MODEL BASED ANALYSIS OF THE INDIAN ELECTRICITY ECONOMICS

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Abstract:

India is a country with a huge electricity system having a transmission network spanning over more than 145,400 circuit kilometres (1), 330 GW of installed power plant capacity (2), and 900 TWh of annual electricity consumption (3). In between an energy transition process towards carbon free energy, India has to successfully manage the transition while maintaining its rapidly increasing economic growth. India's agreement to the COP 21 Paris treaty to reduce its carbon intensity of energy generation has shown its intent towards battling the adverse effects of climate change, on a global level. Additionally, the lessons that were learned from the unchecked expansion of cheap coal power plant capacity resulting from the economic reforms of 1990 (4), puts the Indian policy makers on their toes with respect to the present 'Make in India' industrial initiative. The Indian electricity sector faces several problems already and would face even more challenges when considering such a drastic change in its system.

For a sustainable and successful transition, the country has to strategize its energy transition to such an extent that it not only solves the already prevailing problems of electricity access, security of supply, and exponentially increasing demand, but also prevents the financial failure of the country's energy sector. Thus, a model-based analysis is an absolute requirement, if we are to strategize the energy transition on such a level. Interestingly, the model developed for this study is one of the first of its kind, considering both the physical and the economic structures and limitations of the Indian electricity sector. Using such a techno-economic model, studies can be conducted with several scenarios for a target year of say 2050, to check the sustainability of its energy strategies and if necessary, to provide the best possible alternatives. The development, analysis and the possible results of such a techno economic simulation model is thoroughly discussed in the scope of this study.

Keywords: India, Electricity Transition, Renewable Energies, Model-based analysis

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1 Introduction:

India in today's global energy scenario is known for its large market potential for energy transition, as the country is heavily dependent on conventional sources like coal and oil for satisfying its energy needs. Moreover, the country's economy is booming in the last few years of intensive globalization, and since its economy is closely related with the manufacturing industry, a strong coupling of the country's economic development and its primary energy use has been forcefully established. This creates a situation where an energy transition in the country creates an adverse effect on the manufacturing sector and thus in turn the economic development.

Therefore, a sustainable solution is gravely needed to ensure the energy transition in the country without any adverse effects on the country's economic development. This calls for a careful and detailed long-term planning of the energy assets in the country in the coming future. A detailed analysis of the electricity sector can only performed by a model-based analysis of both the technical and the economic situation of the country's energy sector. Additionally, electricity consumption forms a major part of the primary energy consumption of the country. The electricity sector in India is also heavily dependent on coal and gas-based technologies for electricity generation, so a transition in the electricity sector would be an optimum starting point for the complete energy transition in the country. Since 2003, the Indian electricity market has also gradually in the ongoing process of complete liberalization, bringing it closer to the market situation in the European Union and several other 'developed' countries.

As mentioned before, a detailed analysis of both the technical and the economic situation of the electricity sector in India is also necessary for predicting the future development paths and to calculate several significant indicators for each development path as evaluation. In this study, such a model-based approach has been proposed for the Indian electricity economics, and an attempt has been made to look into several possible futures for the development of the Indian electricity sector.

2 Electricity transition for India:

Electricity has already become the back bone of economy in the world. Similarly, in India, electricity became significantly important to the country during the industrial and economic reforms periods beginning from 1990. Several power plants were continuously added without the necessary planning, to cope up with the rapid industrialization caused due to the economic reforms. The manufacturing sector of India started growing at a rapid pace, increasing the base demand for electricity in the country also at a rapid rate as a result.

The standard of living in the country started improving along with economic development. The number of electric appliances in each household increased at a steady pace. On the other hand, the population of India has also been steadily increasing, creating a requirement for creating more households, resulting in urbanization and thus adding to the increasing demand growth considerably. Poorly maintained transmission networks and distribution networks also inversely affected the prevailing problem of demand and supply gap caused due to deficiency of generating capacities to support the massive population and the industries.

2.1 Dependency of the Indian power sector on coal power

India's electrical transformation requires a bigger push than most of the other electrical economies, due to its unique dependency on its coal fired power plant fleet. After the economic reforms of 1990, India put major priority on the manufacturing sector spurring the economy to improve, thereby creating a large industrial demand. This led to the unchecked continuous addition of coal fired capacities. For a long time now, the Indian electricity system prioritizes base load coverage, which covers up to 52% of the yearly peak. A figure (1) shows the illustration of the base load in India.

