The 1st IAEE Online Conference
June 7-9, 2020

Dynamic Multi Sector Energy Economic Model for Sustainable Development in The Electricity Sector Of Bangladesh

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1.1 Introduction: Objective

The primary objective this research is to investigate the energy-economic relationships in of the developing regions of South-Asia - Bangladesh to analyze different policy scenarios for sustainable development in the Electricity sector.

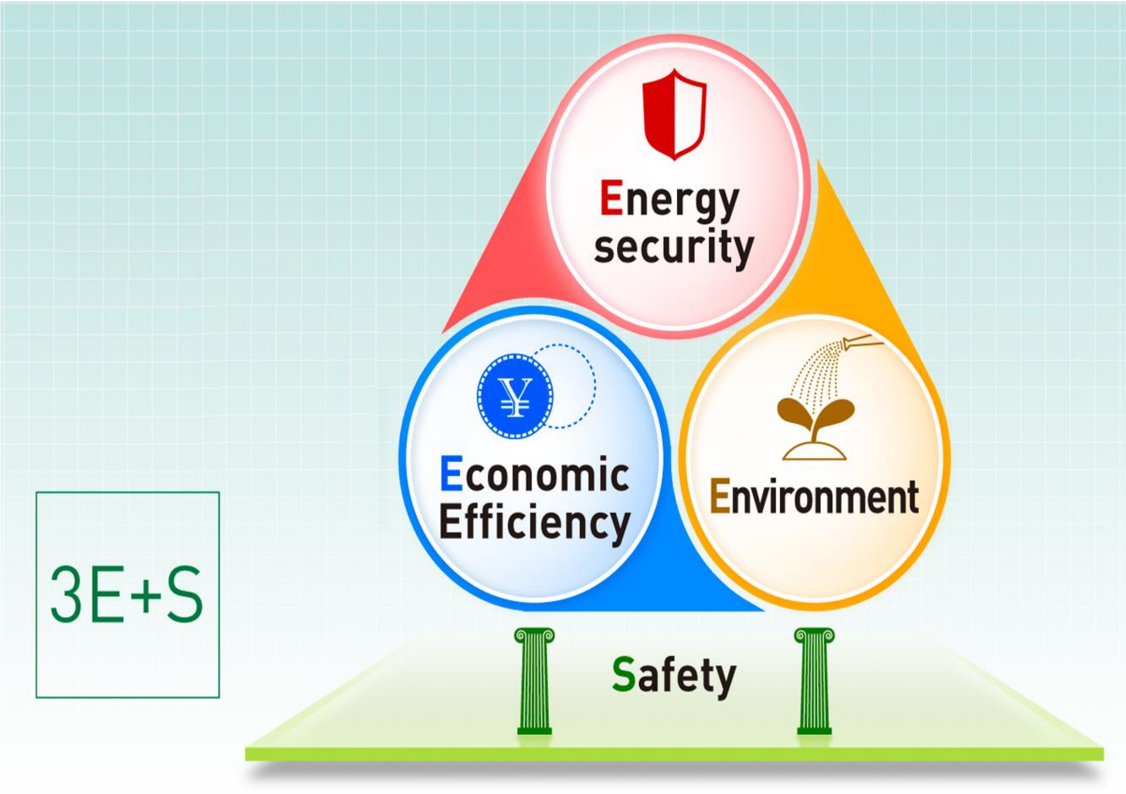


Fig. 1: 3E+S concept

1.2 Bangladesh: Country Facts and Figures

About Bangladesh

Independence: 1971

Land area: ~ 147,570 sq. km

Population: ~167.6 million (2020)

Population Density: 1120 per sq. km

GDP: 302.6 billion USD (2019)

GDP Growth Rate: 8.2% (2019)

GNI per-capita: 1827 USD (2019)

* In February 16, 2021 Bangladesh was recommended for graduation from LDC by UN Committee for Development Policy (CDC)

Fig. 2: Position of Bangladesh in World Map

1.3 Bangladesh: the Developing Economy

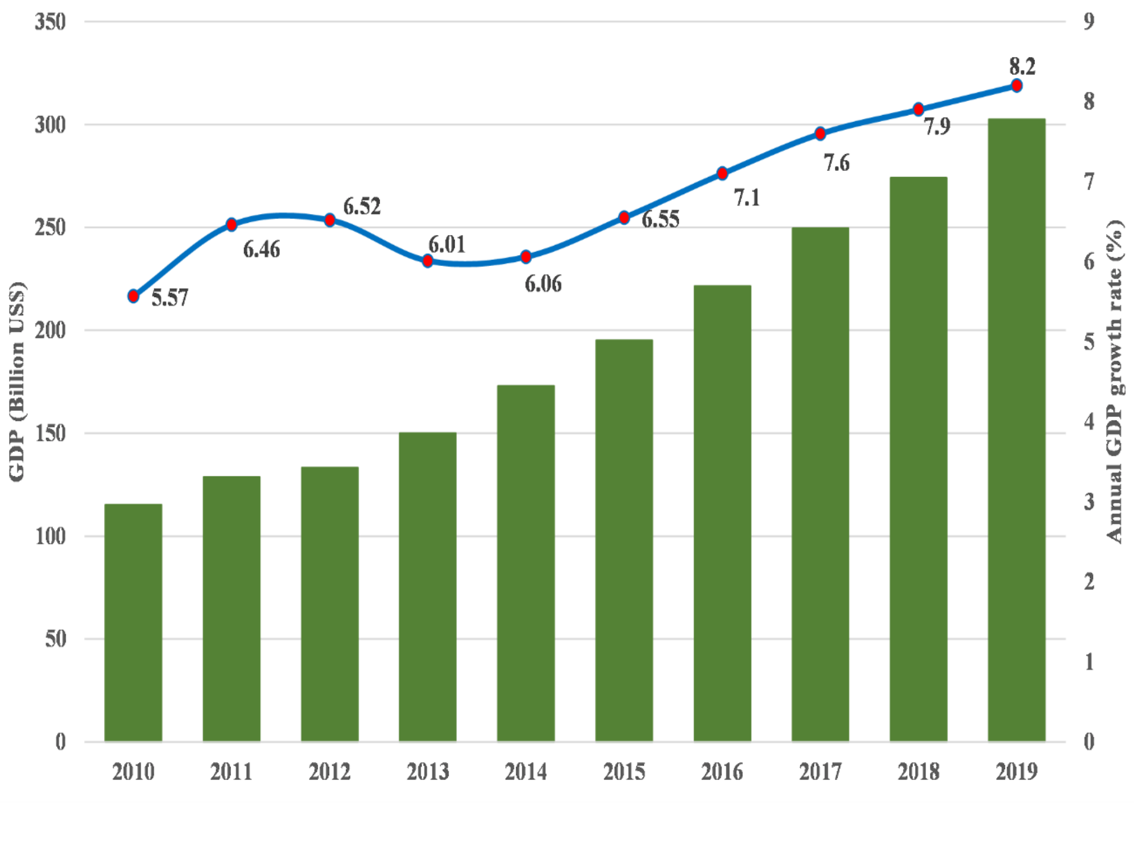


Fig. 3: Bangladesh GDP and Growth [1]

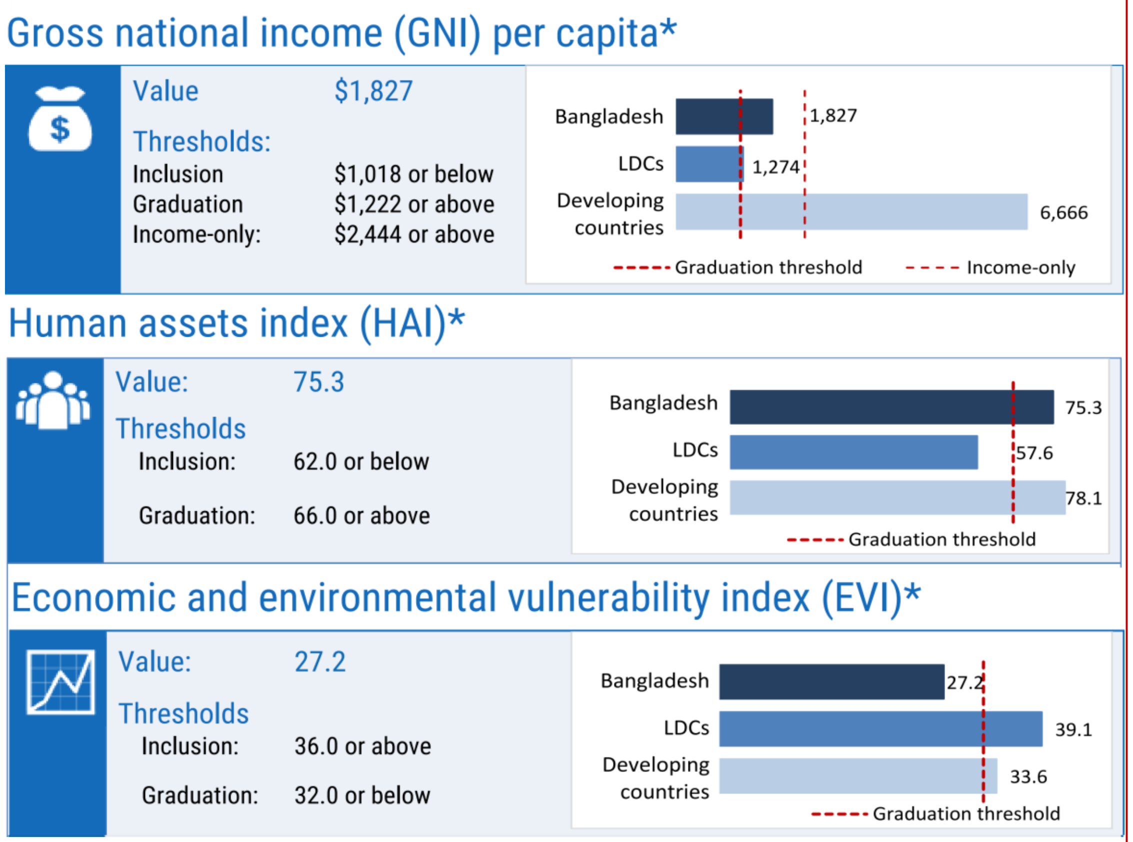


Fig. 4: LDC Graduation Performance Review [2]

