Long term energy system analysis

Using TIMES Modelling Framework

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NORWEGIAN MINISTRY
OF FOREIGN AFFAIRS

Objective

- ***Set-up a pilot:*** Develop a detailed energy system model, which looks into various aspects of the energy system at the regional levels, robust enough to incorporate and analyse changing energy needs, energy transition with intermittent renewables, evaluate relevant energy and climate policies and identify the need for interventions, etc.
- Model development consisted of setting up a pilot model with a ***baseline*** energy system with:
  - Time horizon from 2011 to 2050
  - Spatial disaggregation: 5 Regions
  - Temporal detail: Average Day for every month
  - 5 Demand Sectors
- Several simulations were run to evaluate the model response towards:
  - Zero Emission from power sector (Impact of High Renewable based Power)
  - Impact of High Temporal Resolution(with and Without Zero emission condition)
  - Effect of Demand Load profile (with and Without Zero emission condition)

Assumptions and Considerations

- The Model Baseline captured the relevant policies announced till 2016.
- GDP growth Rate – 5.37% (CAGR between 2015-50)
- Population projections as per Population Foundation of India (Scenario B)
- Share of Urbanization: 50% by 2050
- Detailed sectoral analysis for End-Use service demands
- End-use Demand hourly profile: Residential and Commercial Sector.
    - Developed based on primary survey
    - Developed for the year 2011 and usage pattern of appliances kept constant over modelling time-frame.
    - Variability in the end-use profile can be introduced with further analysis of end-use activity variation
- Agriculture, Industry, and Transport sectors were analysed at annual level due to limited data availability. Can be detailed in subsequent modeling exercises, based on data availability.

MARKAL vs TIMES: Capability Enhancement

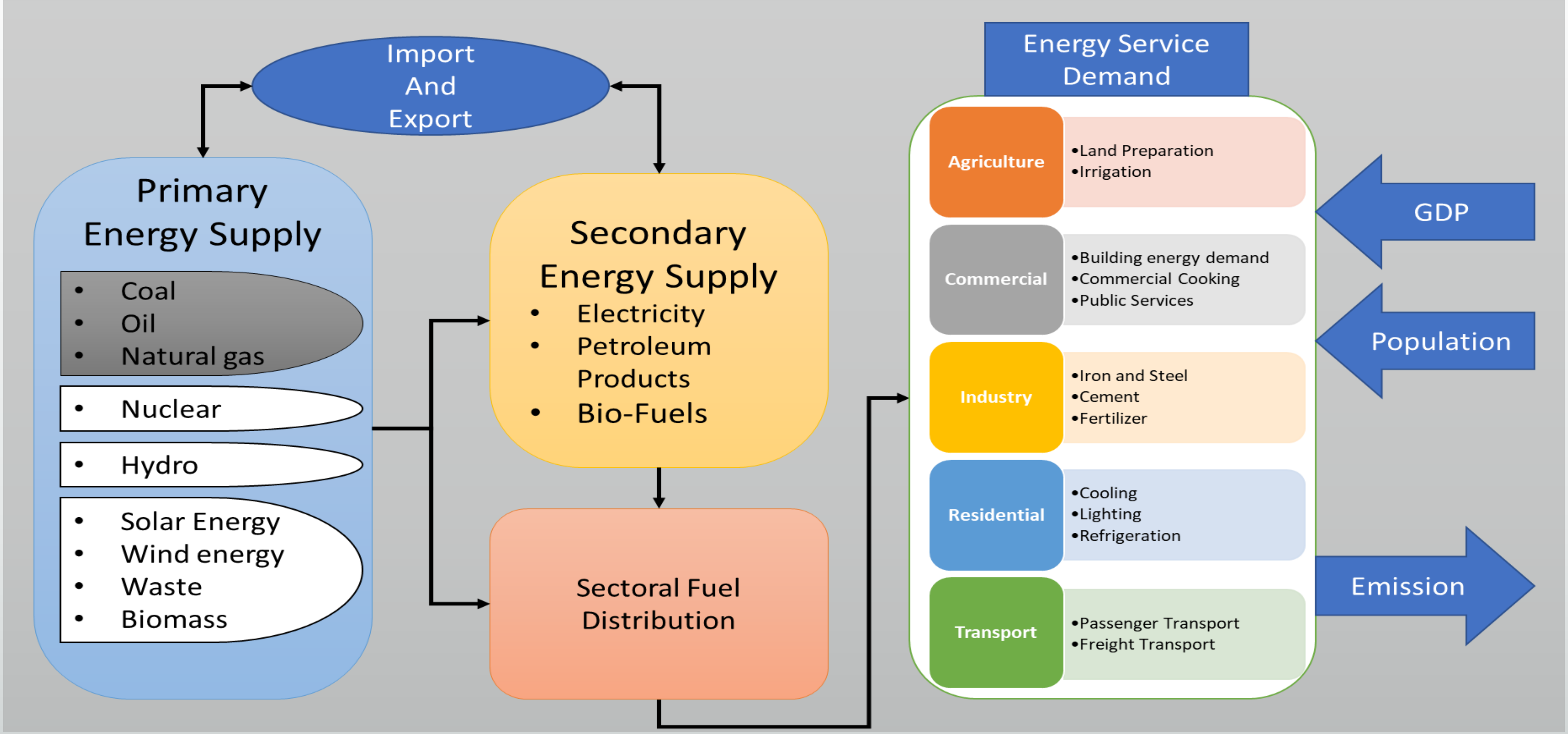
Broadly, MARKAL and TIMES work on the same principle and have a similar model structure.

- In terms of model structure and parameters, TIMES considered all the parameters which MARKAL does at present, here the objective was to make the TIMES model more detailed in terms of power sector representation and endogenize several parameters. Broadly, changes include:
  - Regional level of Resources availability and import/exports (power exchange) among regions
  - End-Use service demand profiles for all regions to capture diverse consumption behavior
  - Residential & commercial sector demands show the largest behavioural variations among regions during different seasons and time of day, Therefore, variability in these 2 sectors was examined and depicted in the model

Model Capabilities

- Granular details of power sector assist in better analysing energy transition possibilities related to:
  - High renewable energy penetration in the overall energy system for electricity and other energy use activity like solar irrigation, solar water heating, industrial solar application etc.
  - Enables better analysis of response towards electrification of various end use energy demands in
    - Transportation
    - Grid electricity
    - Storage
  - Regional variability and overall variation in the load profiles at hourly level
  - Electricity grid optimization for least cost power sector portfolio under different scenarios
  - Better understanding of the time-of-day (TOD) based tariff of electricity
  - Fair analysis of inter-regional power transmission capacity and their utilization
  - Captive power generation at dynamic level

Model Structure

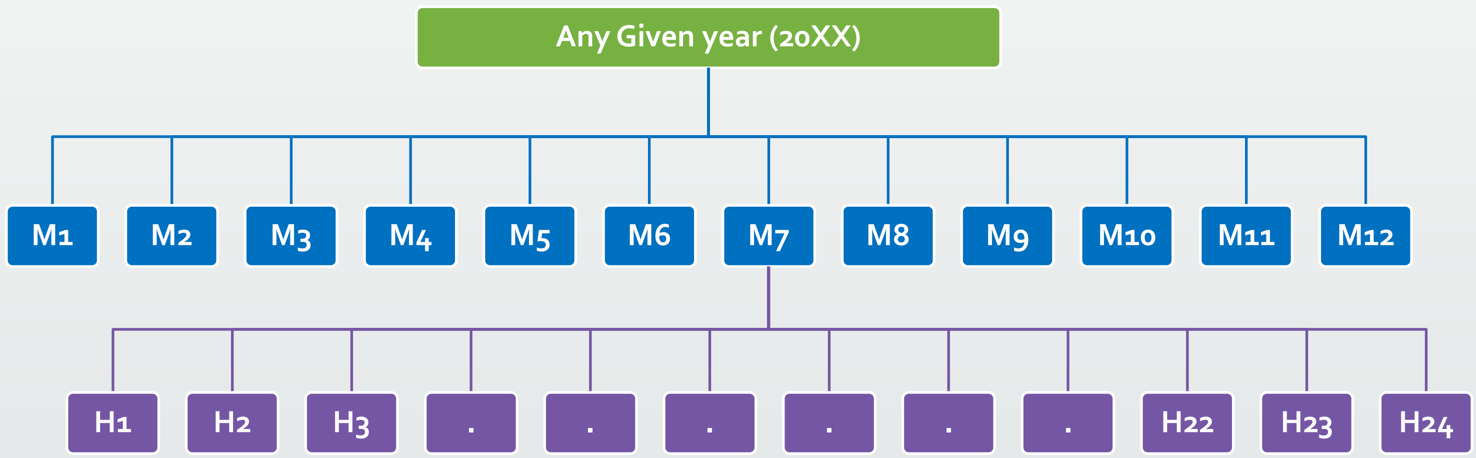


Model Detail: Regions

Power sector Focused Model Regions

- Regionally Disaggregated Model structure
- Captures variability in consumption behaviour across regions
- Captures renewable energy availability across the regions
  - 32 variable generation profiles for Solar
  - 10 variable generation profiles for Wind
- Regional level energy optimization along with inter-region energy exchange among the regions.
- Inclusion of regional level resource availability, variable demands and energy storage requirement provides better understanding of the power system requirements for medium to long term planning.