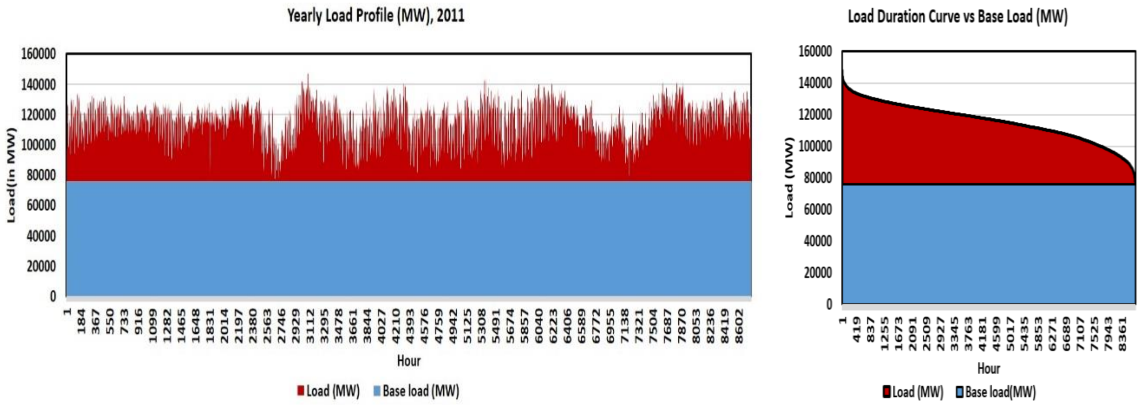

Figure (1) base load situation in India

To sustain the economic development, the manufacturing sector grew larger every year, and without a sustainable strategy, the coal power plant fleet also started to grow at an unimaginable pace. Initially, most of the coal used in the power sector was cheap coal mined internally, but eventually, as the coal fired power plant technology started improving, India started observing a large import in the high grade overseas coal. With time, an unbreakable dependency of the Indian economy on coal imports was established.

Once India agreed to the Paris agreement to curtail the energy related emissions by 30 percent till the year 2030, the importance of the dependency on coal power was identified as a challenge by many experts. With subsequent addition of variable renewable energy capacities like solar PV and wind power, India needed the coal power plants to stabilize the electricity generation. To lose the dependency on coal, a good strategy involving the use of several other possible technology shares has to be planned. This is only possible with a simulation model capable of simulating the electricity system both technically and economically. In the scope of this study, such a simulation model has been used to analyse the Indian electricity economics.

3 The Indian Power sector:

A figure (2) clearly describes the situation of the Indian Power Sector, by providing an overview over the installed electricity generation capacity by technology types (3). As it can be observed, out of 330 GW of installed capacity, around 60 percent of the installed capacity is coal fired, producing around 75 percent share of the overall annual electricity generated. However, there has been a considerable increase in the share of the renewable energy capacity in the last few years, majorly comprised of solar PV and onshore wind energy capacities, leading up to around 18 percent of the installed capacity share.