1.4 Energy Sector in Bangladesh

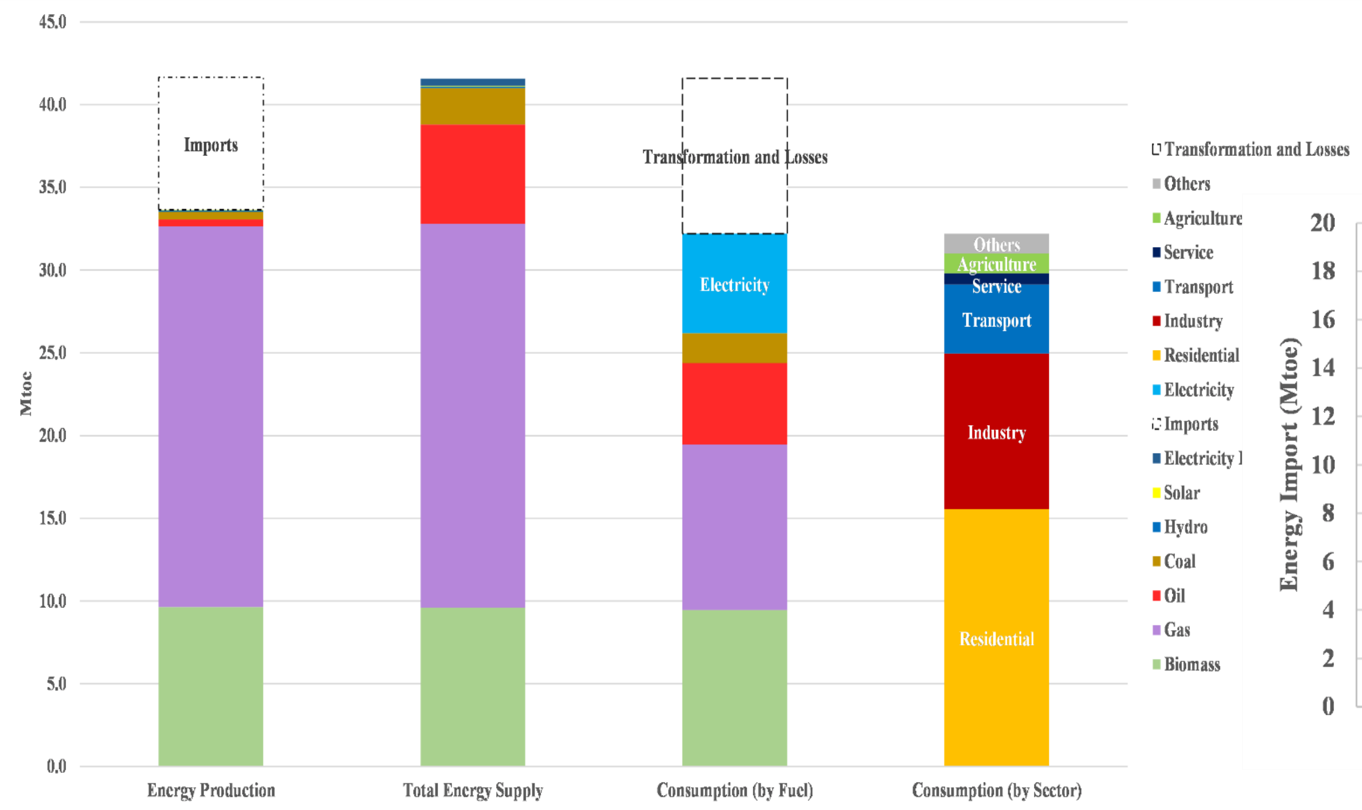


Fig. 5: Energy Balance of Bangladesh in 2019 [3,4]

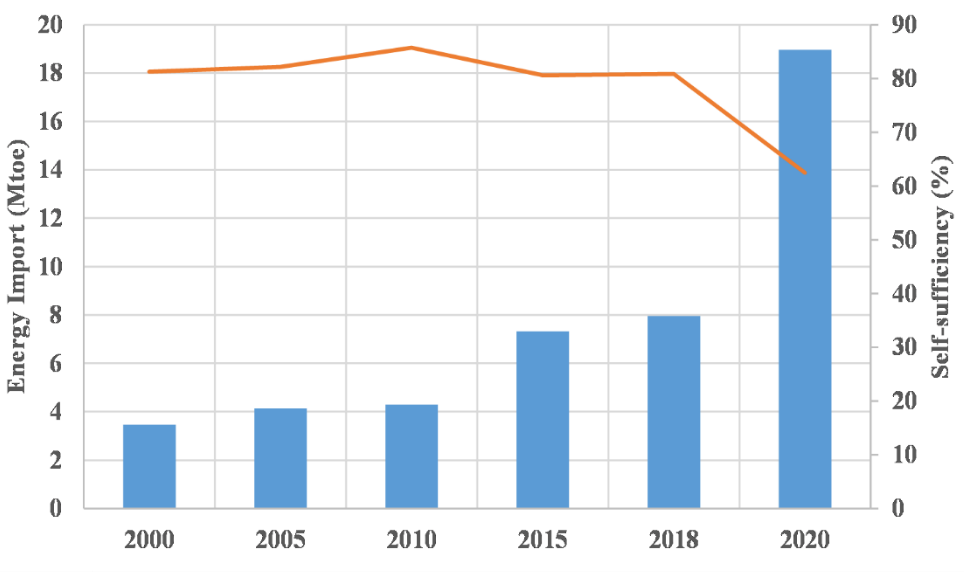


Fig. 6: Energy Import and Self Sufficiency [4]

1.5 Depleting Natural Resource

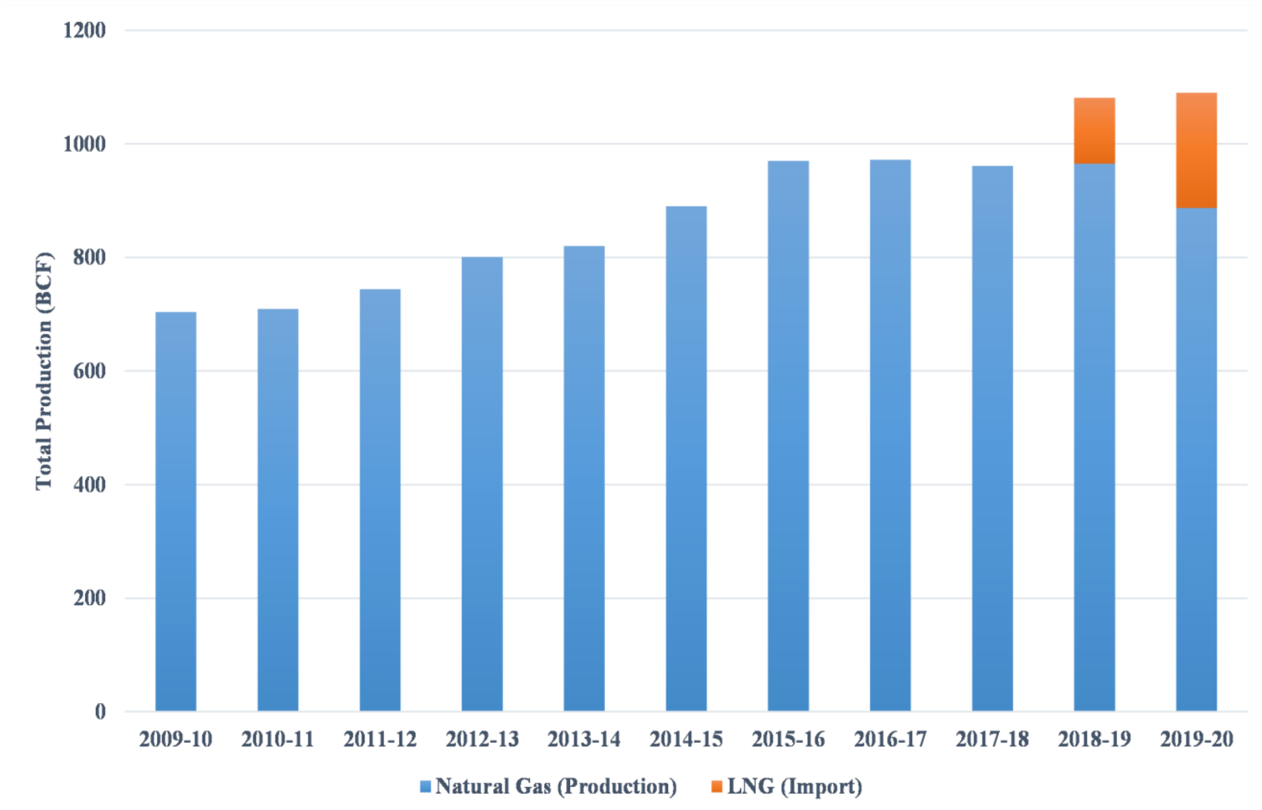


Fig. 7: Historical Natural Gas Production and LNG Import [4]

