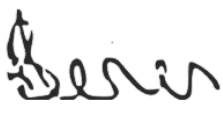





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Demand Projection Model in Support of IRP Update 2023

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EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

Demand Projection Model in Support of IRP Update 2023

OVERVIEW

SANEDI has commissioned the Energy Systems Group at the University of Cape Town to develop a new generation of electricity demand forecasting models, to aid the current and future capacity expansion planning processes, referred to in law as integrated resources planning.

BACKGROUND

Long term scenario-based projections of electricity demand are important for policy formulation and developing generation capacity expansion plans. Econometric methods used for short-term forecasting using statistical time series methods have not been able to provide correct longer term electricity demand projections.

OBJECTIVES

This project aims to develop a spreadsheet-based bottom-up demand projection tool to support generation expansion planning.

RESEARCH METHODOLOGY

Capacity expansion planning requires the hourly profile of the demand, in each of the years spanning the modelling horizon.

Demand scenarios are built up from hourly demand profiles per sector. The annual final electricity demand by sector is first estimated by combining a number of data sources. This is adjusted for onsite generators and for losses, then multiplied by the hourly sector-specific demand profiles obtained from Eskom to try and match the hourly sent-out electricity. Small adjustments are made to the base profiles received from Eskom until a good match is achieved. New demand for vehicle charging uses profiles published by the International Energy Agency.

Projections for the annual electricity demand (GWh) by sector are taken from the SATIMGE model. The economic sectors included are Agriculture, Mining, Manufacturing, Commerce, Traction, Residential, and International Exports. Private electrified road transport is accounted for under Residential and Commerce depending on a user-defined assumption around how much charging is done at home vs at work/public spaces. Public and freight electrified road transport is accounted for under the Commercial sector. SATIMGE combines SATIM, a bottom-up full-sector energy systems model of South Africa with eSAGE, a dynamic, recursive, economywide and multisector computable general equilibrium (CGE) model. This linked model captures both the technical detail needed for full energy systems modelling and

economic detail for assessing the impact of changes in the energy system on various sectors, markets, and agents in the economy. Whilst SATIMGE also generates optimal supply solutions to match the demand forecast, only the demand forecast is extracted here.

RESULTS

A reference high-growth scenario showing hourly projected demand at the sent-out level is presented in this report. In this scenario the electricity demand is projected increase by around 200 TWh between 2023 and 2050, with peak demand projected to grow from around 35 000 MW to around 62 000 MW. Electrification of transport, accelerating after the mid-2030s, and assumed high GDP growth are the two main factors driving electricity demand up in this scenario.

How much of this demand may be met by “Onsite Generators” is not determined, as these are regarded as supply options in the capacity expansion model used in the IRP process.

CONCLUSIONS

It has been possible to calibrate an hourly sector-based demand model against the 2017 hourly record of electricity sent-out. Future scenarios of electricity demand can now be generated by varying assumptions and constraints in SATIMGE runs.

RECOMMENDATIONS

The model in its current form provides demand projections at a high temporal resolution (hourly), but for a single node model. Given current bottlenecks on the transmission network, planning should be done in a spatially disaggregated way. Also, the non-homogeneity in how different sectors may evolve in different geographic locations require future demand forecasts to be spatially disaggregated. The spatial disaggregation, price responsiveness, as well as the exploration of the uncertainty space is left for future work.

INDUSTRY PERSPECTIVE

KEY REFERENCES

KEYWORDS

Electricity demand forecasting

FUTURE REVIEW

ABBREVIATIONS LIST:

Abbreviation	Description
EV	Electric vehicle
ICEV	Internal combustion engine vehicle
IRP	Integrated Resource Plan
PGM	Platinum group metals
PLEXOS	The Energy Analytics and Decision Platform for all Systems, developed and maintained by Energy Exemplar, https://www.energyexemplar.com/plexos
SATIMGE	South African TIMES & General Equilibrium linked model
SSEG	Small-scale embedded generation
TIMES	Energy Systems Modelling platform developed and maintained by IEA-ETSAP (https://iea-etsap.org/index.php/etsap-tools/model-generators/times).

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1 BACKGROUND

Long term scenario-based projections of electricity demand are very important for policy formulation and developing generation capacity expansion plans. A long-term view is required as electricity generation infrastructure has long lead times and footprints that last many decades. Econometric methods used for short-term forecasting using statistical time series methods have some limitations when applied to long term electricity demand projections. Real increases in tariffs not seen prior to 2010, the availability of new cost competitive efficient appliances/equipment, lower than anticipated economic growth and supply constraints have combined to result in a demand trend that could not be anticipated by extrapolating from historical data. This was acknowledged in the discussion of the forecast in the 2019 IRP, however at the time, an alternative method could not be found. In the coming years, we expect further changes such as a continued change in the composition of the economy, electrification of end-uses such as transportation and process heat, hydrogen production, more self-generation etc... which will have major impacts on the evolution and profile of the demand “seen” by the national grid. Thus, the development of a more bottom-up approach of projecting demand is required.

