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LITERATURE SURVEY OPEN ACCESS

India's sustainable electrical energy grid depends on renewable energy: A Review

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ABSTRACT

The enormous disparity between supply and demand for electrical energy in India for the foreseeable future makes the current patterns of supply and demand unsustainable. Exploiting energy savings and making aggressive use of renewable energy systems are the paths to sustainability. The potential for successfully utilizing renewable energy technologies would depend on advancements in technology and a breakthrough in cost-cutting. This calls for insufficient policy directives and actions in the Indian electricity industry. Comprehensive MARKAL simulations for the Indian power sector demonstrate that aggressively implementing renewable energy technology and fully utilizing energy conservation potential lead to sustainable development. Allocations for coal and other fossil fuels, such as gas and oil, stalled after 2015 and remained that way until 2040. The need for gas and coal decreases after the year 2040, and carbon emissions sharply decline. By 2045, renewable energy sources could provide 25% of the electrical energy consumed, and CO2 emissions could be 72% lower than in the base case.

Keywords: Renewable Energy, Basecase scenario, Renewable technology, Energy Resources.

I. INTRODUCTION

The demand-supply imbalance in India's electrical power scenario is notable, standing at 24.7% in 2005. In a business-as-usual scenario, this gap might reach 70% by 2045 (Mallah and Bansal, 2009a). By fully utilizing the potential for energy savings across all economic sectors, this disparity between supply and demand can be lowered by up to 50%. Coal, hydro, gas, nuclear, wind, small hydro, and other renewable energy sources can all help close the mining gap (Mallah and Bansal, 2009b). Models for optimum and least cost solutions are crucial for the logical allocation of different energy sources and aid in the formulation of a rational energy policy.

A sensible energy policy must consider the need to forecast future energy demand and allocate energy resources as efficiently as possible. To date, several research have been carried out to predict future energy consumption. Dincer and Dost (1997) have published estimates of energy demand based on GDP. Galli (1998) projected long-term energy consumption in developing Asian nations to calculate the correlation between income levels and energy intensity. Erdogan and Dahl (1997) investigated the effects of population, income, and price on Turkey's manufacturing, mining, and aggregate energy sectors.

The UK energy consumption for different sectors' underlying trends and seasonality was presented by ***Hunt et al. (2003)***. The paper "Energy Consumption in China: Past Trends and Future Directions" was published in 2005 by Crompton and Wu. A model for mid-term electricity demand forecasting that takes meteorological factors into account was proposed by ***Mirasgedis et al. (2006)***. China's economic growth and power consumption have been analyzed by Shiu and Lam (2004). Electricity consumption and economic growth have been assessed by ***Wolde-Rufael*** (2006) using a time series analysis of 17 African nations. Yoo (2005) examined Korea's data on power usage and economic growth. Nasr et al. (2000) investigated post-war Lebanon's energy consumption using econometric modeling.

Mallah and Bansal (2009c) demonstrated using the MARKAL model that after 2015, allocations for coal and gas become stagnant if the full potential for energy savings is not realized. In proportion, there is a decrease in the emissions of greenhouse gases (GHGs). India has a potential for more than 189 GW of renewable energy (PC, 2006); in comparison, installed capacity for renewable energy is just 9000 MW, or 7% of total installed capacity, apart from huge hydro. Large hydro's contribution is 30 GW (MNRE, 2006). With Mallah and Bansal (2009a) projecting future electricity consumption using time series analysis and an econometric model, MARKAL allocations have been worked out for the installation of renewable energy in a way that is both aggressive and sensible. Naturally, it is believed that the installed electric capacity at this time will remain accessible for the duration of the predicting year.

Because fossil fuels make up most of the energy mix, it is predicted that the importance of producing electricity from renewable sources will increase in the context of the significant negative environmental externalities associated with the production of electricity. In the creation of policies, projects, and operations, managing the effects on the environment and society has received a lot of attention. The poor quality of Indian coal, which has an average ash level of 40% or more, is the primary cause of the growing environmental concern over the contribution of coal-fired power production to air pollutants. According to studies, the electricity industry accounts for almost 40% of all carbon emissions. In this situation, it is essential to create and support alternative energy sources that can contribute to the energy system's sustainability. Even while renewable energy now contributes little to the electrical mix, its capabilities offer flexibility in meeting future demands in the areas of sustainable development, socioeconomics, and the environment. Under the new climate change regime, there are opportunities for renewable energy technologies because they satisfy two fundamental requirements to be eligible for support under UNFCC mechanisms: they support national priorities by promoting the development of local infrastructure and capacities, and they contribute to global sustainability through GHG mitigation. This highlights how crucial it is to generate power from renewable resources. The nation has a great deal of knowledge and expertise with renewable energy technology. The future importance of renewable energy in the power industry is evaluated using an entire energy system framework under baseline and several mitigation scenarios over a 40-year period, from 2005 to 2045.