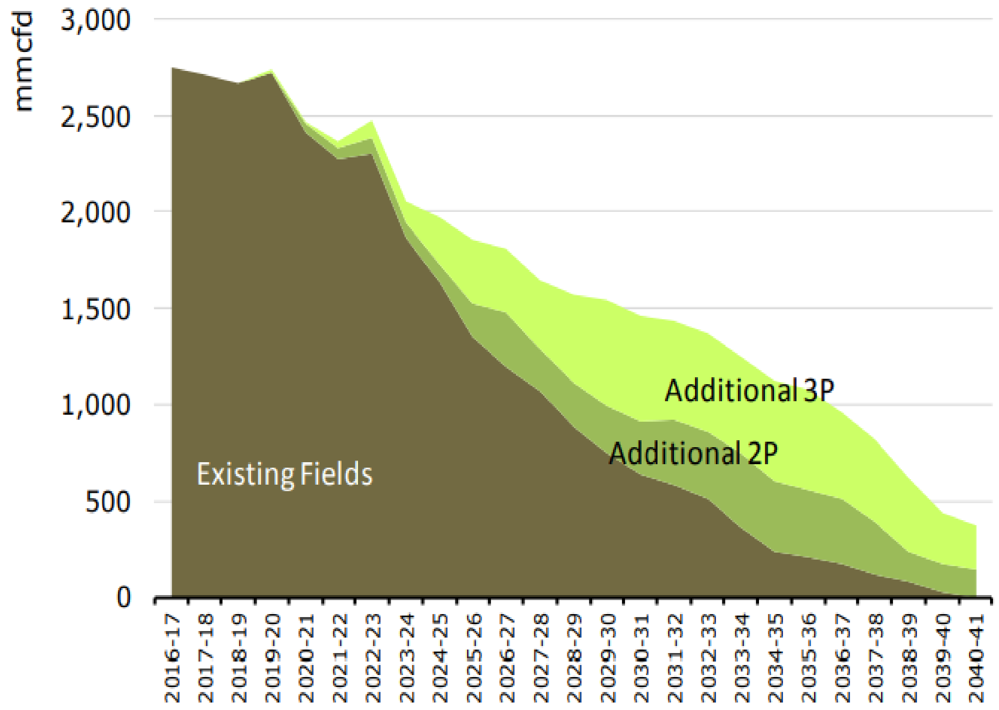


Fig. 8: Natural Gas Reserve and Production Forecast [5]

1.6 Electricity Sector in Bangladesh

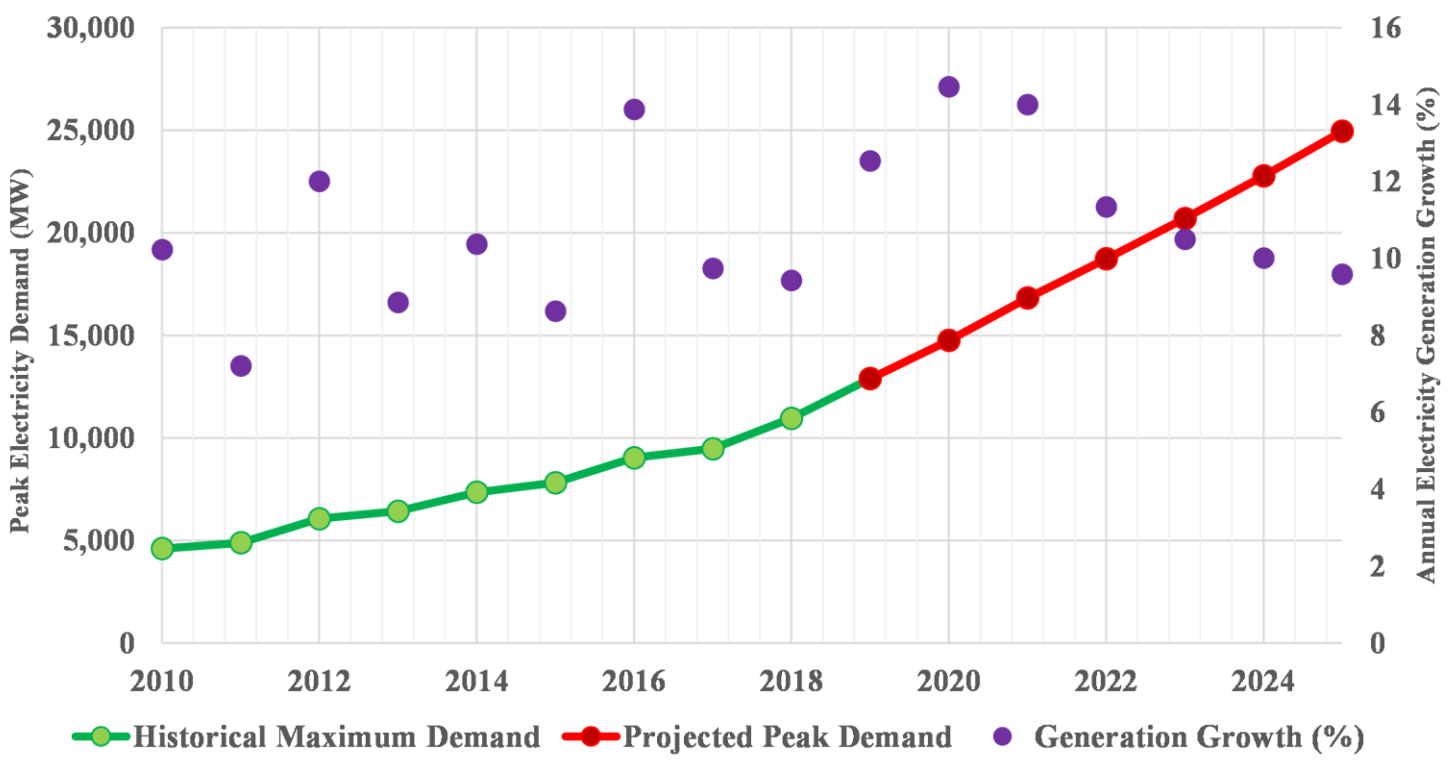


Fig. 9: Historical Electricity Demand and Projected Growth [6]

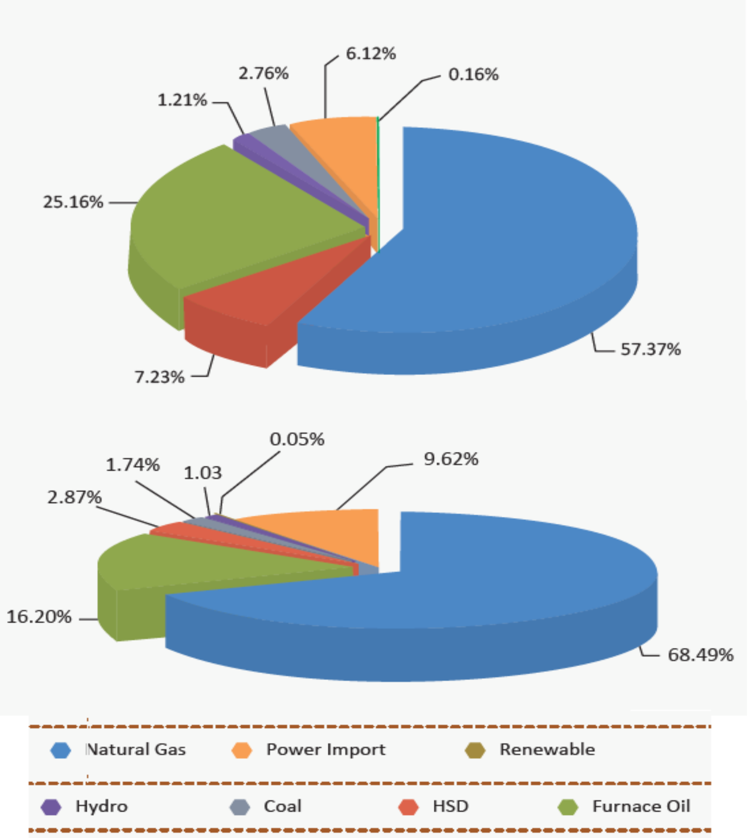


Fig. 6: Installed Capacity and Generation Mix in 2019-20[4]

