21th International Conference on Renewable Energies and Power Quality (ICREPQ'23)
Madrid (Spain), 24th to 26th May 2023
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.21, July 2023

Assessing the effects of energy efficiency and different tariff policies on energy mix for decarbonization

D. Ferreira-Martínez[1] ,C. Barruso and A. Lopez-Agüera[1]

[1] Department of Physics
Facultad de Física, Santiago de Compostela University
Rúa Xosé María Suárez Núñez, s/n (Campus Vida), 15782 Santiago de Compostela (Spain)
Phone/Fax number:+34 688934206, e-mail: dario.ferreira@rai.usc.es

Abstract. The objective of this work is to evaluate the effects of different energy policies designed to favor decarbonization by increasing renewable sources. In particular, the implementation of energy efficiency policies and the application of hourly differential electricity tariffs. The Open-Source Energy Modelling System (OSeMOSYS) has been adopted to visualize the effects of each of the actions in the short, medium, and long term, from 2024 till 2046.

From our results, the application of hourly differentiation tariffs does not favor either the increase in the implementation of renewable sources or decarbonization processes. The implementation of energy efficiency policies (1-1.25% annual demand decrease), in the long term, allows to reach 80% of energy production from renewable sources. In all the scenarios, the energy sources with a greater level of intermittency, such as wind or solar, strongly increased their contribution in the medium-term, thereby stabilizing their long-term contribution. Finally, the implementation of photovoltaic solar energy becomes necessary only in the long-term. It seems clear that this contribution, up to 20% of the renewable, is associated with the nuclear blackout.

Key words. Sustainable Transition, OSeMOSYS, Decarbonization, Energetic Efficiency, Energetic Tariffing.

1. Introduction

Ensuring a clean and adequate supply of energy has been a major concern in recent years and this have been acknowledged among the Sustainable Development Goals [1, 2] and giving rise to initiatives such as the European Green Deal [3]. It is the latter that points, among others, to the *Fit for 55* goal: a 55% reduction in emissions by 2030 compared to 1990 [4].

To ensure decarbonization processes, two main directions are leading current trends: implementing hourly differentiation tariffs [6, 7] or promoting energy efficiency measures [3, 4, 5].

The electricity tariff with hourly differentiation is a tariff (TDT) in which the price of electricity varies depending on the time in which the consumption is made. The objective of hourly differentiation is to avoid peaks in electricity demand, benefiting with a lower price those users who transfer their electricity consumption in the hours of greatest demand to the hours of lower demand, when the production and distribution of electricity is cheaper [7].

Although the TDT does not seem a real energy saving, but only economic, the improvement of the distribution of demand throughout the day avoids over-sizing the park of plants or building new ones. The use of specific plants to meet consumption demands at peak times is reduced and base plants are used near the optimum point for longer [6, 7].

Energy efficiency politics aim to decrease both primary and final consumption. This objective relies in transport and distribution electricity improvements, more efficient electrical appliances and several building retrofits. Such evolution has already taken effect in Europe so far, achieving a 29% reduction so far respect levels in 1990. New goals want to improve the final consumption reduction until a 36% to 2030 [5].

The question to be addressed is to evaluate to what extent the policies designed are useful for achieving the goals for which they were programmed, not only currently, but also in the medium and long term.

On the other hand, any energy policy entails changes in consumption distribution and therefore production needs, which will affect energy mixing. The aim of this work is evaluating the implications that the aforementioned policies induce in the composition of energy mixing, capacity installed, system costs, and emissions.

There are currently different models sufficiently validated that allow to evaluate, in the medium / long term, the multidimensional implications of the different possible scenarios for a sustainable energy transition. Among them, OSeMOSYS [8] has demonstrated its predictive capacity.

