Emissions mitigation by infrastructure improvement and increased renewables share on electricity grid.

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ABSTRACT

In order to foster the development of the nations, it is of high importance to have a holistic approach towards sustainability, particularly the implementation of the UN 2030 Agenda of the Sustainable Development Goals (SDGs) is the key and, when it comes to energy, the grid infrastructure plays a key role to ensure access to affordable, reliable, sustainable and modern energy for all (SDG 7) as it is stated by indicators 7.b; “By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all”; 7.b.1; “Investments in energy efficiency as a proportion of GDP and the amount of foreign direct investment in financial transfer for infrastructure and technology to sustainable development services”. In this line, the aim of this study is to clarify the potential of emissions reduction through decreasing transmission and distribution losses in national grids in developing states, where the issue of losses within the grid is much more severe than in more developed economies. The study was carried out using the Integrated Assessment Model MESSAGE and the region studied involve India, sub-Saharan Africa, South Asia, South America, where the grid deficiencies are larger than 11%. Two main scenarios are simulated with different penetrations of renewables to the grid and compared with the “Business as Usual” case. The essential, direct investment needed for the grid infrastructure improvement is provided by developed nations and the propagation of CO_2 emissions are reported. Simulating those different scenarios will assist in the quantification of the environmental impact as well as to policy implementation.

Key Words
Emissions mitigation, grid efficiency, energy infrastructure, renewables penetration, integrated assessment model, UN 2030 Agenda, SDG 7

INTRODUCTION

The 2030 Agenda of Sustainable Development includes 17 Sustainable Development Goals and 169 associated targets to measure the progress towards its achievement. The balance and integration between economic, social and environmental dimension is fundamental and major attention is given to energy services, indeed as stated in the 7th goal it is necessary to "*Ensure access to affordable, reliable, sustainable, and modern energy for all"*. As it is known, the electricity access as well as the efficiency of the power infrastructure is vital to industry and can have a profound effect on a nation's economy. Moreover, power outages can cause school closures, disrupt services causing huge losses to the economic system [1]. One of the main issues in developing countries, both with a carbon intensive electricity mix, is in fact the access electricity. In these countries there is a mismatch between the growth of the electricity production and electricity demand, highly driven by population growth, for instance, given current conditions, while nearly 1 billion people in Sub Saharan Africa alone may gain electricity access by 2040, due to population growth, an estimated 530 million people in the region will still have no electricity access (IEA 2014). This shows how universal electricity access will not be met by 2030 unless urgent measures are taken [2][10].

Our work was based on the idea of bounding the achievement of universal electricity access with the use of clean energy sources, looking at the effect of right policies, strategic planning, regulations and subsidies. It was decided to pick India to see the specific effects of improvement in grid efficiency and subsidies on renewable energy sources (RES).

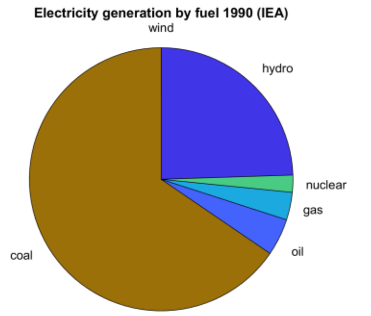

Fig.1 Electricty generation by fuel in 1990-India, IEA source

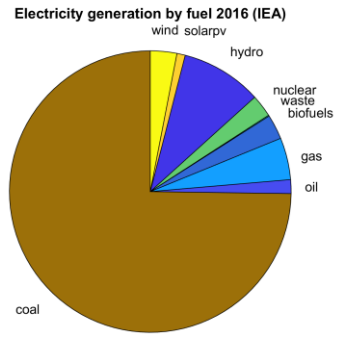

Fig.2 Electricity generation by fuel in 2016-India, IEA source

By 2017, India was already the third largest electricity generator in the world behind China and USA, however its electricity consumption per capita during the same year (1117 kWh) was less than one-fourth that of China, and one-third of the World average [3]. In the figures 1 and 2, we can see how the change of the electricity generation by fuel between 1990 and 2016. It is important to notice that the total generated electricity grew about 5 times in almost 3 decades, passing from 292,732 GWh in 1990 to 1,477,564 GWh in 2016, where there was also an increase in coal share from 65,46% to 74,77% [4]. To further understand the current situation in India, it is important to look at the energy access as well, as shown in Img. 3, the percentage of population with access to electricity grew in the last years but it still must reach the 100%. According to India's Ministry of Power of the 177 million rural households in the country, only 152 million (86%) have been provided with electrical connection. If we look at predictions on population and economic growth for this country, we can see how electricity demand in India is expected to double over the coming decade, and how this electricity will be generated is critically important for both India and the world [5].

