STRATEGIC ANALYSIS FOR THE LONG-TERM RENEWABLE GOALS OF THE INDIAN ELECTRICITY SECTOR

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ABSTRACT

The energy sectors of a majority of countries globally are undergoing a transition from conventional thermal energy to clean renewable energy, with regards to a higher awareness on climate change. The electricity sector forms a major part of any energy sector. The transition of the electricity sector from conventional electricity generation to renewable energy is a tedious and long-term process. Furthermore, the transition process brings about a large number of complications on the electricity system. This has already been observed in the European Union (EU).

India is a country in the middle of such a transition process. Also, the Government of India (GoI) is committed to its stance on battling climate change, with the improvement of its electricity generation shares from renewable energy sources by the year 2030. In order to attain such an objective, the GoI has come up with ambitious objectives for capacity expansions of solar Photo-Voltaic (PV) and Wind power by the year 2025.

This study focuses on the analysis of a scenario with large scale electricity generation from Solar PV and onshore wind power capacities, distributed over the five different power regions in India. For the simulation of this scenario, the techno-economic model ATLANTIS_India, developed at the Institute of Electricity Economics and Energy Innovation, Graz University of Technology, has been used. The simulation results of such a scenario are analyzed and further discussed as conclusions for the study.

1. INTRODUCTION

India can be called as a land of diversity, be it in cultures, languages, cuisines or many more things. Unfortunately, the same cannot be said for the electricity sector, where the electricity generation in the country has been dominated by conventional coal power technology for over more than a few decades. Overall, by the end of the year 2018, the electricity generation from coal-based power plants in India was around 60 percent of the total electricity generation. The share of the Indian coal power plant fleet was about 57 percent of the total installed capacity [1]. The dependency on coal power began with the industrialization reforms introduced in the country, in the early 1990s. Since then, the focus of the GoI to improve the country's standing in the global economy pushed the energy sector for a continuous installation of coal power plant capacities every consecutive year. However, with the recent changes in the energy politics of the country, much focus is on the improvement of renewable energy capacity in regards to India's international commitment to battle climate change [2].

The geographical positioning of the country, places it in a very favorable situation for renewable energy generation. With a staggering amount of over 2300 -3000 sunlight hours, and several identified wind rich areas, the identified technical potential for solar Photo Voltaic (PV) power generation alone amounts up to a staggering 750 GW [3]. This by quantity is enough to replace all the coal generation facilities in the country. However, the intermittent nature of the electricity generation from these renewable energy sources create several complications in the working of the electricity system of the country. This study analyses the long-term plans of the GoI by building a specific scenario, taking an overall stance on the current situation of the energy sector in the country, and the implemention of a strategy for electricity generation from renewables across each power region in the system up to the target year 2040. The simulation of the scenario has been done using the techno economic simulation model *ATLANTIS_India* [4]. The results of the simulation have been discussed, and inferences are proposed as conclusions.

2. THE UNIQUENESS OF THE INDIAN ELECTRICITY SECTOR

With the overall generation capacity of 350 GW and an electrical energy consumption of 900 TWh at the end of the year 2018 [1], the Indian electricity sector is one of the largest electricity systems in the world today. As already discussed, most of the power generation in India comes from its valued coal power plant fleet, which mostly satisfies the industrial load of the country. Traditionally, before the industrial reforms of 1990s, the major source of electric power in India was Hydroelectric power. Hydroelectric power has an installed capacity share of over 18 percent in the Indian power plant fleet today. Small Hydro Power plants are classified separately, along with the other renewable energies' share. After the initial liberalization stages of the Indian electricity market, SHP is one of the fastest emerging technologies in the country considering the improved benefits for private investments in the electricity sector.