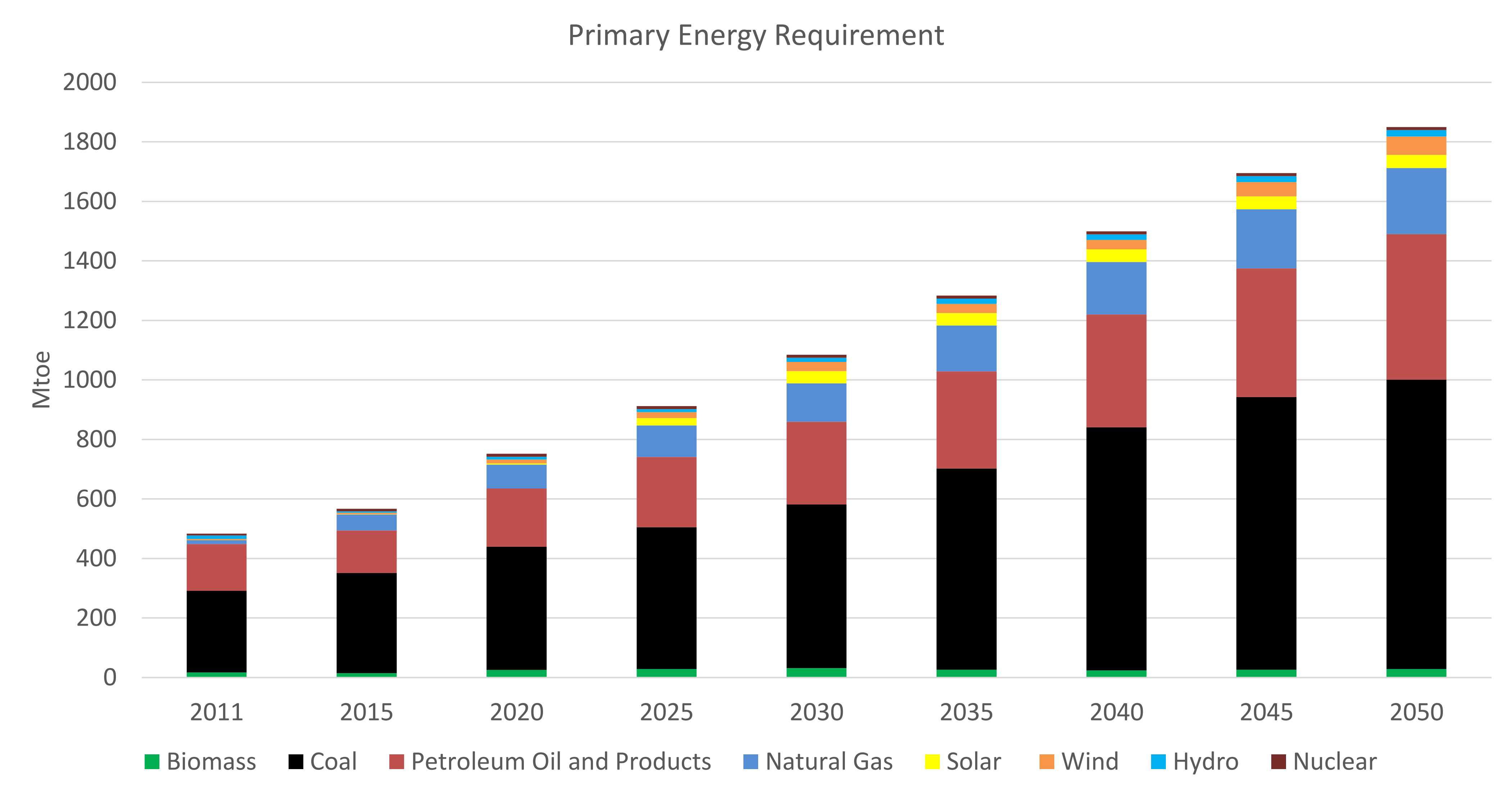
Model Detail: Time-Steps



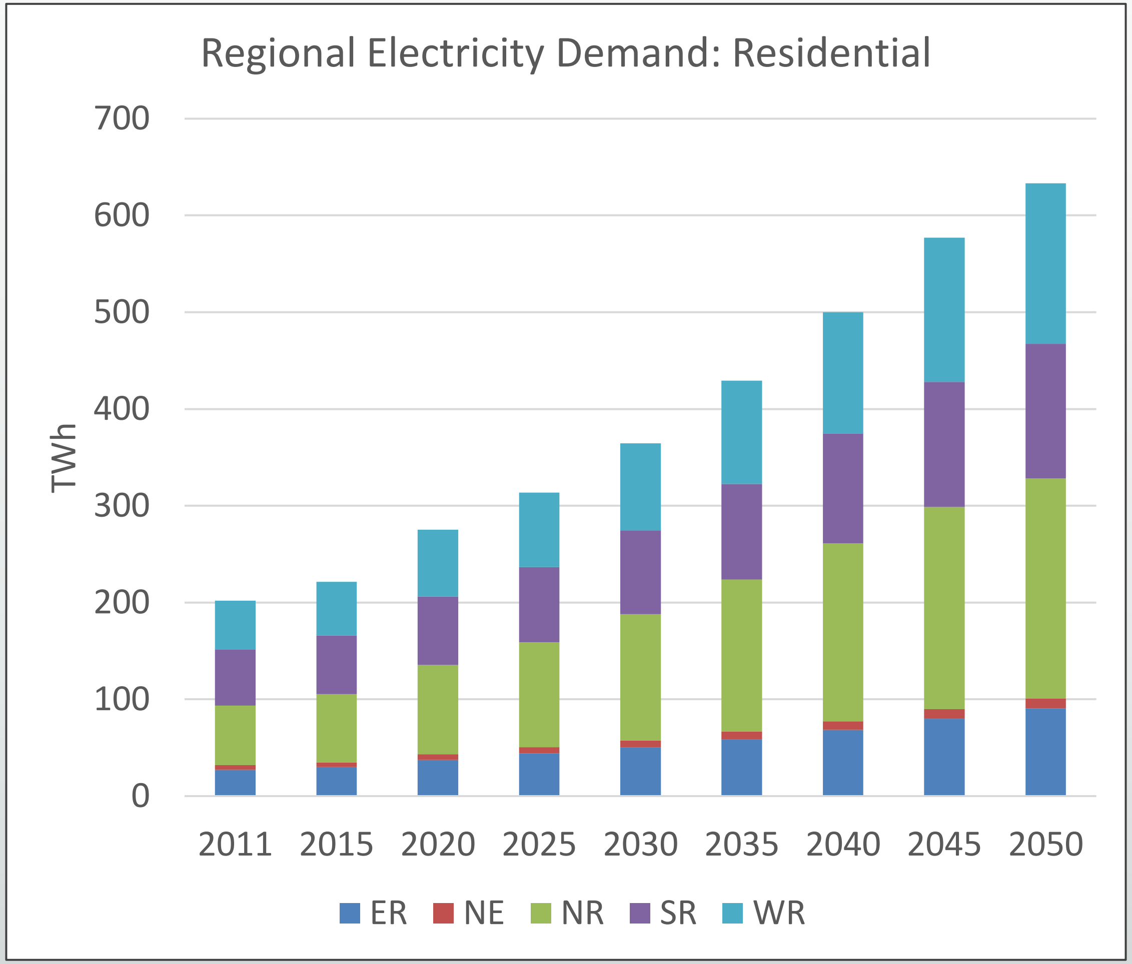
- Year is divided into 288 time-steps
  - Level 1: All months (12)
  - Level 2: Average day, detailed for each hour (For every month) (24)
  - Representation of an average day for all the months
- Hourly level demand and supply analysis over the years
- Captures electricity consumption behavior across various end uses in different regions
- Time of Day variability of renewable power generation
- Load variation analysis over the years, with the detail of the driving factors

