricity are normally used for cooking purposes, while the use of solid fuels for heating purposes is limited to few complementary biomass-based appliances.

Figure 3 highlights the areas of the world with low electricity access and/or high rate use of solid fuels for cooking devices (Karekezi et al., 2012). It can be noted that the regions characterized by the latter point are mostly located in the warm areas of the world, making the use of energy for heating purposes relatively less relevant. As far as the use of solid fuels for cooking purposes is concerned, the most critical areas of the world are Sub-Saharan Africa and South and East Asia. Unsurprisingly, these are also the regions with the highest shares of poverty (Figure 4) (Karekezi et al., 2012).

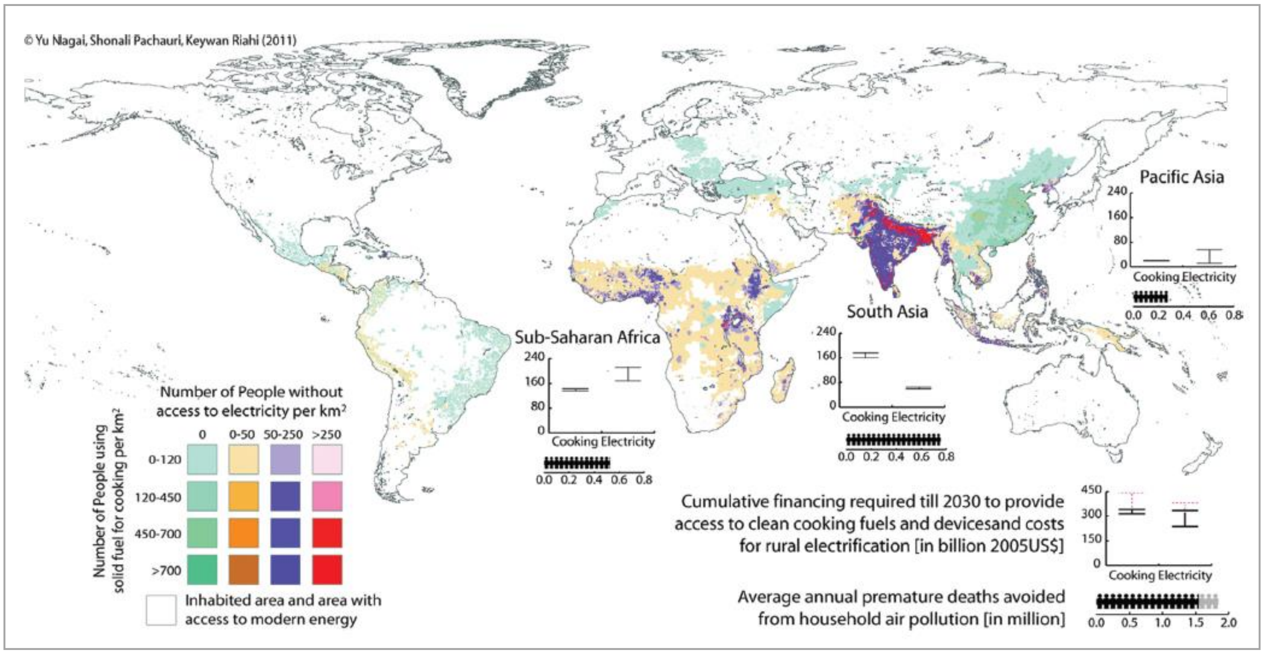

Figure 3 – Areas of the world with low electricity access and high rate use of solid fuels for cooking devices (Source: Karekezi et al., 2012).

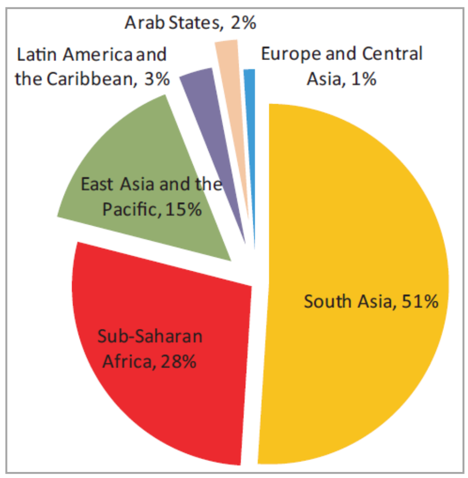

Figure 4 – World regions with the highest shares of poverty (Source: Karekezi et al., 2012).

1.1.2 Target 7.2

There is common agreement in considering renewable energies as a key factor in attaining sustainable, low-carbon energy mixes, especially in the electricity sector (Luderer et al., 2014). Obviously, the concept of sustainability is very broad, but carbon mitigation may be considered the most relevant dimension when analyzing sustainability in energy technologies. For instance, the European Union over the last decade has set progressively more and more ambitious targets for the share of renewable energies over the total final energy consumption by the year 2030, fixed at 27% in 2014 (EU, 2014), raised to 32% in 2018 (EU, 2018), and finally included in the broader target of achieving a 55% reduction in greenhouse gas (GHG) emissions with respect to 1990 as defined in the European Green Deal framework (EU, 2021). The diffusion of renewable energies in future energy scenarios will be better discussed and described in Section 3.

1.1.3 Target 7.3

Similar to Target 7.2, Target 7.3 can be associated to the adjective "sustainable" (and partly "affordable") of SDG 7. The objective is not only to provide energy services, but also to achieve the same (and high) level of energy services with lower energy inputs, which is the concept of energy efficiency. Note that energy efficiency is not only advantageous for the supply side which provides energy services at lower costs, but also for energy consumers who have access to more efficient energy and at lower prices.

Energy efficiency is not an easy concept to be dealt with in general terms, however. It is often evaluated by referring to energy intensity, which is expressed as the ratio between energy and GDP, i.e. the quantity of energy needed to produce one unit of income. An increase in energy efficiency is thus assessed as a reduction in energy intensity (Förster et al., 2013).

1.2 SDG 13 and its targets

As anticipated in the introduction, this paper especially focuses on the relationship between SDG 7 and

SDG 13. Therefore, it is important to analyze the three main targets of SDG 13 as well:

- 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
- 13.2: Integrate climate change measures into national policies, strategies and planning
- 13.3: Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning

1.2.1 Target 13.1

Target 13.1 refers to climate change adaptation. Adaptation means anticipating the adverse effects of climate change by taking appropriate actions to prevent or minimize the damage they can cause, or even taking advantage of opportunities that may arise. Examples of adaptation measures include building flood defenses and raising the levels of dykes; improving efficiency by using scarce water resources more efficiently or adapting building codes to future climate conditions and extreme weather events; working on a more resilient agriculture production by developing drought-tolerant crops; choosing tree species and forestry practices less vulnerable to storms and fires (Bosello et al., 2013).

The IPCC's Sixth Assessment Report (notably the contribution of the Working Group II) (IPCC, 2021) constitutes the scientific base for the assessment of impacts, adaptation, and vulnerability, and evaluates how patterns of risks and potential benefits are shifting due to climate change.

1.2.2 Target 13.2

Target 13.2 calls for integrating climate change mitigation strategies both on adaptation and mitigation into national policies. This target makes implicit reference to the Intended Nationally Determined Contributions (INDCs) submitted by the Country Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in the framework of the Paris Agreement (UNFCCC, 2015) that entered into force on November 4, 2016. The INDCs are national climate change mitigation plans made by Parties intending to commit, on a voluntary basis, to reducing their GHG emissions in order to attain the temperature targets of the Paris Agreement.