Renewable Energy Technologies (RETs) like Solar PV and Wind power have also been gaining a lot of focus in the recent years, with India's stand on RETs improving a lot in the last decade. The installed capacity of solar PV has increased up to four times of its share than in the year 2010, while wind power capacity in the country has almost doubled. The RET share in the power plant capacity mix has already reached 33 percent in the year 2018 [1] and is expected to develop further in the coming decade. Nuclear power plant capacity in India has reached a standstill, due to trading restrictions imposed for not being a part of the non-proliferation treaty. However, with the improvement of research within the country and cooperation with other countries like Russia and Canada, the share of Nuclear energy is also slowly improving. India's long-term stance on Nuclear power is to double its capacity from 6 GW in 2018 to around 10 GW by 2030. Recent advancement of India in the field of Thorium-based nuclear fuel further brings the country closer to its 'Three stage nuclear programme', envisioned to secure the country's long-term energy independence [5]. The overall illustration of the Indian power plant fleet classified by generation technology type is shown in the accompanying figure (1)

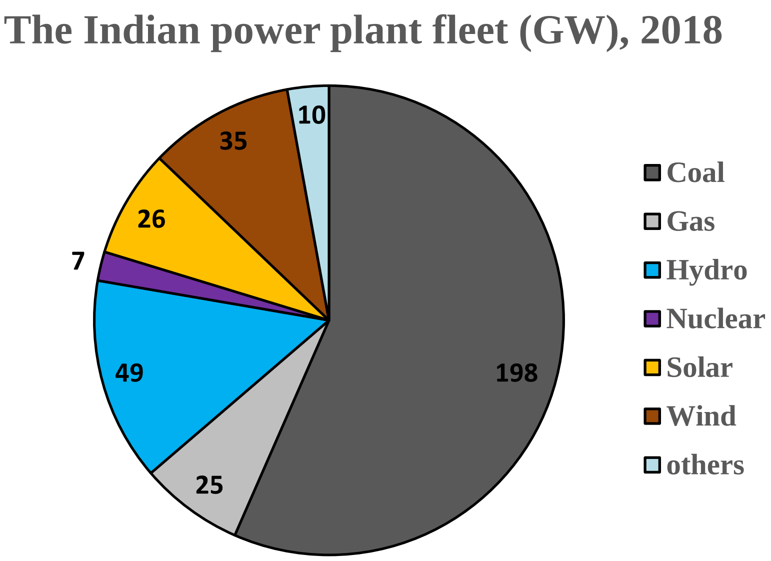

Figure (1) The Indian power plant fleet, capacities by generation type, end of the year 2018

After the agreement to curtail around thirty percent of energy related emissions from their 1990 levels by the year 2030, India has been rigorously investing its efforts into the improvement of their renewable energy power plant fleet. Several energy policies were introduced with strict focus on Solar PV and Wind energies, which had severe impacts on the new investments in coal power. With the rise of awareness of climate change in the country, the GoI was forced in to a situation to manage the economic development, while decreasing its overall energy related emissions. With other challenges of inefficient distribution networks and increasing electricity demands, a severe financial crisis in the energy sector arose with the creation of debts and stranded assets. Thus, a new approach to improve the financial situation of the Indian electricity sector was needed. With the introduction of subsidies for renewable energy generation and Renewable Energy Certificates, the interest of several private energy companies arose and the situation was somehow contained. However, the overall variation in seasonal availability of the renewable sources in India now creates another specific challenge for the electricity sector.

With the vast area of the country, the seasonal variations within each different power region is significantly large. For example, the annual rainfall season (Monsoon) in the South Region (SR) is during the months of June, July and August, whereas the monsoon season in the Eastern Region (ER) is mainly during the months of October and November. Since almost 80 percent of the annual flow of Indian rivers happen during the monsoon months [6], the generation from hydro power in each of the region also varies significantly over the months. With the availability of Solar irradiation, there is also a seasonal variation. Solar irradiation can be considered least during rainfall season in the SR and ER regions. The winter months of November, December and January in the North Region (NR) and North East Region (NE) have the least amount of irradiation. As a result, the availability of electricity generation from PV capacities also varies significantly. Thus, a very innovative distributed renewable energy generation strategy has to be designed for India, to make up for the seasonal variations, as well as for the sustainable and efficient operation of the Indian power grid.

3. THE TECHNO-ECONOMIC SIMULATION MODEL '*ATLANTIS_India'*

The Techno-economic simulation model *ATLANTIS_India* [4] was developed at the Institute of Electricity Economics and Energy Innovation, Graz University of Technology. The model *ATLANTIS_India* is based on the simulation model *ATLANTIS* [7], which was developed to simulate the European electricity economics, at the same institute.

