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Forecasting Analysis Of Energy Consumption And Emissions In India (2021-2047)

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Abstract

Energy sector related emissions is considered as mainly responsible for anthropogenic climate change in the World and in India as well. The study considered energy consumption for both direct consumption and for its use in the electricity generation also in case of both the total economy and three highly polluting sectors – Industry, Transport and Residential. It used Holt–Winters non-seasonal smoothing method to forecast the energy consumption and emissions for the period 2021-2047. Policy guided measures caused increase in non-fossil fuel consumption at the national level and is projected to increase in coming years. The share of non-fossil fuels is going to increase in Industrial sector due to increased use of biofuels and wastes, while that of fossil fuels is going to decrease in both direct and indirect use. Fuel efficiency of vehicle engines, gradual increase in urban metro rail services would cause decline in energy consumption in Transport sector but the share of fossil fuel would remain high. Due to increased urbanisation, mobility and higher electricity access would raise the projected share of fossil fuel in residential energy consumption. The study suggests increased coverage of Performance Achieve and Trade to include micro, small and medium enterprises with adequate financial assistance for higher research and development purpose to increase energy efficiency through technological improvement. Promotion of EVs with filling up the inadequacy in the related infrastructure, mass rapid transportation and increased fleet of public buses (EVs or CNG-run) for expanding urban areas with expansion of electrified rail networks. Measures like coverage of all types of houses under building code, standard and labels for sustainable consumption, etc. are useful to contain future residential sector emissions.

Key Words: Forecasting, energy consumption, fossil fuel, non-fossil fuel, emissions

1. Introduction –

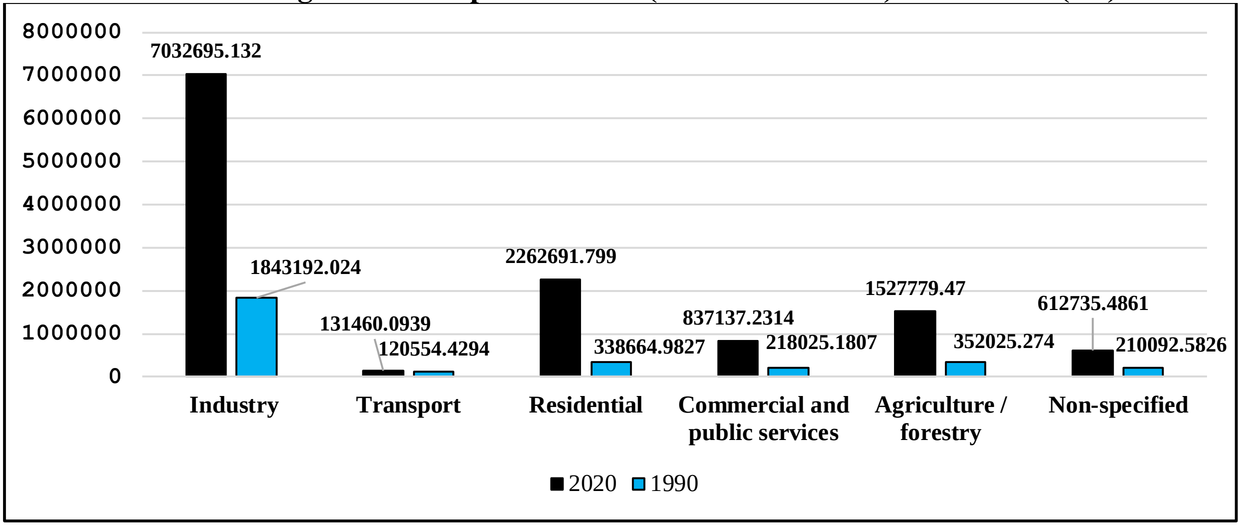
Across the world, most of the energy requirement is met by the combustion of fossil fuels with limited reserves, e,g,, coal, petroleum oils, natural gas, etc., which have gradually become an essential and integral part of modern civilisation. The use of fossil fuels cause air and water pollution with increased health hazards and economic risks and global climate changes, e.g., the increase in mean temperatures on earth – 'global warming' and unpredictable fluctuations around the mean temperature – 'global climate variability'.

On the one hand, energy security ensured by sufficient and cheap energy is imperative in rapid economic growth in emerging economies like India. But at the same time, such huge incremental energy demand in these countries makes emissions reduction more difficult and costly (Ferroukhi et al., 2016). Different manifestations of anthropological climate change shows that the *'grow now and clean up later'* argument is proved to be costly as it is more economical to reduce or prevent pollution at an early stage of growth than to incur the higher clean-up costs at later stages, even when future costs and benefits are discounted (The World Bank, 2012). In such a situation early action is critical because of the problem of *'lock in'* of high-carbon or polluting lifestyles or economic structures with the choice of technology, investment and infrastructure. Thus, in replacement of previous policies, there is need of low carbon policies. Low carbon energy transition is the key to make a balance between economic growth and environmental protection and climate change, in particular. Such transition is to happen through energy efficiency improvements, carbon intensity reduction and expansion of renewable energy use.

Carbon Footprint (CF) describes CO_2 emissions by carbon footprint value for final demand of a particular sector with both domestic and imported environmental load (Vetné Mózner, 2013). The consumption-based carbon emission (CBE) accounting is a *'carbon footprint'* approach which is different from the territorial or production based emission (PBE) approach of Intergovernmental Panel on Climate Change (IPCC) (endorsed by UN Framework Convention on Global Climate Change (UNFCCC)) which accounts for carbon emissions occurred within the country, whereas CBE takes into account emissions needed to produce the consumed goods and services in a country and thereby, points out the need for decoupling emissions with change in consumption and lifestyle pattern (Tukker et al., 2020) (Rahman et al., 2022). This study is based on PBE accounting of CO_2 emissions in India (1990-2020).

The energy sector is responsible for about 75% of the total GHG emissions in India in 2016 (Ministry of Environment, 2021). India's Total Emissions from the Energy Sector have increased from 16,51,928 $GgCO_2$ Equivalent (2011) to 21,29,428 $GgCO_2$ Equivalent (2016), i.e., 28.9% increase. The Energy Industries hold the major share in contribution to total emissions related to Energy Sector (with marginal increase from 55.95% (2011) to 56.66% (2016). High dependence on fossil fuel is the root cause of this phenomenon in India. Use of coal has increased during 1990-2020 in all sectors (Fig. 1), especially in Industry sector (281.5%), because industries like iron & steel, cement, paper, fertilisers, chemicals are dependent on coal for specific processes, which mostly involve firing of the furnaces. Electricity use in Industry increased leading to increased emissions – indirect coal consumption (738632.024 TJ) was initially lower than direct coal consumption (1104560 TJ) in 1990 but the former (3555044.132 TJ) surpassed the latter (3477651 TJ) in 2020. It resulted in Industry as bottom-ranked in efficiency ranking in almost all the study years. Use of electricity would increase as there is scope for electrification of more industrial processes, especially, Micro, Small and Medium Enterprises (MSMEs) (Pal & Hall, 2021). In transport sector, due to electrification of railways and expansion of surface railways and metro railways, the consumption of electricity increased by CAGR of 5.02% [electrification in metro transit – 100%, conventional passenger rail activity – 54%, freight activity – 65%](*Elements of the Electrification Strategy for India*, 2022) and as a result, burning of coal has increased for generation of electricity from 28765.43 TJ to 131460.09 TJ during 1990 – 2020 in this sector, adding more carbon emissions. Similarly, the coal indirectly used for meeting high residential sector electricity demand which increased from 223807.98 TJ (1990) to 2141494.80 TJ (2020) with CAGR of 1.41%, primarily because of increase in electricity access $(= \%\ of\ population)$ from 50.9% (1993) to 96.5% (2020)(World Bank Open Data) and increased use of electric appliances.

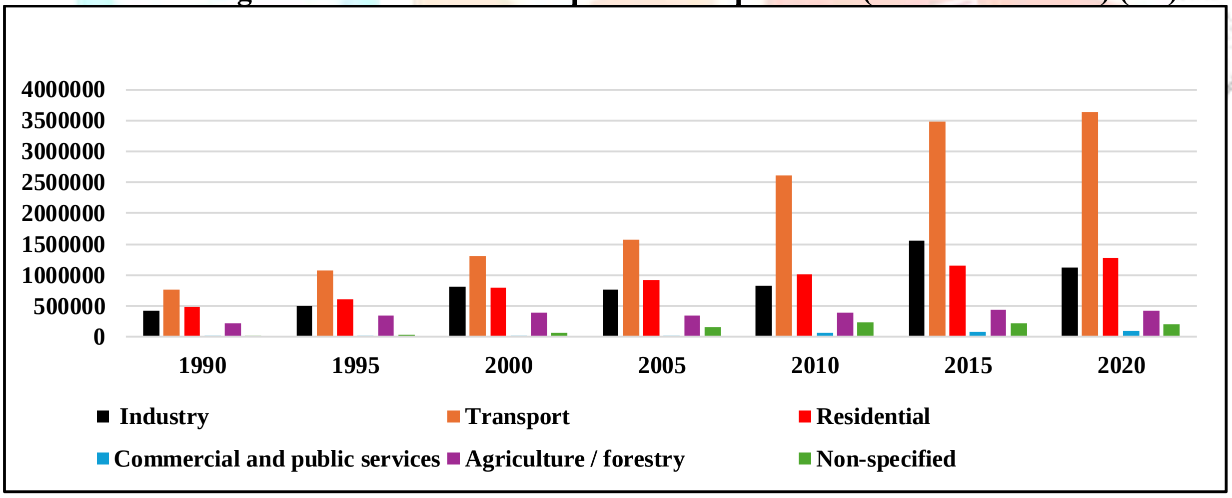
Fig.1: Consumption of coal (direct & indirect) sector wise (TJ)