IMPLEMENTATION OF THE MODEL

The IIASA's model MESSAGE for Austria was been modified in order to analyse India and see which was the best combination of subsidies both for the grid and the integration of RES, as well as the results in terms of reduction of greenhouse gases emissions in the electric energy sector of the country in comparison to the emission levels in 2012 which, for the electric generation sector, accounted for around 1000 Mton of CO2e [6].

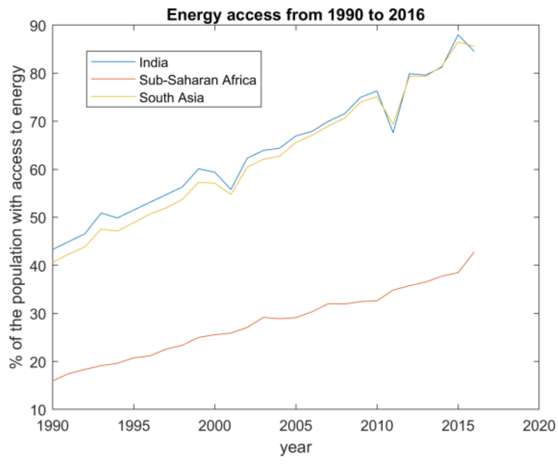

Fig.3 Energy Access from 1990 to 2016 in different world areas, The World Bank sources [3]

Demand function and data

The electricity consumption can be expressed in general as a function of GDP, electricity tariff, gas price and population in the rural and urban areas. Analysing it in this way, we have been able to better characterize electricity demand having different growth of rural and urban population. It has been implemented as follows in the code [9]:

$$EC_{rel}(t) = Y_{rel}(t)^{\beta_1} * Pe_{rel}(t)^{-\beta_2} * R_{rel}(t)^{\beta_3} * U_{rel}(t)^{\beta_5}$$

TERM	DESCRIPTION	COEFFICIENT	DESCRIPTION
$EC_{rel}(t)$	Electricity demand at time t relative at the reference year*	-	-
$Y_{rel}(t)$	Income at time t relative to the reference year	0.825 [7]	India's income elasticity
$Pe_{rel}(t)^{**}$	Relative price of electricity at time t	1.3 [7]	Elasticity of price of electricity
$R_{rel}(t)$	Relative rural population at time t	0.005286 [8]	Growth rate for rural population
$U_{rel}(t)$	Relative Urban population at time t	0.0232 [8]	Growth rate for urban population

*Reference year: 2015; **The model used, predict the Pe so it was assumed the relative one be equal to 1