The unique feature of this model is that it combines the physical structure of the Indian energy system, along with the economical part of the sector. This makes the model *ATLANTIS_India* a one-of-its-kind model in the global energy field. The physical model covers the transmission network, transformers, power plants and demand center nodes over the five different power regions in India, along with Bangladesh, Bhutan, Nepal and Sri Lanka. The five power regions are as defined by the Transmission System Operator in the country: East Region (ER), North East Region (NE), North Region (NR), South Region (SR) and West Region (WR)

The transmission network, nodes and the power plant data are geographically accurate, to simulate an as-close-to-reality scenario. Transmission lines of voltage levels 132 kV, 220 kV, 400 kV, 500 kV, 765 kV and High Voltage DC (HVDC) are considered in the model. The economic part contains four different market models and a business model for companies (smaller companies are segregated together for simplicity) involved in the energy sector. The possibility to simulate the energy economy of the fastest growing region in the world is a very interesting one, and through *ATLANTIS_India*, it can be realized.

The node-specific demand distribution in the model has been done through the assigning of weightages with respect to the total regional electricity demand, based on population, agricultural activity and industrial activity around the region of the specific node. The identification of the agricultural activities and industrial activities was done by superimposing the model node GIS data with the opensource GIS maps of agricultural lands and Special Economic Zones in the countries involved.

The model *ATLANTIS_India* can simulate up to four different market models, out of which specific market model types are selected for analysis of each study, based on the requirement. The market models are defined based on load flows and transmission constraints. The four different market models can be explained using simple terms:

1. **Copper Plate model:** Without load flow calculations, and Net Transfer Capacity restrictions, where the cheapest operational power plant in each region is taken into consideration as the best power plant.
2. **Total (Overall) Market model:** With load flow calculations, and no Net Transfer Capacity restrictions. This market model type considers the transmission lines within each model.

3. **Zonal Pricing model:** The Copper Plate model, along with Net Transfer Capacity restrictions, limiting the power exchange between each region.
4. **Re-Dispatch model:** Considers both load flow calculations, and Net Transfer Capacity restrictions, giving an as-close-to-reality-as-possible approach

For the scope of this study, a large focus is on the Re-Dispatch model, as we would like to simulate the reality as close as possible. Both the load flow distribution and the transmission constraints, along with the Net Transfer Capacity restrictions are being simulated for the realistic case study. The physical structure and the market model of *ATLANTIS_India* is visually represented with the *ATLANTIS VISU* visualization tool [5], and is as shown in the accompanying figure (2)