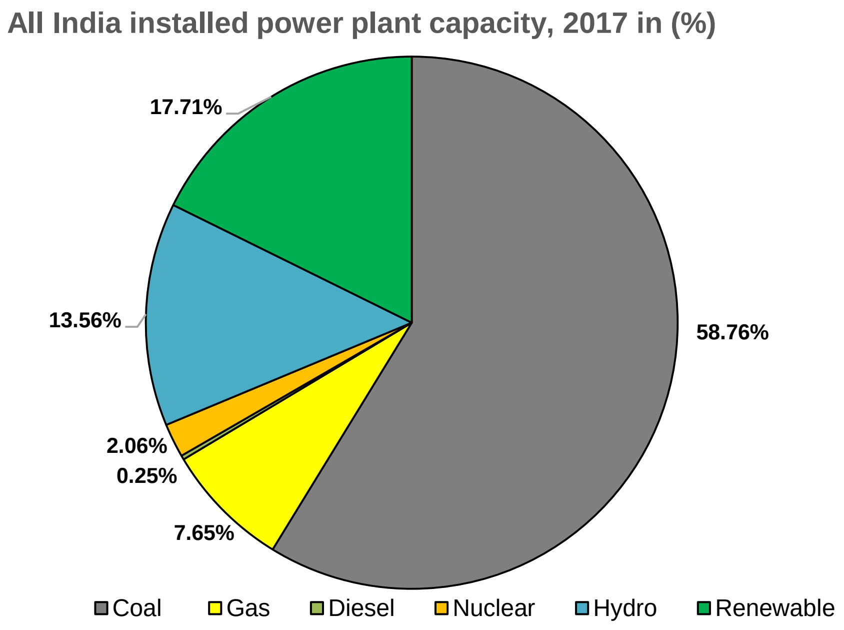

Figure (2) Installed power plant capacity of the Indian Power sector, 2017

4 ATLANTIS_India:

The Techno-economic simulation model ATLANTIS_India 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 (5), 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 (BA), Bhutan (BH), Nepal (NP) and Sri Lanka (SL). 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 (3)

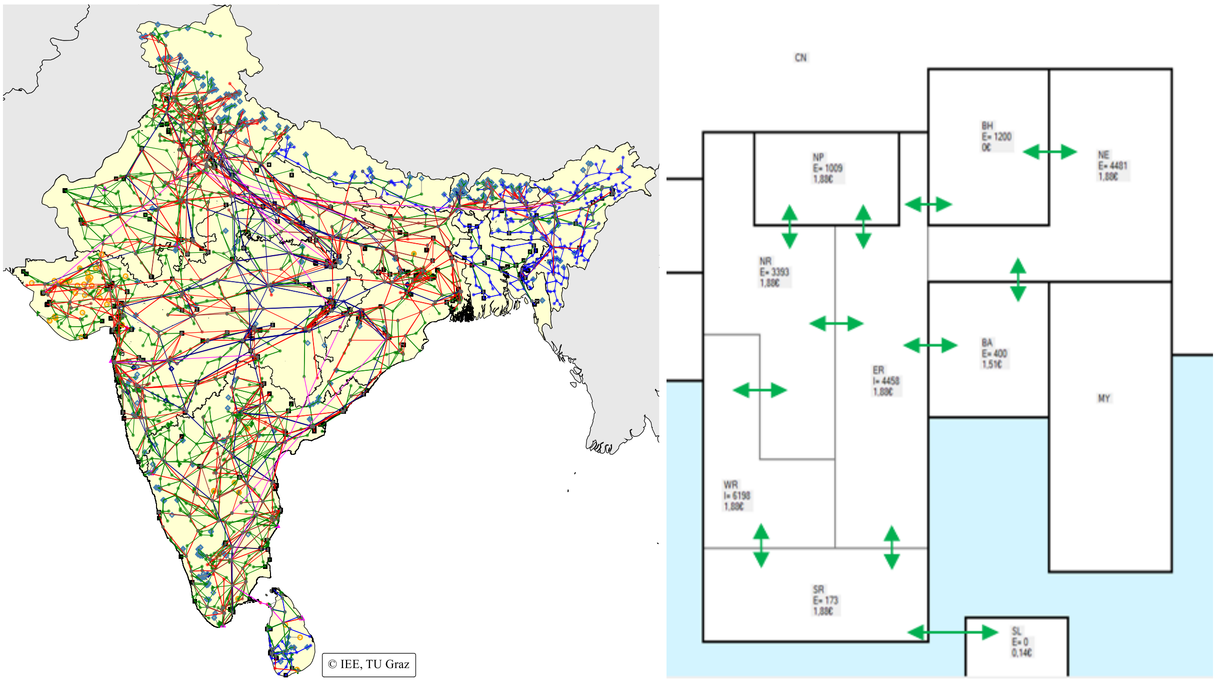

Figure (3) Visualization of the physical structure in ATLANTIS_India (left) and Zonal Pricing market model example (right)

4.1 Power plant fleet

Over 3500 power plants with total capacity of over 330 GW have been defined, with both technical and geographical specificity in the model. Each of the power plant is defined to feed in the power generated to the nearest defined node, possible at the highest available transmission voltage level at the specific node. Normally, power plants in a model are defined as close to the demand centres as possible, as this is the case in ATLANTIS_India. However, with certain renewable energy technology types like Hydro power, Solar PV and Wind energy, the power plants are geographically located where the available potential is optimum. When this is the case, a feed in line is defined to a connected nearby node already defined in the transmission network.