Being the energy sector responsible for about two thirds of global greenhouse gas emissions (IEA, 2021), the INDCs are to be turned into concrete national energy plans, each according to countries' national resource endowments and financial capabilities. Most of the INDCs set adaptation strategies as well. Any national climate mitigation policy needs to encounter both mitigation and adaptation strategies as well as the water-food-energy nexus approach in an integrated manner (Cervigni et al., 2015).

1.2.3 Target 13.3

Target 13.3 is the most qualitative of the three targets, although not the least relevant. Indeed, it calls for improving education and raising awareness and institutional capacity towards climate change mitigation and adaptation actions. As it refers explicitly to education, Target 13.3 is closely correlated with SDG 4 on inclusive and equitable education for all.

1.3 Scope and Methodology

The 2030 Agenda is the first international agenda for sustainable development whose Goals and Targets are closely integrated. The integration can be assessed at two levels: the integration of sustainability among the SDGs (OECD, 2015) and the multiple interactions existing among Goals and Targets. Regarding the first level, the SDGs adopt an integrated vision of sustainability in its dimensions allowing us to understand the complexity of current issues and the links among different topics: for instance, SDG 2 ("End hunger, achieve food security and improved nutrition, and promote sustainable agriculture") contains targets related to social (e.g. malnutrition and vulnerability), economic (e.g. agricultural productivity and financial services), and environmental dimensions (e.g. genetic diversity and climate resilience). In relation to the second level, the interactions existing between Goals and Targets allow to view the SDGs within a network, with links among Goals through their respective Targets. In this perspective, an analysis of the interactions among Goals is essential for supporting policymakers in adopting an integrated approach in their policy definition and investment decisions.

In this analysis we have neglected SDG 17 since it refers to the means of implementation which are addressed to the whole set of the SDGs. Accordingly, we also have discarded the Targets of each Goal that are referred to the means of implementation of the same Goal (hence, 7.a and 8.a). This is not to underestimate the importance of the means of implementation, but the analysis is focused on thematic areas underlined by the SDGs. This exclusion leaves us with 107 Targets under 15 Goals (excluding SDG 7). The nature of interactions between SDG 7 and the other SDGs has been identified by using the framework developed by Nilsson et al. (2016) (Figure 5) which allows qualitatively scoring the interactions and identifying their nature. The seven-point ordinal scale in Figure 5 highlights the explanation for each value indicating how a specific type of interaction occurs. For instance, an indivisible interaction exists when one Goal or Target is inextricably linked to the achievement of another Goal or Target: e.g., achieving Target 5.1 ("End all forms of discrimination against all women and girls everywhere") would in itself lead to the achievement of Target 5.5 "Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life". Instead, a reinforcing interaction occurs when one Goal or Target directly creates conditions that lead to the achievement of another Goal or Target. For example, strengthening resilience and adaptive capacity to climate-related hazards (Target 13.1) will directly reduce losses caused by disasters (Target 11.5).

Figure 5 – SDGs scoring (Source: Nilsson et al., 2016).

The score for each SDG in relationship with SDG 7 is evaluated by summing all the scores of the relevant Targets, divided by the number of Targets. This is done in order to obtain an average value independent of the number of Targets, which allows a comparison across SDGs. Thus, we obtain a scale between -3 and 3, coherent with the scale described in Figure 5. The procedure is repeated for the three SDG 7 main Targets, then an average value is calculated in order to obtain an aggregated value for the whole SDG 7 in relationship with the other SDGs. The same methodology was applied to SDG 13 with the aim to understand how this Goal relates to SDG 7, both at aggregate and disaggregate level.

With the aim to cover the whole spectrum of continuous values, we assume that the interaction name associated to one specific score is actually valid for a band whose mean value is the specific score. Thus, values between -0.5 and 0.5 are considered consistent (mean value: 0), values between 0.5 and 1.5 are enabling (mean value: 1), values between 1.5 and 2.5 are reinforcing (mean value: 2), while values above 2.5 are indivisible (mean value: 3). The same applies to the negative values.

With the aim to understand the existing trade-off between SDG 7 and the other SDGs, the research also studies the directionality of each interaction in terms of unidirectionality or bidirectionality (Figure 6).

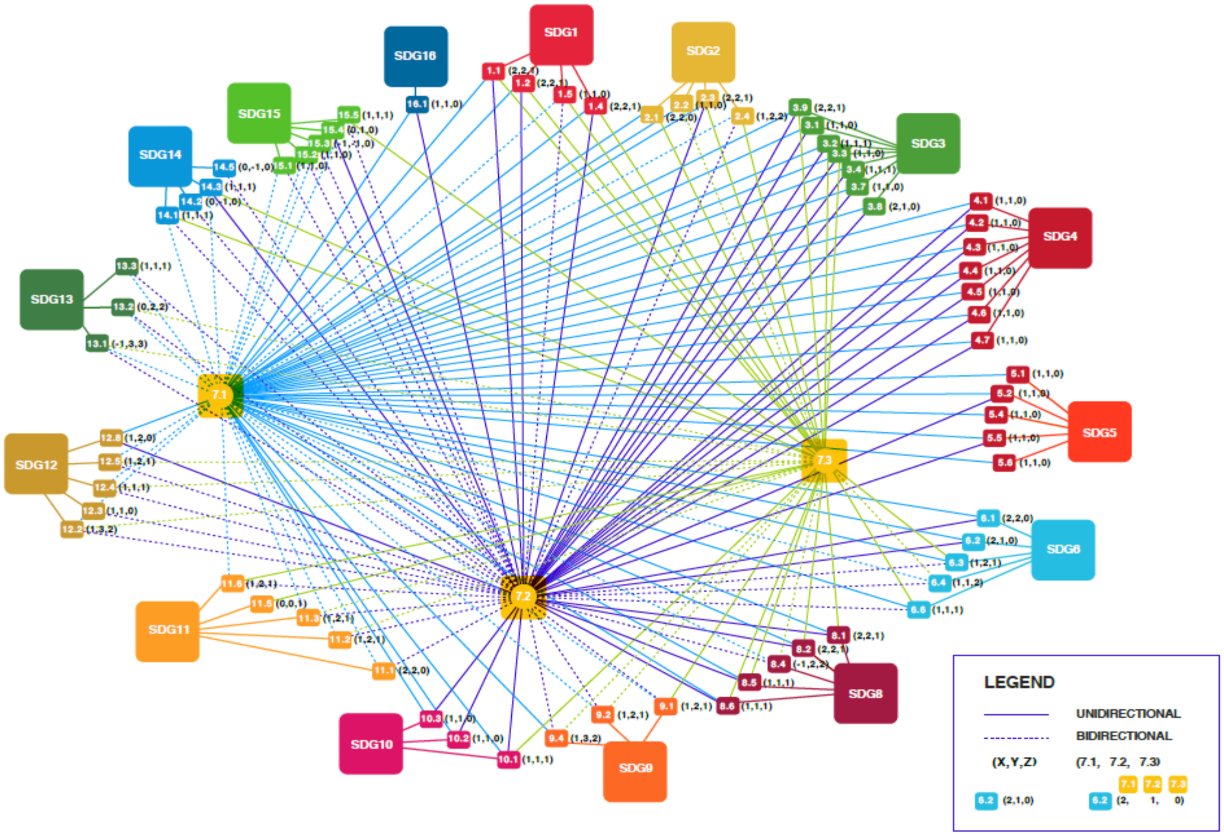

Figure 6 – Interactions between SDG 7 and the other SDGs.