Model working structure

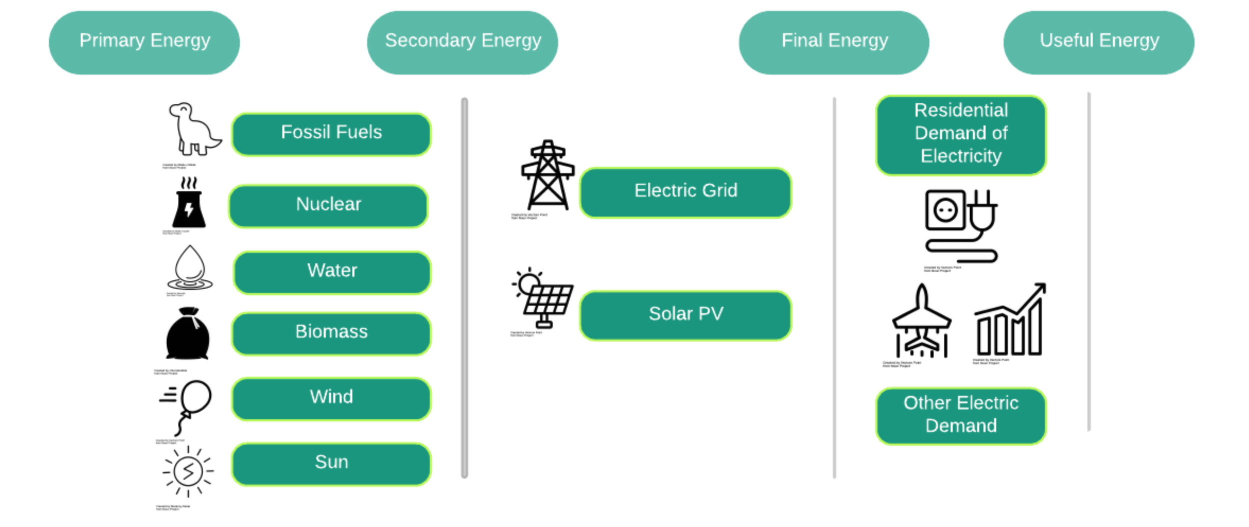

Fig.4 BAU model scheme

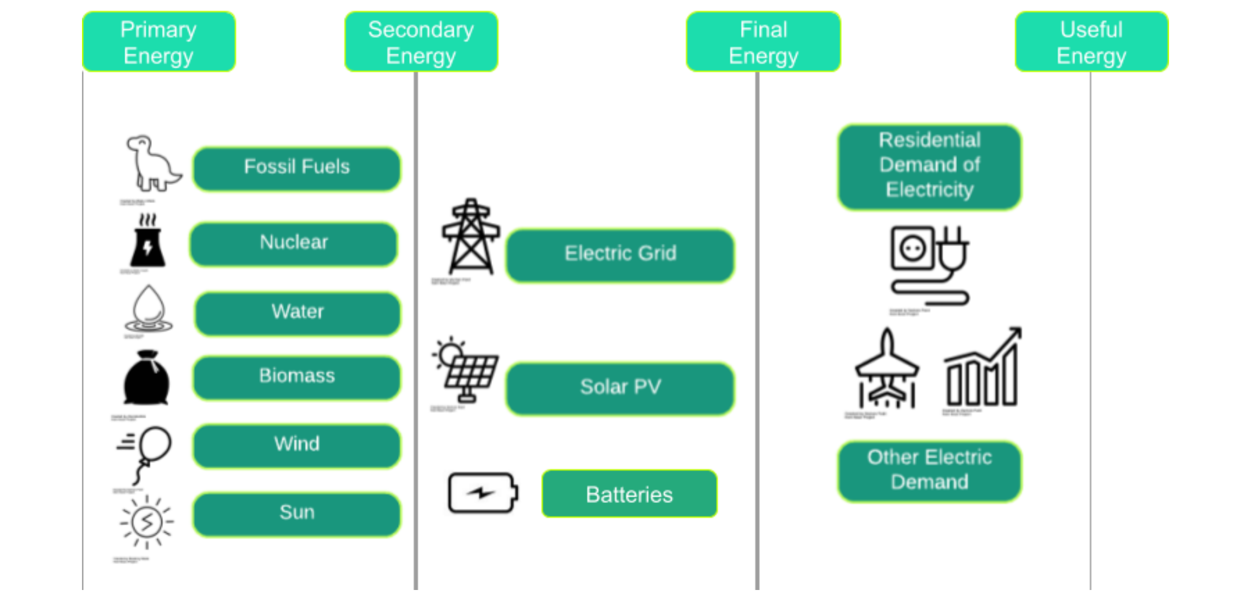

Fig.5 Model scheme -to be modified

The scheme in figure 4 is the standard structure of the MESSAGE model, and it is the one that we used as a guideline for both the business as usual scenario and the new policy scenario. On the other hand, the Img.5 represents the modified scheme of the model used for our simulations and for further research, indeed, to increase the integration of renewables into the grid, is necessary to add the accumulation stage to the model to handle with the time gap between the production time lapse and the energy consumption.

The model works on a time period that goes from 1990 to 2051 with a five years step and it has been constraint and calibrated for the years 1990 and 2015, aiming to obtain reliable results for the vintage years.

RESULTS AND DISCUSSION

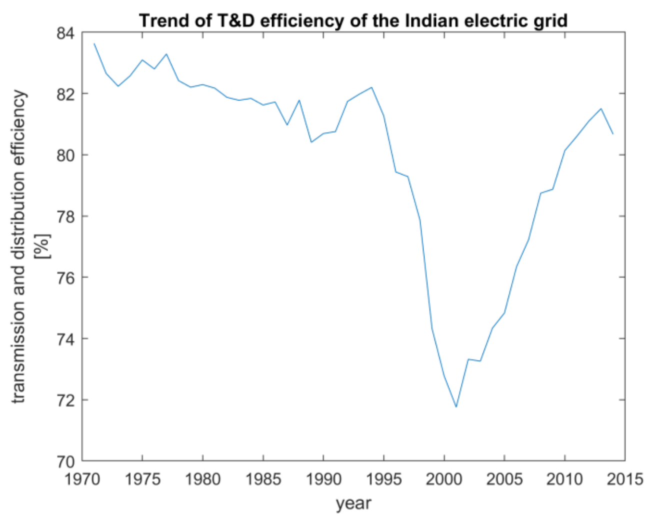

Fig.6 Trend of electrig grid T&D efficiency in India from 1970 to 2014-The World Bank source [3]