Several scenarios reproducing proposed energy policies are constructed and evaluated [3, 4]. For each, the renewable contribution to global energy demands, as well as the capacity needs, costs, and associated emission levels, have been evaluated. The new scenarios have been compared to a pattern scenario in which no type of improvement policy is incorporated. This makes it possible to determine the main trends driven by the proposed policies. The temporal evolution between 2023 and 2046 is considered.

Methodology

In the present work, OSeMOSYS is chosen as energetic modelling tool. A fictional framework, named Atlantis [9, 10] is considered as starting Reference Energy System. Atlantis has proven to be representative for both developing and developed country in a g-local (local to global) spectrum.

A. Energetic modelling tool: OSeMOSYS

OSeMOSYS is a dynamic, bottom-up linear optimization model with a medium-to-long time horizon that is used for integrated evaluation and energy planning. This modeling tool computes the energy supply mix in terms of generation capacity and delivery, while also fulfilling demand for energy services throughout the year and at each step of the case under inquiry by optimizing the overall discounted costs on a global basis [8].

The total cost includes the capital, fixed, variable, and emission costs. The variable cost is related to the expenses in fuel, while the fixed cost accounts for the maintenance of the existing capacity. The capital cost factors investment in new installed power capacity. And the emission costs allow the introduction of pollution penalties.

Linear optimization is linked to diverse input variables that are related to technological constraints, economic realities, or environmental aims; as a result, it relies on a single decision-maker, flawless foresee, and competitive markets.

C. Case of Study: Atlantis

Atlantis is a fictitious country developed by the OSeMOSYS community as an example for validation and software control.

Atlantis energy modelling system parameter data is described in [9, 10, 11], specifying the different full characteristic of the technologies under consideration. No storage technology has been incorporated. Both Transmission and distribution grid losses are accounted.

To bring the work closer to current trends, costs for wind and solar are actualized [12, 13, 14]. In addition, operational life of nuclear installations is set to end on schedule in 2036, in accordance with Spanish integrated plan of energy and climate [15, 16].

The energetic demand is categorized in industrial, residential, and services. Figure 1 shows the corresponding energetic demand shapes [9, 10]. To consider the seasonality of demand, we have worked under the following hypotheses:

- Three annual seasons: 6 months of winter and 3 months for both summer and intermediate.
- Two daily divisions: day and night. Day and night are distributed as 16 and 8 hours respectively.

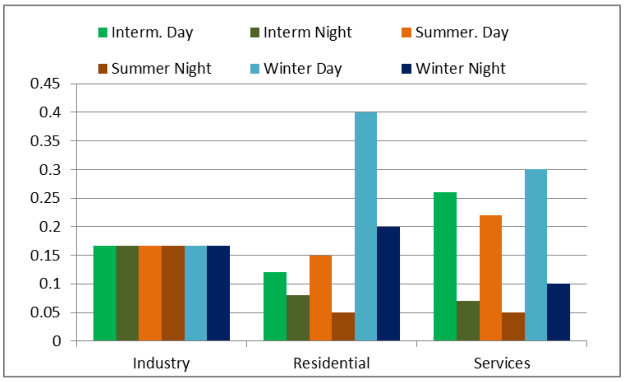

Figure 1. – Distribution of the energetic demand during the year (%)

For the emission calculation, Atlantis database was revised and, instead, cradle-to-crave emissions were considered for most of the technologies [17, 18], with diesel technologies being the exception [19]

D. Definition of Scenarios

1) *Standard scenario (STD).* Also called "*Business As Usual scenario*". No changes are applied with respect to the Atlantis base, so that the trend of demand grows annually and tariffication is constant.

2) *Differential tariff (DT).* Scenario based on the implementation of a differentiated hourly electricity tariff, leading a flattening on the consumption shape. The change only applies to residential demand, as industrial demand is constant and consumption in services is not adaptable. Therefore, as a working hypothesis, the residential demand curve is considered flat throughout the day.