Source: Author

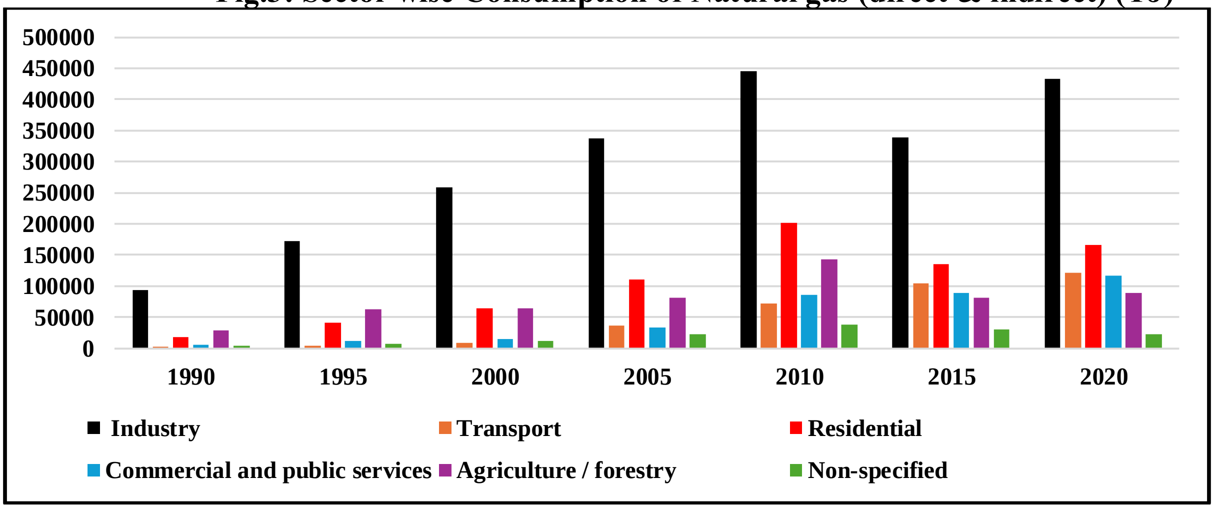
Fig.2 depicts that in all the study years, oil consumption is highest in Transport sector (CAGR of 5.16%), where direct oil use has increased due to rise in total registered vehicles (both private and public) from 21.40 million (1991) to 295.8 million (2019) (ROAD TRANSPORT YEAR BOOK, 2021). Use of private vehicles increased due to growing middle class population, increasing urbanisation from 26% (1990) to 35% (2020) (World Bank Open Data), which is projected to grow to 50% by 2050 and increased mobility, which would grow further in the event of improvement in Labour Force Participation Rate (48% in 2020) (World Bank Open Data).

Fig.2: Sector wise Consumption of Oil products (direct & indirect) (TJ)



Source: Author

Fig.3: Sector wise Consumption of Natural gas (direct & indirect) (TJ)



Source: Author

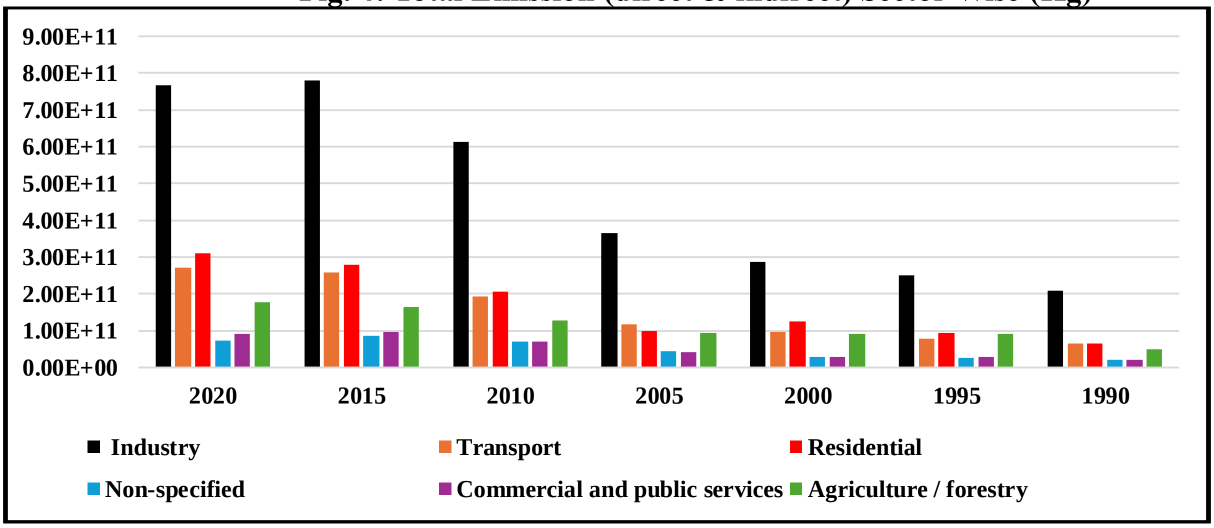
From Fig.3, it can be seen that direct use of natural gas in Transport sector increased in later years due to introduction of Compressed Natural Gas (CNG) and gradual replacement of the oil products (diesel and gasoline) with natural gas would reduce emissions due to its low relative emissions factor. The Transport sector has already introduced Bharat Stage (BS) – VI fuel standards since April, 2020, under Vehicle Fuel Efficiency Program (2014) (*Elements of the Electrification Strategy for India*, 2022). India has raised the target of natural gas share from 6.5% to 15% by 2030. Use of natural gas is consistently found to be highest in industry due to direct consumption in industries like fertiliser, etc. Under the City Gas Distribution (CGD) network, 95.21 lakh Piped Natural Gas (PNG) connections to domestic consumers and 4531 CNG stations have been established for transport purpose (as on 31st May, 2022) and under the 'One Nation One Gas Grid', 21,715 km Natural Gas Pipeline network has been operational (M. of P. & N. G. of I. Press Information Bureau, 2022), which increased natural gas consumption in Transport and Residential sectors in India.

In Residential sector, the energy consumption is increasing for high use of Air distribution appliances like fans, coolers, etc. (57% rural and 30% urban), followed by lighting appliances (24% rural and 20% urban), household and entertainment appliances (19% rural and 50% urban) (*Elements of the Electrification Strategy for India*, 2022) and projected penetration of air conditioning in residential and commercial buildings to 40% by 2037-2038 due to increase in disposable income and temperature rise(*Elements of the Electrification Strategy for India*, 2022).

In order to meet the growing energy demands in populus country like India, the Govt. has given thrust to building installed capacity of power or electricity which would reduce dependence on primary fossil fuels (National Statistics Office, 2022). In power generation, technological development and policy efforts centred on optimisation of diversified use of energy resources in sustainable manner and reliable power supply at competitive price. It is to be noted that all potential capacity is not viable to be transformed into overall capacity and again this overall capacity does not generate equal amount of electricity due to losses during production, etc. (National Statistics Office, 2022). Total installed capacity of electricity generation is 459151 Mega Watt in 2020-21 with 83.23% coming from utilities (National Statistics Office, 2022).

Industrial fuel consumption structure is found to be comparatively more intensive in fossil fuels [direct (final) and indirect (intermediate) consumption (for electricity generation)], mainly due to increased coal consumption (with compound annual growth rate (CAGR) of 4.41% for the period of 1990-2020) and its emissions factor is very high in comparison to other fossil fuels and low energy efficiency in MSME sector. As a result, Industry has evidenced highest emissions in all seven (7) years – 1990, 1995, 2000, 2005, 2010, 2015, 2020 spanning the period 1990-2020 (Fig. 4). In terms of CAGR of emissions, Residential sector (5.12%) is a leading sector followed by Commercial and Public Services (4.81%), Transport (4.74%), Industry (4.29%), Agriculture / forestry (4.21%), non-specified (4.07%). This emission growth in Residential, Commercial and Public Services sectors are due to urban aggregation and expansion in economic activities leading to high electricity demand, higher electricity access over the years at the household level, which is mostly met from power stations run on fossil fuels.

Fig. 4: Total Emission (direct & indirect) Sector Wise (Kg)



Source: Author

2. Review of Literatures –

In the research of Deng et al. (2021), forecasting of electricity consumption in USA, China (2002-2019) has been done with the help of particle swarm optimization (PSO) algorithm based Seasonal exponential smoothing (SES) model which is stated to outperform the other forecasting models – SARIMA, SVR, NA-PSO, MA-PSO, AA-PSO and BPNN.

The study of Choi et al. (2014) used Double Exponential Smoothing (DES) forecasting method to find that the transport sector emission in USA since 2008 is not transitory and it would continue to decrease at the national level till 2021. Policy action has emerged as an important tool to contain transport related emissions as emission reduction was evident only in those 10 provinces which enacted climate action plans.

Zhou & Chen (2023) applied a novel three-layer decomposition-ensemble (DE) forecasting approach is proposed, which combines the positive traits of trend decomposition (TD), empirical mode decomposition (EMD) and wavelet decomposition (WD) which decomposes energy consumption dataset into more simpler trend subseries and non-trend subseries in China and prediction (2021–2035) has been performed under different scenarios which indicates predominance of fossil fuels in China, which underlines the requirement of optimisation of industrial structure, low carbon energy structure, enhanced energy efficiency, etc. for reaching carbon peaking target by 2030. Qader et al. (2022) applied different forecasting methods on CO_2 in Bahrain and observed that neural network time series nonlinear autoregressive is better performer than Holt's methods, Gaussian Process Regression and found that as per CO_2 emissions (2019) Bahrain lags behind the Doha Amendment (2012) of Kyoto Protocol.