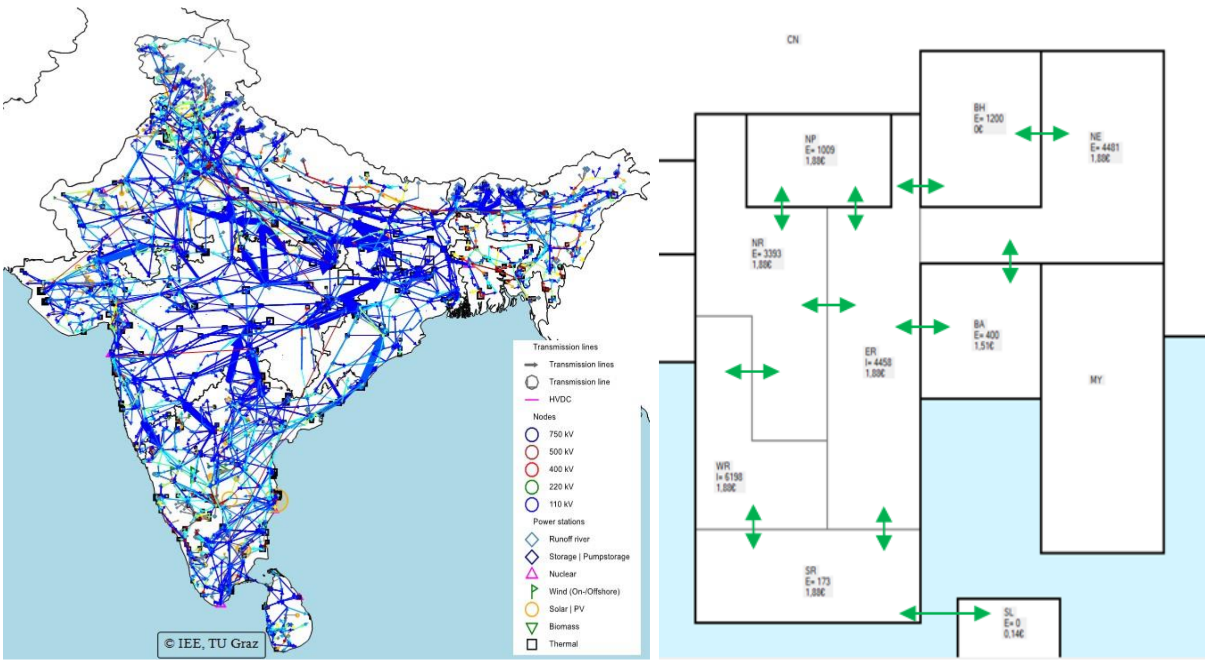

Figure (2) Visualization of the physical structure and load flows in ATLANTIS_India (left) and Zonal Pricing market model example (right)

4. DEVELOPMENT OF A SCENARIO

Using the model *ATLANTIS_India*, and the long-term plans listed by the Ministry of Power (MoP) in India, a scenario was developed in the scope of this study. The scenario is named as the 'Current Strategy scenario', where the long-term plans of the MoP are included as they are listed in the annual reports of the MoP India [1]. The overall development of the scenario is usually done by altering the input data to ATLANTIS_India, be it altering power plant data, transmission line data, and/or changing the overall demand projections. The detailed buildup of the scenario used in this study is as discussed.

4.1. CURRENT STRATEGY SCENARIO (CSS)

The CSS is just a representation of the Business as usual scenario, taking the current proposed policies of the MoP including both the present short term and the long-term goals of the Indian energy politics. The plans to reach 100 GW of PV and wind capacity by 2030 has been taken in to account in this scenario, and most of the planned power plants are considered to be operational in their planned year of commission, by 2025. A Figure (3) represents the increase in the overall power plant capacity by generation type, describing the scenario CSS. The average monthly availability of RET sources is also implemented by the use of 'Erzeugungsfaktoren' or simply termed as Generation Factors, along with the power plant input data. The seasonal variability in the availability of solar irradiance, wind and rainfall are represented by the generation of power plants in each region by defining different generation factors in different periods of the year. The gap between supply and demand, which is an ever-present situation in the Indian electricity sector, is mostly covered up by additional increase in gas power plant capacity. The scenario is simulated till the target year 2040, with consideration of peak load duration from 08:00 to 21:00 and off peak from 21:01 – 07:59.