3) *Energetic efficiency (EE).* This scenario evaluates the implementation of measures such as the usage of high efficiency technologies or practices and improvements on electricity transmission and distribution. As working hypothesis, we suppose a yearly linear reduction of 1% till 2030 increasing to 1.25% in the period 2030-2045, which goes in line with the annual reduction expectations for Europe [5].

2. Results

The goal of this work is to evaluate the effects of application of different energy policies favouring the increase in the use of renewable sources and the corresponding decarbonization of the energy mix. For this reason, the energy production per technology has been evaluated for each scenario.

A. *Standard scenario (STD)*

Standard scenario (Fig. 2) is characterized by the high contribution of fossil fuels and large hydropower plant in the short-term.

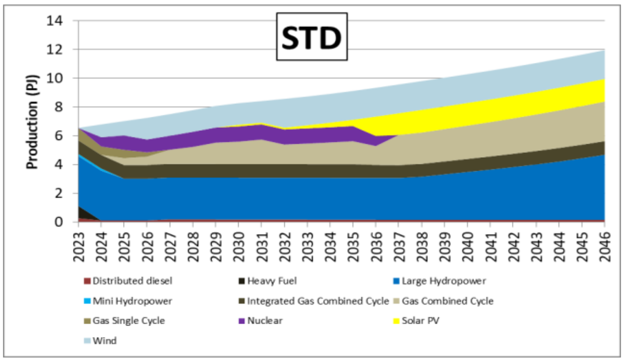

Figure 2. – Annual energetic production for each technology in STD scenario.

The medium-term trend is the growth of both wind and nuclear energy contribution, as well a small contribution of solar PV. The closure of nuclear plants induces a gradual growth of the solar energy. In the long-term, both fossil fuel and hydropower technologies took a role of covering the needs mainly due to the intermittency of solar and wind renewable sources.

B. *Differentiated hourly electricity tariff scenario (DT)*

The main remark (see figure 3) is the lower contribution of nuclear plants with respect to the STD scenario. Otherwise, the behaviour is completely similar to the previous scenario during the complete period under study.

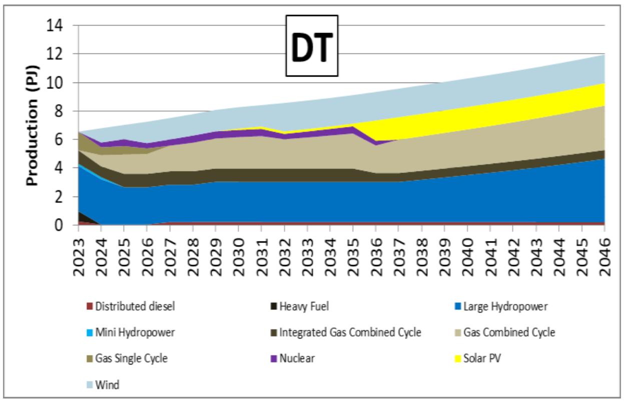

Figure 3. – Annual production for each technology in DT scenario.

The deficit associated with the nuclear contribution is covered in the short and medium term by fossil fuels.

C. *Energy efficiency (EE) scenario*

Figure 4 shows how the implementation of policies of energy efficiency induces a long-term decrease on the global demand, as expected.

Regarding the commitment between the different technologies to fulfil the demand, it is observed how, in this scenario, wind and nuclear energies leads the energy mix. A lower contribution from hydropower plants has also been observed.

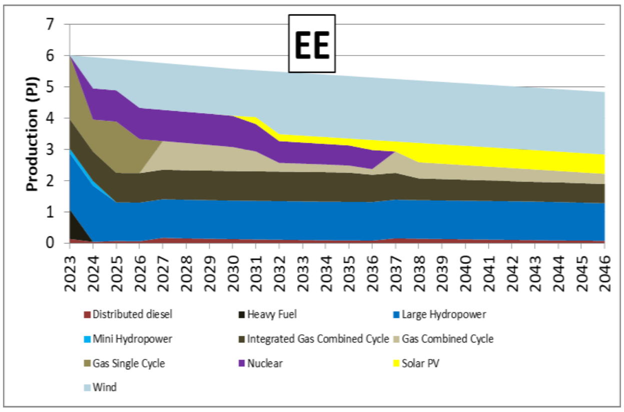

Figure 4. – Annual energetic production for each technology in EE scenario.