Literatures based on the H-W forecasting method is found on other countries, e.g., annual energy demand (GWh), GDP per capita, Industry GDP in Colombia have been forecasted for the period 2007-17, using the method of Holt's model by (Salinas et al., 2020), (Lepojević & Anđelković-Pešić, 2011) used Holt-Winters forecasting method with seasonality to forecast electricity consumption in the area covered under Elektroistok Ltd. Nis in Serbia for the period of November 2011 - October 2012. Therefore, this study fills the gap by employing the H-W forecasting method to forecast the energy consumption and emissions in India.

3. Research Aim & Objective –

3.1 Research Aim –

Despite enacting different policies to promote expansion of renewable energy and to reduce the overall energy consumption, India's energy structure is still in favour of fossil fuels. Amidst the growing energy demand, it is thus pertinent to forecast the energy consumption pattern and emissions in India in the coming decades which would help the policy makers to chalk out suitable policies.

3.2 Research Objective –

To forecast the energy consumption of both fossil and non-fossil fuels and CO_2 emissions in the whole economy and the high emitting sectors – Industry, Transport and Residential sectors during 2021-2047 based on the data for the period 1990-2020.

4. Research Method & Data

4.1 Research Method –

4.1.1 Trend & Forecasting Method –

Apart from the forecasting analysis using IESS-2047 (NITI Aayog, 2023), this study applied univariate forecasting method for predicting the future trend pattern of the major variables – emissions and total primary energy consumption (fossil and non-fossil) for the whole economy and the three sectors – Industry, Transport and Residential as well and also energy and emission intensity of GDP. From the graphical plot of these variables, it is found that the graph is trending upwards or downwards and there is no seasonality is found, therefore, Holt–Winters non-seasonal smoothing is preferred over Holt–Winters seasonal smoothing (Additive method).

Following (StataCorp LP, 2013), the Holt–Winters non-seasonal smoothing method forecasts series of the form:

$\widehat{x_{t+1}} = a_t + b_t t$

where $\widehat{x_t}$ is the forecast of the series of original variable x_t, $a_t =$ mean which drifts over time; $b_t =$ coefficient on time which drifts over time. This method is an extension of double-exponential smoothing with 2 parameters. These parameters can either be explicitly set or chosen to minimise in-sample sum-of-squared forecast error.

For the series x_t, the smoothing parameters are: α and β, while the initial values are: a_0 and b_0.

Therefore, $a_t = \alpha x_t + (1-\alpha)(a_{t-1} + b_{t-1})$
and $b_t = \beta(a_t - a_{t-1}) + (1-\beta)b_{t-1}$

After computing the parameters and series of linear terms – a_t and b_t , the τ -step-ahead prediction of x_t: $\widehat{x_{t+\tau}} = a_t + b_t\tau$

4.1.2 Data Calculation Methods –

4.1.2.1 Calculation of Total Primary Energy Consumption for the total economy:

$$\text{Total Primary Energy Conumption } (TPEC_T) = \text{Total direct primary Energy Conumption } (TPEC_D^T) + \text{Total indirect primary energy consumption (for electricity generation) } (TPEC_{Ind}^T)$$

$$\text{where, Total direct primary Energy Conumption } (TPEC_D^T) = \sum_{j=1}^{n} TPEC_D^{T,j}$$

$$\text{Total indirect primary energy consumption } (TPEC_{Ind}^T) = \sum_{j=1}^{n} TPEC_{Ind}^{T,j}$$

$$\text{Total primary Fossil energy consumption } (TPEC_F^T) = \sum_{j=1}^{n} TPEC(F)_D^{T,j} + \sum_{j=1}^{n} TPEC(F)_{Ind}^{T,j}$$

$$\text{Total primary non} - \text{Fossil energy consumption } (TPEC_{NF}^T) = \sum_{j=1}^{n} TPEC(NF)_D^{T,j} + \sum_{j=1}^{n} TPEC(NF)_{Ind}^{T,j}$$

where, j = j-th fuel (j = 1,2,….,n), T= Total, D = Direct, Ind. = Indirect, F = Fossil Fuels, NF = Non-fossil fuels

4.1.2.2 Calculation of Total Primary Energy Consumption for the sectors of the economy:

$$\text{Total Primary Energy Conumption } \left(TPEC_T^i\right) = \text{Total direct primary Energy Conumption } \left(TPEC_D^{T,i}\right) + \text{Total indirect primary energy consumption (for electricity generation)} \left(TPEC_{Ind}^{T,i}\right)$$

$$\text{where, Total direct primary Energy Conumption } \left(TPEC_D^{T,i}\right) = \sum_{j=1}^{n} TPEC_D^{T,j}$$

$$\text{Total indirect primary energy consumption } \left(TPEC_{Ind}^{T,i}\right) = \sum_{j=1}^{n} TPEC_{Ind}^{T,j}$$

$$\text{Total primary Fossil energy consumption } \left(TPEC_F^{T,i}\right) = \sum_{j=1}^{n} TPEC(F)_D^{T,j} + \sum_{j=1}^{n} TPEC(F)_{Ind}^{T,j}$$

$$\text{Total primary non} - \text{Fossil energy consumption } \left(TPEC_{NF}^{T,i}\right) = \sum_{j=1}^{n} TPEC(NF)_D^{T,j} + \sum_{j=1}^{n} TPEC(NF)_{Ind}^{T,j}$$

where, i = i-th sector; j = j-th fuel (j = 1,2,….,n), T= Total, D = Direct, Ind. = Indirect,
F = Fossil Fuels, NF = Non-fossil fuels

Therefore, the principle of total emission calculation follows the energy consumption principle as shown above.

Total Emissions $\left(\boldsymbol{E_T^i}\right)$ = Emissions from direct consumption of primary fossil fuels $\left(\boldsymbol{E_D^i}\right)$ + Emissions from indirect consumption of primary fossil fuels for electricity generation $\left(\boldsymbol{E_{Ind}^i}\right)$

4.1.2.3 Method of Emissions Calculation (Sectoral & Total) –

Step-1: Calculation of sectoral indirect fossil fuels consumed –

The indirect fossil energy consumption for electricity generation is calculated in the following process – Say, 'a' units of coal, 'b' units of oil, 'c' units of natural gas were used in production of 'w' units of electricity produced in a particular year for India. In that year if 'v' units of electricity is consumed in a particular economic sector then for producing 'v' units of electricity the use of coal $=$ $(a/w) \times v$ units, use of oil $=$ $(b/w) \times v$ units, use of natural gas $=$ $(c/w) \times v$ units. Similar process is followed for other economic segments in all other years.

Step – 2: Calculation of sectoral total fossil fuels consumed –

Similarly, fossil fuels consumption in each of the three sectors – Industry, Transport, Residential are calculated.

Sectoral Total Fossil Fuels conumption $\left(\boldsymbol{TPEC(F)_T^i}\right)$
= Sectoral direct consumption of primary fossil fuels $\left((\boldsymbol{TPEC(F)_D^i}\right)$ +
Sectoral indirect consumption of primary fossil fuels for electricity generation $\left((\boldsymbol{TPEC(F)_{Ind}^i}\right)$

where, i = i-th sector; j = j-th fuel (j = 1,2,….,n), T = Total, D = Direct, Ind = Indirect,
F = Fossil fuel

Step-3: Emission calculation in total economy and in sectors

A. Calculation of sectoral emissions from consumption of fossil fuels –

CO_2 emissions is calculated on the basis of total amount of fuels combusted and averaged carbon content of fuels (Garg et al., 2006b)

$$Emission = \sum[Fuel_a \times EF_a]$$
$$Emission = Emissions\ of\ CO_2\ (kg)$$
$$Fuel_a = Fuel\ sold\ (TJ)$$
$$EF_a = Emission\ Factor\ (kg/TJ)$$

EF_a is equal to the carbon content of the fuel multiplied by 44/12.
a = type of fuel (e.g., petrol, diesel, natural gas, LPG etc.) (Garg et al., 2006a)

Default emissions factors used are on the basis of the assumption of 100 per cent oxidation (i.e., fraction of carbon oxidised is assumed to be 1) (Garg et al., 2006a).

Appendix Table-4B: Emissions factor calculation used in the study

Fuels	Values of effective CO_2 emissions factor* (Kg/Tj) (Default/Calculated)	Remarks
Coal	94600	In India most of the coal used are either coking coal or Bituminous type so the average of the emissions factors are considered {i.e.,(94600+94600)/2=94600}
Oil & Oil products	68833.3333	The average of the following 3 oil products are mostly used in India and thus the average of their emissions factors is considered Motor Gasoline = 69300 Gas/Diesel Oil = 74100 Liquefied Petroleum Gases = 63100 {i.e., (69300+74100+63100)/3=68833.3333}
Natural Gas	56100	IPCC, 2006 default value

* **Effective CO_2 emissions factor** = Default carbon content (kg/GJ) × Default carbon oxidation factor × (44/12) ×1000; 1Tj = 1000 Gj

Source: (Garg et al., 2006a) & calculated by author

B. In Total Sectoral Emissions Calculation method, both the primary direct energy consumption in different sectors and indirect primary energy consumption used in power generation are considered to get the total sectoral Emissions [direct and indirect emissions from fossil fuel (coal, oil products and natural gas) consumption].

Data for the period (1990-2020) for energy consumption for the total economy and its sectors have been calculated and data for total emission (Mt of CO_2) of the total economy has been derived from International Energy Agency (2022).