1.7 CO_2 Emissions in Bangladesh

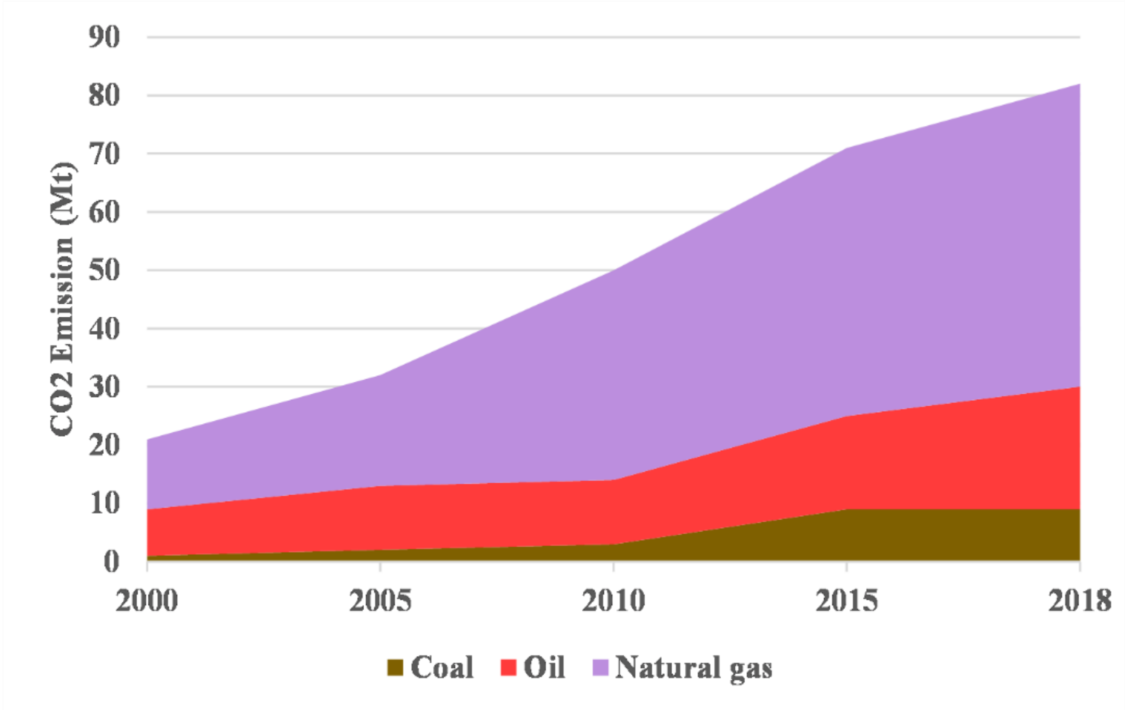


Fig. 11: Historical CO_2 Emission by Fuel[7]

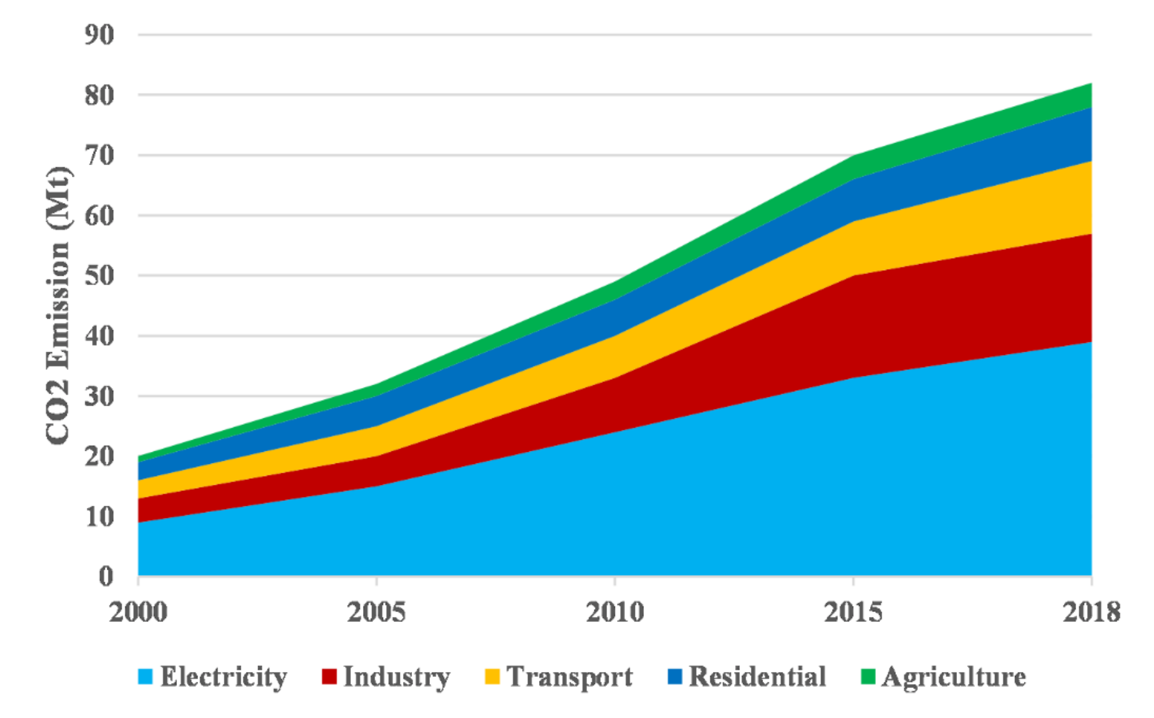


Fig. 12: Historical CO_2 Emission by Sectors[7]

2.1 Dynamic Multi-Sector Energy Economic Model

<u>DMSEE</u> uses a linear approximation method to calculate nonlinear utility functions and production functions using linear programming. To consider substitution of goods, CES (Constant Elasticity of Substitution) type utility and production functions are considered.

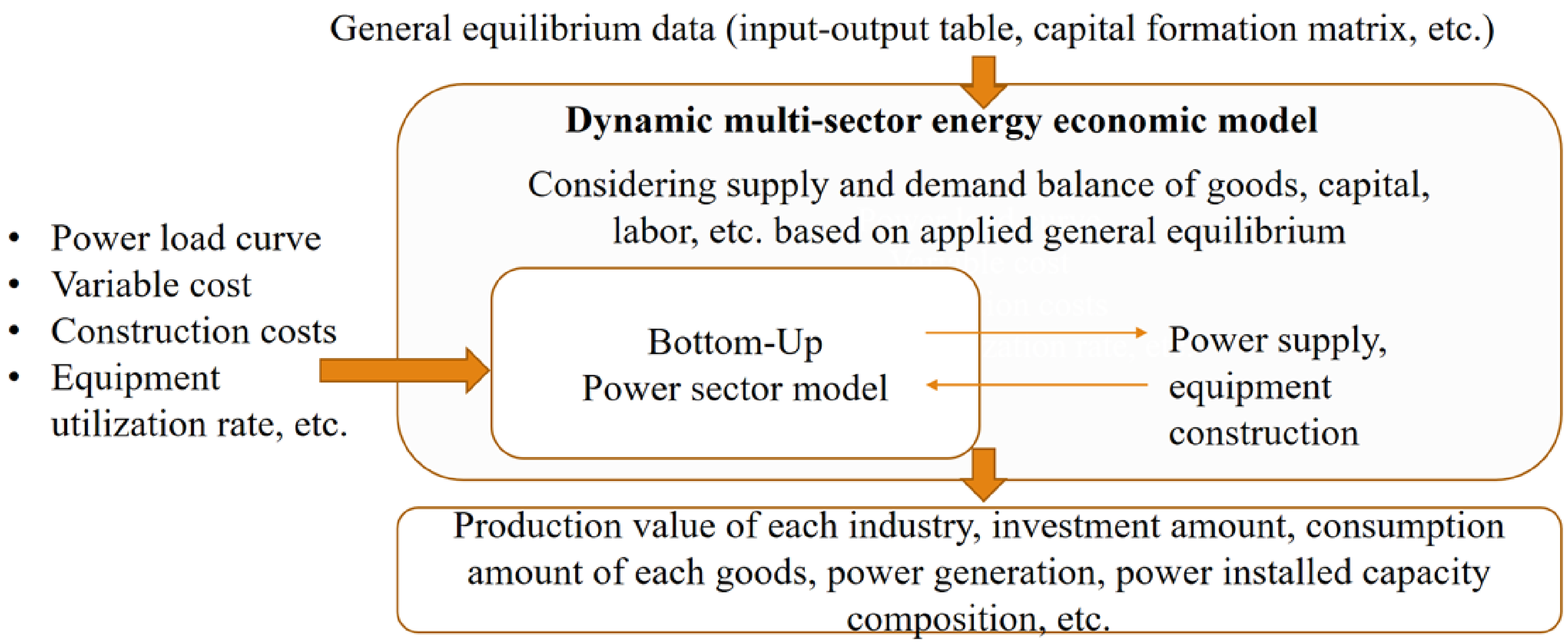


Fig. 13: Structure of DMSEE Model

2.2 DMSEE Model Structure

<u>Objective function</u>: Maximize $obj = \sum_{r \in RR} \sum_{y=0}^{Y-1} \sigma_{r,y} \left(\left(util_{H_{r,y}} + util_{g_{r,y}} \right) - \left(tax_{T_{r,y}} + tax_{B_{r,y}} \right) \right)$