D. *Energy mix comparative between the proposed scenarios*

In the previous sections, the short, medium, and long-term trend has been qualitatively evaluated.

To highlight a comparative study, Figure 5 shows the percentages of contribution of each technology in three representative years: 2024 (currently), 2030 (medium term) and 2046 (long-term).

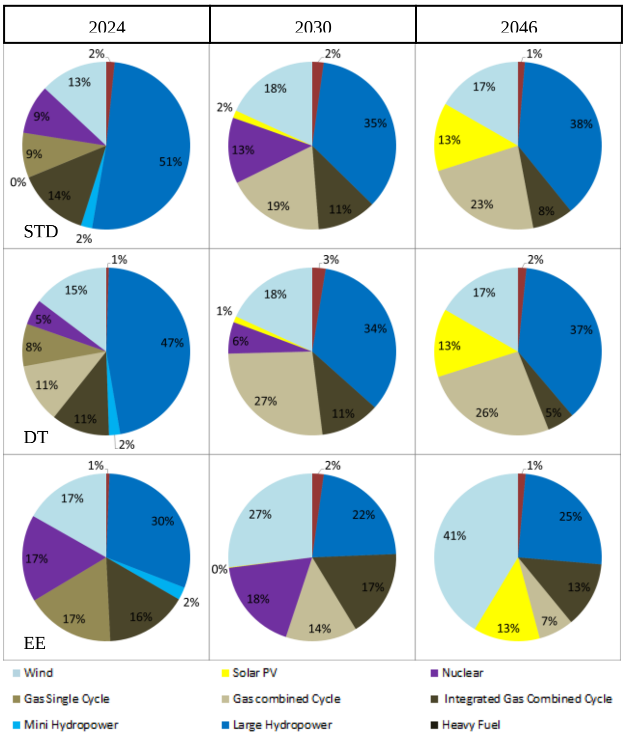

Figure 5. – Percentage of energetic contribution of difference technologies.

Table I shows the contribution of the different energetic sources categorized in renewables, nuclear and fossils.

Table I. - Percentage of each source in the energy mix

Year	*2024*			*2030*			*2046*		
(%)	*RE*	*Nuc*	*Fos*	*RE*	*Nuc*	*Fos*	*RE*	*Nuc*	*Fos*
STD	*66*	*9*	*25*	*55*	*13*	*32*	*68*	*0*	*32*
DT	*64*	*5*	*31*	*53*	*6*	*41*	*57*	*0*	*43*
EE	*49*	*17*	*34*	*49*	*18*	*33*	*79*	*0*	*21*

Starting with the global implications, evaluating table I, it should be noted that in no case does the application of hourly differentiation tariffing favour renewable sources. In fact, fossil fuel participation appears to be increased. This effect can be associated with the lack of solar resource during the night, when demand in DT scenario is increased. And hence the first conclusion: it does not help to improve expectations. The inclusion of storage systems would change this trend.

The implementation of initiatives favouring energy efficiency policies looks more effective in achieving the targets. Moreso, although in the medium term the effects are small, in the long-term, this type of initiative allows to reach 80% of energy production from renewable sources with lower dependence on fossils. As in the previous case, the installation of storage systems even will reinforce the tendency.

Distribution of each renewable source can be seen in Table II. In all scenarios, solar energy appears only weakly at the medium term. The implementation of photovoltaic solar energy, even if limited to 20%, becomes necessary only in the long-term. Previous studies [20] show how solar is not competitive in poorly irradiated areas such as the Atlantis assumption. As for hydraulics, its loss of dominance over time is consistent with the expected decrease in water resources associated with the climatic change.