The power plants in ATLANTIS_India are also defined by their technology types, fuel used, region, owner company, and starting years. The end of use year of the power plant, if not available, is assumed based on the assumption that the power plant operates throughout its technical useful life time. This gives us a realistic simulation of the real case as most power plants with long lifetimes usually end up operating more than their economic life times mentioned in the accounting books of the owner company. The amount of annual energy generation, along with the operational full load hours are also to be defined for the power plant, as it gives us with an exact if not almost exact value for the amount of generation done by the power plant during its life time. The generation of the power plant is also distributed on a monthly basis, by defining the generation factors, to give an estimation of the average power plant usage in different months in the year. This helps in giving an accurate description of the generation by renewable resources like wind, hydro and solar, whose availability is also dependent on the seasons in the year. A visual representation of the power plants in the model is as shown in the Figure (4)

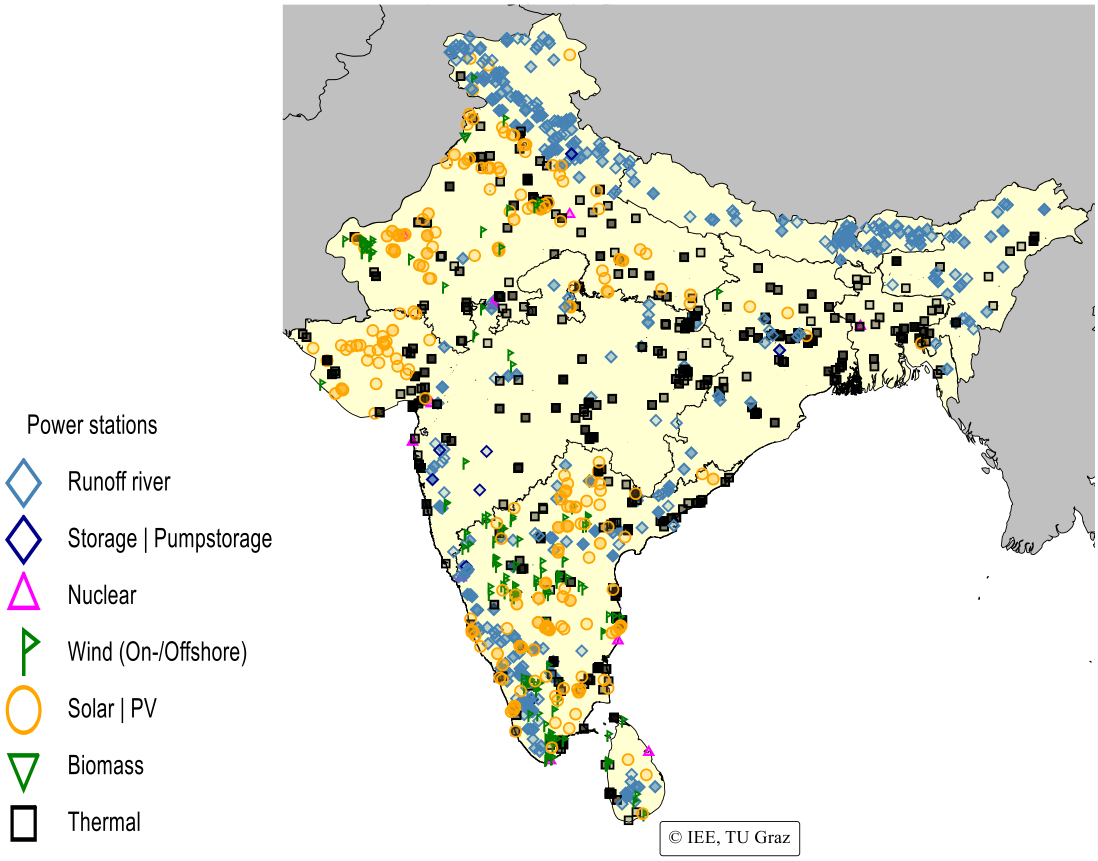

Figure (4) The visual representation of the power plant fleet in ATLANTIS_India

4.2 Node-specific demand model

The electricity demand distribution in the model is node- specific. This means that each node defined in the physical model accounts for a weightage value, which distributes the overall electricity demand and the additional demand of the specific region accordingly based on several parameters. In the case of ATLANTIS_India, the demand distribution is carefully done after considering the concentration of industrial, residential and agricultural areas in the country. The three areas are targeted as they form almost 80 percent of the overall electricity demand in the country. A visual representation to identify the concentration of these areas and their specific nodes are as shown in the figure (5)