5. Results & Discussion –

5.1 Forecasting Analysis of Energy Consumption & Emissions

5.1.1 Forecasting by India Energy Security Scenarios (IESS) 2047, NITI Aayog (2023)

Table – 1: Forecast of Energy Demand (2022-2047) (Least effort scenario)

Energy Demand (Mtoe): Least effort scenario						
Year	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**
Total	611.15	805.52	1021.05	1261.35	1545.13	1878.23
Buildings	36.22	51.33	72.84	103.42	146.8	208.17
Industry	271.87	369.77	498.08	643.66	824.27	1043.3
Transport	120.18	182.11	226.49	267.93	302.61	326.18
Agriculture	34.81	43.14	53.47	61.61	70	79.99
Telecom	8.95	11.89	14.32	16.64	18.38	19.66
Cooking	96.58	92.21	87.21	83.1	77.83	70.43
Miscellaneous	43.04	55.07	68.64	84.99	105.25	130.49

Source: Author; Collected from (NITI Aayog, 2023)

Table – 2: Forecast of Energy Demand (2022-2047) (Net Zero Scenario)

Energy Demand (Mtoe): Net Zero Scenario						
Year	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**
Total	597.04	735.79	869.74	1001.05	1140.37	1284.1
Buildings	36.17	49.87	68.38	93.51	124.7	162.18
Industry	260	324.06	399.01	472.5	555.61	648.6
Transport	119.63	167.85	194.31	214.15	225.61	224.95
Agriculture	34.46	41.63	50.3	55.56	60.94	67.12
Telecom	8.93	11.75	13.95	15.84	16.88	16.99
Cooking	95.3	88.5	81.33	75.08	67.98	58.54
Miscellaneous	42.54	52.12	62.46	74.41	88.65	105.7

Source: Author; Collected from (NITI Aayog, 2023)

Table – 3: Per capita GHGs emissions (energy related) (tonne CO_2e /person)

Year	2022	2027	2032	2037	2042	2047
Least effort scenario	1.93	2.45	3	3.53	4.19	5.07
Net zero scenario	1.86	2.15	2.32	2.33	2.26	2.21

Source: Author; Collected from (NITI Aayog, 2023)

Table – 4: Energy Intensity of GDP (MJ/Rs.)

Year	2022	2027	2032	2037	2042	2047
Least effort scenario	0.24	0.22	0.2	0.17	0.15	0.13
Net zero scenario	0.23	0.21	0.17	0.14	0.11	0.09

Source: Author; Collected from (NITI Aayog, 2023)

Table – 5: Energy emissions intensity to GDP (Kg CO_2e/Rs.1000)

Year	2022	2027	2032	2037	2042	2047
(Least effort scenario)	17.96	17.02	15.42	13.32	11.54	10.09
(Net Zero scenario)	17.33	14.95	11.94	8.79	6.21	4.39

Source: Author; Collected from (NITI Aayog, 2023)

The IESS, 2047 forecasting is explained in Tables – 1 to 5:

The share of Industry in energy consumption is forecasted to be higher in comparison to other sectors in both the Least Effort and Net Zero scenario of IESS, 2047, followed by Transport and Residential sectors. Per capita energy consumption is forecasted to increase due to increased access to energy, economic growth, more use of energy services in the residential and transport sectors causing increase in energy consumption in both the Least Effort and the Net Zero Scenario. Per capita GHGs emissions (energy related) is also forecasted to increase which implies the continued dependence on fossil fuels in the coming decades as well. Energy Intensity of GDP is going to decrease to 0.13 MJ/Rs. (2047) from 0.24 MJ/Rs. (2022) due to technical improvement. The Energy emissions intensity to GDP is going to decrease due to compositional change in energy portfolio in favour of REs, Superior technologies, especially in thermal power plants (e.g., super critical boilers, etc.), etc.

5.1.2 Forecasting Analysis by Holt–Winters Non-seasonal Smoothing Method –

Apart from the detailing of the forecasted valued of different energy-environment parameters using NITI Aayog (2023), India Energy Security Scenarios (IESS) 2047, this study also used single variable Holt–Winters (H-W) forecasting method. As the graphical plots of the selected variables (Table – 6 & Appendix Fig. – 1) show no seasonal pattern so the study used the non-seasonal H-W forecasting method following (StataCorp LP, 2013).

In applying the Holt–Winters non-seasonal smoothing method for forecasting the time series of the variables till 2047 (Table – 6), the parameters (α and β) of the forecasting method is chosen by selecting that pair of parameters (α and β) which has lowest Root Mean Square Error (RMSE) of the forecasted values for the period 1990-2020 (for example, Table – 6, Appendix Fig.5.1). The results of H-W forecasting results is based on the data of the period 1990-2020, on the assumption of business-as usual (BAU) situation, i.e., with existing policy measures and economic conditions.

Table – 6: List of variables for forecasting

Variables	Measurement	Unit
Total CO_2 emissions	CO_2	Mt
Per capita CO_2 emissions	CO_2/Total Population	t CO_2//Capita
Total Primary Energy Consumption per unit Gross Domestic Product (2015 USD)	TPEC/GDP	TJ//$(2015)
Total Primary Energy Consumption (Fossil Fuels) (TFFE+TFFNEC = TPEC(F))	TPEC(F)	TJ
Total Primary Energy Consumption (non-Fossil Fuels) (TNFFE+TNFFNEC = TPEC(NF))	TPEC(NF)	TJ
Total Primary Energy Consumption (Fossil Fuels)-Industry (TFFE+TFFNEC = TPEC(F))(Industry)	TPEC-Industry(F)	TJ
Total Primary Energy Consumption (non-Fossil Fuels)-Industry (TNFFE+TNFFNEC = TPEC(NF)) (Industry)	TPEC-Industry (NF)	TJ
Total Primary Energy Consumption (Fossil Fuels)-Residential (TFFE+TFFNEC = TPEC(F)) (Residential)	TPEC-Residential (F)	TJ
Total Primary Energy Consumption (non-Fossil Fuels)- Residential (TNFFE+TNFFNEC = TPEC(NF)) (Residential)	TPEC-Residential (NF)	TJ
Total Primary Energy Consumption (Fossil Fuels)-Transport (TFFE+TFFNEC = TPEC(F)) (Transport)	TPEC- Transport (F)	TJ
Total Primary Energy Consumption (non-Fossil Fuels)- Transport (TNFFE+TNFFNEC = TPEC(NF)) (Transport)	TPEC- Transport (NF)	TJ
Total Primary Energy Consumption (Fossil Fuels)-Electricity (TFFE+TFFNEC = TPEC(F)) (Electricity)	TPEC- Electricity (F)	TJ
Total Primary Energy Consumption (non-Fossil Fuels)- Electricity (TNFFE+TNFFNEC = TPEC(NF)) (Electricity)	TPEC- Electricity (NF)	TJ

Source: Author

where, **TFFE** = Total Fossil fuel (Primary) Consumption in electricity production (indirect primary energy consumption)
TFFNEC = Total Fossil fuel (Primary) Consumption in non-electricity use (direct primary energy consumption)
TPEC(F) = Total Primary Energy Consumption (Fossil Fuel) = TFFE + TFFNEC (direct + indirect primary energy consumption);
TNFFE = Total non-Fossil fuel (Primary) Consumption in electricity production (indirect primary energy consumption)
TNFFNEC = Total non-Fossil fuel (Primary) Consumption in non-electricity use (direct primary energy consumption)
TPEC(NF) = Total Primary Energy Consumption (non-Fossil Fuel) = TNFFE + TNFFNEC (direct + indirect primary energy consumption)

The iteration with different values of parameters of H-W non-seasonal smoothing method α and β, it is found that with parameter combination $\alpha = 0.9$ and $\beta = 0.1$, the Root Mean Square Error (RMSE) value is lowest (Table – 7 & Appendix Fig. – 5.1), so $\alpha = 0.9$ and $\beta = 0.1$ are chosen for forecasting total CO_2 emissions by the Holt–Winters nonseasonal smoothing method. Following (StataCorp LP, 2013), the forecasting of the total CO_2 emissions by H-W non-seasonal smoothing method, the selection of parameters of α and β is done and the results are shown in Table – 7.

Table – 7: Selection of α and β in H-W nonseasonal smoothing (Forecasting) (Total CO_2 emission) (Mt)

	$\alpha = 0.5$	$\beta = 0.5$	$\alpha = 0.1$	$\beta = 0.9$	$\alpha = 0.2$	$\beta = 0.8$	$\alpha = 0.3$	$\beta = 0.7$
RMSE	69.26662		134.4417		90.5205		74.7332	
	$\alpha = 0.4$	$\beta = 0.6$	$\alpha = 0.6$	$\beta = 0.4$	$\alpha = 0.7$	$\beta = 0.3$	$\alpha = 0.8$	$\beta = 0.2$
RMSE	70.54214		68.78781		68.54354		68.27153	
	$\alpha = 0.9$	$\beta = 0.1$						
RMSE	67.44933							

Source: Author

The forecasted value of total CO_2 emissions (Table – 8) due to energy consumption increase at CAGR of 1.6% during 2021 -2047 due to expected economic growth and consequent energy demand increase and continuity in dependence in fossil fuels in each forecasted period. Due to energy efficiency improvement, fuel mix shift backed by Govt. policies, structural shift in GDP would continue to play their roles in carbon emission mitigation as evident in slower CAGR of CO_2 emissions (1.6%) during the forecasted period (2021-2047) in comparison to CAGR of 4.5% in the study period (1990 – 2020), but in absolute term total CO_2 emission is projected to increase to 3293.88 Mt (2047) from 2075 Mt (2020). The slower growth rate is due to lower forecasted emission intensity of GDP – from 0.79 (in 2020) to 0.26 $KgCO_2$/$ (constant 2015) (in 2047) and also lower forecasted energy intensity of GDP – from 0.0000135 TJ/$ (constant 2015) (2020) to 0.00000433 TJ/$ (constant 2015) (2047) due to both structural change in energy sectors and technological improvement through policy incentives.

After forecasting the Total CO_2 emissions, in forecasting analyses of other variables also (see Table – 8), the selection of α and β in H-W nonseasonal smoothing has been done in a similar method as mentioned in Table – 8.