Table II. - Percentage of each renewable energetic source contribution.

Year	*2024*			*2030*			*2046*		
(%)	*PV*	*Wind*	*Hydr*	*PV*	*Wind*	*Hydr*	*PV*	*Wind*	*Hydr*
STD	*0*	*19.7*	*80.3*	*3.6*	*32.7*	*63.6*	*19.1*	*25*	*55.9*
DT	*0*	*23.4*	*76.6*	*1.8*	*34*	*64.2*	*19.4*	*25.4*	*55.2*
EE	*0*	*36.2*	*63.8*	*0*	*55.1*	*44.9*	*16.4*	*51.9*	*31.6*

As first remarks, the application of renewable energy has no appreciable differences between DT and STD along the time.

As for EE, the differences are remarkable: in the short and medium term, the strong performance of wind energy is already highlighted against the lower application of hydraulics. As for the long term it favors the installation of wind over solar and hydropower.

E. Installed Power comparative.

If well in previous section the share of production of each technology was evaluated, it's also from interest to evaluate the need of new power installation (named installed capacity). Figure 6 and 7 summarize the results of the different energy sources in the short, mid and long term for DT and EE scenarios respectively, along with STD.

In particular, the most remarkable point is the maintenance and even increase of installed power in DT scenario respect STD, specifically from fossil fuels. This trend goes against some expectations, which claims the reduction of capacity need due to the decrease of demand in the hours of maximum power demand [6, 7]. These results, if well coherent, could be affected by limitations in Atlantis' realism in the demand distribution, as night demand was already higher than day demand when considered in terms of power instead of energy.

On the other side, as expected, EE scenario shows smaller power needs than STD. It can also be seen that fossil capacity used in the medium term still operative in the long term, which could be useful for grid stabilization at the view of the high amount of renewable production (although not considered as a working hypothesis).

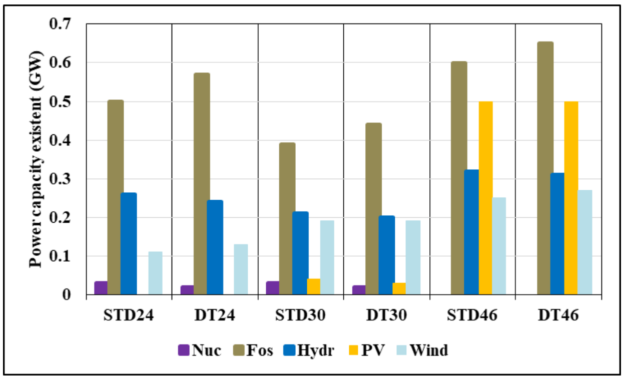

Figure 6. – Power capacity existent of each source in 2024, 2030 and 2046 for STD and DT scenarios.

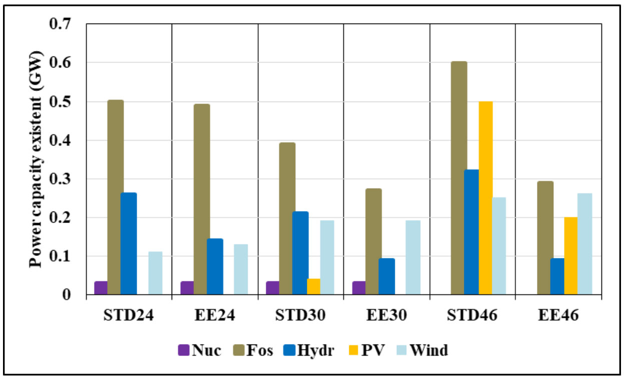

Figure 7. – Power capacity existent of each source in 2024, 2030 and 2046 for STD and EE scenarios.