Model Results and Observations

Primary Energy Supply



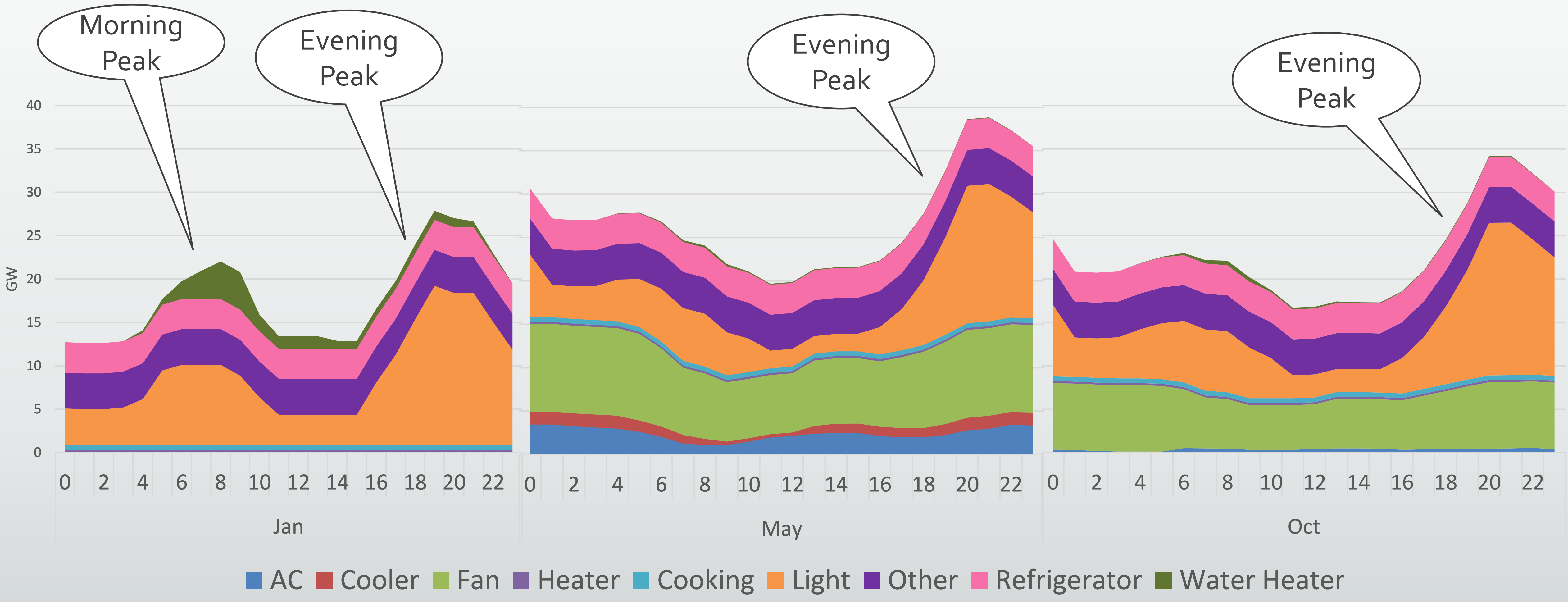
Residential Sector Electricity Demand



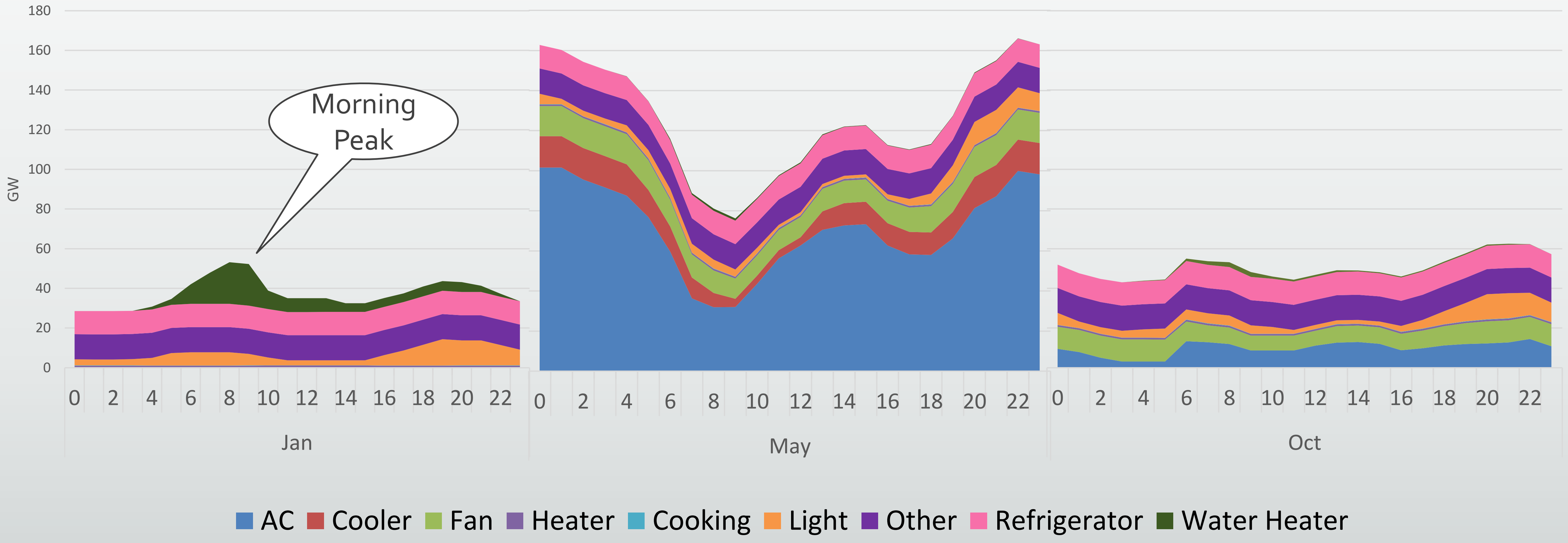
- Sector largely dependent on electricity and exhibit high amount of load variation through out the day.
- Apart from cooking, all the end use activity demand is catered by electricity.
- Residential sector demand increases by almost 3 times while the electricity accounts for about half of the final energy demand
- As the model look at the energy demand at regional level, electricity demand in each region is also captured here which shows, Northern regions growth is maximum over the years and accounts for the maximum electricity demand followed by western region.

Residential sector Load curve: 2011

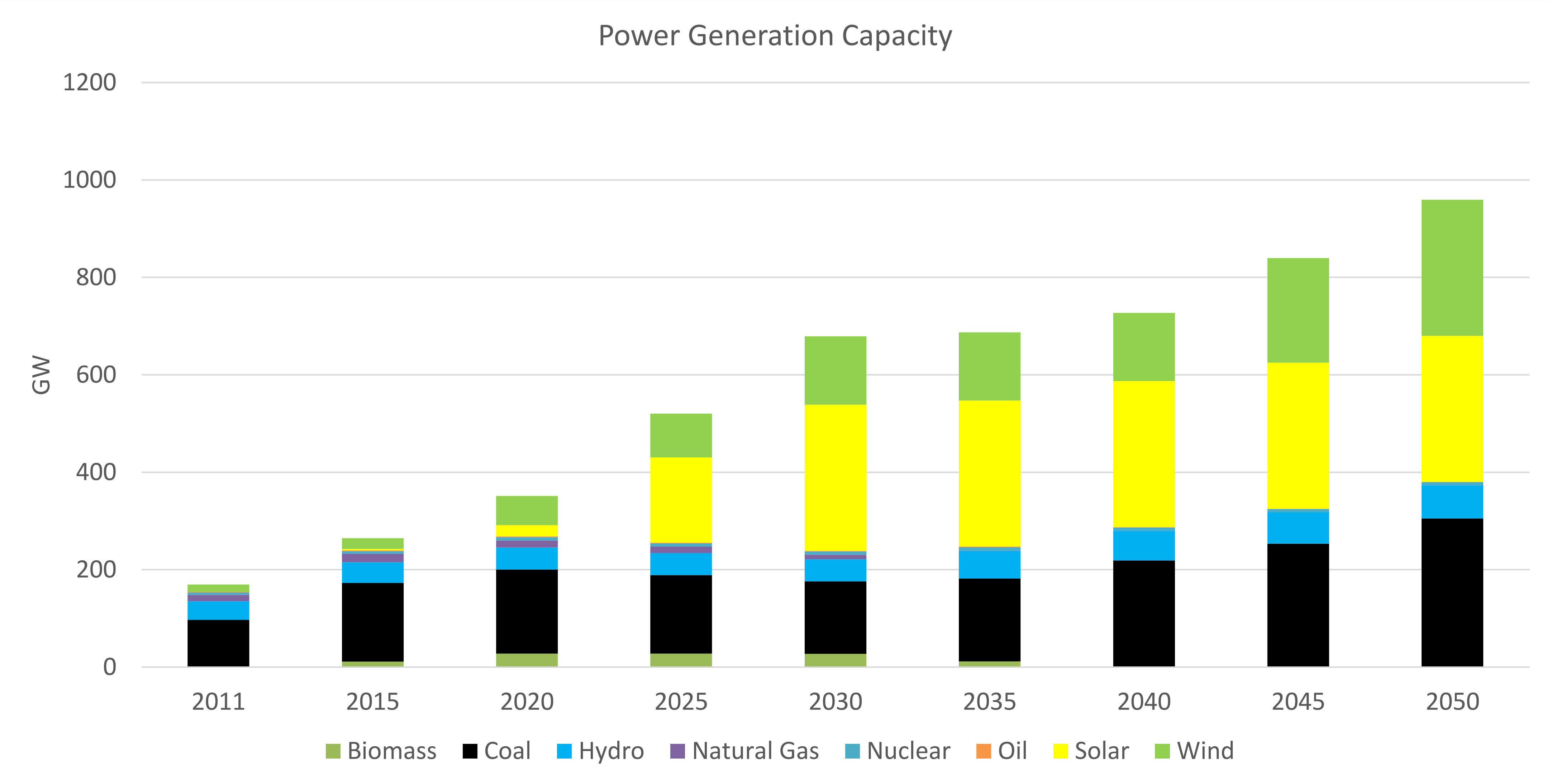
Based on the estimated appliance penetrations and usage patterns, the model generates the load curves