Table – 8: Forecasted values of variables using H-W nonseasonal smoothing

Year	α	β	2022	2027	2032	2037	2042	2047
Total CO_2 emission (Mt CO_2)	0.9	0.1	2191.48	2411.96	2632.44	2852.921	3073.401	3293.881
Emissions (Industry) (Kg)	0.6	0.4	7.93E+11	7.70E+11	7.46E+11	7.22E+11	6.98E+11	6.75E+11
Emissions (Transport) (Kg)	0.9	0.1	2.84E+11	3.17E+11	3.50E+11	3.83E+11	4.16E+11	4.49E+11
Emissions (Residential) (Kg)	0.6	0.4	3.34E+11	3.68E+11	4.02E+11	4.36E+11	4.70E+11	5.04E+11
Emissions Intensity of GDP = CO_2/GDP (kg CO_2/2015 USD))	0.9	0.1	0.7678187	0.6672354	5.67E-01	4.66E-01	3.65E-01	0.2649021
Energy Intensity of GDP = (TPEC/GDP) (TPEC/2015 USD))	0.9	0.1	0.0000127	0.0000111	9.38E-06	7.70E-06	6.01E-06	4.33E-06
TPEC (F) (TJ)	0.9	0.1	26200000.00	28900000.00	31600000.00	34300000.00	37000000.00	39700000.00
TPEC(NF) (TJ)	0.7	0.3	9439239	1.07E+07	1.19E+07	1.32E+07	1.44E+07	1.56E+07
TPEC-Industry (F) (TJ)	0.7	0.3	8892101	8877370	8862639	8847908	8833177	8818446
TPEC-Industry (NF) (TJ)	0.6	0.4	4050981	5118031	6185080	7252129	8319179	9386228
TPEC - Transport (F) (TJ)	0.9	0.1	4114928	4595520	5076112	5556704	6037296	6517888
TPEC - Transport (NF) (TJ)	0.4	0.6	101758.5	154438.1	207117.6	259797.2	312476.7	365156.2
TPEC – Residential (F) (TJ)	0.5	0.5	3978539	4748731	5133828	5518924	5518924	5904020
TPEC – Residential (NF) (TJ)	0.5	0.5	4806696	5003741	5200786	5397831	5594876	5791922
TPEC – Electricity (F) (TJ)	0.4	0.6	1.21E+07	1.15E+07	1.09E+07	1.02E+07	9594854	8966699
TPEC – Electricity (NF) (TJ)	0.8	0.2	1885537	2295620	2705703	3115785	3525868	3935951

Source: Author

Table – 8 and Appendix Fig. – 1 suggest that the emissions intensity of GDP (CO_2/GDP) would be reduced steadily in the coming years due to energy composition shift along with improvements in energy productivity, i.e., reduction in overall energy consumption per unit of GDP. The revised INDC commitments (2021-2030) has set the target of Emission Intensity of GDP reduction by 45% of its 2005 level. The H-W non-seasonal forecasting method reveals that by 2030, India's emission intensity of GDP would be reduced by (-41.65)%, i.e., with the current rate of decline in emission to GDP ratio, India would be unable to meet its NDC commitment. Therefore, India requires more policy effort for technological innovation to harness RE from other sources to broaden its base as far as possible. The expenditure on R&D (% of GDP) has decreased by CAGR of (-3.3)% in the post-Paris agreement period (2015-20) which needs to be revived and channelised to clean and green energy technology innovation which would increase energy productivity. Thus efforts on both RE and energy productivity would reduce emissions intensity of GDP.

Similar to the NITI AAYOG's IESS forecasting data (2023) on Energy Intensity (EI) which is projected to decrease from 0.24MJ/Rs. to 0.13 MJ/Rs. in the Least Effort (LE) Scenario and from 0.23 MJ/Rs. to 0.09 MJ/Rs. with greater carbon emissions mitigation effort under Net Zero Scenario (Table – 4). The H-W forecasting analysis also found that the economy is expected to experience energy efficiency improvement as measured by energy intensity (EI) due to technology improvement (Table – 8 and Appendix Fig. – 1F). As a result of reduction in EI and continuous expansion in non-fossil energy source, the carbon intensity of GDP is also expected to continue to decrease during 2021-2047, which would expect to restrain the growth in emissions.

From Table – 8 and Appendix Figs. – 1G & 1F, it is found that total energy consumption is going to increase due to growth in industrial production to meet the direct consumer demand and also to meet the secondary demand originated from other sectors as well. For producing products and services, other sectors require machineries and other semi-finished raw materials which is supplied by the Industry sector, so increased demand in any other sector would cause increased production demand which would increase industrial raw materials and energy input as well.

Total primary non-fossil fuel consumption has increased by CAGR of 5.5% during 1990-2020 and is expected to increase in next 27 years at CAGR of 2.93% due to continuation of traditional policies like solar power under JNNSM and fiscal incentives like AD and GBI for solar and wind power. In addition to these policies, new policies to exploit the potential of renewable energy sources like solar-wind hybrid policy, PM-KUSUM to replace fossil fuel use with renewable energy in agriculture use and make the agriculturists as prosumers of renewable energy from consumer of fossil fuels, expansion of biofuel sources under National Biofuels policy, Green Hydrogen Policy for exploiting hydrogen as an alternative clean energy source produced with renewable power have been under taken and these new polices would continue to be in effect in the coming years also. Therefore, India is going to reap the benefits of these policies in coming years and the non-fossil fuel energy production is forecasted to increase during 2021-2047 (Table – 8 and Appendix Fig. – 1G). Total CO_2 emissions increased by CAGR of 4.5% (1990-2020) and is forecasted to increase by 1.6% (2021-47) (Table – 8 and Appendix Fig. – 1A).

Due to growth of electrification of industrial production process as evidenced from the increase in share of primary energy consumption in electricity production in TPEC in industrial sector from 32.05% (1990) to 36.96% (2020). As a result, the total fossil fuel consumption in industrial sector has increased but its share has decreased from 76.6% to 70.3% due to increase in non-fossil fuel use, especially in electricity production which in fact, replaced oil products used in electricity production – the share of oil product in electricity production decreased from 7.8 to 0.52% during 1990-2020. The share of primary fossil fuel in electricity production decreased during that period from 87.9 to 86.9% and the share of primary RE in electricity production increased from 12.02 to 13.06%.

The primary fossil fuel (both direct and indirect) is projected to decrease by (-0.86)% during the forecasted period of 2021-2047 in the industrial sector (Table – 8 and Appendix Fig. – 1I). The share of non-fossil fuel (direct and indirect) in industry sector would continue to increase by 144.6% during the forecasted period (2021-2047). As a result, the emissions in Industry sector is forecasted to decrease by CAGR of (-0.62)% during 2021-2047.

In the industrial sector due to improvement in energy efficiency led by technical development and supported by utilisation of outcome of R&D, the total energy consumption is projected to grow (CAGR of 4.53%) at a slower rate during 2021-47 period in comparison to the actual CAGR of 1.64% during 1991-2020. The market-based measures, e.g., PAT scheme has been useful in bringing down the energy intensity of the industrial sector. The primary fossil fuel consumption in Industrial sector has increased from 2359296.1 TJ (1990) to 8562242.3 TJ (2020) at the CAGR of 4.25% but it is also encouraging to note that the non-fossil fuel consumption in Industrial sector is forecasted to grow at a higher rate (CAGR of 3.37%) (Table – 5.9 and Appendix Fig. – 1J), while that of primary fossil fuel consumption is forecasted to decline (at CAGR of (-0.032)%) (Table – 8 and Appendix Fig. – 1I) due to growth in electrification of the Industrial process which is increasingly sourced from non-fossil fuels (from 12 to 16.8% during 1990-2020). The growth in direct non-fossil primary energy consumption (CAGR of 5.13%) in Industrial sector (CAGR of 3.86%) was more than that of fossil fuel during 1990-2020. This is due to increase in direct use of biofuels and wastes at CAGR of 4.84% in Industrial sector resulting in the increase in share of TPEC(NF) in industrial sector from 28.7% to 37.17% during 1990-2020.

While TPEC in the transport sector is projected to decline from CAGR of 4.9% (actual) during 1990-2020 to CAGR of 1.85% in the forecasted period (2021-47) due to fuel efficiency of the vehicular engines, growth in metro services connecting more suburban areas with the city hubs. In the Transport sector the share of non-fossil fuel consumption increased very marginally from 0.52% (1990) to 2.19% (2020) due to increased share in direct non-fossil fuel consumption from zero (0) to 1.68% at the same time. But the CAGR of non-fossil fuel consumption (9.9%) is higher than that of fossil fuel (4.84%) during 1990-2020 due to measures like mandatory blending of biofuel (ethanol) with fossil fuels, e.g., gasoline, diesel, etc. and periodic upgradation to higher level a target of 20% from the initial 5% blending requirement. The non-fossil fuel consumption (direct and indirect) in transport sector is projected to increase by CAGR of 5.27% (Table – 8 and Appendix Fig. – 1N), while the fossil fuel consumption (direct and indirect) is projected to increase at a relatively lower rate 1.81% during 2021-47 (Table – 8 and Appendix Fig. – 1M), but even then the fossil fuel is forecasted to hold a major share (94.7%) in TPEC in 2047. This would result in reduced forecasted transport emission growth at CAGR of 0.02% (2021-47) (Table – 8 and Appendix Fig. – 1C) in comparison to CAGR of 5.41% (1990-2020).