Reduction of installed power in 2030 respect to 2024 comes partially from the shutdown of old installations that are considered in the in Atlantis' starting system, specifically: 0.15 GW from diesel generators (not distributed), 0.03 from heavy fuel technology, and 0.3 GW of large hydro [9, 11].

F. CO2 Emissions comparative between the proposed scenarios

Given the current paradigm of promoting measures to mitigate climate change, reducing polluting emissions is crucial. Table IV shows the global CO2 emissions integrated in the period under study for each scenario.

Table IV. – Total modelled period emissions (CO_2 Mton).

Scenario	*STD*	*DT*	*EE*
Tot. Emiss. (Mton)	15.31	16.27	10.93

The application of energy efficiency measures is associated with a decrease in global emissions close to a 30% respect to the STD. Conversely, as expected, the differentiated tariff even increases the level of pollution (until a 6%) because of its greater participation in fossil sources.

As for the evolutionary trend of the emission, Figure 8 shows how although the EE scenario appears to be more polluting in the short medium term, the situation changes drastically in the long-term, obtaining the most favorable outlook. Remarkably, DT scenario achieves smaller emissions that STD in the last years, even relying in a higher amount of fossil fuels. This is because it choses natural gas combined cycle over the most emissive coal technology (integrated gas combined cycle). However, DT scenario is the most emissive considering the entire period.

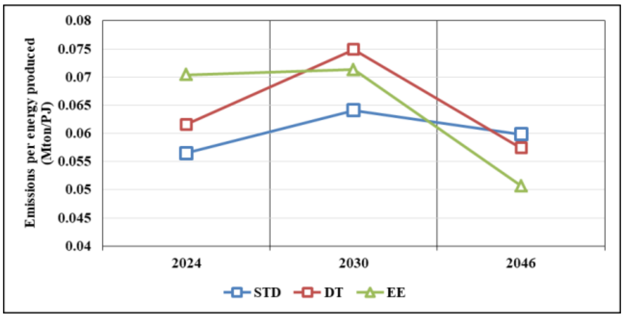

Figure 8. – Emission per energy produced (Mton CO2/PJ).

G. *Comparative costs*

The economic characterization of the different scenarios is shown in Table V. In particular, the overall global costs and the corresponding investments in repowering the current capacity (named *capital investment*) both integrated along the modelled period. Highlight the savings of around 50% achieved by energy efficiency measures associated with the lower need for repowering (see figure 9 for details). However, it's important to remark that only the costs associated with the energetic generation system are considered. Meanwhile, other costs (such as the ones of building retrofits and electrical appliances) are needed for the application of energy efficiency policies [21].

Table V. – Total modelled period capital investment and total cost (Millon $).

Scenario	*STD*	*DT*	*EE*
Tot. Global Cost (Millon $)	4158	4210	2256
Tot. Cap. Invest. (Millon $)	2732	2765	1282

As expected, no significant differences are observed when hourly differentiation tariff is applied.

Figure 10 shows the annual cost which includes production, maintenance, and employment costs (called *variable* and *fixed* cost respectively). With respect to the STD, DT scenario appears slightly more expensive, probably because of both the higher fraction of fossil fuels and repowering needed.

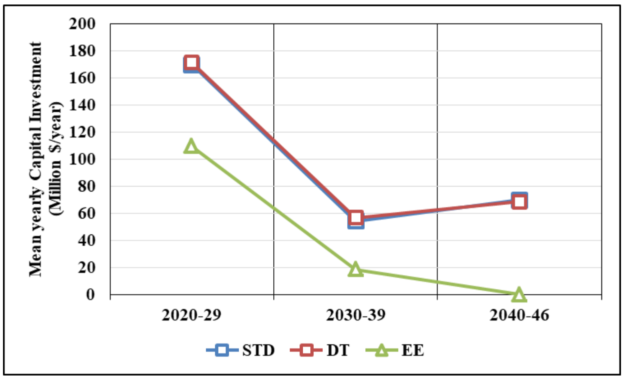

Figure 9. – Mean capital investment each year during the simulated decades: 2020-2029, 2030-2039, and 2040-2046 (Millon $/year).