The three scenarios listed below, which includes the basic case scenario, have been created to integrate renewable energy into the Indian power industry:

1. Base case scenarios (BCS)
2. Renewable technology scenario
3. Aggressive renewable technology scenario.

The Base Line Scenario (BCS) serves as a benchmark for evaluating the effects of different policies or futures while assuming the continuance of the existing energy and economic dynamics. It operates under the assumption of "business-as-usual" dynamics. This scenario assumes that conventional non-market policy interventions pertaining to energy and technology will be the only measures used to limit greenhouse gas emissions.

II. LITERATURE REVIEW

The Renewable Technology Scenario takes ministry predictions and government strategies for the next two to three planning periods' adoption of renewable energy into account. By 2012, an extra 15,000 MW of installed grid power capacity will come from renewable energy sources, and by 2022, an additional 30,000 MW of capacity expansion is anticipated. As a result, by the end of 2022, renewable power capacity is probably going to reach 54,000 MW, or 5% of the then-current energy mix (MNRE, 2006).

The country's potential for renewable energy is fully explored in the Aggressive Renewable Technology Scenario, which runs through 2045. The Aggressive Renewable Technology Scenario was taken into consideration because, because of international pressure to reduce greenhouse gas emissions from the environment, renewable energy has been used more quickly during the past 20 years and appear to be doing so in the future. Potentials for energy saving have also been considered using the scenarios created by Mallah and Bansal (2009b).

III. THE MARKKAL MODEL

MARKAL, an abbreviation for MARKET AL location, is a commonly used bottom-up dynamic approach that was primarily created as a linear programming (LP) model by the International Energy Agency's Energy Technology Systems Analysis Program (ETSAP) (Loulou et al., 2004). Both the supply and demand sides of the energy system are shown in MARKAL. It gives planners and policy makers in the public and private sectors comprehensive information on technologies that produce and use energy, and it can help them comprehend how macroeconomies and energy consumption interact. Consequently, the creation of carbon mitigation plans as well as national and municipal energy planning have benefited from this modeling paradigm. With applicability in a broad range of contexts and worldwide technical assistance from the global research community, the MARKAL family of models is exceptional. Wide acceptance is indicated by the fact that it has been implemented by more than 80 institutions in more than 40 nations, including developed, transitional, and developing economies.

Energy carriers in MARKAL connect the conversion and consumption of energy, as they do in most energy system models. All energy providers that are engaged in primary supply (such as mining, petroleum extraction, etc.), conversion and processing (such as power plants, refineries, etc.), and end-use demand for energy services (such as boilers, cars, residential space conditioning, etc.) are included in this user-defined network. The demand for energy services can be broken down into many categories, such as residential, commercial, manufacturing, and transportation, as well as into individual sector categories like heating, lighting, hot water, and air conditioning in homes. The model's optimization procedure chooses the least-cost option, considering several limitations, from among the sources, energy carriers, and transformation technologies. The user specifies the pricing of technology, as well as its technical specs (such as conversion efficiencies) and energy service requirements. This integrated strategy matches the demands for energy services with the supply-side technology as mentioned in the previous slide.

IV. MARKHAL MODEL DEVELOPMENT

4.1: Base Case Scenario (BCS) Development

Scenarios are used to help visualize possible technological futures and to help comprehend how complicated systems could change. According to Manne and Wene (1992), scenarios are internally coherent projections of possible future outcomes based on assumptions about social, political, technical, and economic changes as well as consumer preferences. Using a model or models to produce an outcome (or group of alternative outcomes) compatible with a set of driving assumptions—sometimes referred to as a "storyline"—scenarios investigate conceivable futures. It is crucial to emphasize that these outcomes should not be taken as forecasts regarding, say, the rates at which new technologies will be adopted by the market or the paths of emissions. It is preferable to think of the technical parameters and economic data as initial assumptions that represent a range of realistic estimations.