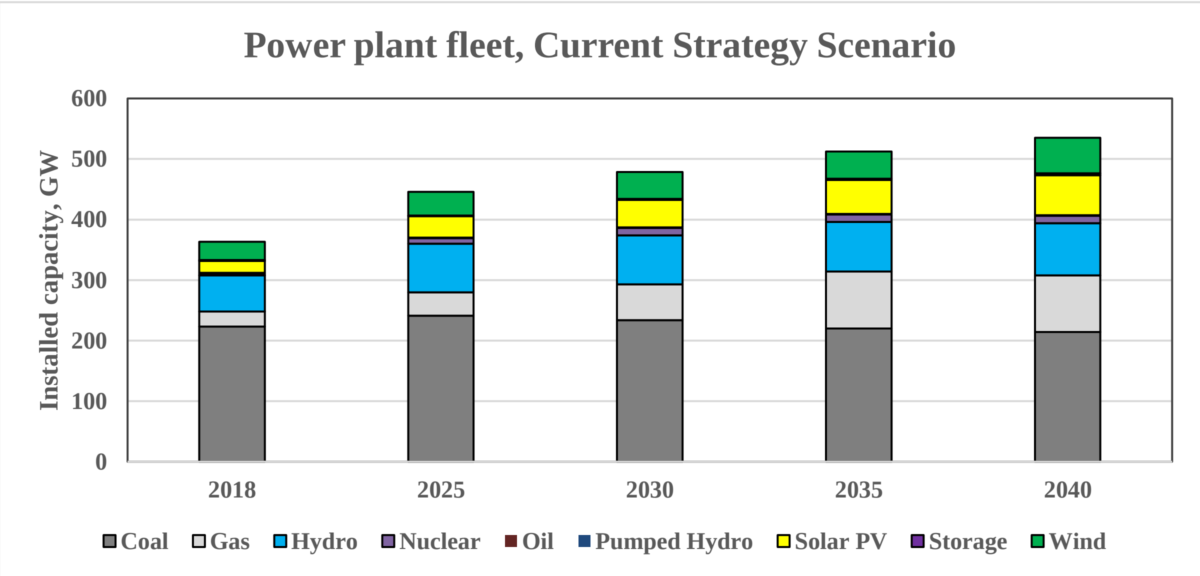

Figure (3) Current Strategy Scenario: Installed power plant capacities in the five power regions

A large increase of PV and Wind capacities can be seen, from the years 2018-2025. The overall installed PV and wind capacities together has an increase with a factor of five until the target year 2040. The dominance of coal and gas (thermal energies) in the power plant fleet still remains, a decrease in the coal power plant capacity is covered up by the increase in gas capacity. However, in the overall share, an increase in the share of Hydro power and Nuclear capacities can also be seen. The newly built Thorium fast breeder power plants [5] in India are also defined in the scope of this scenario, and are represented as EPRs.

It is also important to observe that this scenario focuses almost all of the large wind and solar PV capacities installations only in the NR, SR and the WR power regions. The identified solar potential in these regions is dramatically larger than in the ER and the NE power regions. Most of the areas in the SR and WR have annual solar irradiation averaging up to more than around 2700 hours. Availability of strong winds is also high in the southern peninsula, i.e. majority of the SR region, and the eastern part of WR region. The NR region has desert wastelands in the North west area, where there is a rich usable potential of solar irradiance and wind.

The available potentials in the two regions ER and NE, falter in comparison to the NR, SR and WR regions. Several of the planned expansion of capacities in the ER and the NE regions are not large enough to be taken into consideration, in comparison to the other three regions. Also, the regions NR, SR and WR are home to the most prominent demand centers in the country, most of which are high priority industrial regions. The figure (4) shows the classification of Solar and Wind installed capacities by region, from 2018 - 2040. The region SR remains in both cases, the largest region with installed PV and wind capacities.

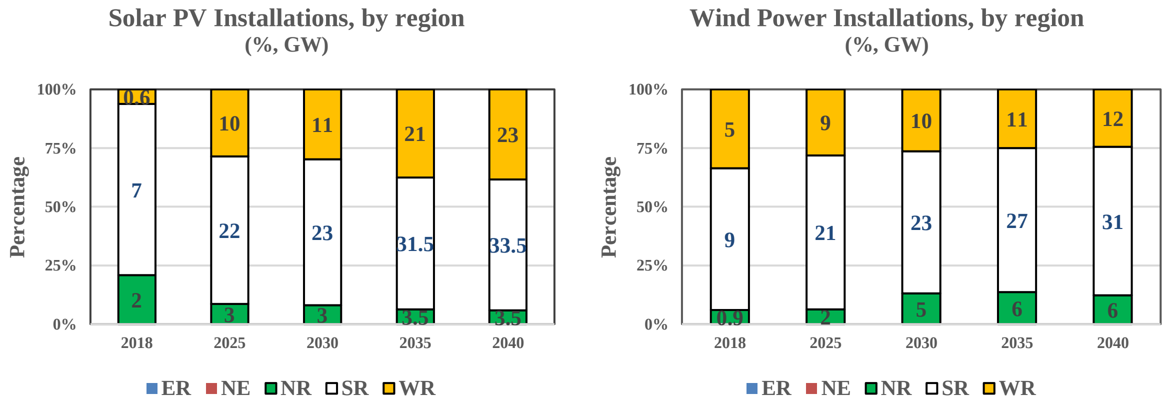

Figure (4) Solar PV installations (left), and wind power installations (right), classified by the various power regions defined in the scenario CSS

It was mentioned before that the SHP capacities in India are usually categorized under 'other renewables' share. However, in the scope of this study, and in the model ATLANTIS_India, SHP capacities are segregated into the 'Hydro power' category, and are defined as run-of-river capacities for simplicity.