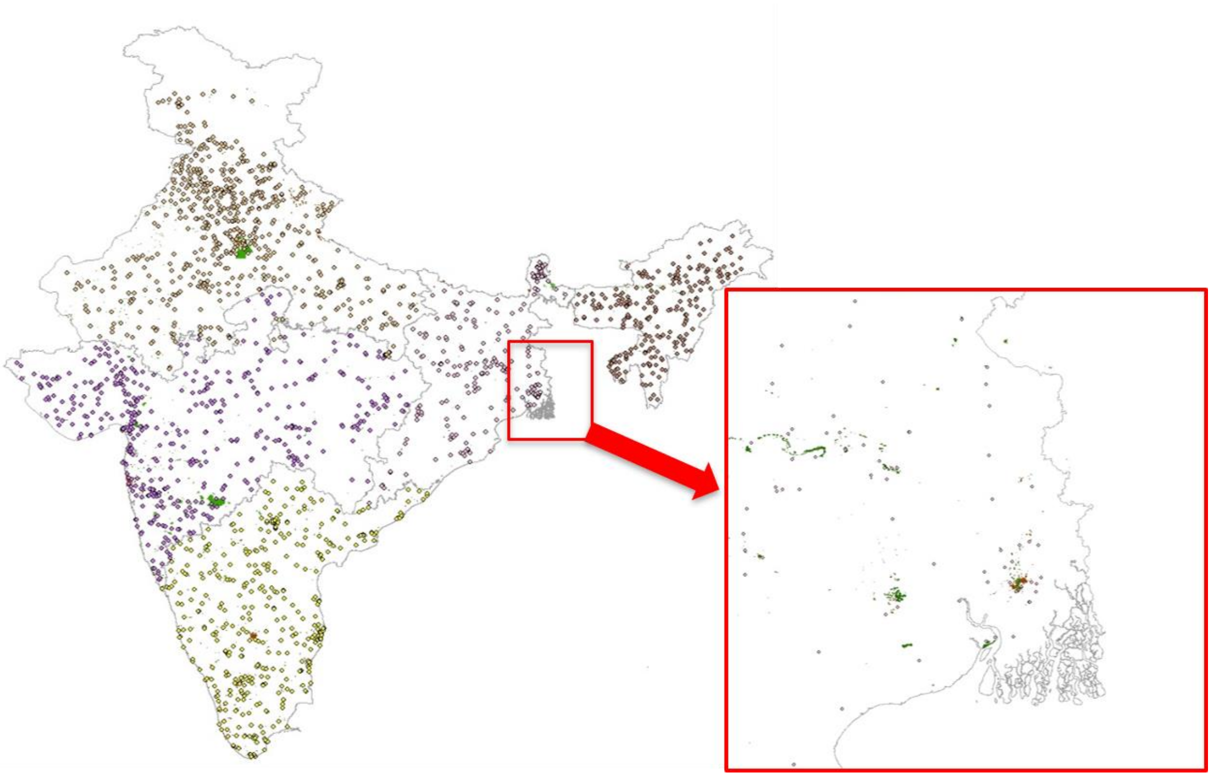

Figure (5) (Left) Visual representation of the methodology followed to distribute electricity demand (right) identification of agricultural and industrial land use in the region ER as example

Demand patterns can be immensely complicated, in the case of such a large and complex electricity system like India. These demand patterns can vary with each region, considering the economic growth and population densities in these regions. Higher economic development would generally mean an increase in the intermediate and peak load region of the load duration curve, and a higher population would mean a general increase in the base and intermediate load region of the load duration curve. Additional demand increases like due to electro mobility (6) and other unprecedented causes of change in demand should also be considered, as they play a significant role in the development of the demand pattern.