Rather than concentrating on the outcomes from a specific scenario, scenario analysis tries to investigate how changes in model parameters (inputs) impact outputs across sets of linked storylines. Not all potential futures are attempted to be considered. These comparative assessments alternate between looking backward to determine the energy technology routes available to fulfill some future technical or environmental objective and looking forward to analyzing how rival sets of input assumptions affect technology adoption and emissions. Therefore, scenarios make it easier to evaluate the effects of different assumptions, the variety of potential futures, and the trade-offs and branch points that determine which of these futures to choose ***(Fishbone and Abilock, 1981).*** The MARKAL energy-systems modeling framework has been implemented to study scenarios of future electric generating technologies and their effect on future emissions of air pollutants. All economic sectors are included, including commercial, residential, industrial, agricultural, and transportation. As previously mentioned, the large linear programming model, MARKAL, computes the criterion pollutant and greenhouse gas emissions by identifying the least-cost pattern of technology investment and usage needed to satisfy given needs and model limitations.

The basic case scenario has been prepared for future energy supplies and reference, considering the current policies of the government (i.e., energy supply through fossil-based power plants and no defined objective to encourage renewables to minimize CO2 emissions) and resource availability. Table 1 lists the many techno-economic aspects of the Indian MARK AL. There has also been discussion about the study's bounds and presumptions. Due to technical advancements in the various technologies throughout time, the techno-economic parameters in Table 1 have been assigned upper and lower bounds for new and renewable technologies, whereas they have been assumed to remain constant over the planning horizon for base case scenarios.

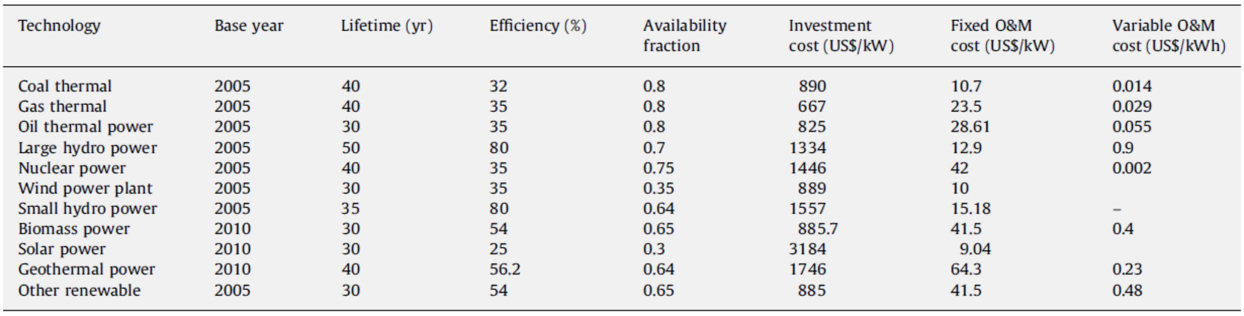
4.2: Generic Details

- Base year: The year 2005 has been used as the study's base year. Since MARKAL only allows a single year as a parameter, this has been stated in this study as the year 2005.
- Study duration: This investigation has lasted a 40-year period. Most comparable studies have covered around the same amount of time. While several 10-year studies have been carried out, the 40-year horizon has not been lowered since MARKAL is thought to be more beneficial for long-term analyses. Options with longer time spans have also not been taken into consideration, as the degree of uncertainty around economic and technological factors grows with future time.
- era length: In this study, five years have been maintained for each era. Eight periods, each lasting five years, have been created from the 40 years total. The government plans that are formulated as "Five Year Plans" have influenced the value of five years.
- Discount rate: This work has maintained a financial discounting rate of 8% annually. The model uses this rate to calculate the "net present value" of any price or expense in the base year compared to the price or cost in the nth year of the future. The discount rate of 8% has been maintained mostly because nationalized banks often pay interest rates on "fixed deposits of money" that are very close to 8%.
- All the plants included in this research are there to supply energy to the electrical grid. However, the primary purpose of renewable energy systems, such as wind power plants, in industrialized nations is to shorten the load time of conventional plants. Since India's economic development is unstable and the expansion of many industries is hampered by power scarcity, there is always a chance that more electricity may be consumed.
- The RES does not consider any heating load that is satisfied by the thermal energy generated during energy conversion procedures. Like India, where the need for space heating is only needed for two months out of the year, electricity use is favored, and heat transmission through pipes and other means is avoided, in contrast to Western and European nations.
- The national average for transmission and distribution losses is 20% of the total power generated. Although these are significantly greater in various regions of the nation, the regional differences are not considered in our research.
- Instead of translating foreign expenses into Indian rupees, the costs of different power plants are exclusively derived from Indian sources. our has been done since prices in other nations could have some unstated additional charges that are irrelevant to our situation. For instance, various nations require different types of pollution control systems due to differences in fuel quality and environmental regulations. Globally, there is a discrepancy in power plant expenses.