The Img. 6 presents the trend of transmission and distribution efficiency of the Indian electric grid. As shown in the plot, in 2000, 28% of the energy produced would get lost in the transmission and distribution stages, so working on the efficiency of the grid is fundamental to reduce the losses and surplus and lost electric energy.

The first step of this analysis is the business as usual scenario (BAU), in this case the grid transmission and distribution losses in 2050 will only decrease of 1%, assuming that fossil fuels will also be addressed of the largest slice of the total energy mix in electricity generation. Indeed, as we can see from Img.7, the activity of power plants will reach more than 3000 TWh in 2050 following current constraints on the share of the sources that have been planned by the Indian government. Also, in the BAU scenario, the needed surplus due to growth of the demand will be satisfied by an increase in the share of fossil sources of energy, while the renewables share, without accounting for large scale hydro, will not increase much and the emissions will reach a value of around 1600 MtonCO_2e and a cost of electricity being constant around 15 centUSD/kWh. It is important to notice that nowadays electricity price in India is 4 INR/kWh for domestic usage (around 6 USD/kWh).[7]

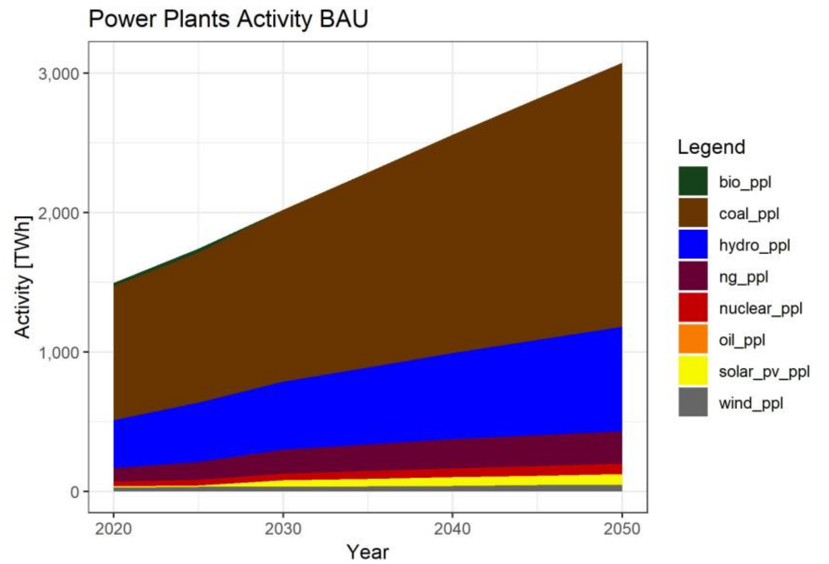

Fig.7 BAU predictions on the share for electricity generation

The BAU scenario has been then compared with the New Policies Scenario (NPS), in this scenario the prevision for grid losses in India by 2050 is 16%, lower than the 19.33% losses of 2015, to reach this value of efficiency both grid and renewables are subsidised and thus their share on the total mix is higher.

As we can see from Img.8, the Total Activity of coal power plants is reduced compared to the BAU scenario, this is related to subsidies in renewables energy systems. The combined action of grid efficiency and increased renewables share will lead to emission reduction of the electric energy sector as it is possible to notice from figure 10.