Though the electricity consumption in the Transport sector has increased from 14803 TJ (1990) to 52804 TJ (2020) due to electrification of railways with gradual replacement of coal and diesel run engines, metro railways expansion and recent increase in sales of EVs/PHVs, etc., the share of primary fuel consumption due to indirect use (i.e., electricity consumption) has decreased while that of direct primary fuel consumption has increased due to increased number of vehicles at CAGR of 9.58% (with 2and3-wheelers at CAGR of 10.02% followed by cars, jeeps, taxis (CAGR of 9.4%) and goods vehicles (CAGR of 8.2%)) with rise in per capita GDP from 532.75 to 1817.82 during 1990-2020 which provides more purchasing ability to the consumers and increased urbanisation from 25.5% to 34.93%, better connectivity between the suburban areas with major urban areas due to various road construction projects under different schemes like Bharat Nirman, Bharatmala project, etc. and other demographic factors like higher proportion of youth in population.

The share of primary fuels for electricity production in TPEC in residential sector (i.e., indirect energy consumption in residential sector) was 6.65% (1990) and increased to 32.7% due to high electricity consumption (at CAGR of 7.6% during 1990-2020) with increase in access to electricity [36.9% to 99% during 1990-2020] and growing use of electrical appliances. The electricity consumption replaced the use of biofuels in residential sector for lighting as evident from decline in its share in TPEC – from 86.3% to 74.1% during the same period. The expansion of cleaner cooking fuels with subsidised programmes, e.g., National Biogas and Manure Management Program (NBMMP) (1981), National Program on Improved Chulhas (NPIC) (1986), National Biogas and Manure Management Programme (NBMMP) (2002-03), Unnat Chula Abhiyan (2014-17), subsidised kerosene and later LPG which is cleaner fuel than kerosene with subsidised LPG programmes (e.g. PMUY). Most of the electricity is produced by burning fossil fuels (especially, coal) share of fossil fuel in electricity generation in TPEC was as high as 86.9% in 2020 (87.98% in 1990). Therefore, these Govt. supported programmes for electricity expansion as well as modern cooking and lighting fuels caused fuel shift in domestic sector in favour of higher share of fossil fuels in TPEC. The expansion of RE in remote areas with no grid access and roof top off-grid solar power systems would continue in future. Despite the access to electricity and subsidised cooking fuels, the use of traditional biomass-based fuels continues to dominate, especially in the rural areas because it is freely available while RE-based energy services suffer intermittency problem. Therefore, the biomass use mainly for cooking purposes would continue in India. As a result, growing expansion of RE in urban and remote rural areas and continuation of dependence on traditional biofuels would keep the share of non-fossil TPEC in residential sector growing and it is forecasted to increase though at a slower rate of CAGR of 0.72% (2021-47) (0.83% in 1990-2020) (Table – 8 and Appendix Fig. – 1P), whereas, the TPEC(F) in the Residential sector is projected to increase by CAGR of 1.55% (Table – 8 and Appendix Fig. – 1O). But overall, due to growing dependence of modern energy services like electricity, clean cooking fuels, etc. the share of fossil fuel in TPEC in Residential sector is 44.09% which is projected to increase to 50.48%. Hence, the CO_2 emissions is also projected to increase by 1.6% (CAGR) during 2022-47 in the Residential sector.

Even though the electricity demand is expected to rise in coming years, the primary fossil fuels use in electricity production is expected to fall due to growth in renewable energy (RE) and also energy efficient production techniques in power plants which reduced overall primary energy consumption in production of one unit of secondary energy (i.e., electricity). This progress is led by initiation and evolution of policies like NSM for solar power, wind power, newly initiated green hydrogen/ammonia, National Smart Grid Mission (NSGM) (2015) for making grid suitable to RE sources, Green Energy Corridors, Renewable Energy Certificate (REC) Mechanism, National Wind-Solar Hybrid Policy, etc.

As a result, the primary fossil fuel consumption in electricity generation is forecasted to decline at CAGR of (-1.13)% during 2021-47 (Table – 8 and Appendix Fig. – 1K) in comparison to CAGR of 5.18% during 1990-2021. Whereas, the non-fossil primary energy consumption for electricity production is forecasted to increase by CAGR of 2.93% (2021- 47) (5.5% in 1990-2020) (Table – 8 and Appendix Fig. – 1L). Moreover, India has achieved (2021) the committed target of 40% of installed capacity from non-fossil energy sources by 2030 under Paris Agreement (2015) with installed electricity capacity of 157.32 GW [solar power: 48.55 GW, wind power: 40.03 GW, Small hydro Power: 4.83 GW, Bio-power: 10.62GW, Large Hydro: 46.51 GW)] which is 40.1% of total installed capacity of 392.01 GW (M. of N. and R. E. G. of I. Press Information Bureau, 2021).

6. Conclusion –

Therefore, from the foregoing analysis, it is found that due to economic growth and higher energy consumption with skewed energy structure in favour of fossil fuels, the total emissions is projected to increase during 2021-47. While during the same time period, both Transport and Residential sectors are going to experience positive CAGR of emissions at 1.79 and 1.62%, respectively (Table – 8 and Appendix Figs. – 1C & 1D). But the Industry sector is going to have lower growth of sectoral emission with CAGR of (-0.62)% (Table – 8 and Appendix Figs. – 1B). This forecasted emissions scenario can be related to the energy consumption composition in these sectors. Though in all sectors, the consumption of fossil fuel consumption is going to decrease in comparison to the 1990 level, such decrease is more evident in Industry sector due to higher use of biofuels in direct industrial consumption and higher electrification of the industrial process which increases the scope for penetration of REs. In fact, the growth in TPEC in industrial sector is forecasted to reduce from CAGR of 4.53% (1990-2020) to 1.16% (2021-47) due to technological improvement with successful implementation of market-based energy efficiency measures like PAT, etc. The emission increase in Residential sector (CAGR of 5.14%) is found to be higher than that of the Transport (CAGR of 4.69%) and Industry (CAGR of 4.27%) sectors during 1990-2020 due to higher energy access at the household level, replacement of traditional renewable sources like biomass and as per the forecasting analysis the residential sector would continue to experience high share of fossil fuel 50.48% and the transport sector also would have 94.7% fossil fuel in TPEC (transport sector) due to continuation of oil products as transport fuels with lack of suitable RE alternative.

In all the three major energy consuming sectors, though both the energy consumption and emissions are forecasted to increase but the CAGR of energy-related emissions increase in the forecasted period (2021-47) is found to be lower in all three sectors in comparison to the period – 1990-2020: from 4.27% to (- 0.62)% in Industry sector, from CAGR of 4.69% to 1.79% in Transport sector and from 5.14 to 1.62% in Residential sector. Thus it is seen that the emission is going to decrease in the Industry sector most in comparison to other 2 sectors due to successful implementation of policies like PAT which played a significant role in industrial sector energy efficiency. In the industrial sector the share of fossil fuels is forecasted to decrease from 70.33% (2020) to 48.44% (2047) due to gradual increase in direct use of non-fossil fuels in industrial purpose and also through growing electrification of mechanisation where electricity is increasingly sourced from non-fossil fuels. In the Transport sector the share of fossil fuel is 97.81% in 2020 and it is projected to decrease to 94.7% in 2047 due to targeted measures of biofuel mixing with traditional auto fuels, but it is a cause of concern that in comparison to other sectors, the energy structure in the transport sector is more skewed in favour of fossil fuels, due to factors like lack of alternatives and limited progress of penetration of new age vehicles (e.g., EVs/HEVs, etc.), suitable low carbon alternatives and also due to limited scope for biofuel expansion due to competing demand for land and water demand from other sectors. The modern biofuel processing, e.g., 3rd generation biofuel, etc. is in still-to-be-matured stage. But even then growth rate of emissions is going to decrease due to lower Carbon Intensity (CI) in transport sector with periodical upgradation of auto fuels with lesser emission potential under Bharat Stage (BS) norms which follows the Euro vehicular emission norms.

In the electricity sector, 86.94% of electricity is produced from fossil sources and it is forecasted to decrease to 69.5% due to continuous progress in harnessing the RE in electricity generation through multi-pronged approach to source as much electricity as possible from the clean energy sources with various target-oriented policy directions –

The forecasting results of declining trend of the parameters like EI_t, CI_t are found to be consistent with the IESS-2047 projection data also, which is also explained by improvement in Energy Efficiency due to various factors like technological improvement which consumes less energy, upgradation of auto fuels to emit less CO_2 in transport sector, use of natural gas (especially in transport sector) within the fossil fuel group, adoption of coal washing in thermal power plants, use of super critical boilers in thermal power plants, use of cleaner fuels in residential sector, etc.

7. Recommendations –

As electricity has turned out to be a vehicle for energy transition for low carbon economy, so integration of digitalisation and energy sector is necessary to reduce energy intensity in the economy and as electrification is medium of energy sector transition. Therefore, IoT based smart grid system can be effective and digitalisation helps facilitate electrification with higher connectivity among producers, grid operators and end users. Since share of electricity generated from coal has increased from 65.34% (1990) to 71.52% (2020) (International Energy Agency, 2022), so reduction of high T&D losses emerged as an important measure to prevent wastage of Exergy (i.e., useful energy) which would in turn ensure lower use of primary fuels to generate secondary energy (i.e., electricity) to meet the actual electricity demand. India has planned 80 GW new power capacity addition on the basis of Peak Load Factor (PLF) of 80%. But the PLF factor is low (average 64%) in India during 2010-20, which requires improved optimisation of plant capacity to prevent new investment in fossil fuel-based power plants.

As the forecasting result shows that Industrial energy consumption is going to decrease due to energy efficiency measures which is dependent on TI, which is going to be an important factor for improvement in carbon intensity of industrial sector with measures like Carbon Capture, Utilisation and Storage (CCUS) with adequate financial support, increased electrification industrial mechanisation which also help shift energy composition. The inclusion of MSME sector under the PAT scheme as the industries under this sector is operating with low energy efficient production techniques due to lack of fund for R&D for energy efficiency improvement, low expertise and low transfer of technologies, etc. and such measure would reduce energy consumption to a great extent.