The interaction is unidirectional when A (in our case SDG 7) impacts B and not vice versa. For instance, energy is crucial for providing electricity for hospitals and clinics but these infrastructures are not necessary for providing energy. With bidirectionality we mean that both A impacts B and B impacts A. For instance, ensuring universal access to energy may limit the achievement of Target 13.1, which in turn can limit the option for access to energy. As bidirectionality can help analyze the existing trade-off between SDG 7 and the other SDGs, it would be useful to identify through a further analysis the interactions among the Goals in terms of means of implementation: for instance, although no Target of SDG 7 impacts on

Target 13.a (“Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible”), this Target is fundamental for raising investments in modern energy services, renewable energies and energy efficiency.

Finally, an analysis of interactions should take into account the dimension of reversibility in order to understand which Goals cannot be achieved if the world fails in pursuing SDG 7: for instance, failing on SDG 7 can generate irreversible consequences on the mitigation and adaptation of climate change. The awareness of these interactions could thus support policymakers in understanding how important SDG 7 is in relation to the other Goals and prioritizing investment decisions where an irreversible correlation may exist.

1.4 Energy as a driver for development

The main result of this analysis is that energy is a cross-cutting agent for tackling the economic, social and environmental dimensions underlined by the SDGs. Energy is a key driver for social inclusion, economic development (as already discussed in Section 2.1.1), and environmental protection. From a social point of view, the lack of access to energy is one of the biggest constraints to the main scope of

Agenda 2030 that lies in the eradication of extreme poverty (SDG 1). Energy access contributes to improving the quality of life since it provides better health-care services and a greater life expectancy (SDG 3), and the possibility to have access to quality education (SDG 4). Moreover, the use of electricity allows replacing or facilitating time-consuming rural activities, especially for women and children, allowing them to develop their human and social potential empowering their role within their households and society (SDG 5). In addition, energy provides access to electricity, the use of less polluting systems for cooking and heating (SDG 2), it promotes industrialization (SDG 9), telecommunication services (SDG 9), and it is critical for the supply of safe and drinking water (SDG 6) as well as for the development of inclusive human settlements (SDG 11). In relation to the economic dimension, it is difficult to imagine an economic development without access to modern energy that is a key factor for the majority of products and services enabling the development of companies which, in turn, allows the creation of jobs (SDG 8). Lastly, from the environmental perspective, if produced in a sustainable way and/or from sustainable sources, energy is crucial to mitigate the risk of climate change (SDG 13) and limit the use of unsustainable firewood reducing deforestation and soil degradation (SDG 15).

At an aggregate level (Figure 7), SDG 7 can be considered as an enabling factor for sustainable development since the value of correlation is between 0.5 and 1.5 for eleven SDGs out of fifteen. In terms of intensity value of interactions, SDG 7 shows the strongest correlation with respect to SDG 13, followed by SDG 1, SDG 9, SDG 6, and SDG 2. The lowest interactions are found with SDG 14, SDG 15, and SDG 16. Results also highlight the strong correlation existing between energy, water, and food that is analyzed by the water-food-energy nexus approach.

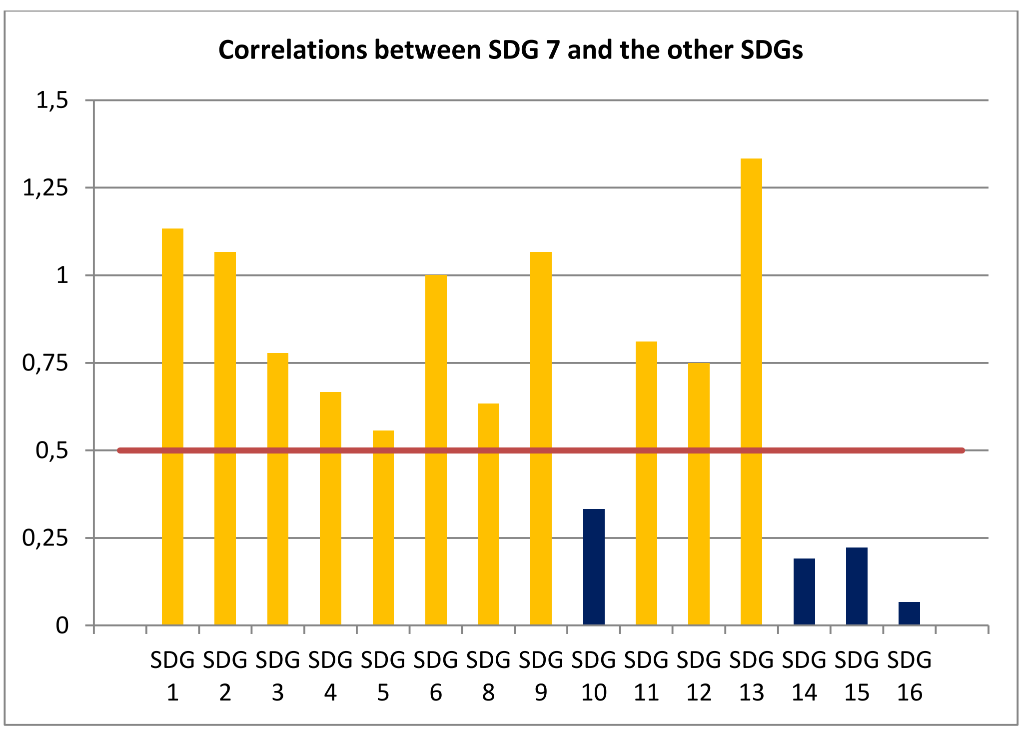

Figure 7 – Values of correlations at aggregate level (values below 0.5 indicate a consistent relationship, highlighted in blue; values from 0.5 to 1.5 indicate an enabling relationship, highlighted in yellow).

1.4.1 The interactions from SDG 7 to SDG 13

Figure 8 shows that SDG 7, at aggregate level, acts as enabling factor for the achievement of SDG 13 with an average intensity value of about 1.3.

However, to really understand the relationship between SDG 7 and SDG 13 we have to analyze the interactions at disaggregate level, i.e. considering how the three single Targets of SDG 7 relate to the three single Targets of SDG 13.

The analysis shows that Target 7.1 is consistent in relationship to SDG 13 with an average intensity value of 0, which results from the scores that Target 7.1 records in relation to the three targets of SDG 13 under analysis. Table 1 reports that Target 7.1 is constraining in relationship with Target 13.1 since the first Target of SDG 7 does not require that universal access to energy go through sustainable energy services, but only through affordable, reliable, and modern services. Thus, if we take into consideration that not all forms of modern energy are sustainable, the achievement of Target 7.1 could limit the options for the achievement of climate mitigation and adaptation strategies failing on strengthening resilience to climate change-related events. A further point that suggests this kind of relationship is that the world cannot immediately abandon fossil fuels, which means that these energy sources will be a part of the energy landscape for several decades into the future (WEF, 2015). Moreover, if universal access to modern energy is achieved by 2030, global energy-related CO2 emissions will rise by 0.7% (IEA, 2011), a value that suggests the absence of a positive relation between Target 7.1 and Target 13.1.