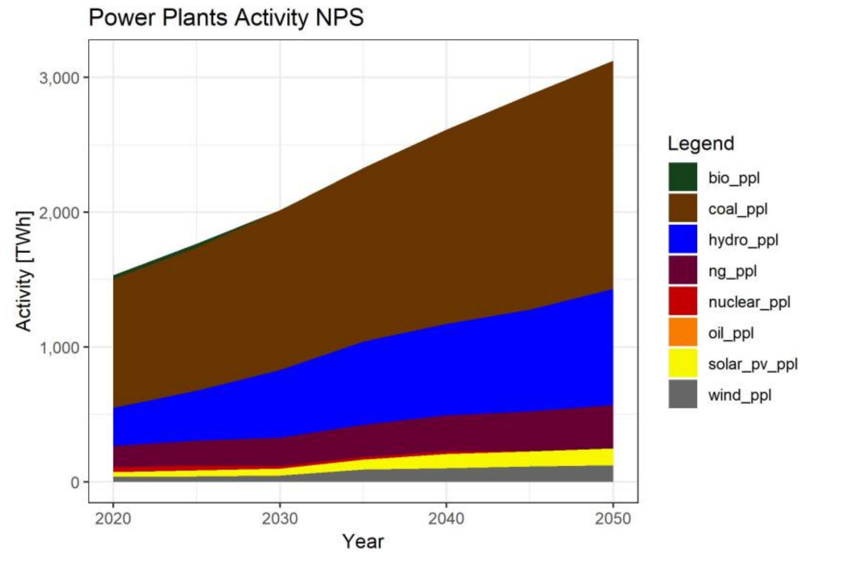

Fig.8 NPS predictions on the share for electricity generation

In addition to the main scenarios already discussed, also other options have been considered:

- NPS with only grid efficiency improvement,
- Sustainable Development Scenario with only grid efficiency improvement,
- Sustainable Development Scenario with renewable subsidies.

In the last two scenarios, a further reduction in the distribution and transmission losses was assumed with India following the path of another country with a similar human development index, Peru. For this reason, these two scenarios are referred in the plots as "Peru scenario".

The figure 9 shows the prediction on electricity generation by fuel type in the framework of the sustainable development scenario. Not surprisingly, the further improvement of the efficiency of the grid, results in the reduction of the power plants' activity from more than 3000 TWh in BAU to less then 3000 TWh by 2050 in SDS. Indeed the constant demand and less losses in the grid leaded to a decrease in production levels for electricity generation.

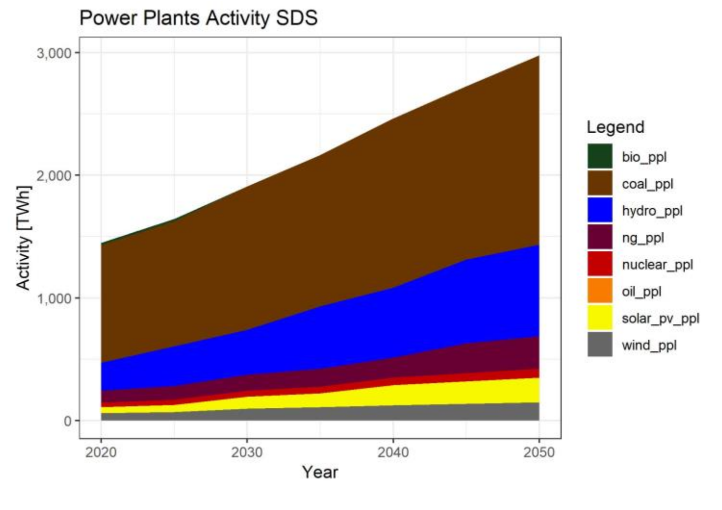

Fig.9 SDS predictions on the share for electricity generation

From Figure 10, it can be observed that the joint effect of improving grid efficiency and increasing the renewables integration has a positive effect on the emissions levels, reducing them to 1408 Mton CO2eq. On the negative side, it is necessary to take into account that renewables have to be connected to the grid and/or to storage devices both if it's not feasible to handle the power produced due to the distance of the energy hub to the grid, a surplus of production that will otherwise cause a congestion in the grid, this represents a challenge since batteries, as every other device, have an efficiency lower than the unity, meaning that the overcoming this additional loss should be considered as soon as the share of renewables increases.