The points served as the input parameters for the Markal analysis. Since this study's goal is to determine how best to generate and utilize electricity, phases such as end-use technology—which considers information about lighting, cooling, and other loads—have been combined with the corresponding sector-specific power needs. This modeling experiment did not need end-application stage details, as these demand estimates address total sectors demand rather than end-use demand. Similarly, as the final fuel prices for the power plants incorporate the costs of all earlier stages, the cost of fuel extraction and other comparable data have not been stated individually.

4.3: Assumption and Boundaries of the Study

Mostly, centralized utilities have been addressed. Until 2005, wind power was seen as a decentralized method of producing considerable amounts of electricity. This study does not cover non-utilities, such as the creation of captive electricity. Daily and seasonal variations in load are not considered. Modern plants will be favored for the addition of new capacity.



Technology	Base year	Lifetime (yr)	Efficiency (%)	Availability fraction	Investment cost (US$/kW)	Fixed O&M cost (US$/kW)	Variable O&M cost (US$/kWh)
Coal thermal	2005	40	32	0.8	890	10.7	0.014
Gas thermal	2005	40	35	0.8	667	23.5	0.029
Oil thermal power	2005	30	35	0.8	825	28.61	0.055
Large hydro power	2005	50	80	0.7	1334	12.9	0.9
Nuclear power	2005	40	35	0.75	1446	42	0.002
Wind power plant	2005	30	35	0.35	889	10	
Small hydro power	2005	35	80	0.64	1557	15.18	–
Biomass power	2010	30	54	0.65	885.7	41.5	0.4
Solar power	2010	30	25	0.3	3184	9.04	
Geothermal power	2010	40	56.2	0.64	1746	64.3	0.23
Other renewable	2005	30	54	0.65	885	41.5	0.48

Table No. 1: Overview of key characteristics of candidate generation technologies in the Indian MARKAL model in the year 2005

Old power plants that were operational at the start of the base year will stay operational for the duration of this research. It is vital to make this assumption since, in India, even very old plants are maintained in operational order with little retrofitting and necessary maintenance. A similar kind of action has also been recommended for the future by the Power Reforms Committee to enhance the performance of older plants that are nearing the end of their theoretical lives. Because the private sector was allowed to enter the power generating industry, there are no restrictions on the amount of money that may be invested in capacity creation. All costs have been expressed in US dollars to ensure that the study is accepted worldwide.

The price of any good or technology in any future year can be calculated using the prevailing inflation rate in India, as opposed to the price from the base year. It is anticipated that during the duration of this trial, the same pricing will apply. For the duration of this investigation, the discount rate that was utilized as a global factor would be maintained. The GDP growth rate that is now occurring will not veer from the previous ten years' pattern. A few very good or bad years for the economy have caused some brief rises and falls in the trend plot. Nonetheless, the GDP's overall growth has demonstrated constancy, and this tendency is probably going to continue. Even though it wasn't immediately relevant, this assumption controls the upward trend in energy consumption.

Apart from the situations where the impact of restricted infrastructure support is examined through confined growth, it has often been believed that there would be adequate infrastructure support for manufacturing, transportation, refining, etc. It does not address the option of using imported or domestic power plant equipment. While the costs and efficiency of various sources may vary, including this variance would have complicated the RES without improving the caliber of the output. Ideally, any option within a single conversion technology—that is, according to the manufacturer or specification—should be considered as a single technology to provide precise suggestions from the model, provided that genuine data are available. The figures of specific emission and efficiency correspond to many plants operating at full load and steadily. The facilities are expected to run at nearly constant load levels near full capacity since all of them—aside from the wind power plant—have historically been thought of as base load plants. Because wind speed is unpredictable, wind power plants are thought to operate in a decentralized and non-steady manner.

V. MODEL RESULT AND DISCUSSION

5.1: Base Case Result

The basic case scenario is performed from 2005 to 2045 to provide the base case findings that are shown in this section. The market distribution of different power producing methods is displayed in Fig. 2. From 2005, the base year, to 2015, the total amount of energy generated increased at a growth rate of 10% per year. The growth rate declines from 2015 to 2030. There is only a 1.4% yearly rise. The average yearly growth rate rises once again after 2030, reaching 6%.