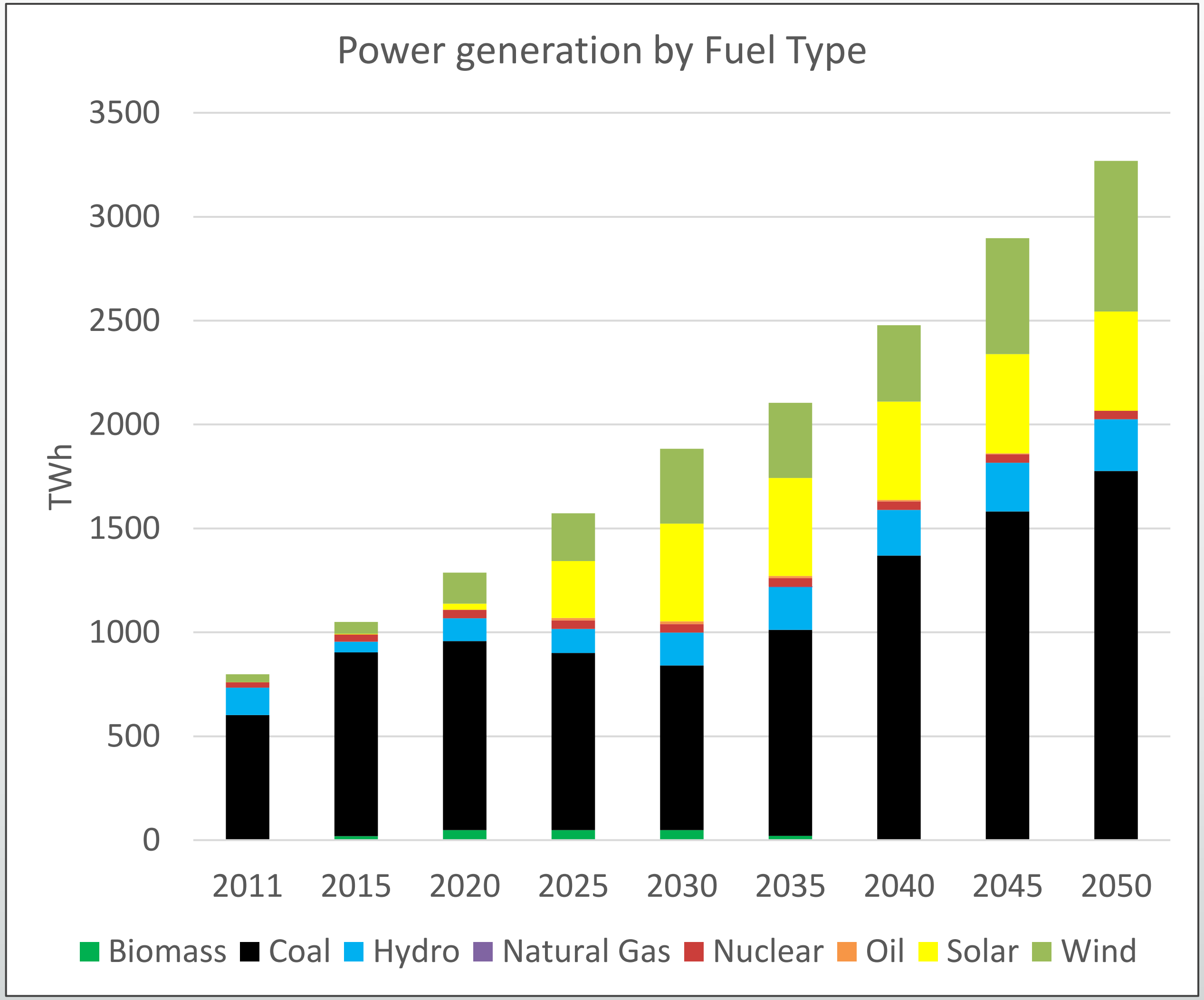
Residential sector Load curve: 2050

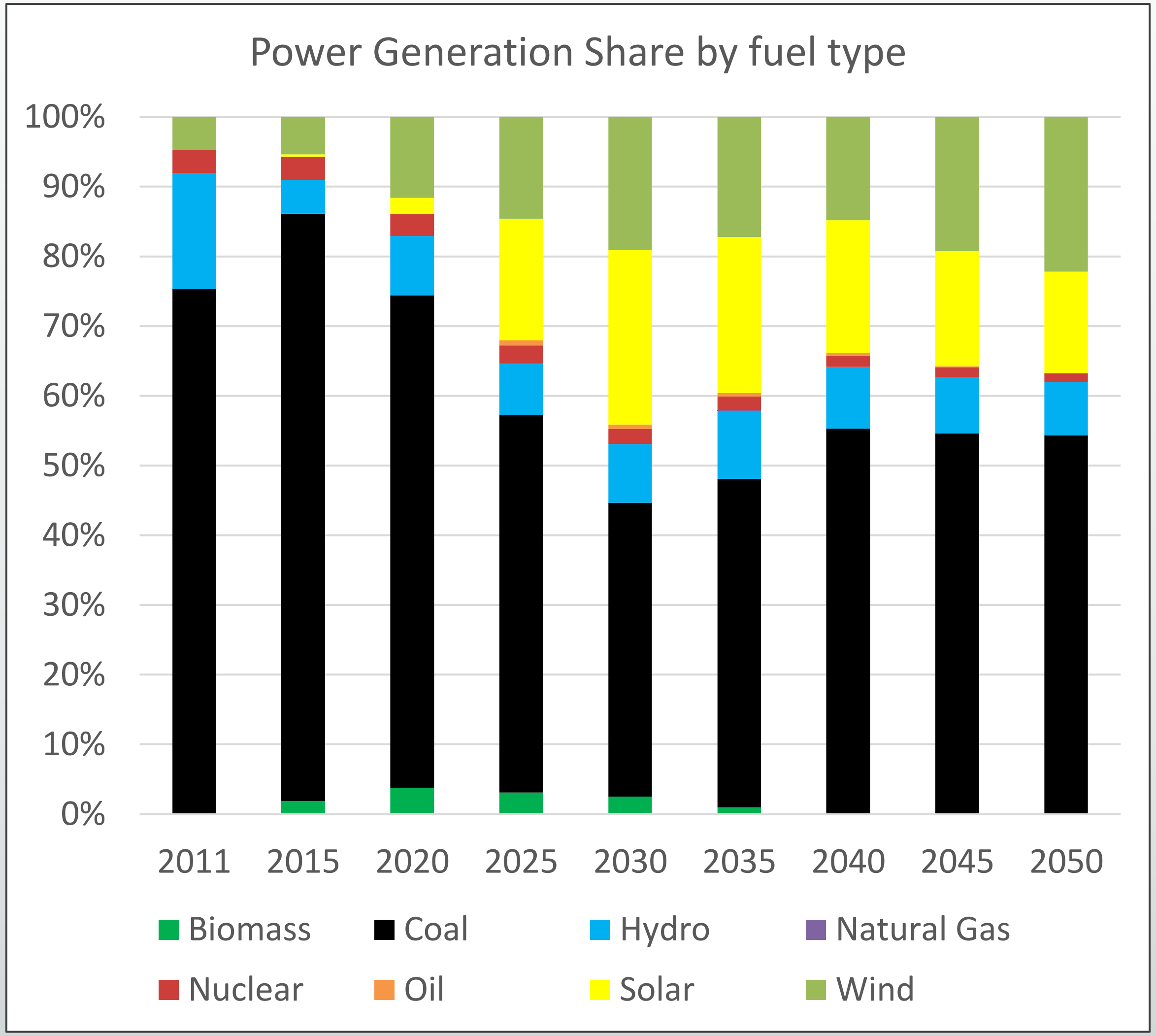


Power Generation Portfolio