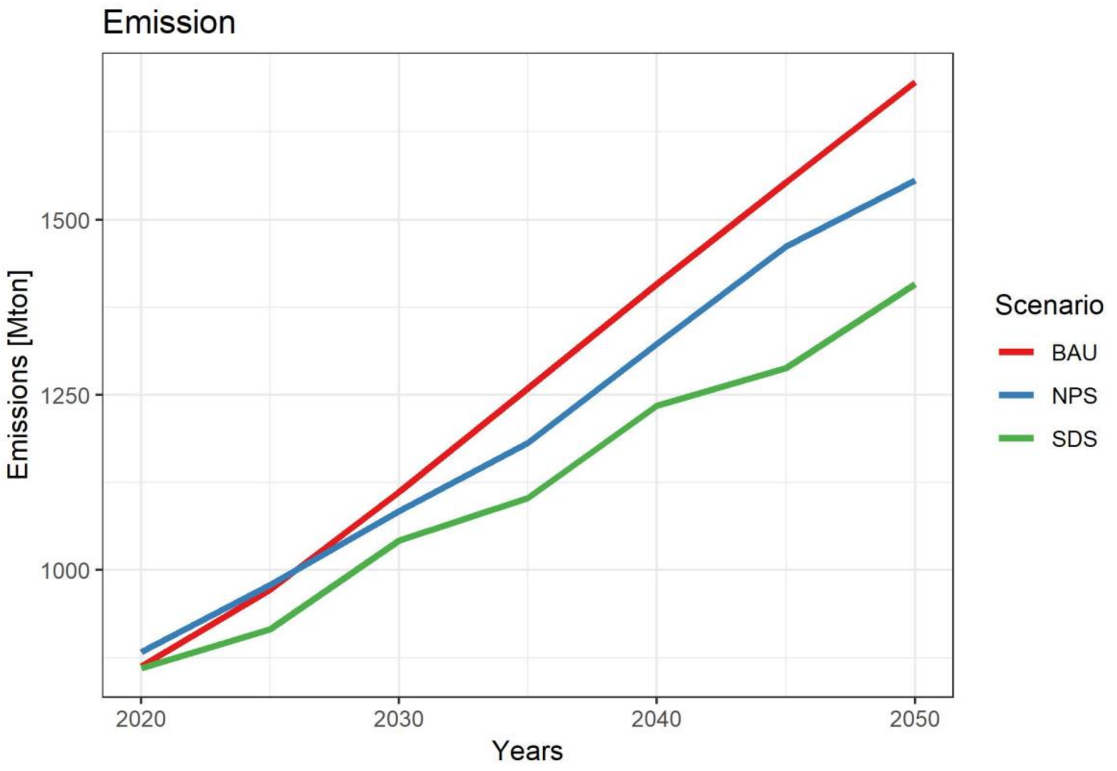

Fig.10 Emissions comparison between the two different scenarios

CONCLUSION & FURTHER DEVELOPMENT

In order to come in line with the UN 2030 agenda and secure reliable and clean energy for all, the barrier of poor energy infrastructure in many developing states needs to be overcome. In this paper, the effect of grid efficiency improvement on the GHGs emissions is studied thoroughly for India, as it presents significant grid efficiency losses. Such study is important in order to determine the extent of improvement needed to facilitate the essential energy transition. Moreover, countries like India, with its fast growth, are reaching incredible shares of the global energy consumption, GDP and population, meaning that just as developed nations have a great responsibility for previous levels of emissions and the resulting environmental damages that their development implied, developing economies should find a way to reach levels of richness following a greener path, in that manner they have the opportunity to become an example for the nations. This path is difficult and steep, it needs major investments, awareness of current worldwide situation and, thus, knowledge-based policy design. To provide the needed basis for developing informed environmental policymaking, integrated assessment models (IAMs) are used.

In the presented study, the simulation took place using the IAM MESSAGE that is calibrated to match real values and simulate the future, under three main scenarios. The first one is the Business as Usual (BAU), with only grid efficiency improvement and no measures are taken for renewables penetration. For the latter cases, the emissions reduction is due to further penetration of the renewable energy sources (RES) at the energy mix. Particularly, in the second case, the grid efficiency is increased exogenously under the IEA's Current policies scenario; while in the Proposed Sustainable Development scenario, the grid efficiency follows the historical trend of Peru. It is important to state that no carbon tax or any other policy measures are considered at this study. The improved grid infrastructure resulted in a significant reduction of emissions and further reduction was found under the joint effect of grid improvement and increased renewables penetration. By comparing the BAU scenario with the combined effect of both grid efficiency improvement and renewables penetration, we determine that better grid infrastructure fosters the integration of renewables into the grid, resulting in further emissions reduction and thus, enabling a secure pathway to green energy transition. Further development of this study would consider more fitting implementation of energy access into the model to simulate the real-world behaviour of the energy demand, electric grid efficiency and greenhouse gases emissions, allowing a better understanding of the real behaviours.

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