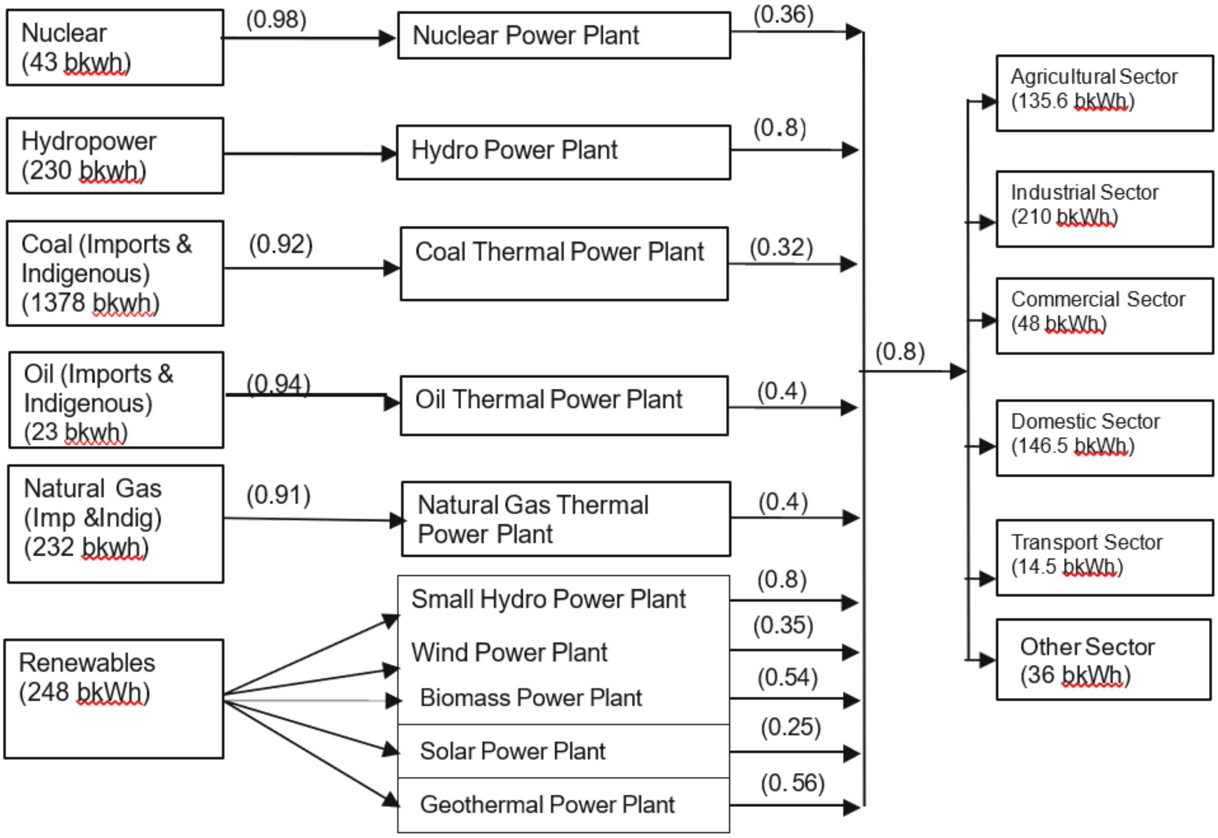


Figure No. 1: Modified reference energy system in aggressive renewable technology scenario