2 OBJECTIVES

This project aims to develop a spreadsheet-based bottom-up demand projection tool to support generation expansion planning. This tool provides a first step towards improving the approach for generating long-term electricity demand projections by addressing some of the short-comings of time-series based projection methods by allowing the user to explore scenarios:

- With projected structural changes in the economy, and what this means for the evolution of overall demand profile;
- With the addition of new demands such as electrified transport and hydrogen production, assuming different charging profiles and locations for private transport (home vs elsewhere);
- If required, to specify different rates of penetration of on-site generation such as roof-top PV.

3 METHOD

3.1 PREAMBLE AND DEFINITIONS

There are different interpretations of what is meant by “Electricity Demand”, and so it is useful at this point to clarify how this term and others are used in this report, and what they mean. The figure below shows some components of the energy system, from extraction on the left to use on the right.

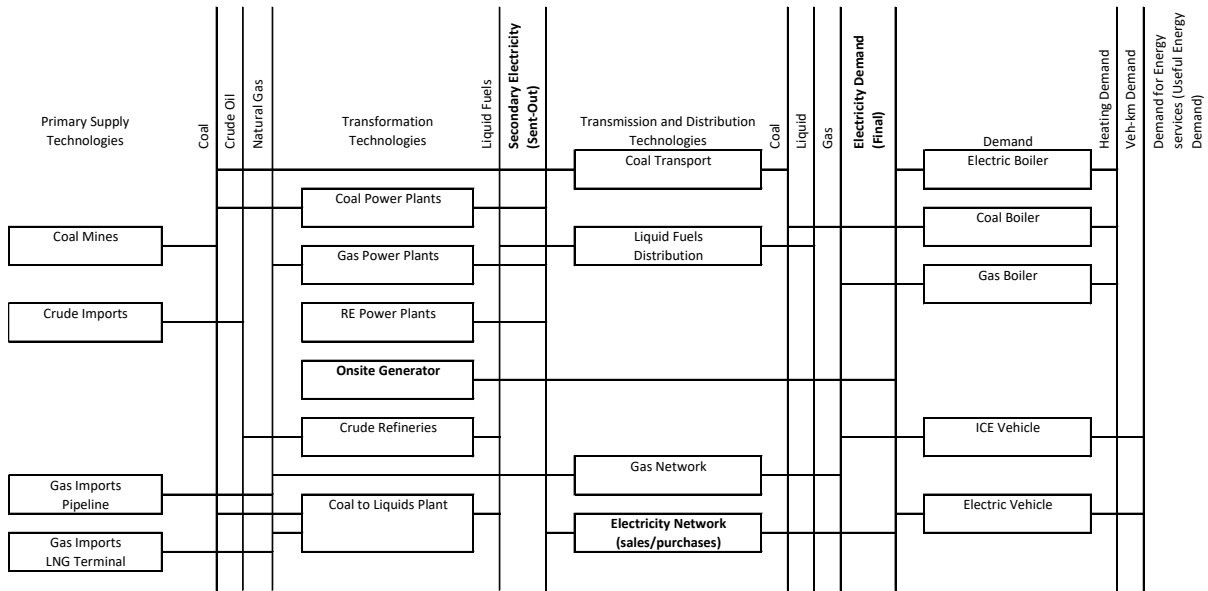


Figure 1 Reference Energy System Diagram

“Secondary Electricity (sent-out)”: Sum of Electricity sent out (i.e. net of own auxiliary consumption) of large generators that are “upstream” of the electricity transmission and distribution grid. Hourly data for Secondary Electricity is published by Eskom here:

<https://www.eskom.co.za/dataportal/supply-side/station-build-up-for-the-last-7-days/>

“Electricity Demand (final)”: Electricity consumed by different electrical devices/machinery such as refrigerators, geysers, pumps and geysers. In a system that does not include any onsite generators (i.e. “downstream” of the grid), “Electricity Demand (final)” in GWh could be observed directly in the electricity sales data. In the South African system, Eskom tracks monthly sales to its own customers at multiple levels of SIC code resolution but reports it for each financial year in its annual reports aggregated up into: Mining, Other Manufacturing, Traction (freight + passenger rail), Commerce, Households, Redistributors (municipalities), and Exports. Municipalities collect and report sales at varying levels of detail and frequency. NERSA used to collate and publish monthly sales by municipalities but has not done so since 2012. Also, there is an increasing capacity for on-site generation, and so “Electricity Demand (final)” cannot easily be observed from one source of data.