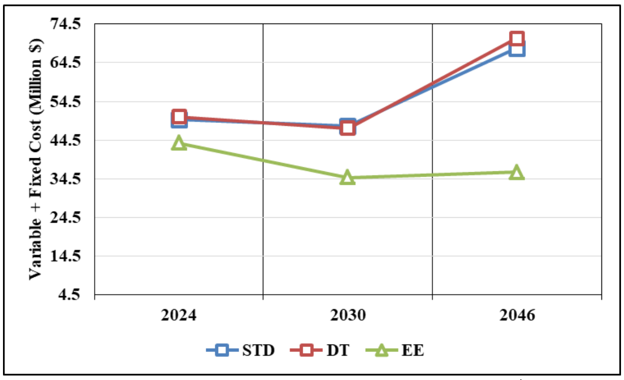

Figure 10. – Variable + Fixed Costs (Millon $).

As expected, the EE scenario, with a mix leaded by renewable sources and without new power installation, would be the less costly.

4. Conclusions

In this work, the effects of application of different energy policies favouring the increase in the use of renewable sources and the corresponding decarbonization of the energetic mix have been evaluated.

The two most popular directions of current policies trends, that is, promoting energy efficiency measures or implementing hourly differentiation tariffs, has been modelled using the OSeMOSYS utility. The different transition scenarios have been applied and evaluated in the frame of a fictional country called ATLANTIS (well representing a global north country). Short-, medium- and long-term evolution has been studied and compared.

On the main findings, the effects of the application of hourly differential tariffing are negligible with respect to a flat tariff, except for a higher dependence (around 10%) on the fossil fuels. This comes with a 6% of increase in emissions during the modeled period, although the use of natural gas over coal the last years makes it slightly less polluting than STD. Differential tariffing also fails in the reduction of the generation capacity needs (and therefore at the reduction of investment and maintenance). This is probably a consequence of moving the demand towards hours with smaller solar power, requiring a system for the day and the night or storage implementation (which was not evaluated in this paper). Last results encourage a precise calculation taking into account peak hours of demand to ensure the viability of renewable energy increases along differential tariffing. Better evaluation of the consequences in transmission and distribution grids could provide some advantages to this politic.

As for the promotion of energetic efficiency policies, are a promising opportunity to ensure decarbonization. In fact, supposing a decrease of consumption of 1-1.25% annual, an energetic mixing where the 80% of the global demand are covered by renewable energetic production can be achieved. In this case, wind technology will lead the contribution (51%), being the solar PV limited to 20%. Such shares of renewable production, however, come with further stabilization needs, making necessary an evaluation of those consequences over the energy mixing, capacity installed, and costs. Some thermal plants used for energy production during the transition process to a smaller consumption could still be providing support in that matter. Cost reduction reach a 53% of the STD cost during the entire modeled period in the generation system. However, this doesn't account the necessary cost to achieve the energy efficiency.

References

[1] SUSTAINABLE DEVELOPMENT GOALS. 7 *Affordable and clean energy*. https://www.un.org/sustainabledevelopment/energy/. [Accessed: 12-Jan-2023].

[2] SUSTAINABLE DEVELOPMENT GOALS. *13 Climate Action*. https://www.un.org/sustainabledevelopment/climate-change/. [Accessed: 12-Jan-2023].

[3] EUROPEAN COUNCIL, *European Green Deal*. https://www.consilium.europa.eu/en/policies/green-deal/. [Accessed: 12-Jan-2023].

[4] EUROPEAN COUNCIL, *Fit for 55*. https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/. [Accessed: 12-Jan-2023].

[5] EUROPEAN COUNCIL, *Infographic - Fit for 55: how the EU will become more energy-efficient*. https://www.consilium.europa.eu/en/infographics/fit-for-55-how-the-eu-will-become-more-energy-efficient/. [Accessed: 12-Jan-2023].