Subject to the constraints from both top-down (TD) and bottom-up (BU) sectors including:

<u>Top-Down (TD) Constraints:</u>

❖Supply-demand balance,

❖Physical / resource balance,

❖Capital investment,

❖Labor (population and skills),

❖Linearization of CES function,

<u>Bottom-Up (BU) Constraints:</u>

▲ Technical limitations of each electricity technologies:

▲ Load following constrains of thermal power plants,

▲ Capacity factor of renewable generation technologies,

▲ Annual maintenance schedule,

▲ Capacity reserve & electricity supply-demand balance

2.3 Single Region DMSEE Model for Bangladesh

Main features of the model:

- 8 aggregated economic sectors: AgL (Agriculture and Livestock), Coal, Oil, Gas, Ind (Industry), Tra (Transport), Ser (Service), Ely (Electricity)
- Single regions: Bangladesh (BGD)
- 6 time points, from 2025 to 2050 considering 2020 as base year
- Base year data for consumption and international trade has been obtained from GTAP 10 data-base.
- BU Electricity Sector has been subdivided into Nuclear, Coal, Oil, Gas, Hydro, Biomass, Solar PV and Wind power generation technologies.

2.4 Energy Resources Assumptions

Table: Reserves and Resources of Non-Renewable energy sources

Fuel Type	Unit	Reserves (value)	Reserves EJ	Reserves Gt CO_2	Resources (value)	Resources EJ	Resources Gt CO_2
Hard Coal	Giga ton coal-eq. (Gtce)	624	18,288	1,730	14,966	438,625	41,494
Lignite		123	3,601	364	1,776	52,037	5,256
Coal (Total)		**747**	**21,889**	**2,094**	**16,742**	**490,662**	**46,750**
Conventional Crude Oil	Giga ton (Gt)	173	7,234	530	168	7,034	516
Shale Oil		2.2	91	6.7	60	2,496	183
Oil Sand		26	1,086	116	67	2,785	298
Extra Heavy Oil		42	1,752	187	42	1,767	189
Oil Shale		0.5	7.2	0.77	111	4,653	498
Oil (Total)		**243**	**10,070**	**841**	**448**	**18,734**	**1,683**
Conventional Natural Gas	Trillion Cubic Meter (Tcm)	191	7,261	407	312	11,855	665
Shale Gas		6.1	230	13	203	7,713	433
Tight Gas					61	2,332	131
Coal-bed Methane		1.8	69	3.9	51	1,950	109
Aquifer Gas					24	912	51
Gas Hydrates					184	6,992	392
Gas (Total)		**199**	**7,560**	**424**	**836**	**31,754**	**1,338**
Fossil Fuel (Total)	**EJ**		**39,619**	**3,359**		**541,150**	**49,771**
Uranium	Million ton (Mt)	1.2	618		12	5,855	
Thorium					6.4	3,178	
Nuclear (Total)		**1.2**	**618**		**18.4**	**9,033**	
Non-Renewable Fuels	**EJ**		**40,237**	**3,359**		**550,183**	**49,771**

Table: Energy Reserve Assumption [4, 8]

Fuel Type	(Unit)	Global Reserve	Bangla-desh
Coal	Giga ton coal-eq. (Gt-coal eq.)	**747**	**0.293**
Oil	Giga ton oil-eq (Gt-oil eq.)	**243**	**0.004**
Gas	Trillion cubic meter (Tcm)	**199**	**0.186**
Fossil Fuel	Exa-Joule (EJ)	**39,619**	**15.817**

2.4 Labor and Population Assumptions

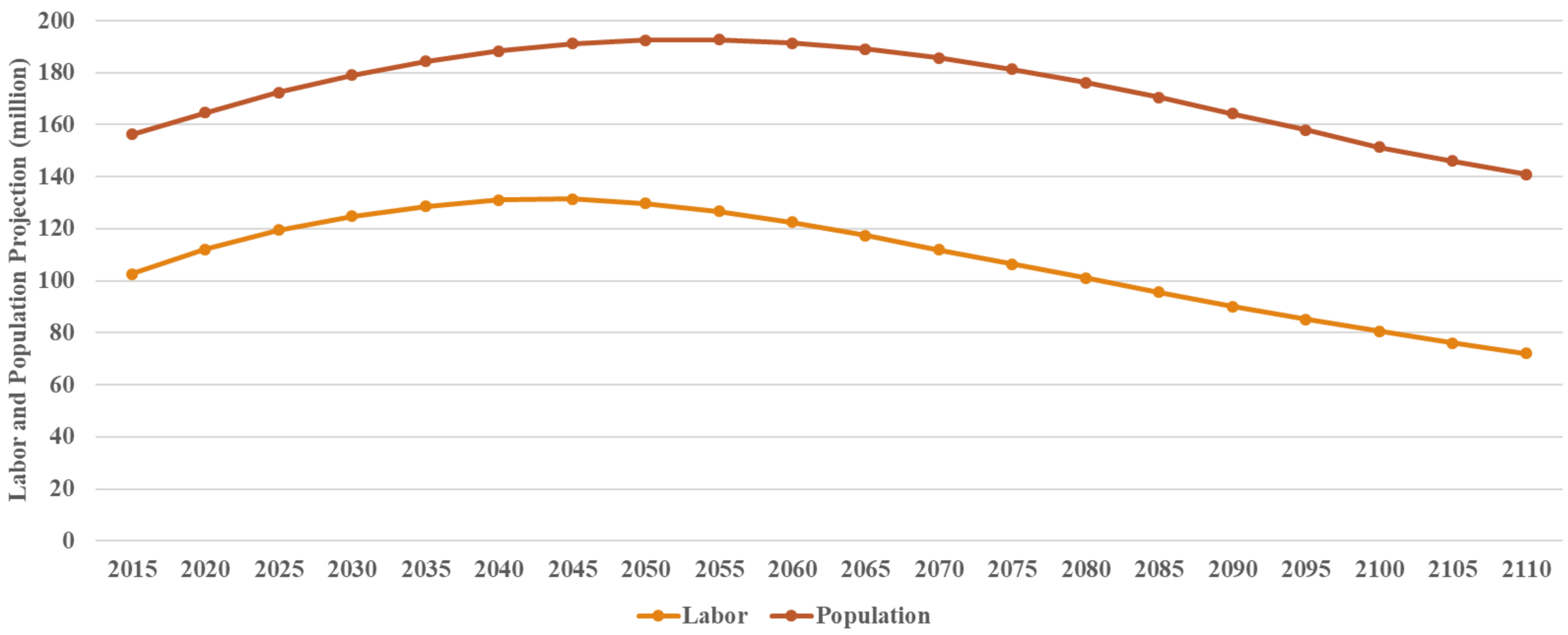
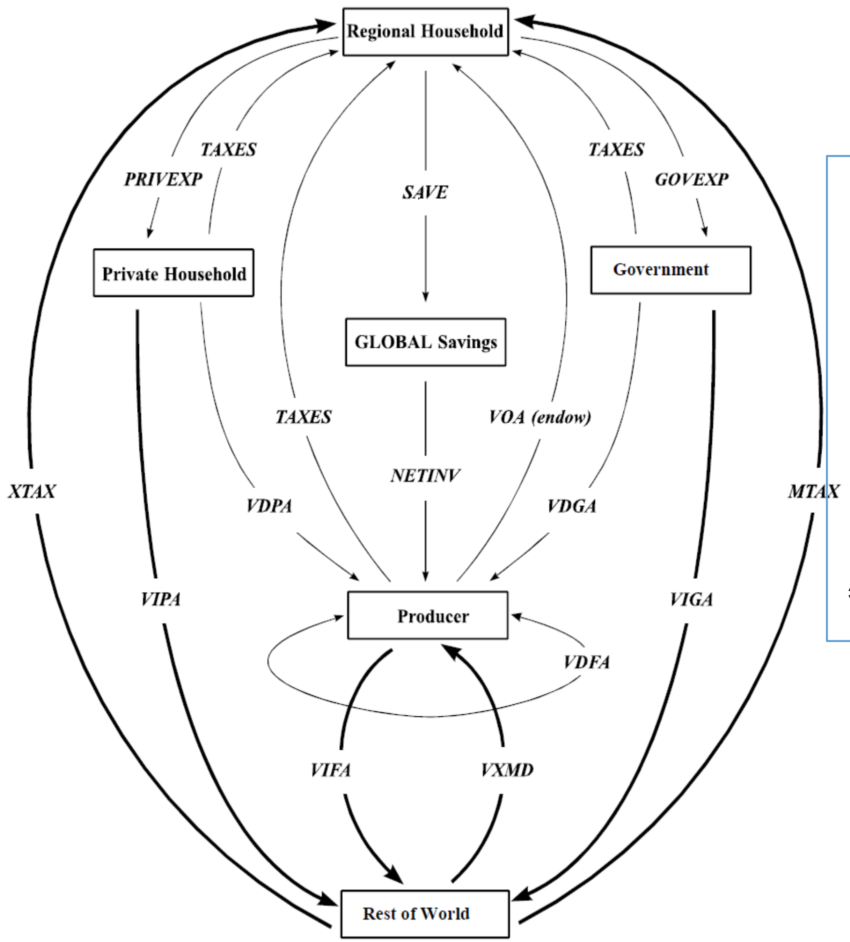