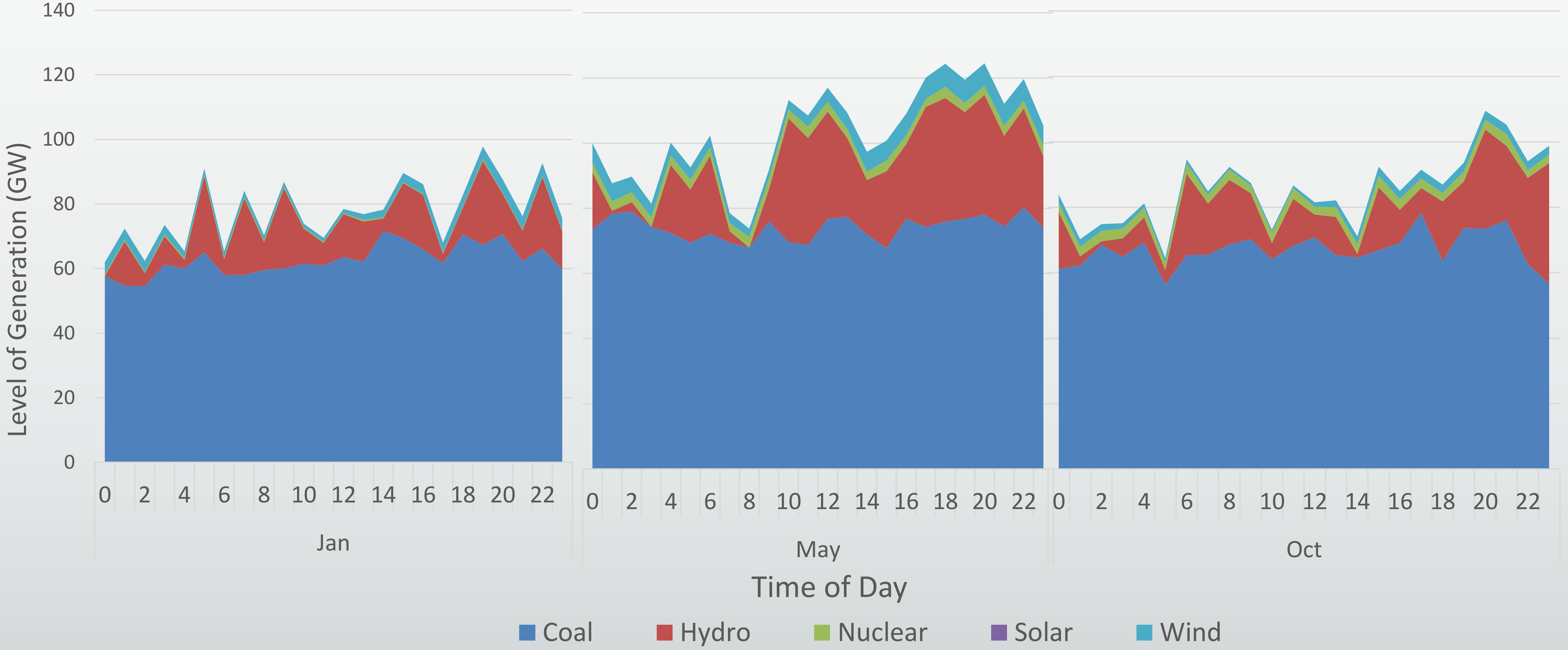


Fuel Wise Power Supply

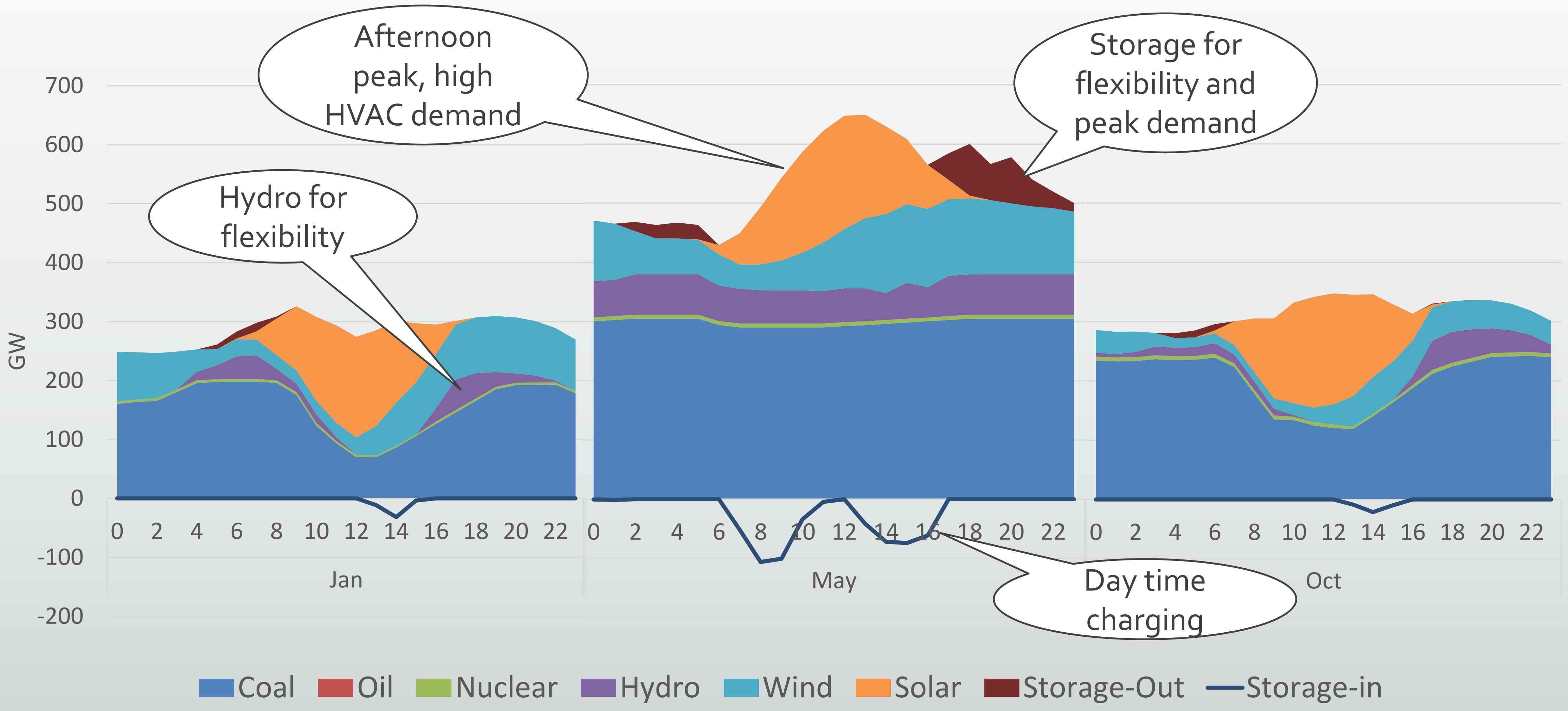




Electricity Supply 2011 (Average month Day)