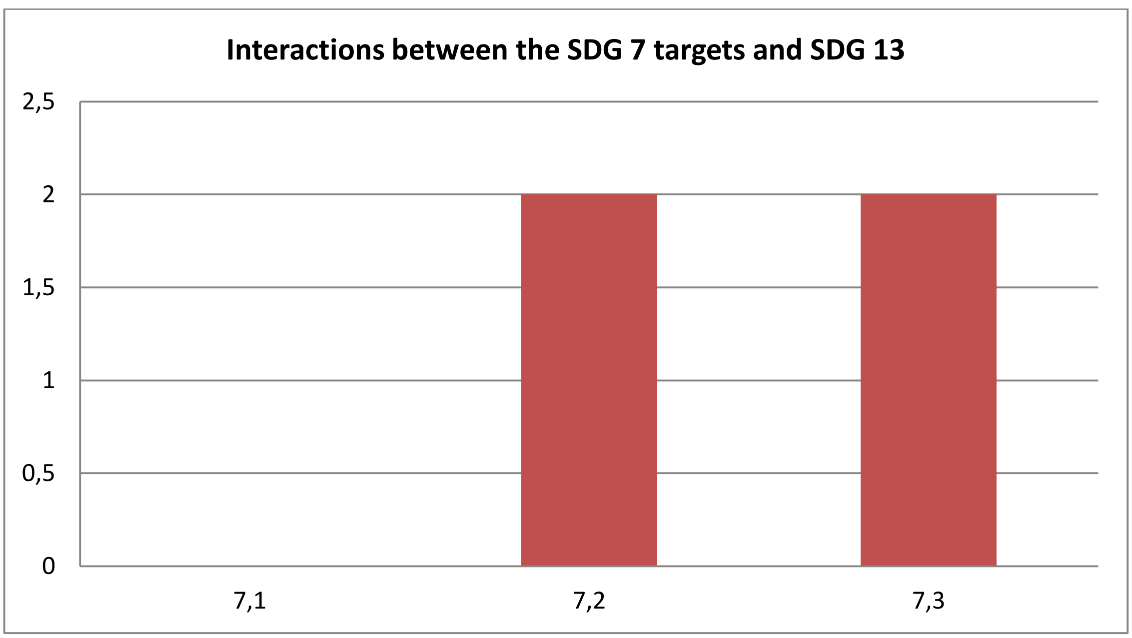

Figure 8 – Values of correlations between SDG 7 and SDG 13 at disaggregate level (between 1.5 and 2.5 indicate a reinforcing relationship, highlighted in red; for Target 7.1, the value is 0).

		SDG 7		
		7.1	**7.2**	**7.3**
Goal 13: Take urgent action to combat climate change and its impacts	**13.1** Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	-1	3	3
	13.2 Integrate climate change measures into national policies, strategies and planning	0	2	2
	13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	1	1	1
	Total	0	6	6

Table 1 – Values of interactions from SDG 7 to SDG 13.

On the other hand, Target 7.2 and Target 7.3 have a reinforcing relationship with climate change: the average value of intensity is equal to 2. Table 1 highlights the relationship existing between Target 7.2 and Target 7.3 with Target 13.1 that underlines the critical role of renewable energies as well as energy efficiency measures in reducing GHG emissions. Indeed, in terms of Target 7.2, investments in renewable energy technologies eventually lead to CO2 emission reductions, which suggests an interaction of indivisible nature (+3) with Target 13.1.

An indivisible relation also exists between Target 7.3 and Target 13.1. For instance, in a scenario compatible with the Paris targets developed by the International Energy Agency (IEA), energy efficiency improvements in end uses make the largest contribution (38%) to global emissions reductions through 2050 (IEA, 2016). Another relevant example is the following: the IEA estimates that if efficiency had not improved since 2000, GHG emissions would have been 12% higher in 2017 (IEA, 2018). Energy efficiency is indeed an important tool for carbon mitigation (by reducing greenhouse gas emissions from energy production and consumption with the aim to avoid or reduce climate change) and for climate adaptation: energy efficiency can contribute to addressing increased energy demand and constrained supply due to regional weather shifts and greater temperature volatility, such as increased building cooling needs and lowered efficiency of thermal generating plants.

Target 7.1 does not show any significant positive or negative relationships with Target 13.2 since the latter aims at developing policies that allow the reduction of GHG emissions and because, as already explained, climate impacts of achieving universal access to modern energy technologies might be negative, should access be provided from unsustainable energy sources.

Targets 7.2 and 7.3 reinforce the integration of climate change measures into national policies, instead. The climate benefits resulting from renewable energy and energy efficiency technologies act as a driver for the development of enhanced climate-related policies. Also, the huge market of renewables and energy efficiency (the total investment in energy transition investment is estimated to have reached USD 500 billion annually in 2020, see BNEF, 2021) can induce policy makers to favor the deployment of sustainable energies systems within the market through dedicated policies. In this perspective, policies can be seen as a result of a clear awareness by local governments and institutions about the environmental, social, and economic benefits resulting from the adoption of more sustainable energy systems. There is also another important reason for the justification of climate-related policies: a full and effective deployment of renewable energies and energy efficiency is constrained by a variety of barriers (costs and prices, legal and regulatory, institutional, etc.) that put renewable energy at an economic, regulatory, or institutional disadvantage relative to other forms of energy supply. This means that a full achievement of Targets 7.2 and 7.3 is not possible without policies that contribute to overcoming market failures of new technologies, thus suggesting that the achievement of these Targets positively trigger the adoption of climate policies.

Finally, in relation to Target 13.3, the three main Targets of SDG 7 can create the conditions that lead to greater awareness on climate change mitigation, adaptation, impact reduction, and early warning by showcasing the climate benefits resulting from the deployment of sustainable modern energy services as well as renewable and energy efficiency technologies, which indeed are means for adaptation and mitigation strategies.

1.4.2 The interactions from SDG 13 to SDG 7

By applying the same methodology used for the analysis of interactions existing between SDG 7 and the other SDGs, it is possible to quantify the relationships between SDG 13 and SDG 7. The analysis shows that SDG 13 enables the achievement of SDG 7 with an average intensity value of 1.3.

However, also for these relationships the analysis shows different and interesting results at disaggregate level (Figure 9).