[6] GREENPEACE. *Nueva tarifa de la luz: lo que tú puedes ganar y las eléctricas pueden perder*. https://es.greenpeace.org/es/noticias/nueva-tarifa-de-la-luz/. [Accesed: 05-03-2023].

[7] MITECO. *La nueva factura eléctrica, que entrará en vigor el próximo 1 de junio, fomentará el ahorro energético, la eficiencia, el autoconsumo y el despliegue del vehículo eléctrico*. https://www.miteco.gob.es/es/prensa/ultimas-noticias/la-nueva-factura-el%C3%A9ctrica-que-entrar%C3%A1-en-vigor-el-pr%C3%B3ximo-1-de-junio-fomentar%C3%A1-el-ahorro-energ%C3%A9tico-la-eficiencia-el-autoconsumo-y-el-despliegu/tcm:30-525865. [Accesed: 05-03-2023]

[8] M. Howells et al., "OSeMOSYS: The Open Source Energy Modeling System. An introduction to its ethos, structure and development", Energy Policy (2011), Vol. 39, no. 1', pp. 5850-5870.

[9] OSeMOSYS. 'GET STARTED'. Atlantis datafile. http://www.osemosys.org/get-started.html. [Accessed: 02-Dec-2021]

[10] Almulla, Y. et al. *Model Management Infraestructure (MoManI) Training Manual KTH Royal Institute Technology* http://www.osemosys.org/get-started.html. [Accessed: 02-Dec-2021]

[11] OSeMOSYS. 'GET STARTED'. MoManI v. 1.10. http://www.osemosys.org/get-started.html. [Accessed: 02-Dec-2021]

[12] IRENA, "Renewable Power Generation Costs in 2021", International Renewable Energy Agency, Abu Dhabi (2022), pp. 59, 72, 79, and 95.

[13] IRENA, "Future of Solar Photovoltaic: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation: paper)", International Renewable Energy Agency, Abu Dhabi (2019), pp. 27.

[14] IRENA, "Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation paper)", International Renewable Energy Agency, Abu Dhabi (2019), pp. 33.

[15] MITECO. *Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030*. https://www.miteco.gob.es/es/prensa/pniec.aspx. [Accessed: 12-Jan-2023]

[16] MITECO. *El Miteco somete a información pública la propuesta de 7º Plan General de Residuos Radiactivos y su Estudio Ambiental Estratégico*. https://www.miteco.gob.es/es/prensa/ultimas-noticias/el-miteco-somete-a-informaci%C3%B3n-p%C3%BAblica-la-propuesta-de-7%C2%BA-plan-general-de-residuos-radiactivos-y-su-estudio-ambiental-estrat%C3%A9gico-/tcm:30-539191. [Accessed: 12-Jan-2023]

[17] Steffen Schlömer (ed.), "Technology-specific Cost and Performance Parameters", Annex III of Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014)

[18] Tarannum, Israt & Mohammedy, Farseem. "Life Cycle Assessment of Natural Gas and Heavy Fuel Oil Power Plants in Bangladesh". TENCON 2019 (2019), pp. 2240-2244. Doi: 10.1109/TENCON.2019.8929492.

[19] N. D. Strachan et al. "Emissions from distributed generation", CEIC Working Paper (2004), 02-04, pp. 1–14.

[20] Mahamat Habib, Bechir, Lopez-Agüera. "Modeling of the optimal impact of photovoltaic technology on a sustainable energetic mix as function of the climatic conditions". 11. Eur. Conf. Ren. Energy. 18-20 May 2023, Riga, Latvia.

[21] ENEFIRST, "Quantifying Energy Efficiency First in EU scenarios: implications for buildings and energy supply". Deliverable D3.3 of the ENEFIRST project, founded by the H2020 programme (2022). Available at: http://enefirst.eu