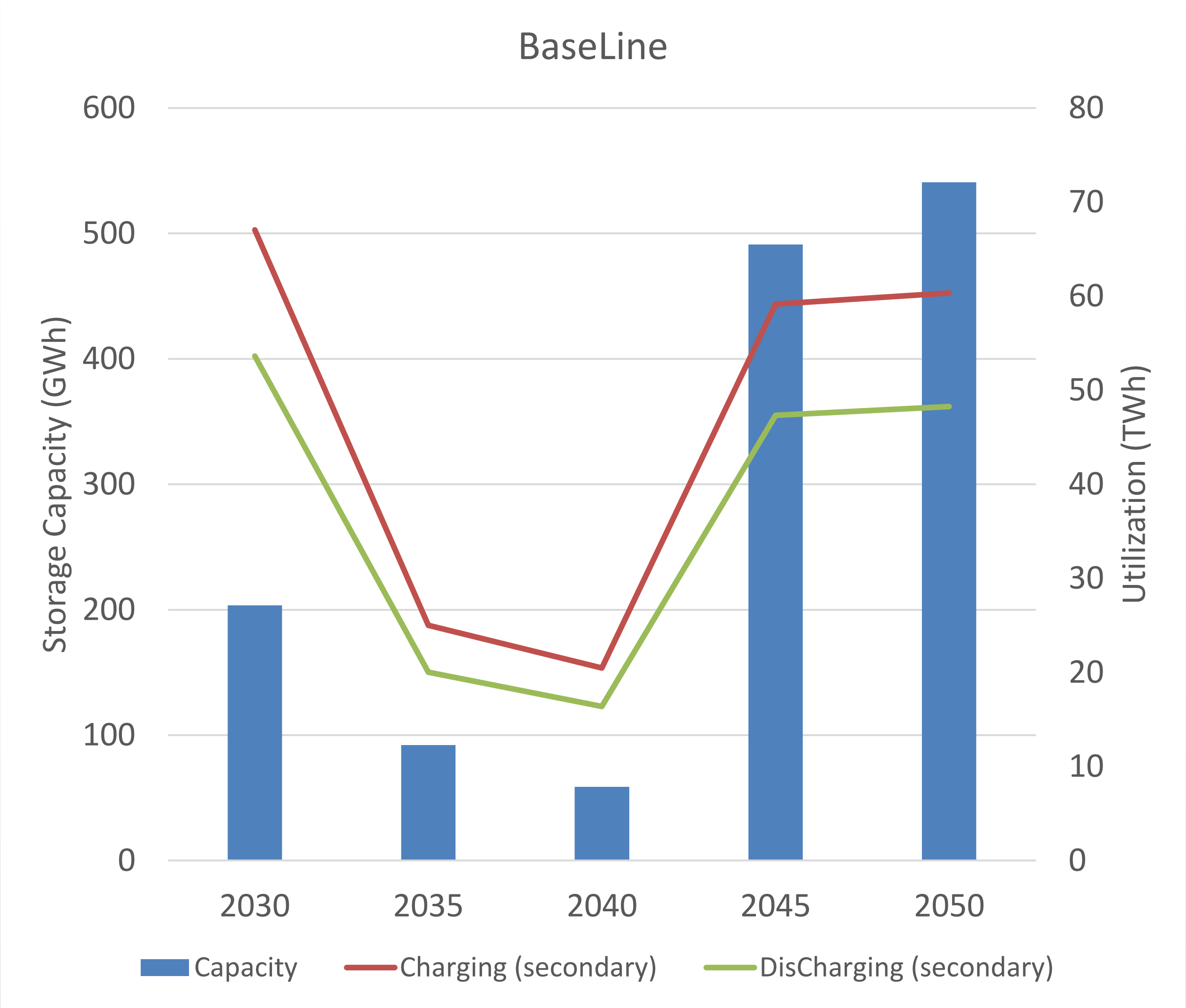
Electricity Supply2050 (Average month day)



Observations: Power Sector

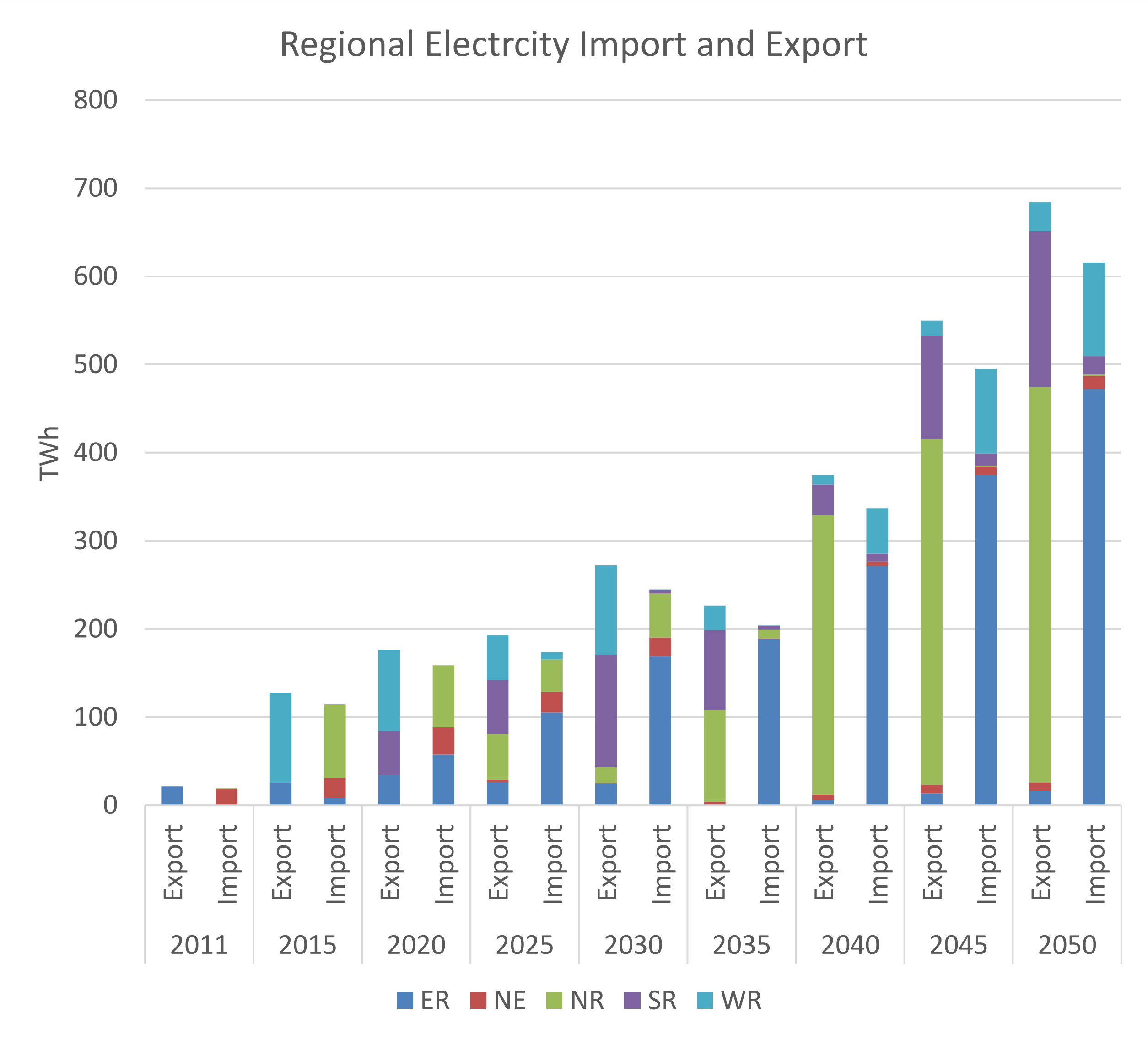
- With higher emission mitigation requirement, a larger share of renewable energy in the overall generation can be seen and higher utilization of battery storage is required during summer months where electricity demand is peaking
- Peak load observed close to 701 GW in 2050 during the summer months (May, June, July); increasing from 125 GW in 2011
- Key driving factor behind rise in peak demand is building cooling requirements.
- Multiple factors contribute to the observed changes in results by 2050:
  - These include increases in various end-use demands, penetration of efficient appliances, inter-regional electricity trading, energy storage to support short term change in the electricity demand, option for avoiding renewable energy curtailment, flexibility in the power system, optimization of the overall load to provide least cost electricity.

Electricity Storage Capacity and Utilization



- To ensure better utilization of battery energy storage, life based on charging cycles and technical life has been provided for better optimization and longevity of the batteries along with remaining system flexibility.
- With increasing variability due to renewable energy in the overall grid supply, requirement of electricity storage becomes important in future
- With high share of Renewable energy in 2030, a spike was observed initially, while gradual increase in RE capacity resulted in additional storage capacity requirement
- The role of existing pumped hydro based capacity was observed during 2025 for the first time.