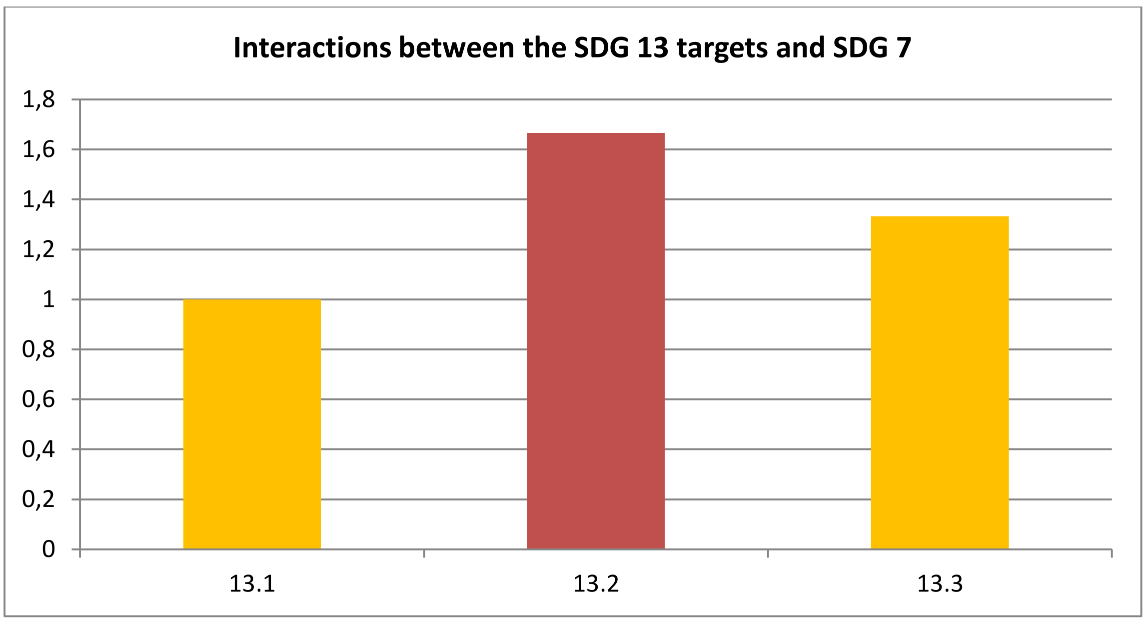

Figure 9 – Values of correlations from SDG 13 to SDG 7 at disaggregate level (values between 0.5 and 1.5 indicate an enabling relationship, highlighted in yellow; values between 1.5 and 2.5 indicate a reinforcing relationship, highlighted in red).

First of all, Target 13.1. is enabling in relation to SDG 7. Table 2 highlights that Target 13.1 is constraining with Target 7.1 since the objective of resilience and adaptive capacity to climate change can limit the options on how to pursue energy access, especially because Target 7.1 does not mention sustainable energy services to reach its goal. Instead, Target 13.1 can create conditions that lead to the achievement of

Target 7.2 and Target 7.3, since renewable energies and energy efficiency measures represent crucial means for mitigating climate change. According to the World Meteorological Organization (WMO, 2016) the first decade of the 21st century saw 3,496 natural disasters from floods, storms, droughts, and heat waves which may have been influenced by climate change. Thus, since climate change can be one of the causes of natural disasters, the deployment of renewable energies and energy efficiency measures can be boosted with the aim of strengthening resilience and adaptive capacity to climate-related events.

		SDG 13		
		13.1	**13.2**	**13.3**
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all	**7.1.** By 2030, ensure universal access to affordable, reliable and modern energy services	-1	1	1
	7.2 By 2030, increase substantially the share of renewable energy in the global energy	2	2	2
	7.3. By 2030, double the global rate of improvement in energy efficiency	2	2	1
	Total	3	5	4

Table 2 – Values of interactions from SDG 13 to SDG 7.

Secondly, Target 13.2 reinforces the achievement of SDG 7, especially Targets 7.2 and 7.3. According to a research conducted by the World Future Council (WFC, 2016) on the role of renewable energy in the Intended Nationally Determined Contributions, 142 INDCs out of the 158 analyzed mention renewable energy within their mitigation strategy, 108 name the increase of renewable energy as one of their mitigation actions, and 75 include quantified goals. Thus, if INDCs are fully implemented, we will see a substantial growth of renewable energies deployment creating the conditions for the achievement of Target 7.2. This is true for Target 7.3 as well, since several INDCs highlight actions to achieve energy efficiency in terms of: energy efficiency standards; modernization of energy generation and transmission infrastructure; promotion of smart grids; efficiency improvements in industrial processes and the building sector; energy conservation standards. In detail, out of the 163 INDCs submitted, 143 mention energy efficiency as a means to implement adaptation strategies (WMO, 2016). Target 13.2 is consistent with Target 7.1, since it does not have any kind of relation with universal access to energy.

Finally, in relation to Target 13.3, activities and investments toward educational programs on climate change issues can enable the achievement of the three main Targets of SDG 7. Education and awareness raising through dedicated communication and dialogue initiatives can indeed create a favorable (or, according to the terminology used above, enabling) environment for the deployment of renewable energies presenting them as one means for mitigation and adaptation strategies. Also, in relation to energy efficiency, educational initiatives can enable its deployment since energy efficiency is an important tool for climate mitigation and adaptation, i.e. preservation of natural resources. The same consideration applies to Target 7.1, since educational initiatives have the power to raise awareness toward the adoption of modern and more sustainable services, especially in developing countries.

The analysis shows that according to the adopted methodology, SDG 7 enables the achievement of SDG 13 with an average intensity value of 1.3 and, at the same time, it underlines how the struggle against climate change is positively driven by the deployment of sustainable energy services given the average intensity value of 1.4. SDG 7, through Targets 7.2 and 7.3, plays a crucial role for the achievement of SDG 13 and carbon mitigation targets, given the indivisible relation existing among them. Moreover, Target 13.2 reinforces the achievement of Targets 7.2 and 7.3 since the integration of climate change measures into national policies (i.e. the INDCs) positively contributes to the deployment of renewable energies and energy efficiency measures.

2 TECHNOLOGY INNOVATION IN THE NEXT DECADES: THE POWER SECTOR AND RENEWABLE TECHNOLOGIES

2.1 Mitigation pathways and compliance with SDG 7

As discussed in the Introduction, carbon mitigation has been identified as a vital target for the coming decades. The transition towards a low-carbon economy will entail deep changes in the economic, social, climatic, and environmental dimensions. Integrated Assessment Models (IAM) are widely adopted tools in the scientific community to explore the interaction between these dimensions (Clarke and Kejun, 2014). In this work, we have used the WITCH model to develop scenarios consistent with the long-term 2°C mitigation target, in order to frame the macro-economic and energy prospects which will serve as a background for the following analysis on the importance of technology innovation.

WITCH (World Induced Technical Change Hybrid) is an integrated assessment model aimed at developing socio-economic trends in the 21st century with respect to climate change and its relevant impacts and constraints. The calibration year is 2015. It is defined as a hybrid model because it combines an aggregated macro-economic model with a more disaggregated description of the energy sector. WITCH scenarios should not be considered as predictions, but rather projections: the aggregated economic model is an optimal growth mitigation model which maximizes each region's welfare in order to yield the economically optimal solution under a set of constraints, the most important of which is the carbon mitigation policy, if any. The model is defined on a global scale: world countries are grouped into thirteen regions, defined on the basis of geographical or economic coherence. One distinguishing feature is the endogenous modeling of technological change in energy efficiency and specific clean technologies. A more detailed description of the model can be found in Emmerling et al. (2016) or in the web, see www.witchmodel.org.

Figure 10 shows the evolution of greenhouse gas emissions from 2005 to 2100 in the baseline and in the 2°C policy scenarios. The baseline case (also identified as BaU, Business-as-Usual) is a benchmark scenario where no mitigation policies are implemented. The 2°C scenario is obtained by applying a carbon tax on GHG emissions starting from 2020. It can be easily seen that the achievement of ambitious mitigation targets implies a complete phase-out of GHG emissions over time.

How can the zero emission scenario be achieved? The mitigation target requires major changes in the energy landscape. Overall, carbon mitigation is likely to take place through an electrification of the energy sector and a simultaneous decarbonization of the electricity sector (Wei et al., 2013 and Capros et al., 2012). This is likely to happen because the power generation sector features many effective and efficient decarbonization options (both from a technical and an economic point of view), while the same hardly applies to other sectors (industrial, residential, transport). Figure 11 reports the evolution over time of the global share of the electricity sector over the total secondary energy (left), and the global share of low-carbon technologies (renewables, nuclear, and Carbon Capture & Storage, CCS) over the total electricity generation (right), as obtained in the WITCH scenarios.