Fig. 14: Labor (15-64 years) and Population Projections [7]

3.1 Input: GTAP Database [8]

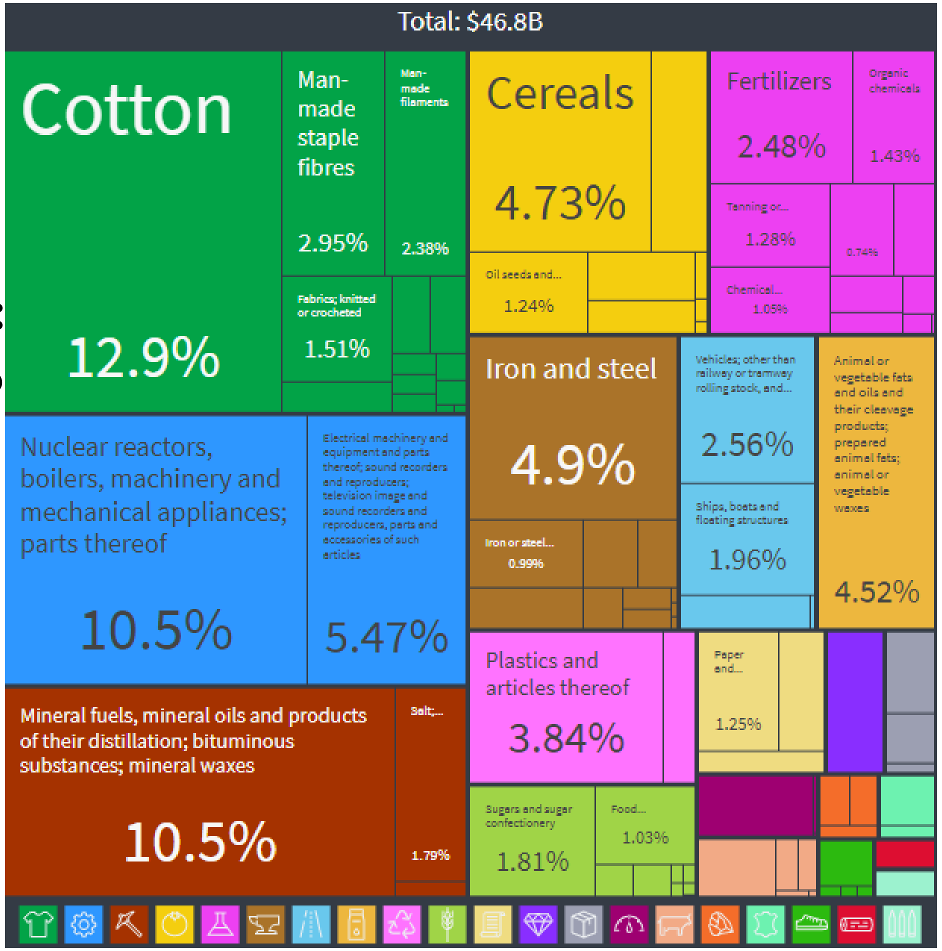
* *PRIVEXP : PRIVate household EXPenditures*
* *GOVEXP : GOVernment EXPenditures*
* *SAVE : savings*
* *VOA : Value of Output at Agent's prices*
* *VDGA : Value of Domestic Government purchases, evaluated at Agents' prices*
* *VDPA : Value of Domestic Private household purchases, evaluated at Agents' prices,*
* *NETINV : investment*
* *VDFA : Value of Domestic Firm Purchases (intermediate inputs to other producers) evaluated at Agents' prices*



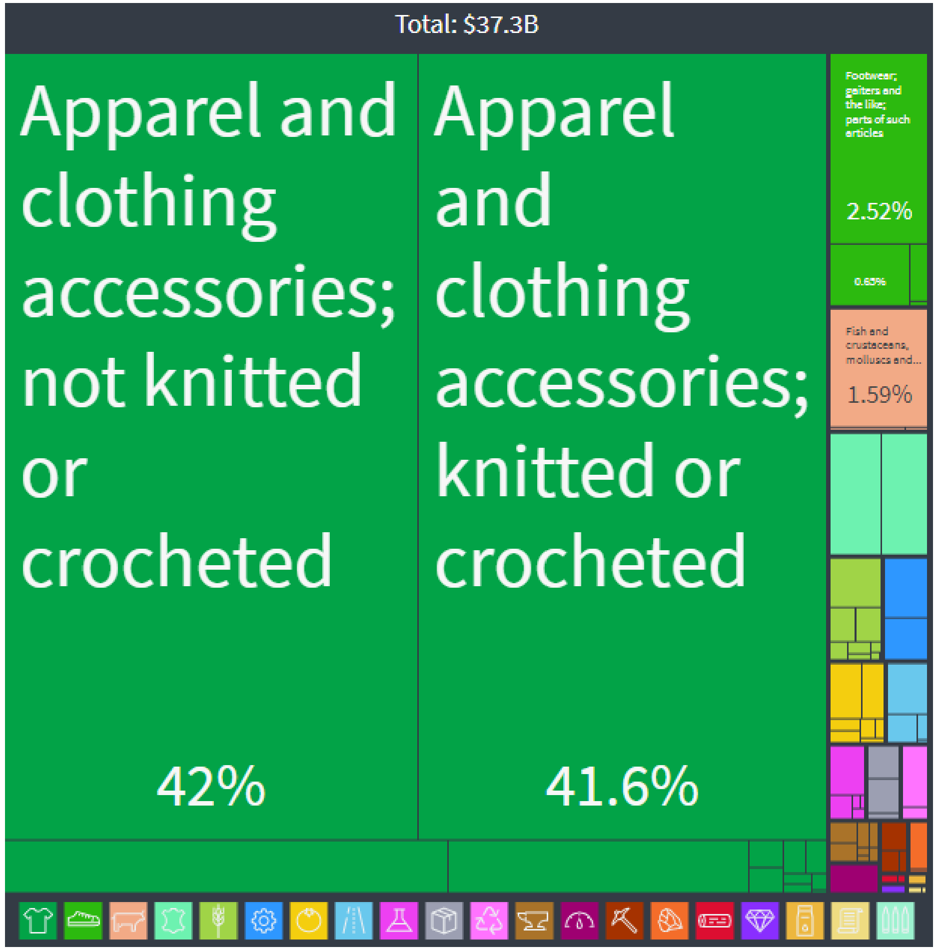
* *VXMD : Firm's Exports*
* *VIFA : Firm's Imports*
* *VIPA : Household Import*
* *VIGA : Government Import*
* *MTAX : Import Tax*
* *XTAX* : Export Tax

3.2 Bi-Lateral Trade Information (2015)

Import: 47 Bln$



Export: 37 Bln$



3.3 Scenario Development

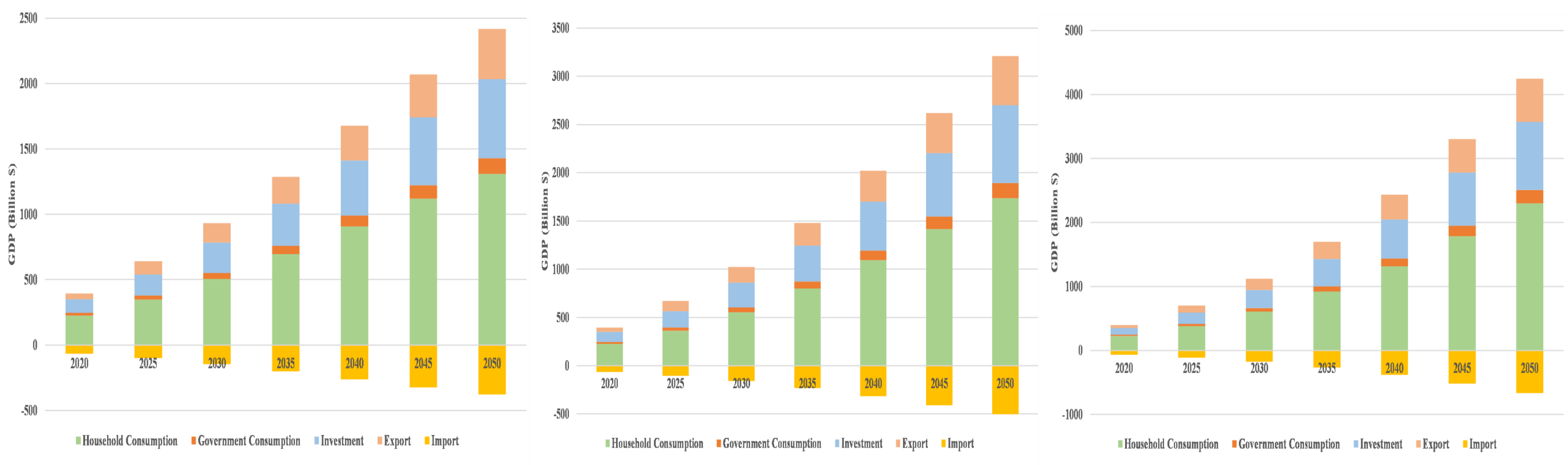
3 Different Scenario Based on per-capita Annual Consumption Growth:

- Low Growth (LG): average per-capita annual consumption growth 3.5%
- Business As Usual (BAU): average per-capita annual consumption growth 5.5%
- High Growth (HG): average per-capita annual consumption growth 7.5%

2 Different Scenario Based on CO_2 emission:

- No Carbon Restriction (BAU)
- Restrict CO_2 emission by 50%

4.1 Results: GDP Growth and Composition



(a) (b) (c)

Figure 15: GDP Composition at (a) Low growth, (b) BAU growth and (c) High growth Scenarios

4.1 Results: Primary Energy Production and Import

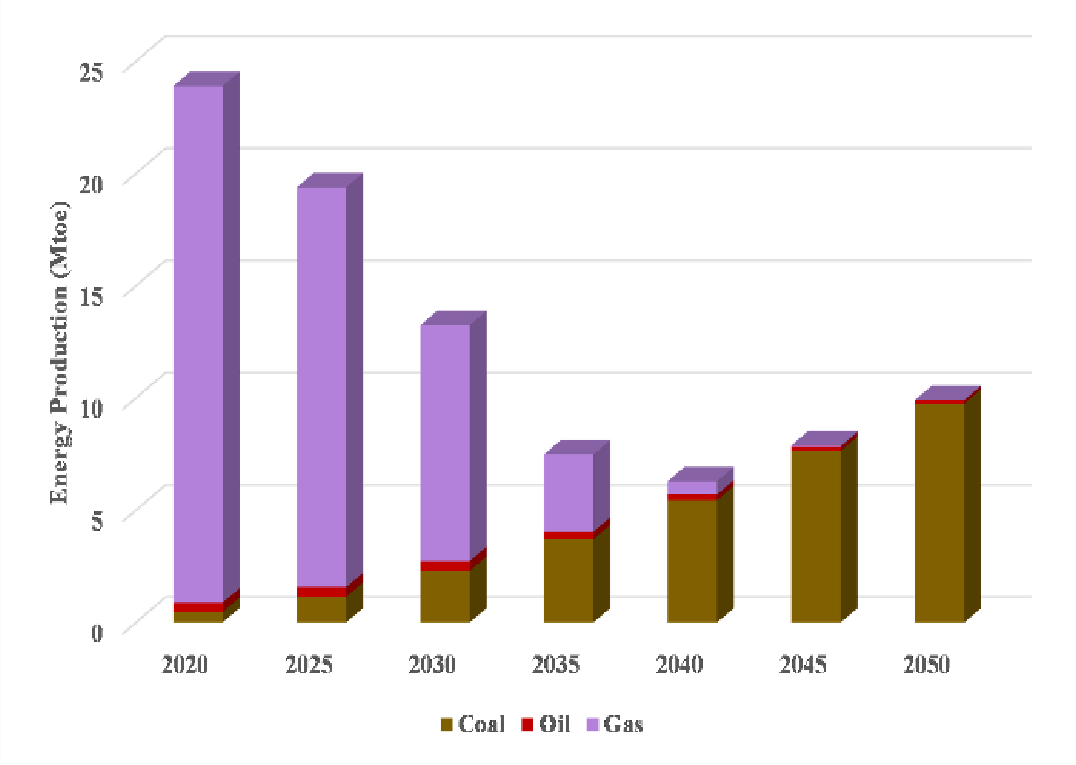


Figure 16: Energy Production at BAU case

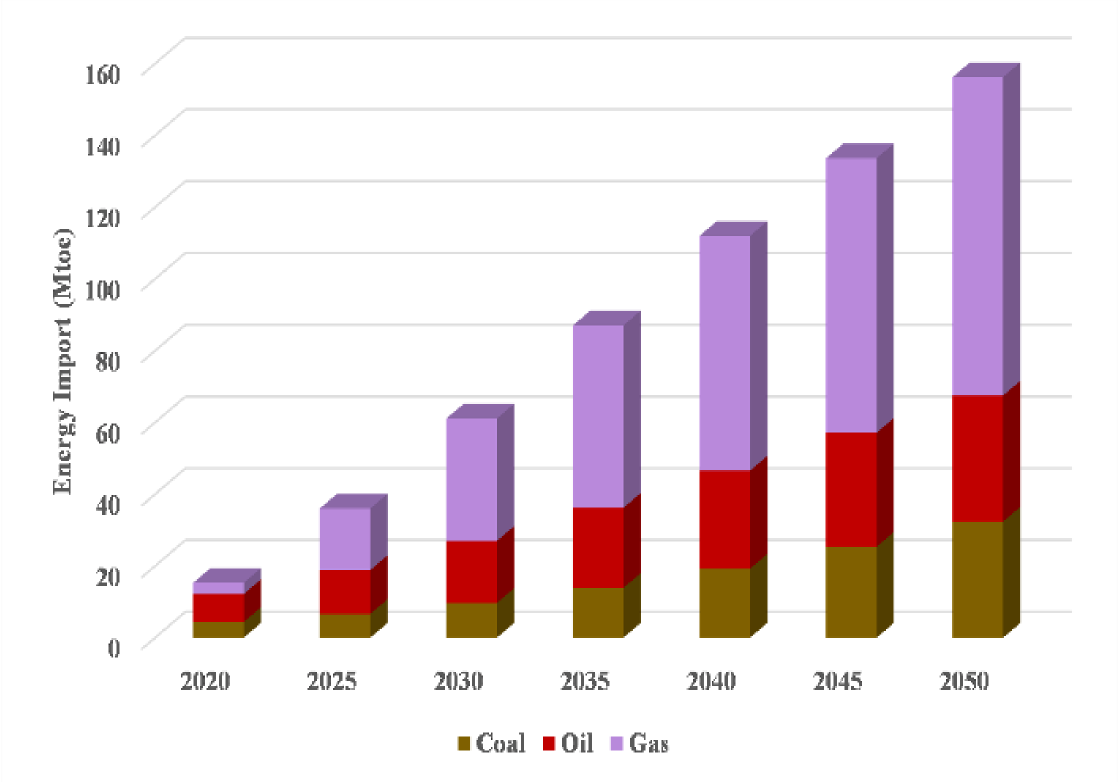
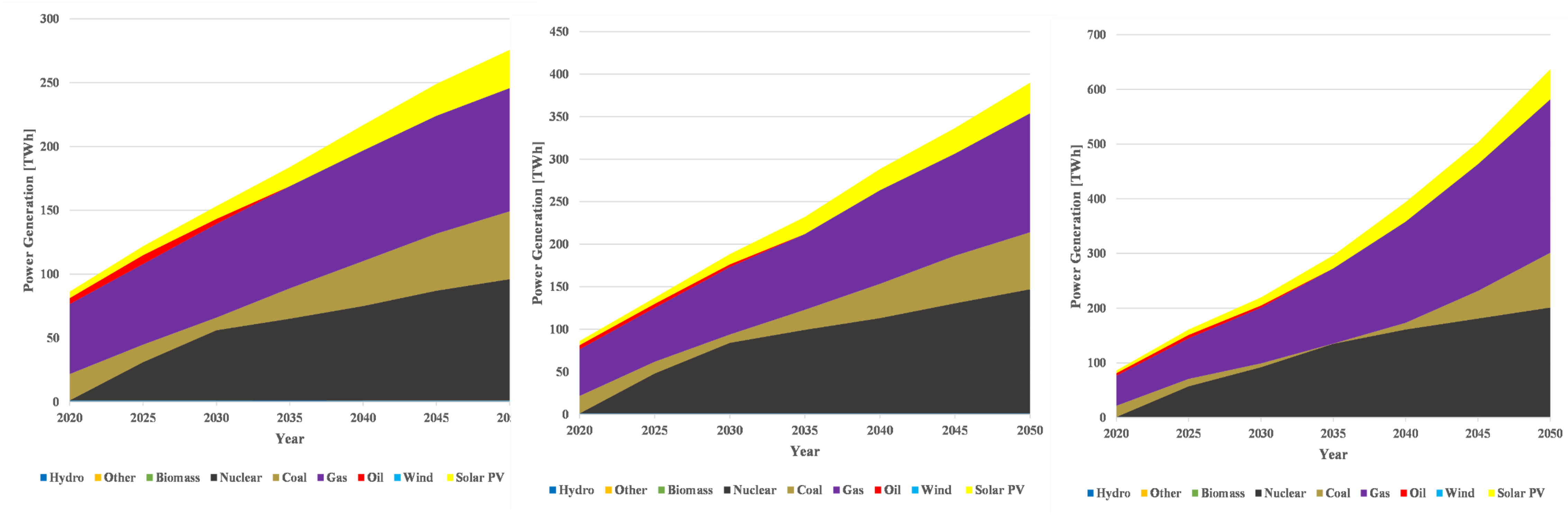