5. SIMULATION RESULTS

The results of the scenario simulations are analyzed in two different ways, in the scope of this study. The first way being the evaluation of the load flows in the transmission network. The second way is to compare the installed capacities of renewable power plants and their respective energy generation shares. Analysis of the load flows gives us an overall view in to the bottlenecks of the transmission system in the model. A comparison of the transmission load flows is as shown in the figures (5) and (6) below.

Since the addition of renewable capacity is majorly done in the SR and WR regions in the CSS, the transmission networks of the two regions are used to represent the results. The load flows in the 220 kV network is shown, for simplicity and easier identification of bottlenecks.

The load flows in the 400 kV and 765 kV network were also considered, but the changes in load flow were more prominent in just the 220 kV networks in the two regions.

For the WR region, in the simulation year 2018, several transmission bottlenecks are identified, around the feed in points of the renewable energy plants show the highly loaded transmission lines. With the additional increase in PV and wind capacities, and a subsequent increase in transmission capacities, the WR region still shows a large number of bottle necks in the target year 2040. This is due to the highly centralized increase in the PV capacities in the WR region. However, the subsequent addition of HVDC lines connecting WR to the other regions alleviate the constraints as shown by the green marking in the figure (5).

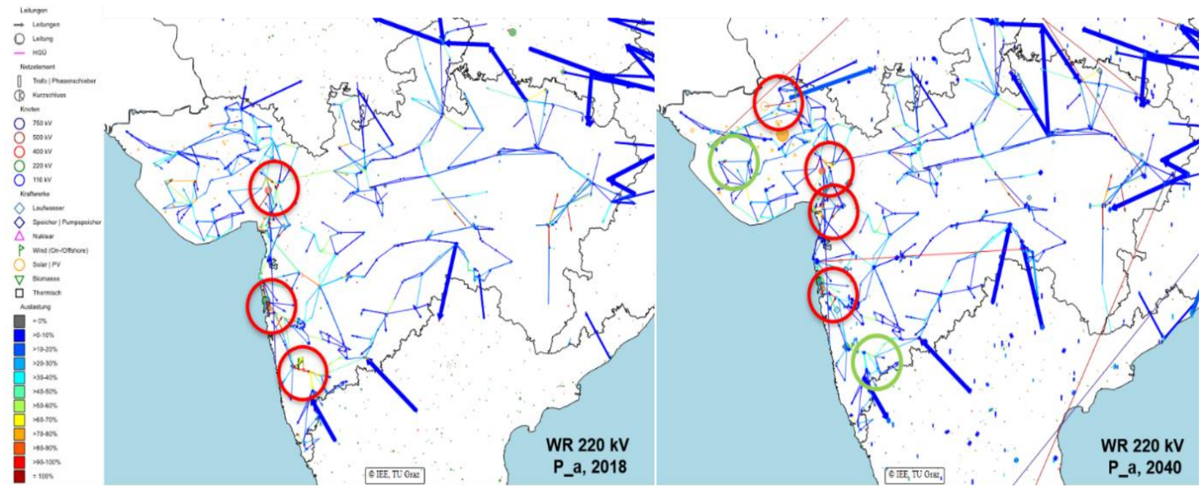

Figure (5) Load flow comparisons in the WR region, in 2018 (left) and in 2040 (right)

The effect of the improvement of cross-border transmission capacity and the increase of the NTC between SR and WR becomes really prominent, especially with WR importing a large share of electricitiy from the SR region. The initial transmisison constraint between the two regions (south-west) is seen to be relieved considerably, with the increase in the NTC values between the WR and SR regions.

Similarly, the simulation results for the SR region also highlights the already existing bottlenecks in the simulation year 2018, which would justify the improvement of the transmission network in the region, along with the addition of renewable capacity. The load flows are in the North-South direction, indicating the electricity flow from the other regions in to the SR region. However, in the target year 2040, it is seen that majority of the load flows are in the opposite direction. The addition of renewable capacities, as seen are usually around the region of the demand centers, and it can be seen to improve the transmission conditions around the load centers. The comparison of the load flows in the year 2018 and the target year 2040 is as illustrated in the figure (6).