The graph of the left shows that the share of electricity over the total secondary energy grows over time in both the explored scenarios. However, in the baseline case this growth substantially follows the historical patterns, while in the mitigation scenario the growth accelerates after the initial decades, leading to a scenario where electricity dominates the energy sector by the end of the century. In terms of technologies, the graph on the right clearly shows that low-carbon technologies (which in 2015 accounted for about one third of the total, especially thanks to nuclear and hydro) mildly grow over the century in the baseline case, while fossil-fueled plants (without CCS) are completely phased out within mid-century in the mitigation scenario.

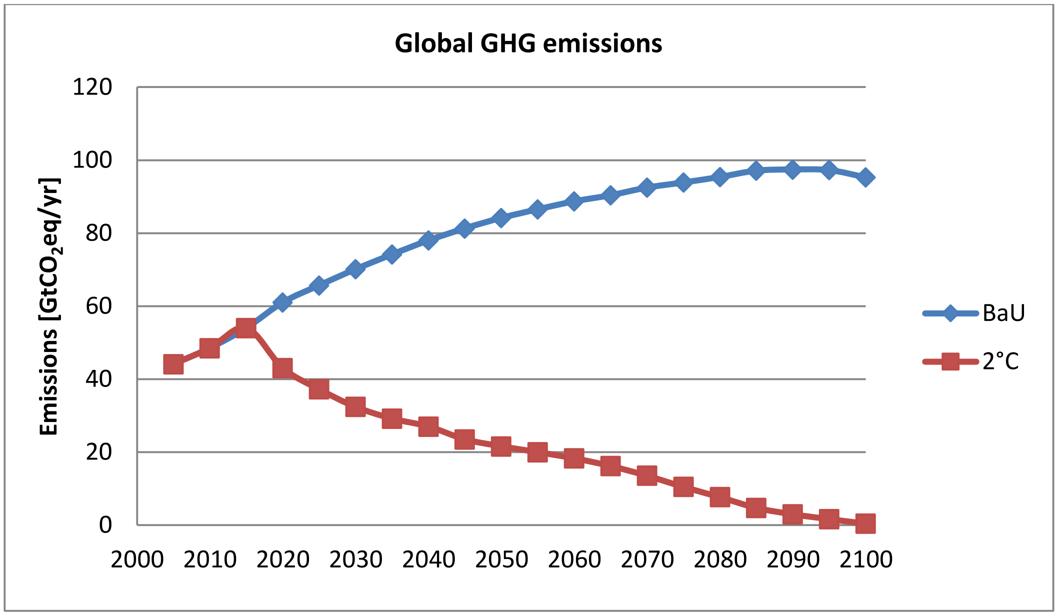

Figure 10 – Global GHG emissions in the WITCH scenarios.

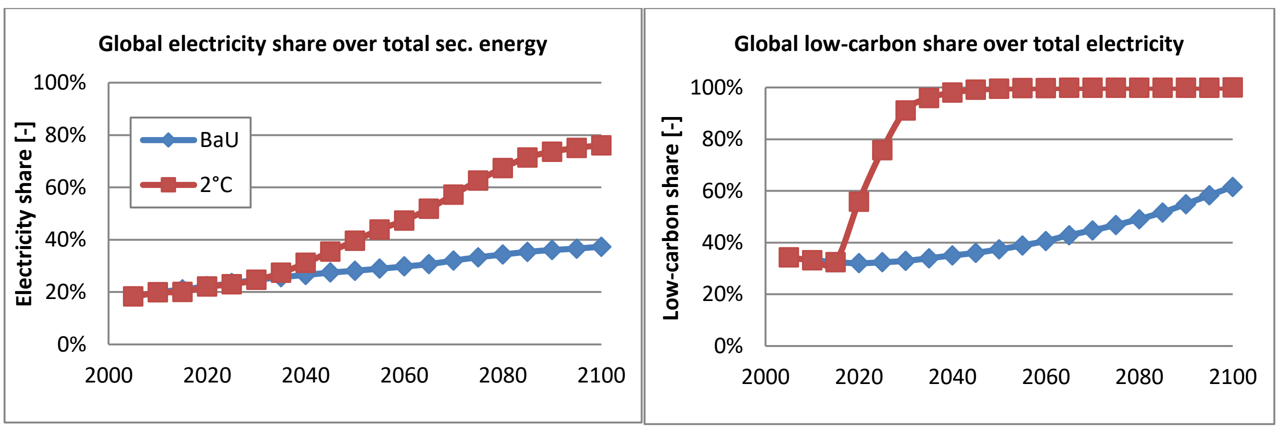

Figure 11 – Global electricity share over total secondary energy (left) and low-carbon generation share over total electricity (right) in the WITCH scenarios.

Having outlined the overall scenario context, we will now show that the mitigation scenario is compatible with the SDG 7 Targets, thus confirming also from a modeling point of view the positive correlation between SDG 7 and SDG 13 qualitatively highlighted in Section 2.

The increase in the electricity share over the total energy demand is clearly in line with Target 7.1, since electricity is the most valuable form of energy, which allows the delivery of a great number of modern services, as already discussed in Section 2. With the aim to stress the concept, Figure 12 reports the absolute electricity demand in the WITCH scenarios, highlighting the different behavior in OECD and non-OECD countries. In the two groups of regions, results are quite similar in the two policy scenarios, although it should be noted that the total secondary energy is much lower in the 2°C scenario than in the BaU scenario, therefore the relative share of electricity in the total secondary demand is much higher in the former, as already highlighted in Figure 11. More importantly, the growth in non-OECD countries is much higher than in the OECD ones (in the 2°C scenario, the average yearly growth in the 21st century is 2.7% in the non-OECD regions against 1.5% in the OECD regions).

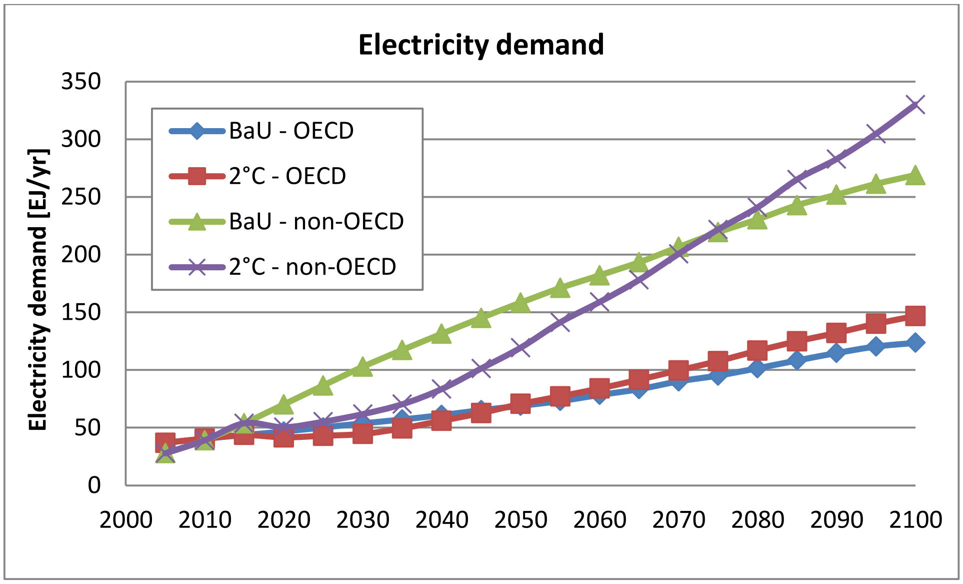

Figure 12 – Electricity demand in OECD and non-OECD countries in the WITCH scenarios.