The hourly demand throughout the region is to be distributed at each node, to calculate the load flow to and from the region. However, the important fact is that the type of demand at each node has to be classified before distributing a certain weightage at the node. The different demand sectors that can be classified in India include Industrial, Agricultural, Residential, Services and Commercial. Of course, the industrial and residential loads compromise the majority share of the electricity demand very similar to most of the economically developing countries. However, it is to be noted that Agriculture also occupies a major share along with the industrial and residential sectors.

Therefore, these three demand sectors have to be classified, and then used for the calculation of the weightage of the demand distribution at each node in the region.

The several agricultural, industrial and residential regions in India are identified with the help of GIS maps, and these three maps are overlaid to see the influence of each demand sector at each geographical region. These 'influences' are quantified subsequently, and the weightage at each node for the demand distribution is eventually calculated.

The following summarizes the demand distribution methodology, and gives a clear bird's eye view explanation of the step by step process:

1. Identification of population intensive nodes based on general population census data
2. Classification of Special Economic Zones and agricultural land with GIS maps
3. Assigning the specific 40% (Industries) 30% (residential) and 30% (agricultural) weightage classification at the node
4. Final demand distribution weightage at the particular node

5 Scenario definition

The base scenario for the Indian sub-continent was derived from the India Energy Outlook, world Energy Outlook 2015, a report published by the International Energy Agency. Scenario definition in ATLANTIS includes defining the overall increase in electricity consumption, change in fuel prices, projecting additional installations of a specific power plant type, defining the economic parameters like depreciation rates, interest rates, inflation rates and many more specific data inputs in the model, All the required information for defining the scenario was taken from the IEO, and a representation of such a scenario can be seen in the figure (6) below.

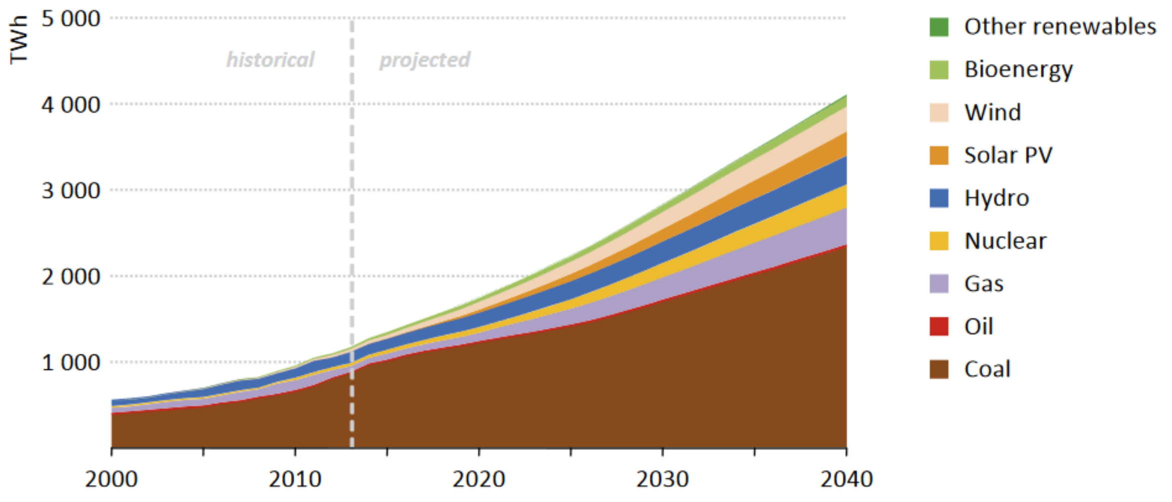

Figure (6) definition of a base scenario with the NPS (IEA, 2015, (3)) as reference for India

In the business as usual case, no new power plants are built, only the lifetimes of the existing power plants and the automatically added gas power plants are to be considered. This would mean that there are no specific changes to the power plant fleet.