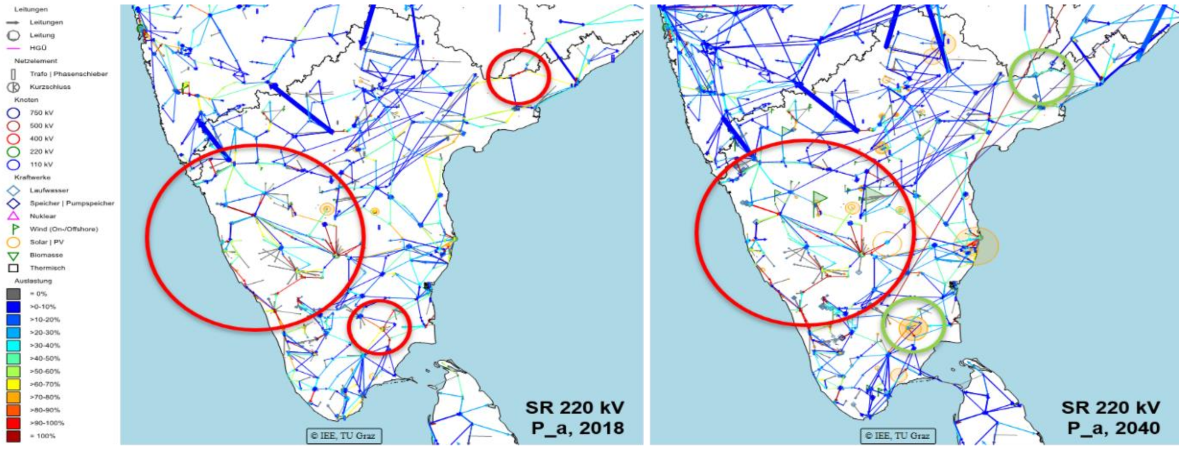

Figure (6) Load flow comparisons in the SR region, in 2018 (left) and in 2040 (right)

The comparison of the shares of installed capacity and the electrical energy generated over the year represents the usage of the planned RET power plant capacity. From this comparison, several inferences can be made about the sustainability of the overall power plant fleet and the effectiveness of the RET expansion strategy. The comparison is made as shown in the figure (7).

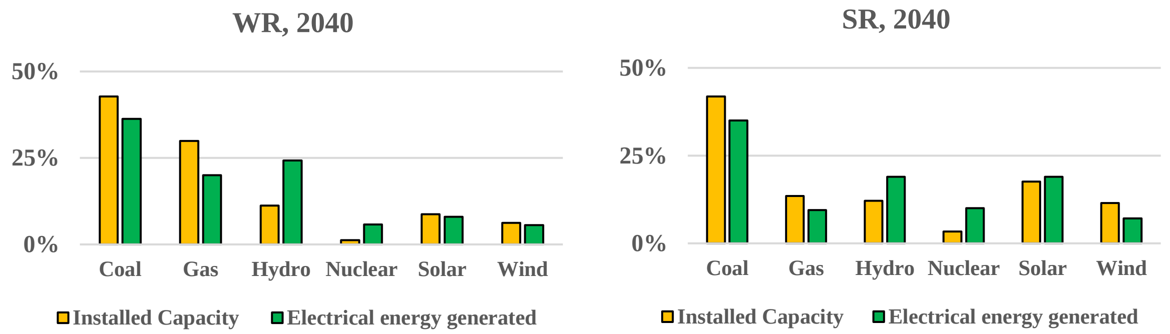

Figure (7) Comparison of installed capacity and the energy generated shares by technology types in WR (left) and in SR (right)

The comparison of installed capacity share and the calculated electrical energy generation share for SR and WR in 2040 indicates the effectiveness of the PV and Wind installations. It is to be noted that the installed capacities and the electrical energy generated from the automatically added gas power plants are not considered in this comparison. In WR, the solar PV share of 9 percent of the total installed capacity produces around 8 percent of the total generated electrical energy, whereas a 6 percent share of wind in the total capacity mix produces around 6 percent of the total electrical energy generated. In SR, a higher effectiveness of the PV installations can be seen, where a 17 percent share of total installed capacity produces 19 percent of the total electrical energy generated, whereas a 11 percent share of wind in the total installed capacity produces only 7 percent of the total electrical energy. The improvement of hydro power capacities in both the regions prove to be highly effective, as the decrease in share of electrical energy generated from coal and gas seem to be compensated/ mostly replaced by the additional hydro power capacities.