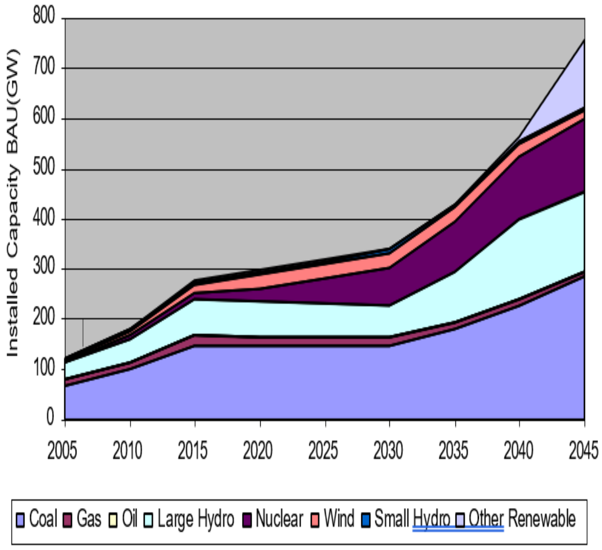


Figure No. 2: Resource-wise installed capacity for base case scenario

It is noted that in the BCS, nuclear and massive hydropower are the next most common methods of producing electricity after coal. About 4% comes from wind (Fig. 3). Only until 2040 do the other renewable energy sources—solar, biomass, etc.—begin to make a difference. The model projects that by 2045, there will be 752 GW of added capacity to fulfill the increasing demand (Fig. 4). Large hydro accounts for 20% of the additional capacity, with coal accounting for more than 37%. 135 GW, or around 18% of the total capacity development within the projected horizon, is added by other renewables.

5.2: Result and Discussion with Energy Saving

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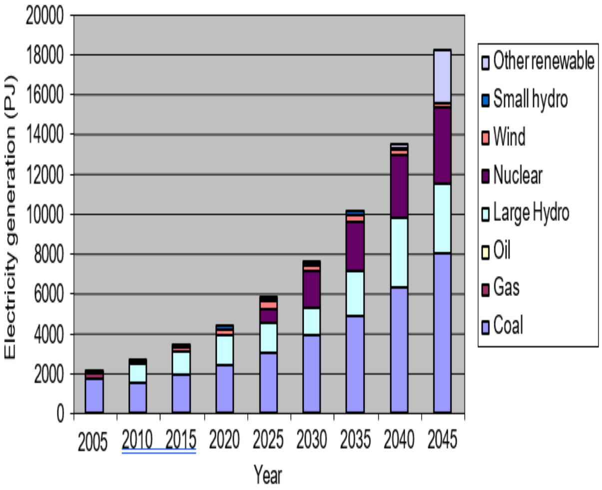

Figure No. 3: Resource-wise electricity generation in base case scenario

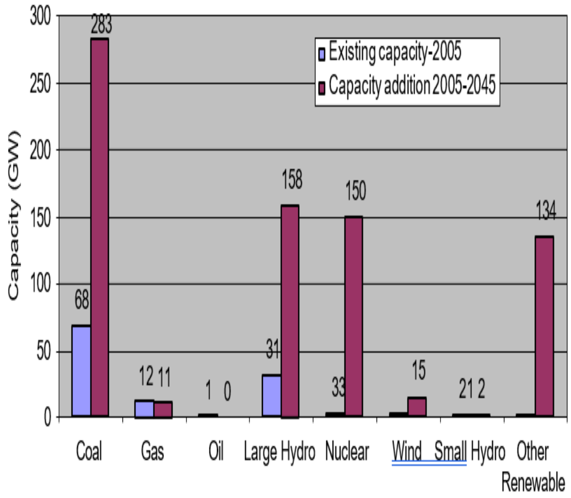

Figure No. 4: Current capacity and capacity additions in base case scenario

Table 2 (Aggressive Renewable Technology Scenario) shows another scenario in which we made it imperative to employ additional renewables to fully use them possible. The resource allocations that have been optimized are shown in Fig. 6. It has been noted that while nuclear, wind, and other renewable energy sources continue to grow, the percentage of coal and hydrocarbons stays constant between 2015 and 2035. After 2040, coal use will decline sharply while massive hydro, nuclear power, and other renewable energy sources will expand dramatically to supply the world's energy needs.

It is evident that the amount of coal-based power generated rises until 2015, stays steady until 2040, and then abruptly declines in 2045 to around 2005 levels. This demonstrates that the adoption of renewable energy producing policies by the populace will require some time due to technical advancements.

Between 2015 to 2035, the huge hydro almost stays the same, only doubling by 2040. Nearly half of the electricity produced in 2045 will come from major hydropower plants. All renewable energy sources, including wind, small hydro, biomass, sun, and geothermal, cease to provide power beyond the year 2035. The overall amount of power consumed in 2045 will rise by around nine times when compared to the base year of 2005. Fig. 3 displays the CO2 emissions under the various scenarios that have been addressed. Table 1 lists the equivalent CO2 emissions from different fuels. Compared to the base case scenario, CO2 emissions decrease after 2030 when renewable energy sources are used, although they continue to rise. After 2040, CO2 emissions decline when an aggressive approach to renewable energy sources (maximum potential utilization) is permitted, resulting in sustainability.