Inter Regional Power Exchange Observation



- Electricity exchange among the regions is a normal practice to maintain grid stability and ensure uninterrupted power supply among the regions.
- With increasing demand, and geographically concentrated renewable energy production, we observe higher inter-regional power transmission
- To avoid transmission losses and stable grid, regional level optimization tries to minimize the requirement of inter-region exchange
- Eastern region is observed to be the net importer of electricity while Northern and southern regions were observed to be the major electricity exporters in the later years

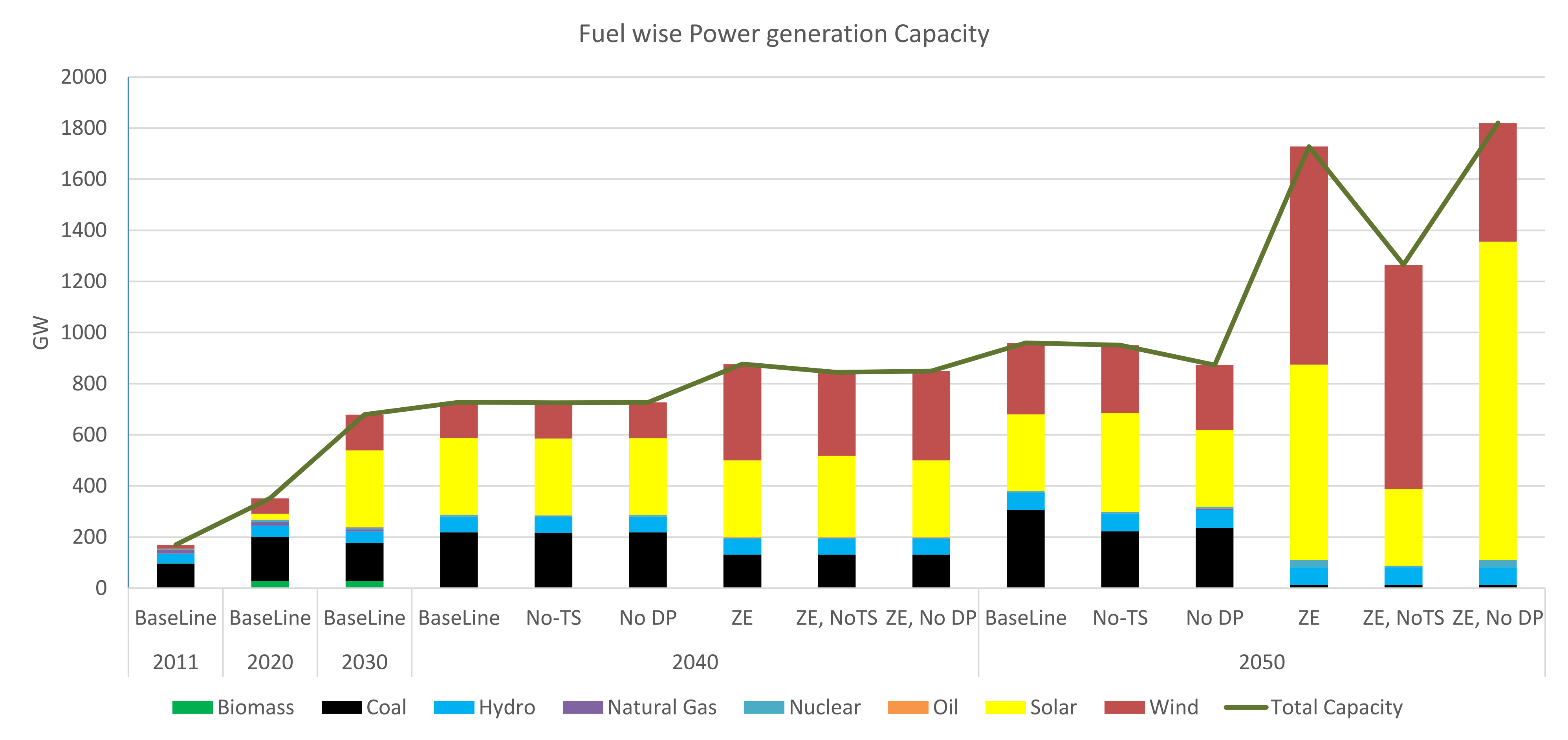
Additional Sensitivity Analysis

Changing Factors	BaseLine	No -TimeStep	No-Demand Profile	Zero Emission (ZE) from Power	ZE + No-timeStep	ZE + No Demand Profile
Demand Profile	End-Use service demand Profile	Uniform Demand across the sectors over the year	Uniform Demand across the sectors over the year	End-Use service demand Profile	Uniform Demand across the sectors over the year	Uniform Demand across the sectors over the year
Supply Profile	Solar and Wind Resource Profiles	Uniform Solar and Wind Availability over the year	Solar and Wind Resource Profiles	Solar and Wind Resource Profiles	Uniform Solar and Wind Availability over the year	Solar and Wind Resource Profiles
Emission Constraint	NA	NA	NA	Zero Carbon Emission from Power	Zero Carbon Emission from Power	Zero Carbon Emission from Power

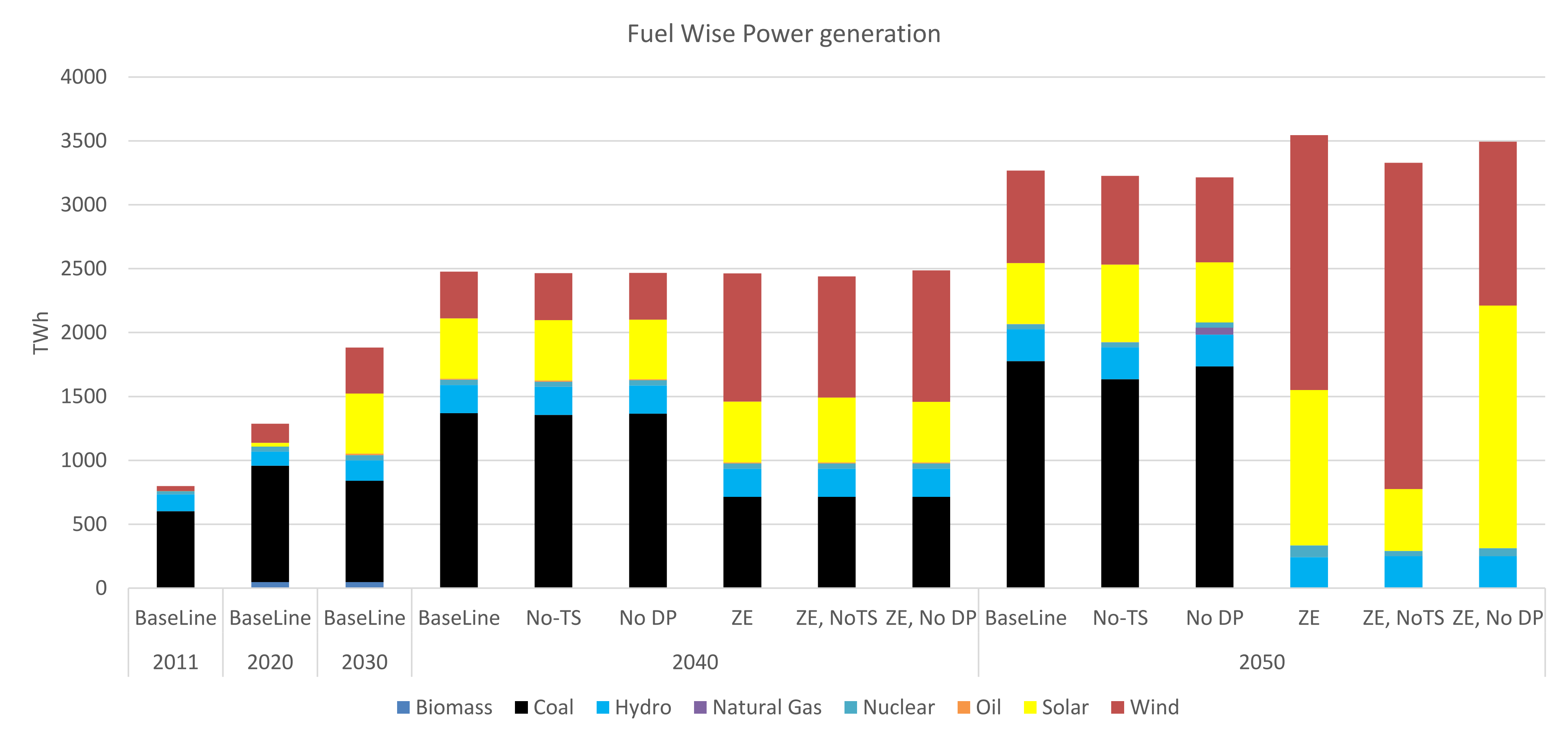
Observation

- Absence of detailed time-steps reflects a lower capacity requirement in power sector, since there are no peaks to be met.
- Also, RE variability and energy storage cannot be assessed due to absence of TOD variability
- In the absence of demand load profiles, demand side issues remain, while from the supply side, variability of RE generation is being captured with the detailed on energy storage, inter-regional power exchange, etc.
- Emission constraint on the power sector leads to high capacity expansion in solar and wind based capacities along with energy storage requirement due to variable nature of renewable energy; inter-regional electricity exchange