The compliance with Target 7.2 is already evident from Figure 11 (right). However, that graph does include all low-carbon technologies, i.e. CCS and nuclear in addition to renewables. Figure 13 thus specifically highlights the global share of renewables in the electricity mix. Indeed, renewables have by far the lion's share among the low-carbon technologies, therefore this graph substantially replicates Figure 11.

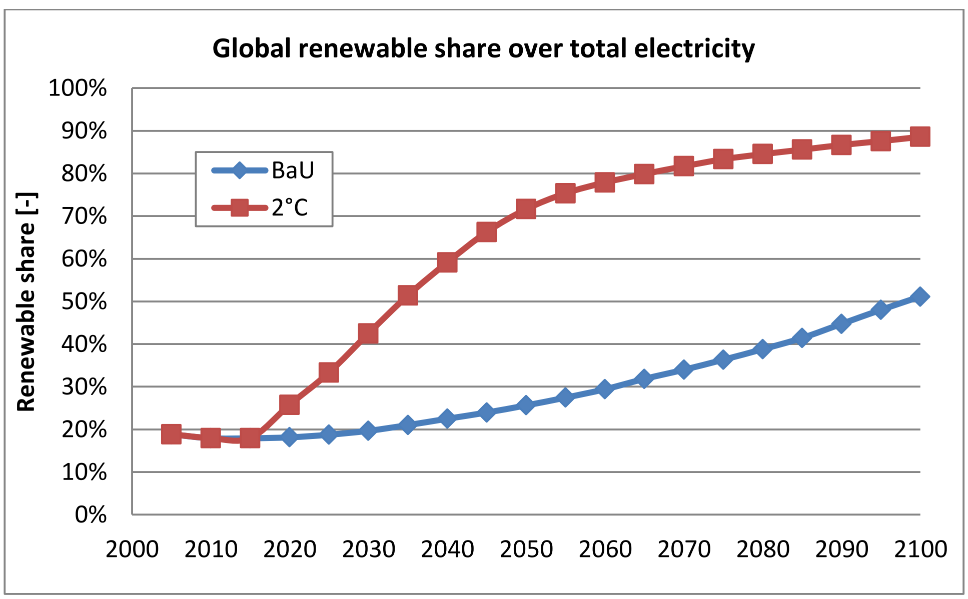

Figure 13 – Global renewable generation share over total electricity in the WITCH scenarios.

Finally, the mitigation scenario as depicted by WITCH is in line with Target 7.3 as well. In this work we assess the increase in energy efficiency as a decrease in energy intensity, following the rationale discussed in Section 2.1.3. Figure 14 reports the global yearly decrease rate of energy intensity (calculated as the ratio between primary energy and GDP PPP). The average yearly rate from 2005 to 2015 was about 0.6%. From 2020 to 2030 it would be 2% in the mitigation scenario, and 1.3% in the BaU. Thus, both results would be in line with the Target, even if the figures in the mitigation scenario are partly biased by the drastic fall in correspondence of the beginning of the policy implementation in 2020. On average, from 2005 to 2030 the energy intensity decreases by 1.3% in the baseline case and 2.7% in the policy case, i.e. about twice as much as the former, perfectly in line with the Target.

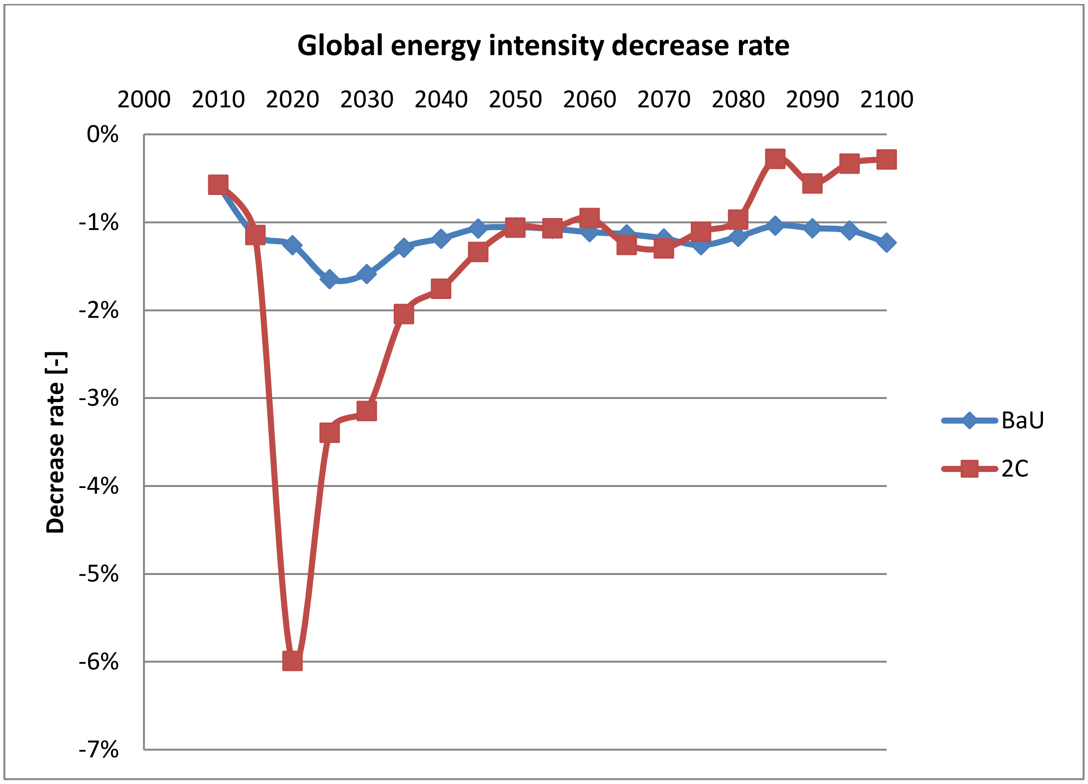

Figure 14 – Global energy intensity decrease rate in the WITCH scenarios.

2.2 The role of technology innovation

All the main changes in the energy sector described in Section 3.1 are possible only via deep transformations from different points of view: technical, social, economic, and regulatory. In this Section we focus on the role of technology innovation in making those changes possible, especially in the perspective of the three SDG 7 Targets. Again, the analysis is carried out adopting WITCH as a tool to explore future scenarios. WITCH is an integrated assessment model, so the level of technological detail is quite limited, nonetheless some interesting considerations can be derived.

Target 7.1 is indeed the Target where the role of technology innovation is more difficult to assess, especially in the WITCH perspective. Actually, the access to modern forms of energy does not seem primarily a matter of technology innovation, but it seems to be more related to financial, regulatory, social, and political issues. Theoretically, energy access could be guaranteed by old, inefficient and highly impacting technologies. The real issue is to promote the actual realization of the needed infrastructure.