5.3: RESULT AND DISCUSSION WITH VARIOUS ENERGY SAVING TECHNIQUE

The resource allocation in the two alternative scenarios—without the use of potential energy conservation—was covered in the preceding section. This section has examined and evaluated MARKAL simulations using different energy conservation potentials. Estimates are used to determine resource allocations and associated CO2 emissions. The Renewable Technology Scenario with different energy-saving choices is covered in the first subsection. Aggressive Renewable Technology with its range of energy-saving solutions is covered in the second subsection.

Figure 4 displays the installed capacity in terms of resources in the Renewable Technology Scenario together with a range of possible energy-saving measures. In the first two examples, coal remained constant until the year 2040, but in the other two, the coal increased from the base year 2005 to 2015. The coal stalemate up until 2035 is depicted in the next two examples. Up to the year 2045, a little growth was noted following the year

2040. In the greatest savings potential scenario, the big hydro also exhibits growth through the year 2015 before remaining constant through the year 2040. After that, there is a modest drop through the year 2045. After 2040, there will be significant hydro increases under the 15% energy savings scenario. The final two examples demonstrate that big hydro will once more become significant starting in 2035. An intriguing scenario involving nuclear power arises. In 2045, the installed capacity of nuclear power is expected to reach 18% in the base case scenario and 33% in the greatest savings potential case. From the perspective of the US-India nuclear agreement and environmentally friendly electricity generation, this may be a very promising scenario. In contrast to the Renewable Technology Scenario, which includes additional renewable energy sources starting in 2030, the Maximum Savings Potential Case includes additional renewable energy sources only much later—after 2040. This is due to a 40% decrease in the amount of power used, from 752 to 465 GW.