In the Transport sector, policy effort for reduction of direct consumption of primary fossil fuels resulted in electrification of railways and mechanisation of industrial process, growth (CAGR of 62.3% in the post-Paris Agreement period) of electric vehicles (EVs) (International Energy Agency). As in future EVs would be a leading player in the car segment so attention for development of infrastructure facility like mandatory charging facilities in the oil pump stations, etc. are important for expansion of EVs. The increase in number of buses, especially the battery-run buses which would be helpful in containing the transport emissions and this measure is also in consonance with the NUTP, 2014. Also in rail transportation which has low carbon footprint, share of rail in freight transport has decreased from 60% to only 27%–28% during 1991 – 2022 and thus the achievement of the target of National Rail Plan to increase the share to 45% of freight share by 2030 is important for increasing the rail transportation which is considered as a Driver factor being less polluting mode of freight transport than trucks, etc. (The Energy and Resources Institute, 2023). The completion of ongoing metro rail network and expansion of metro rail network in other Tier – 2 and 3 cities given the future urban population growth in these cities is important mass rapid transportation. Gradual increase in share of biofuel to meet the present target of 20% under National Biofuel Policy and raising the limit later are important measures for low carbon transport fuels.

Subsidy shift for cleaner cooking fuels is evident in India from kerosene to LPG at the household level, but still the consumption of biomass at the residential sector is quite high 74.15% (2020) of direct TPEC in residential sector (International Energy Agency, 2022) in comparison to other sectors and also in comparison to other developed countries – Germany (14.46%), USA (8.28%), China (34.27%) (International Energy Agency, 2022). Therefore, gradual and balanced reduction of subsidies for crude oil products like LPG, etc. and continuation of RE subsidy for promoting consumption shift to RE based appliances is essential for continued growth in RE through electricity. Especially, the Govt. financial support for installation of roof-top solar PVs in the residential areas would increase the uptake of RE based power system which would reduce the requirement of import of coal for power stations and would reduce emissions from coal-fired power plants. Mandatory building codes for residential buildings and retrofitting the existing building stock to make them compatible with upgraded building codes with smart lighting system is necessary to reduce residential sector emissions.

Standard & Labels promotes the Sustainable Consumption and Production (SCP) behaviour on the part of the producers and consumers. Recently RE appliances are also being brought under this scheme, e.g., the solar inverter which would help increase more acceptance among the consumers and thus such measures should be expanded to more household electrical appliances as with growing electricity access and urban growth, there would be considerable increase in electricity consumption for these appliances in future.

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Appendix Fig.1: Forecasted variables

Fig.1A: Holt–Winters nonseasonal smoothing (Forecasting) (Total CO_2 emission)

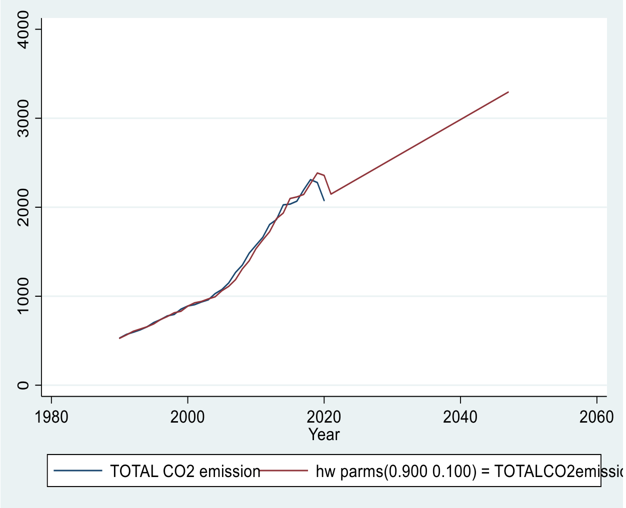


Fig.1B: Holt–Winters nonseasonal smoothing (Forecasting) (Industry Emissions)

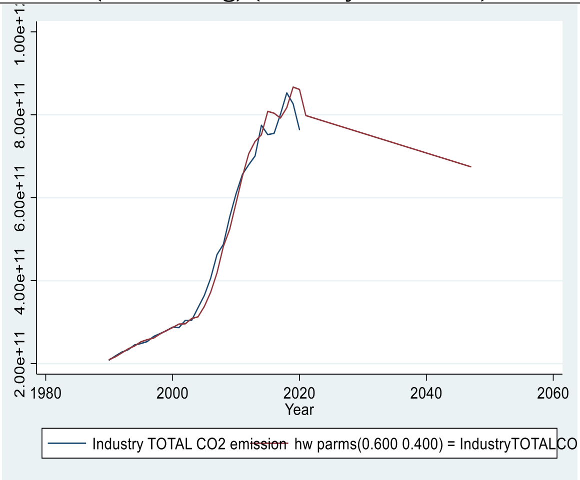


Fig.1C: Holt–Winters nonseasonal smoothing (Forecasting) (Transport Emissions)

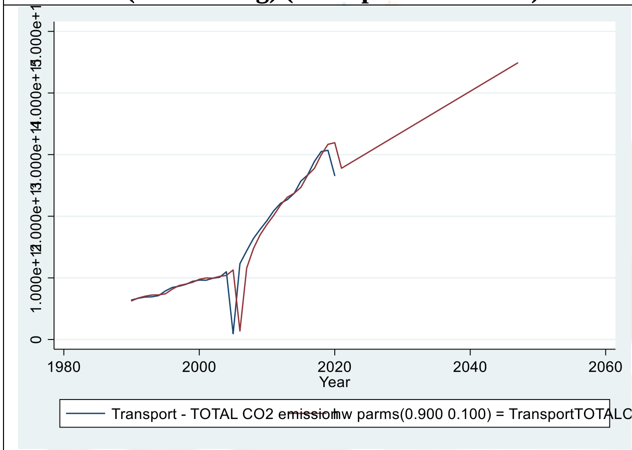


Fig.1D: Holt–Winters nonseasonal smoothing (Forecasting) (Residential Emissions)

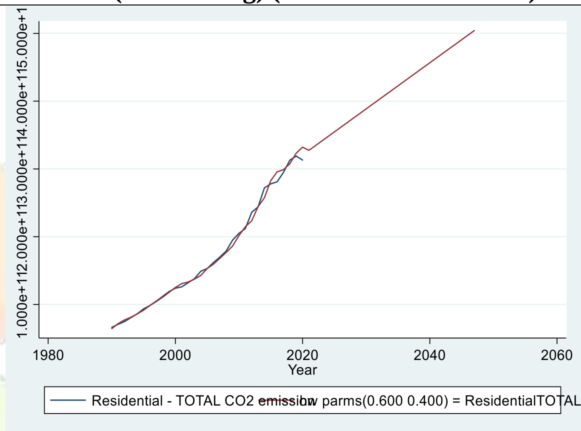


Fig.1E: Holt–Winters nonseasonal smoothing (Forecasting) (CO_2/GDP (kg CO_2/2015 USD))

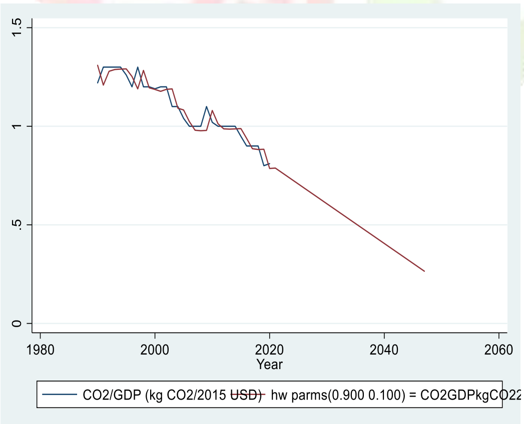


Fig. 1F: Holt–Winters nonseasonal smoothing (Forecasting) (TPEC/GDP (TPEC/2015 USD))

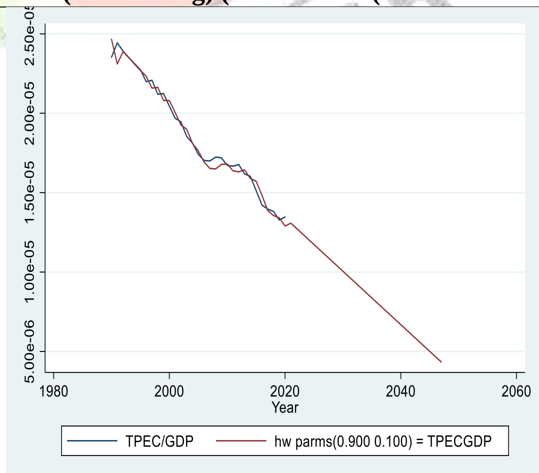


Fig.1G: Holt–Winters nonseasonal smoothing (Forecasting) (TNFFE+TNFFNEC) (TPEC(NF))

Fig.1H: Holt–Winters nonseasonal smoothing (Forecasting) (TFFE+TFFNEC) (TPEC(F))

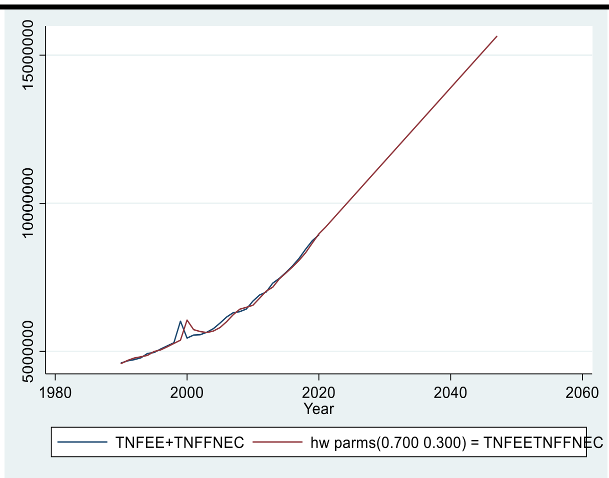


Fig.1I: Holt–Winters nonseasonal smoothing (Forecasting) (Industry (TPEC(F))