Figure 17: Energy Import at BAU case

4.2 Results: Electricity Generation Mix



(a) (b) (c)

Figure 18: Electricity Generation Mix at (a) Low, (b) BAU and (c) High growth Scenarios

4.3 Results: Effect of Carbon Emission Restriction

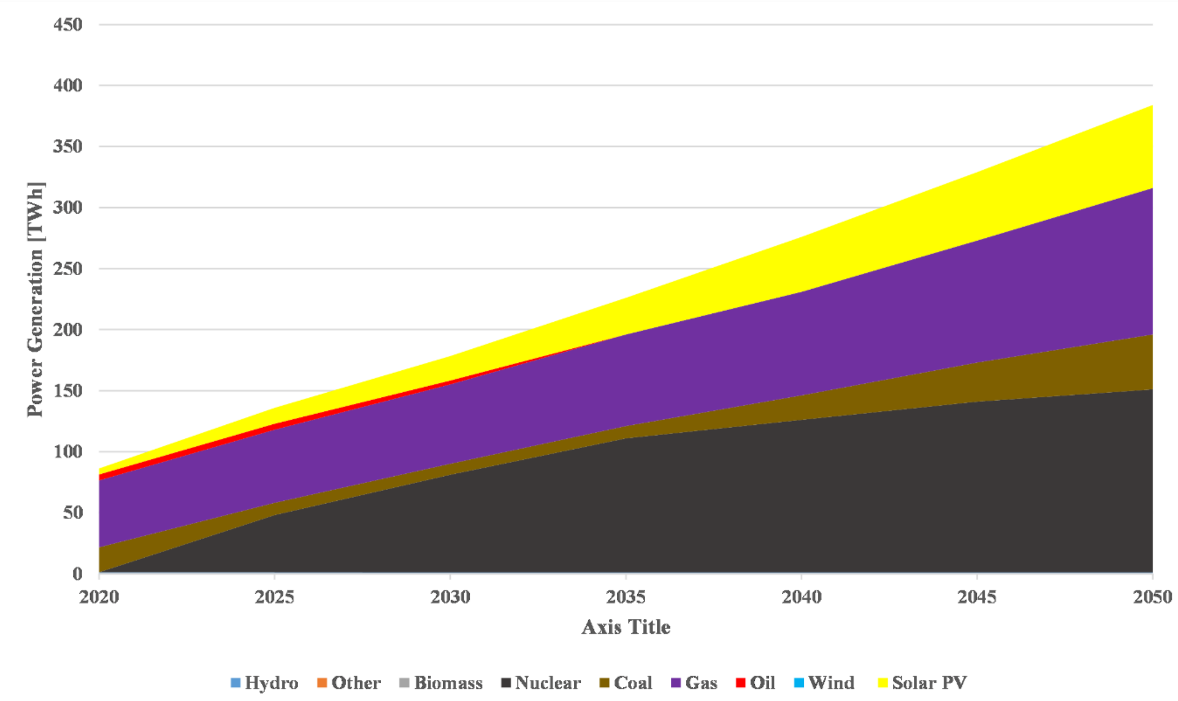


Figure 19: Generation-mix at BAU with 50% CO_2 reduction w.r.t. BAU case

- Solar PV comes into the electricity mix (17%) reducing the contribution of natural gas.
- Contribution from nuclear increases due to low carbon intensity.
- There is a small but negative effect on the GDP and electricity growth.
- Imposing carbon-tax might have negative impact on the economy, however it brings environmental sustainability by reducing CO_2 emissions

5. Conclusion & Future Work

- The DMSEE model relates the growth in electricity sector endogenously with the changes in other economic sectors.
- It also identifies the effect of policy change like carbon emission reduction policies and provides pathways to introduce renewables at larger scale.
- CO_2 emission restrictions could introduce large scale inclusion of solar PV and nuclear power in the electricity generation mix.
- Impact on material and industry sector could be linked with energy and electricity growth.
- The single country model could be expanded into multiple regions including nearby India, Nepal, Bhutan and Myanmar to observe the effect on electricity trade.

6. References

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Thank You

This work was supported by JSPS KAKENHI Grant Number JP20H02679

Appendix: DMSEE Methodology

CES function optimization for CGE model: The general form of CES function is given by $Y = \left(\sum_i b_i x_i^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$

where, *Y*: production function or utility function, *i*: number of goods, b_i: input coefficient of good *i*, x_i: input quantity of good *i*, σ: elasticity of substitution.

As CES function is generally nonlinear and linear programming methods cannot be used to solve a programming problem having nonlinear constraints. Therefore, linearity is achieved by approximation of a linear function by the value of the substitute elasticity as shown below.

$Y = \min\{x_1, x_2, \ldots, x_i, \ldots\}$ if σ → 0 (Leontief type)

$Y = \left(\prod_i x_i^{b^i} \right)^{\frac{1}{\sum_i b_i}}$ if σ → 1 (Cobb-Douglas type)

$Y = \sum_i b_i x_i$ if σ → ∞ (Linear type)

Appendix: DMSEE Methodology (contd.)

DMSEE Model Constraints formulation:

- Balance of demand and supply (considering investment and trade):

$$h_{m,r,t} + g_{m,r,t} + \sum_{n=1}^{N} \left(a_{m,n,r} zf_{n,r,t} + c_{m,n,r} i_{n,r,t}\right) = x_{n,r,t} + \sum_{s=1}^{S} tr_{n,r,s,t}$$

- Constraint of exhaustible resources:

$$\sum\nolimits_{\mathrm{y}} xp_{q,y} \le \sum\nolimits_{g} D_{q,y}$$

- Constraint of Armington elasticities, Top-down products, and household and Government consumptions:

$$Y = \left(\sum_{i} a_i \left(\sum_{j} b_{i,j} \, {A_{i,j}}^{\rho i}\right)^{\frac{\rho}{\rho i}}\right)^{\frac{1}{\rho}}$$

By Linear Approximation

$$\beta_{a,r,t} \, . \, Y_{a,r,t} \le A_{a,r,t}$$

Appendix: DMSEE Methodology (contd.)

- Capital Investment: Each activity increases the depreciation of equipment by investment and enhances the production capacity. So, production is restricted by installed capacity in BU sectors.

$$k_{B_t} = k_{B_0} + \sum_{t'=0}^{t} F_{B_{t,t'}} \eta_{I_{t'}} i_{B_{t'}}$$

where, k_B: installed capacity, F: investment matrix, η_I: construction cost

- Labor and Production: Production requires labor as well as equipment. The labor force is measured in terms of population growth efficiency factors. The labor force at a particular time is related with the previous time point as shown in the following equation:

$$l_{t+1} = (1+\zeta)e_t.(1+\theta)l_t' \quad \approx (1+\zeta+\theta)l_t \quad = (1+\gamma)l_t$$

where, l: labor force, l': number of labors, e: efficiency of labor, θ: population growth rate,

ζ: technology progress rate, γ= θ+ ζ

Appendix: DMSEE Methodology (contd.)

- Physical quantity balance: The production amount should be equal to goods consumed and exported

$$xp_{n=m,y} = xd_{m,y} + xex_{m,y}$$

- Capital investment for equipment: Considering the limited lifespan of equipment and depreciation, capital investment is required

$$xe_{n,y,Capital} = \sum_{y2=0}^{y} F_{n,y,y2} \eta_{I_{n,y2}} xi_{n,y2} + \delta_{n,y} XE0_{n,y,Capital}$$

* Variable renewable generation: By utilizing capacity factor for each time point, renewable electricity generation is limited.

$$xe_{n,y} \cdot CF_{n,s,t} = \eta_{K_{n,y}} \cdot xpS_{B_{ely,s,t,y}}$$

* Electricity supply (spinning) reserve constraint: (for thermal power plants only)

$$\sum_{\substack{n \in ELYS \\ n \neq pv,wnd}} xe_{n,t} \geq (1 + 0.05) \sum_{\substack{n \in ELYS \\ n \neq pv,wnd}} \eta_{K_{n,t}} \cdot MAXLOAD_{n,t}$$

Appendix: DMSEE Methodology (contd.)

Table A1: Assumptions for Thermal Power Generation

	Nuclear	Coal	Oil	Gas
Initial capacity [GW]	0.0	1.5	6.5	12
Construction cost [$/kW]	4,000	2,700	2,000	1,600
Annual Average Availability [%]	80	80	80	80
Seasonal Peak Availability [%]	20~90	90	95	95
Maximum Increase Rate of Output [1/h]	0.02	0.26	0.44	0.44
Minimum Increase Rate of Output [1/h]	0.02	0.31	0.31	0.31
Life Time [year]	60	40	30	40
Share of Daily Start and Stop	0.8	0.3	0.3	0.3

Table A2: Assumptions for Renewable Power Generation

	Hydro	Solar PV	Wind	Biomass
Initial capacity [GW]	0.25	0.5	0.01	0.01
Construction cost [$/kW]	6,500	2,500	3,000	8,000
Annual Average Availability [%]	65	-	-	70
Maximum Increase Rate of Output [1/h]	0.05	-	-	0.05
Minimum Increase Rate of Output [1/h]	0.05	-	-	0.05
Life Time [year]	60	20	30	40

The End