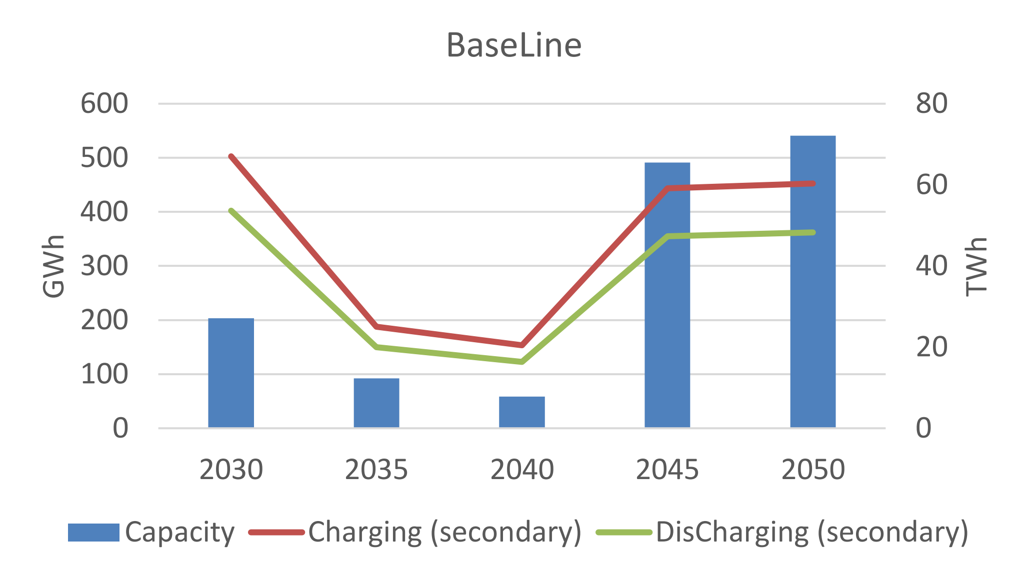
Fuel Wise Power generation Capacity: Sensitivity

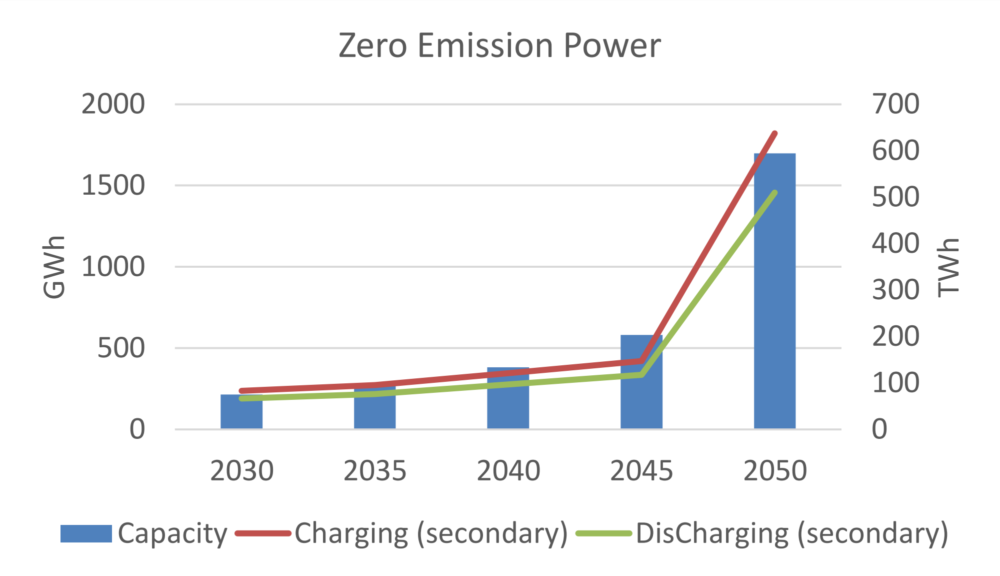


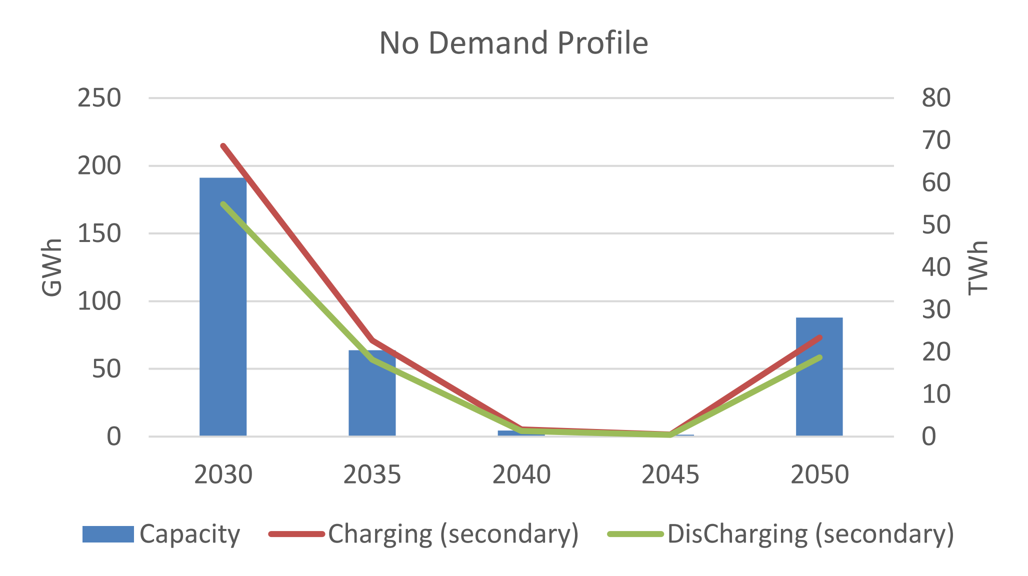
Fuel Wise Power generation: Sensitivity

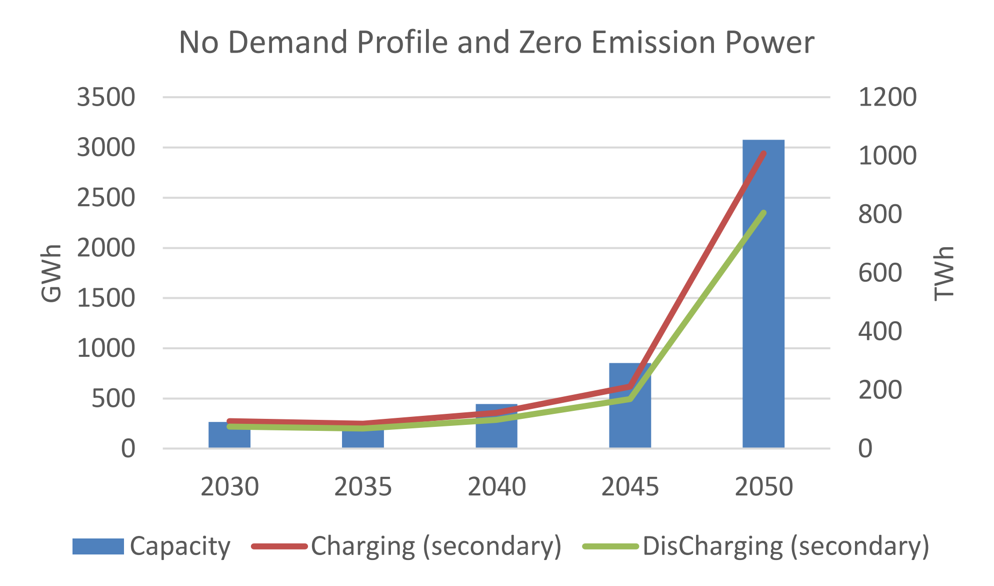


Electricity Storage









Key Takeaways

- Changing temporal resolution results in change in peak electricity demand which eventually affects the overall generation mix and storage requirements
- The high temporal resolution also leads to better optimization of variable renewable energy in the grid mix by
  - capturing details of flexibility in the power system and ToD electricity demand
  - Simultaneous incorporation of variable demand and supply profiles reflect optimized mix within solar and wind based capacities along with optimal storage
- Electricity storage fails to get adequately analysis in the absence of detailed temporal resolution
- Changes in load variation across end-uses can be captured through scenarios reflecting changes in adoption and usage of electricity based processes/appliances

Thank You!!

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