However, simulating the base scenario would only give you results with only the Business-As-Usual case. Hence definition of further various scenarios becomes important. With the energy transition goals, sustainability and long-term economic goals in mind, four different scenarios were thought of. These scenarios were designed based on the extent of liberalization of the power sector, and the extent of renewable transition in mind. A visual representation of the scenarios comparing their situations with each other can be seen in the figure (7)

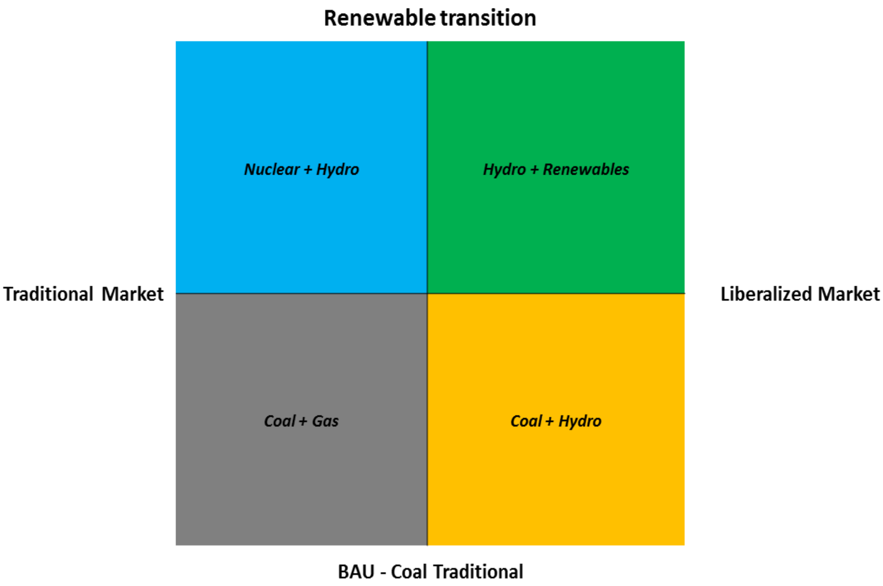

Figure (7) possible Scenario definitions for India for the target year 2050

However, in the scope of this study, for the sake of simplicity and validation, only the BAU case has been simulated and analysed.

6 Results:

The BAU scenario defined was simulated using ATLANTIS_India to validate and check the load flows in the transmission network of the Indian subcontinent, in the scope of this study. This scenario was simulated until the year 2050, and an overall conclusion is taken from the resulting simulations.

The load flow in the Indian electricity system in the year 2050 is as shown in the accompanying figure (8)