In Target 7.2 the role of technology innovation is instead clear. Renewable technologies have been characterized by huge technical improvements in the last decades and further improvements are required for the future. Innovation is twofold: it might be purely technical (e.g. better materials which allow higher conversion efficiencies) or economic (e.g. obtaining the same performance with lower costs). Technology innovation in WITCH is modeled more in the light of the second dimension, and in particular it is described through learning-by-researching and/or learning-by-doing. According to these schemes, the investment costs decrease over time thanks to dedicated investments in R&D and to the experience gained through the progressive plant deployment over time, respectively (see De Cian et al., 2016, and Emmerling et al., 2016 for details). In our model, renewable energies (in particular wind and solar) feature learning-by-doing only. Figure 15 shows the investment cost evolution of solar PV plants in the two explored scenarios. The cost fall is remarkable in both scenarios, even if it is more marked in the 2°C scenario, as the mitigation requirement leads to a greater solar PV deployment. Technology innovation is not explicitly modeled, but it is the condition that makes the shown behavior possible.

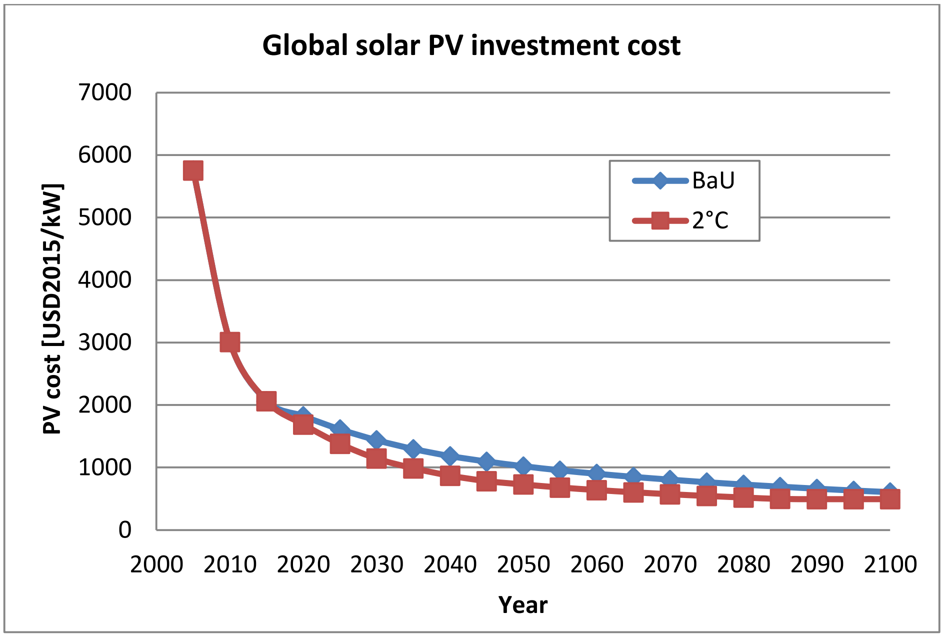

Figure 15 – Global solar PV investment cost in the WITCH scenarios.

Technology innovation is also relevant for Target 7.3. In fact, technology innovation promotes the energy efficiency improvements, or the decrease in energy intensity. In WITCH we endogenously model the investments in the broad R&D sector aimed at fostering energy efficiency, i.e. at decreasing energy intensity, i.e. at obtaining the same final economic output with a lower energy input. Figure 16 reports the global yearly R&D investments in energy efficiency. Unsurprisingly, these investments increase over time, and in particular the growth is much higher in the 2°C scenario than in the BaU scenario, which stresses the importance of energy efficiency improvements under a sustainable carbon mitigation scenario.

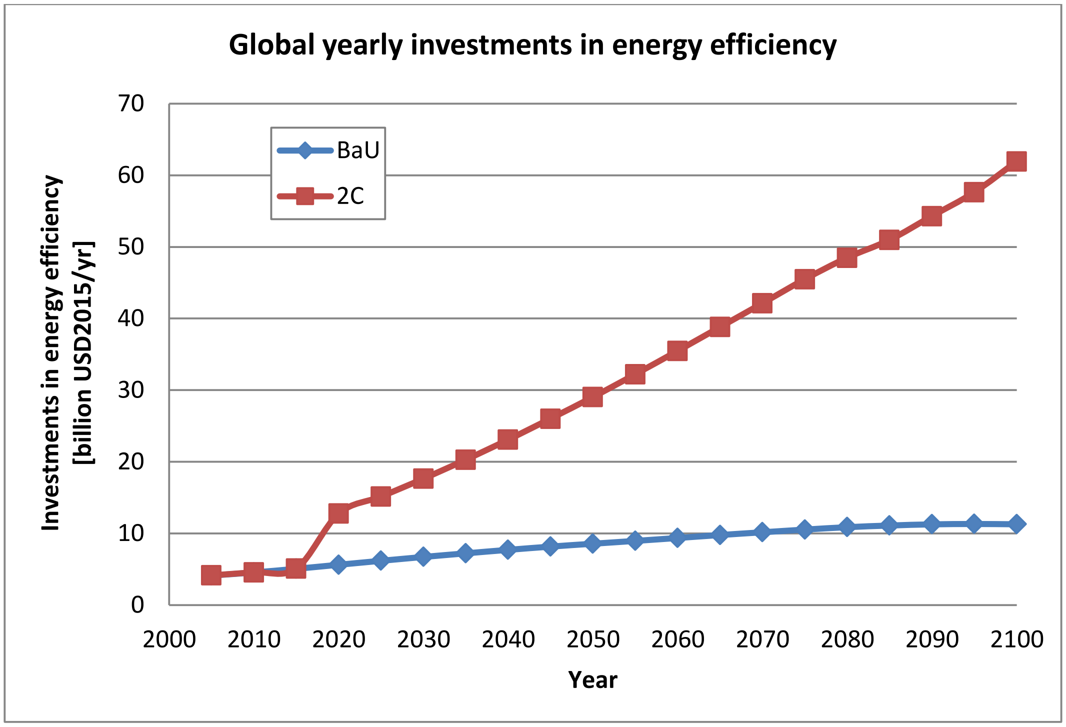

Figure 16 – Global yearly R&D investments in energy efficiency in the WITCH scenarios.

3 Discussion and conclusions

The seventeen Sustainable Development Goals defined in the 2030 Agenda and the Paris Agreement represent the major global frameworks towards a sustainable world. The objectives and targets of these global agreements should drive the political, economic, and social efforts in this decade. In this paper, we have shown that reaching the energy Targets described by SDG 7 enables the achievement of most of the other SDGs, and in particular of SDG 13, which is the goal addressing the pivotal issue of climate change.

In terms of qualitative interaction, the analysis has highlighted a bidirectional relation between SDG 7 and SDG 13. This means that sustainable energy is critical for reducing greenhouse gas emissions and, at the same time, that the measures against climate change can favor the deployment of sustainable energy solutions. In detail, Targets 7.2 and 7.3 show the strongest interactions in relation to SDG 13, meaning that energy generation and use need to be efficient, sustainable, and renewable, if the aim is to achieve a low-carbon energy system and contribute to climate change mitigation.

However, without leveraging and investing in means of implementation (especially technology innovation), it is difficult to favor the transition to a low-carbon energy system and towards the electrification of energy and overcome all those challenges that can prevent the decoupling of economic growth from environmental degradation. In this perspective this paper also shows that investments in technology innovation in the electricity sector are indeed consistent with the energy prospects as resulting in the 2°C mitigation scenario developed by the WITCH model. Here, technology innovation fosters investment in clean energy technologies, which will have the lion’s share in the electricity and, more broadly, in the energy sector in long-term mitigation scenarios aligned with the ambitious climate change mitigation target set in the past years. Thus, the model quantitatively confirms the positive correlation between SDG 7 and SDG 13 previously highlighted from a qualitative point of view.

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