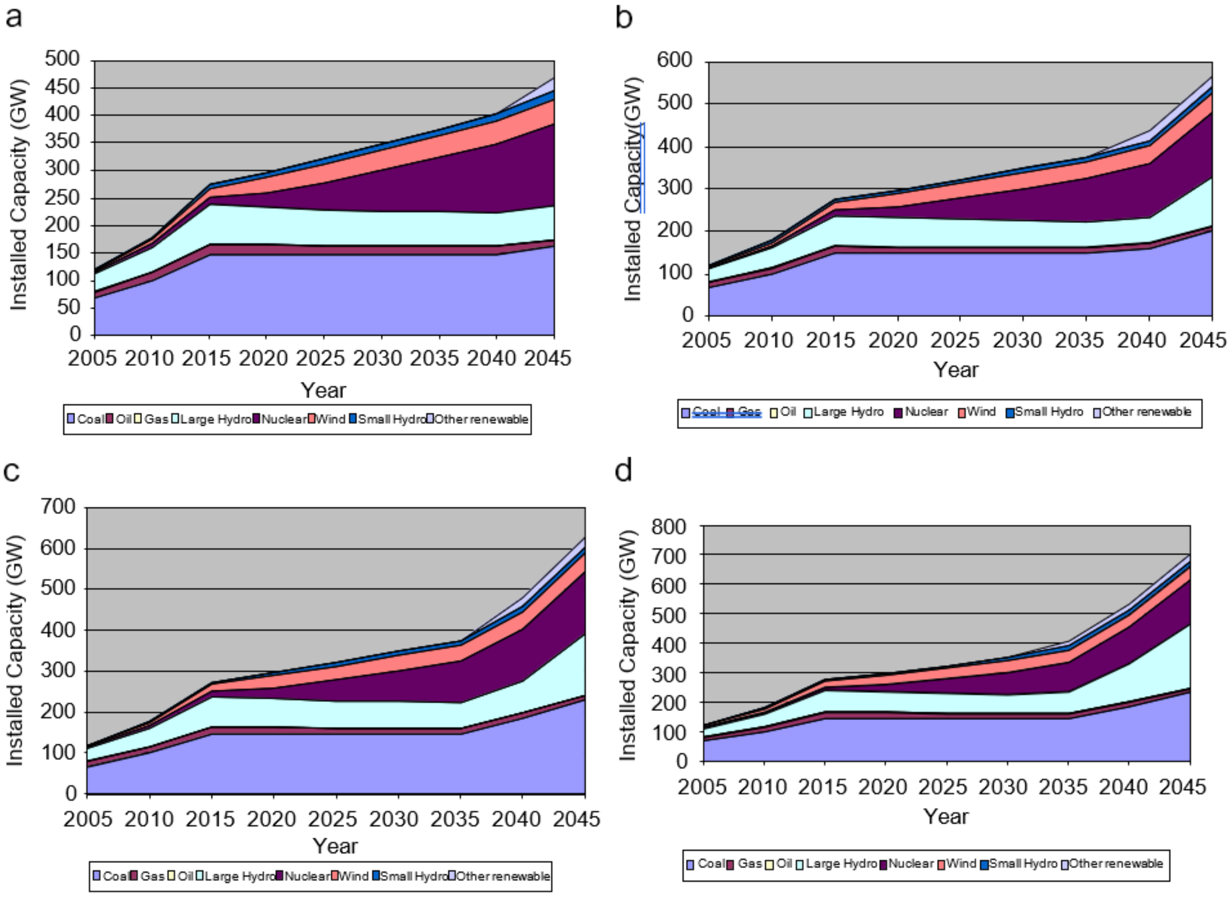

Figure No. 5: Resource-wise installed capacity in various energy savings options in renewable technology scenario.

Fig. 4 depicts the Aggressive Renewable Technology Scenario with various possible energy savings. In all cases, coal remains the primary source of power production until 2040. The highest potential for energy saving drops significantly between 2040 and 2045. Coal stays constant in the 15% savings case starting in 2015 and continuing until the conclusion of the planned horizon. In scenarios where energy savings are between 10% and 5%, coal use increases starting in 2040. On the other hand, large hydro exhibits a growing pattern in the remaining three savings scenarios only after 2040, but it remains constant throughout the planned period in maximum energy conservation potential. In every scenario, there is a constant upward tendency in nuclear. The renewable energy sources, except for massive hydro, will be completely fully utilized possible until 2045. In 2045, this might account for almost 25% of the total installed capacity, assuming the highest possible level of energy saving. Deliver energy while ensuring that it doesn't pollute the environment. If correctly inferred, the two proposed scenarios above demonstrate a significant reduction in carbon dioxide emissions from the Indian power industry. The CO2 emissions in the Renewable Technology Scenario with different potential energy savings are displayed in Fig. 10. By 2045, about 1000 million tons of carbon dioxide will have been saved, or 41% less, to reach the maximal energy saving potential. It's interesting to see that the reduction in GHG emissions begins in 2005. Even if energy savings of 10% and 5% do not affect emission reduction from 2035 onwards in a way that is distinct from the only Renewable Technology Scenario, they do begin to reduce emissions in the base year. By 2045, 15% energy reductions will have reduced CO2 by around 28%.

VI. CONCLUSION

These days, both in industrialized and emerging nations, energy security and sustainable development are major concerns. Clean energy, which can endure for a longer time, is crucial to addressing these problems. Renewable energy sources are the answer to both environmental problems and energy security. MARKAL simulations of energy resources for Indian electrical power supply systems, both with and without energy conservation, have been carried out for the BCS and renewable technologies, keeping these concerns in mind. The base case scenario sees a rise in electrical energy consumption from 600 TWh in the base year 2005 to 5000 TWh in 2045. By 2045, the corresponding CO2 emissions will have increased to 2.3 billion tons. Due to the enormous potential that renewable energy sources offer in the Indian electricity industry, both full and partial utilization have been allocated. The Renewable Technology Scenario indicates a decrease in the use of coal and a corresponding 16% reduction in carbon emissions; nevertheless, this decrease falls short of sustainable levels. With an installed capacity of just 80 GW, the aggressive use of renewable energy results in a significant reduction in coal consumption and a 72% reduction in carbon emissions when compared to BCS in 2045. The use of energy-saving renewable energy sources demonstrates an early decrease in carbon emissions. By 2045, the Aggressive Renewable Technology Scenario with maximal energy savings will have reduced carbon emissions by the same percentage (72%). In both other scenarios for 2045, the percentage of renewable energy in the energy mix is greater than 35 percent.

The various possibilities for the aggressive use of renewables appear like environmentally pleasant and sustainable solutions to the energy shortfall, but a variety of institutional, market-related, and techno-economic impediments hamper the development and diffusion of new technologies. Future target-setting and the creation of a renewable energy portfolio must be coordinated with the overarching goals of the power and energy sectors. The research indicates that to achieve penetrations beyond baseline expectations, specific interventions must be detailed in detail. India will become energy independent in the future thanks to these power sector developments, which also lower carbon dioxide emissions for the purpose of the clean development mechanism's carbon trading system (CDM).

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