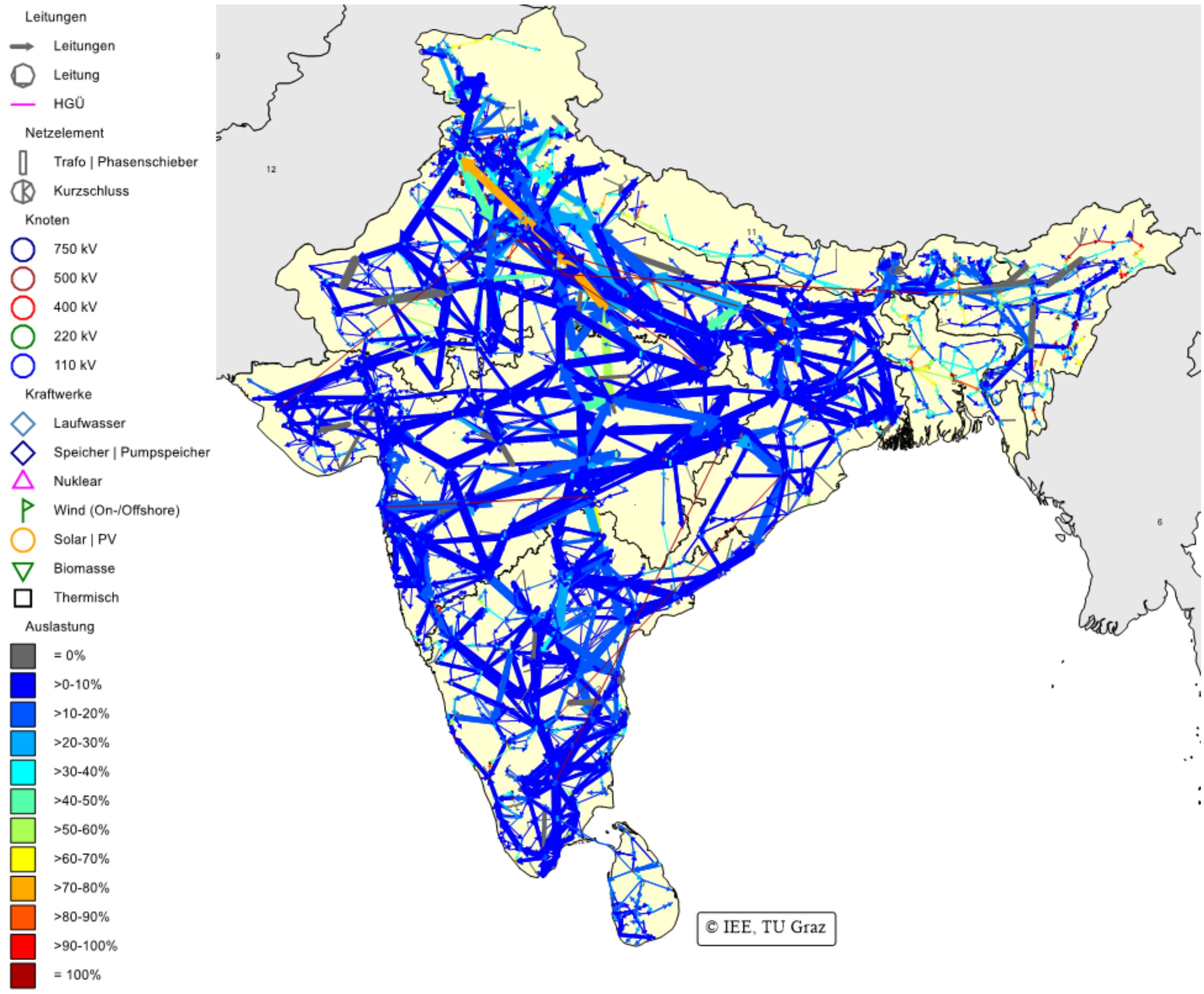

Figure (8) Load flows in the system, 2050, overall market model

It can be observed that there are a few major bottlenecks in the transmission system, especially in the cross-border transmission lines, and in some areas with limited power plant capacity (north east region). Majority of the load flows are towards the NR region, as it becomes the biggest importing region in 2050. The transmission network of the BA region provides a bypass for the congested load flows from NE to ER, thus alleviating some of the majorly loaded transmission lines in the area. The regions NP and BH provide cheap electricity from Hydro power plant capacity, to the NR, ER and NE regions.

7 Conclusions:

From the scenario simulations, several observations have been made and have been studied carefully. In a nutshell, it can be agreed that there is a high requirement for a techno economic model to strategize the electricity transition in India in a much more sustainable way. ATLANTIS_India provides a great platform to achieve such scenario simulations, and gives insights in to the technical, economic and business aspects of such a transition.

Observations of load flows and the loading of transmission lines gives us an overall picture about the bottle-necks in the large Indian transmission network, and also explains the Net Transfer Capacity situation. From the resulting load flows, it is observed that most of the cross-border lines between the power regions are heavily loaded, thus creating transmission bottlenecks in the system. This has to be carefully considered, and the cross-border transmission situation has to be considerably improved.

The regions NR and NE are observed to be importing large quantities of electricity from the NP and BH regions. As the Net Transfer Capacity defines the limit of the total amount of power transfer between two regions, thus for a sustainable renewable power system, the NTCs between these regions also have to be improved.

The market models provide us an overview of the electricity pricing, thus allowing us to optimize the power generating fleet in specific regions, while the Business model gives us a representation of the required investments and company balance sheets for further analysis.

Also, better scenarios (as discussed) have to be built up and analysed to have a complete understanding of the system behaviour, and to develop a suitable strategy for the future of the Indian Electricity system.

8 References:

(1) Power Grid Corporation India Limited (PGCIL), Annual report, Overview, 2016

(2) Executive Summary, August 2017, Central Electricity Authority, Ministry of power, Government of India

(3) India energy outlook , World Energy Outlook Special Report, International Energy Agency, 2015

(4) Panagriya, A., 'India in the 1980s and 1990s: A Triumph of Reforms', IMF working paper, March 2004

(5) U. Bachhiesl, G. Nischler, H. Stigler, 'Techno economic modelling of the European electricity sector', Central European Journal of Operations Research (CEJOR)

(6) 'An analysis on Variable Renewable Energy and the importance of Hybrid systems in India' , Bhat, K et.al, 15th IAEE European Conference, 2017, Vienna