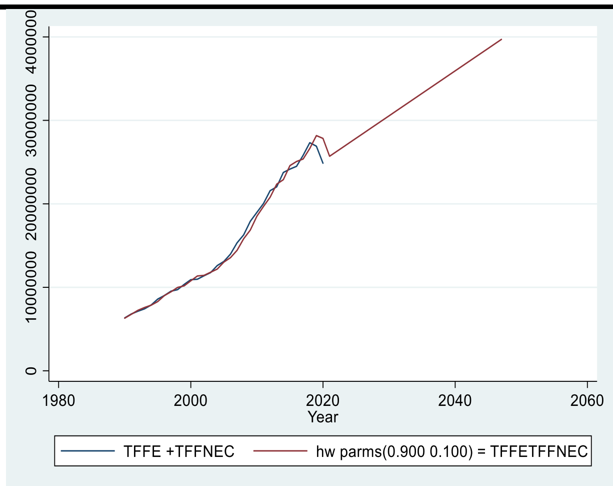


Fig.1J: Holt–Winters nonseasonal smoothing (Forecasting) (Industry (TPEC(NF))

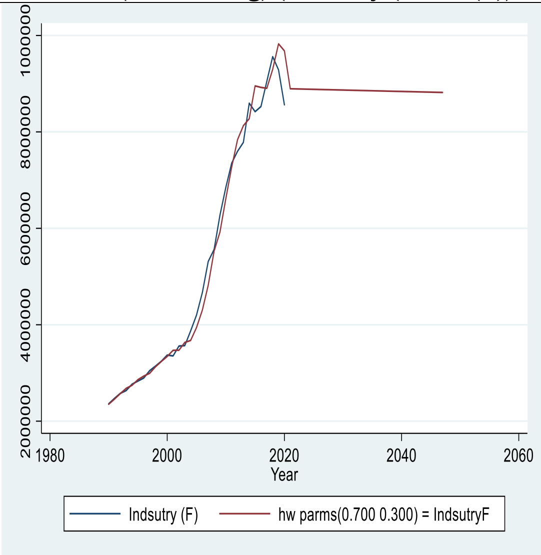


Fig.1K: Holt–Winters nonseasonal smoothing (Forecasting) TPEC (F) (Electricity))

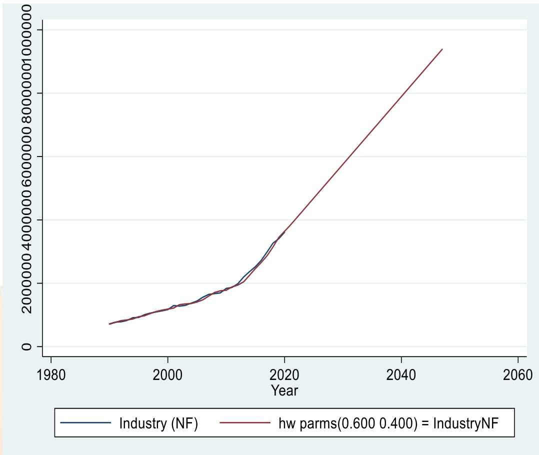


Fig.1L: Holt–Winters nonseasonal smoothing (Forecasting) TPEC (NF) (Electricity))

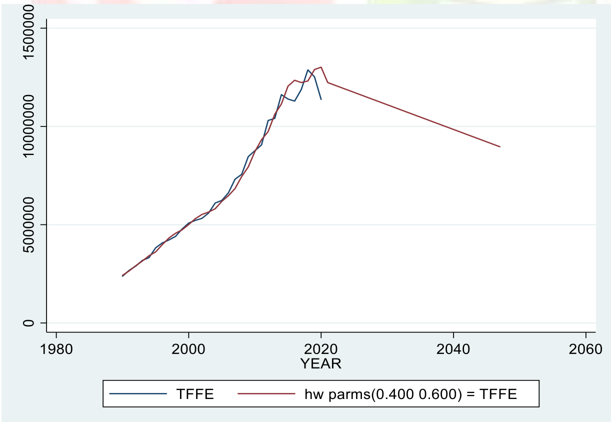


Fig.1M: Holt–Winters nonseasonal smoothing (Forecasting) (Transport (TPEC)(F))

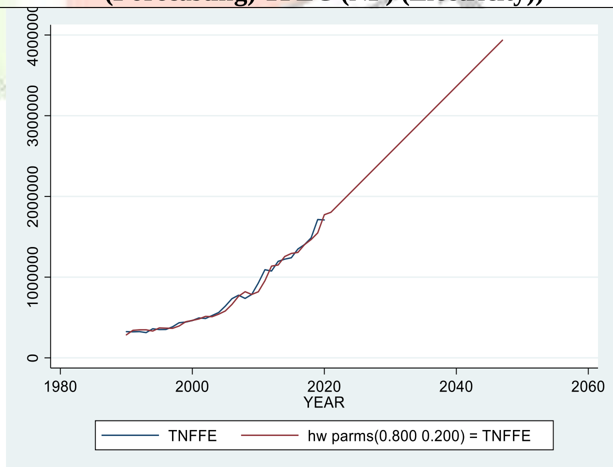
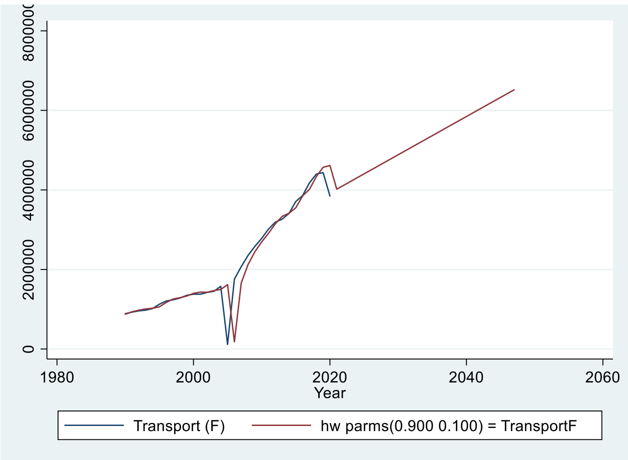


Fig.1N: Holt–Winters nonseasonal smoothing (Forecasting) (Transport (TPEC)(NF))



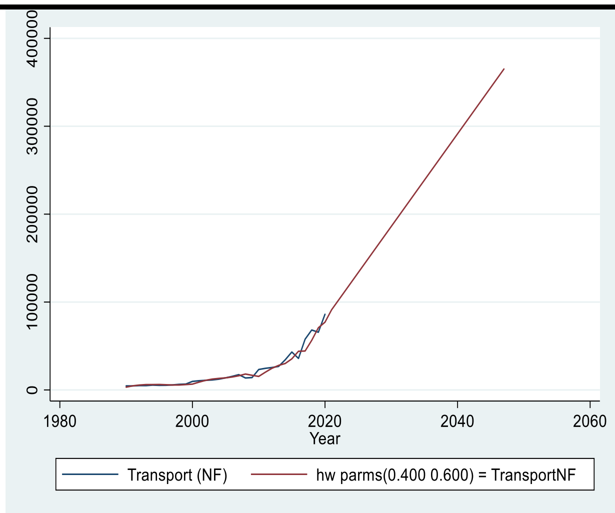
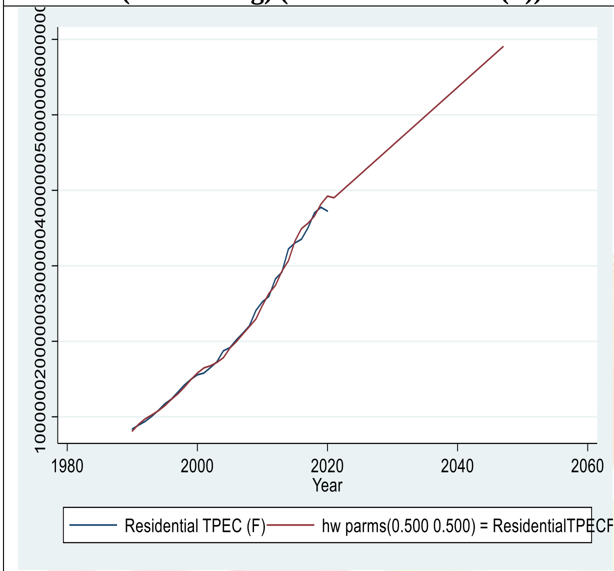
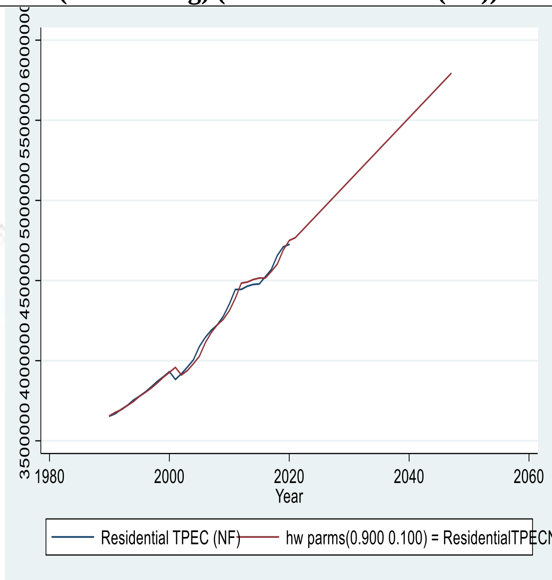


Fig.1O: Holt–Winters nonseasonal smoothing (Forecasting) (Residential TPEC (F))

Fig.1P: Holt–Winters nonseasonal smoothing (Forecasting) (Residential TPEC (NF))





Source: Author