6. DISCUSSIONS

Several inferences can be made from analyzing the load flows in the transmission network in the target year and comparing it with the load flows in the simulation year 2018. The change in the overall direction of the load flow in the SR indicate that the region becomes a net exporter from a net importer of electricity. The further increase in the cross-border capacity and the addition of new HVDC lines make this a real possibility. The large PV and wind capacities in the SR region actually help satisfy the majority of the demand at the nearest demand center, thus decreasing the bottlenecks in the rest of the SR transmission network.

However, in the case of WR, there is an increase in the number of transmission constraints after the addition of the PV and wind capacity. Furthermore, an increase in the severity of the transmission bottlenecks around the largest demand centers in the region is clearly observed form the load flows. The addition of several HVDC lines improve the cross-border constraint situation, and relieves several cross-border bottlenecks in the vicinity of the new HVDC lines. The increase in the bottlenecks in the transmission network of the WR region can be partially explained because of a rapid increase of electrical demand in the region, which leads to a situation where the region imports much more electricity from the ER and SR regions. The ER region has a very meager share of RET capacities, and a majority of the power generated in this region comes from coal and gas. This means that even with a large increase in PV and wind capacity, the WR region would be still dependent on the coal and gas power.

To ensure the successful transition of the country's electricity sector to renewable energy, a further push is necessary in the expansion of renewable capacity. The improvement of PV capacity could also be implemented in the ER region, which could deliver more renewable power to the WR region. Similarly, in the NR and NE regions, the expansion of PV and wind capacity has to be seriously implemented. The region NR could then use a large share of renewable power imported from the NE and ER regions. In a nut shell, an expansion of PV and wind capacities would have to be distributed over all the five regions. This could be more effective than the centralized addition of large capacities in certain regions.

From the comparison of the installed capacities and electrical energy generation shares by technology, it is evident that the solar PV installations in the SR seem to be more effective than the PV capacity expansion in the WR. Whereas, the wind capacity expansions in the WR are more effective than the installations in the SR. Eventually, all further investments in solar PV and wind capacity expansions must be carefully planned by taking these inferences into account. In the CCS, as mentioned before, capacities of SHPs are segregated in to the ‘Hydro power’ category in general, for the sake of simplicity. The add up of SHP capacities make up for the increase in the share of the Hydro power capacities in the region. The subsequent addition of hydro capacities in the regions of SR and WR prove to be highly effective along with the improvement of PV and wind capacities.

7. CONCLUSIONS

The long-term plans for renewable energies in India were carefully analyzed with the use of the techno economic model ATLANTIS_India, and the following several conclusions were drawn from the analysis.

The current long-term plans of the Indian electricity economy would effectively increase the share of the electrical energy generated from renewable energy. However, the allocation of the large portion of the capacity has to be intelligently implemented. The bottlenecks in the transmission system increase due the addition of PV and Wind capacities even with the improvement of infrastructure, especially at the 220 kV level. The HVDC lines (planned by the year 2025) would definitely play a major role in relieving the cross-border constraints between the power regions, all the way up to the target year 2040.

Due to the addition of large PV and wind capacities, the overall load flow in the SR regions has major changes. A large portion of the demand coverage by the RET power plant expansions, around their feed in points relieves the constraints in the other parts of the SR transmission network. The WR region on the other hand has more bottlenecks in its transmission system due to an increased load flow coming in from the SR and ER regions. Thus, a distributed approach on the allocation of RET capacities in all the five regions could prove to be much more effective, as WR and NR show a large import tendency.

The Current Strategy Scenario (CSS) definitely has a large impact on the overall situation of the electricity sector in India. For sustainability of the long-term RET capacity expansion plans included in the strategy, it would prove beneficial to reinforce the 220 kV grid, especially in the regions of NR, SR and WR where most of the capacities are planned. As mentioned before, a distributed approach could be more effective than a centralized expansion of RET capacities in the large demand regions of NR, SR and WR. By keeping the expected electrical energy generated by each technology in each region in mind, further investments and expansions in RET capacities must be carefully planned at each specific power region.

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