“Useful Energy”: Sometimes also referred to as “Demand for Energy Service”. This is what drives the demand for “final energy” and would be the most strongly linked to indicators such as population and GDP, as it is independent (or at least partly independent) of:

- Energy Efficiency improvements
- Fuel Switching

However, “Useful Energy” cannot directly be observed in data that is collected and so one must infer “Useful Energy” from observable data/estimates of “Final Energy” combined with data on estimated stock of appliances that convert final energy to useful energy and their characteristics such as efficiency, by leaning on other sources such as appliance/vehicle sales, fuel use surveys etc...

The Electricity Demand required by the IRP supply model is “Secondary Electricity” + scaled “Onsite Generators” in MWh for each year spanning the planning horizon (2023-2050). This is because “Onsite Generators” are included as supply options in the capacity expansion model used by the IRP. The capacity expansion model also requires the hourly profile of the demand, i.e. what fraction of the annual energy demand is “demanded” in each of the 8760 hours, of each of the years spanning the modelling horizon. When this fraction is multiplied by the annual energy in MWh, the average hourly MW (or MWh) demand is obtained for each of the 8760 hours.

Historical annual data on “Secondary Electricity” + “Onsite Generators” for large and licensed onsite generators is collected by NERSA and published by StatsSA. “Onsite Generators” have in the past consisted mainly of large, licensed installations such as coal and gas plants owned and operated by Sasol, biomass plants in pulp and paper etc... These installations have typically been installed in close proximity to the “Secondary Electricity” level, and so combining their “Sent-out” generation with that from network/grid based Generators upstream of the network without correcting for losses is not too problematic. However, going forward, with more small-scale embedded generators being installed downstream of the network, where network losses are higher, one can no longer combine them without accounting for losses.

The rest of the **Methods** section is split into two parts:

1. Part 1 describes the mechanics of the tool in its current spreadsheet form.
2. Part 2 describes the datasets that were used to populate the tool to make demand projections reported in the results section.

References to specific sheets used in the workbook are made where applicable. The version used in this report is: “HourlyDemandModel_v09” which can be found here (Merven, 2023): https://zivahub.uct.ac.za/articles/dataset/ESRG_Single_Node_Hourly_Demand_Model/24137877

3.2 PART 1: OVERVIEW OF THE MECHANICS OF THE TOOL

The main output of the tool is the hourly electricity demand in MW for each year over the planning horizon (to 2050) at the “Secondary Electricity (sent-out)” level. There are two main modes of operation:

1. **Mode 1:** The user chooses to not subtract “Onsite Generators”. These would then be included and characterised in the supply model to be used for IRP/expansion planning/simulations. The demand here would be what the grid would “see” at the “Secondary Electricity” level if there were no onsite generators. This is the mode selected by the IRP team, as the supply model used includes “Onsite Generators”.
2. **Mode 2:** The user chooses to subtract “Onsite Generators”, having specified the characteristics of those generators in the demand model. This mode is chosen if the user wants to use a supply model that only includes grid-based supply options supplying at the “Secondary Electricity” level. The calibration of the tool is done using this mode of operation, because as mentioned above, historical hourly data for “Secondary Electricity” is available.

In Mode 1, the hourly “Secondary Electricity” demand for each year y and hour h is calculated by summing projections made for hourly “Electricity Demand (final)” by Aggregate sector s , adjusted for projected grid losses (Transmission: Tx and Distribution: Dx), where distribution losses are sector specific.

$$\text{Secondary Electricity (sent out)}[y, h] = \sum_s \frac{\text{Electricity Demand (final)}[y, h, s]}{(1 - TxLossFactor[y])(1 - DxLossFactor[y, s])}$$

In Mode 2, the hourly “Electricity Demand (final)” net of (i.e. after subtraction) sector specific hourly onsite generation, is used to calculate “Secondary Electricity” by again adjusting for losses.

$$\text{Secondary Electricity (sent. out)}[y, h] = \sum_s \frac{\text{Purchases from Grid}[y, h, s]}{(1 - TxLossFactor[y])(1 - DxLossFactor[y, s])}$$

$$\begin{aligned} \text{where Purchases from Grid}[y, h, s] \\ = \text{Electricity Demand (final)}[y, h, s] - \text{on site generation}[y, h, s]. \end{aligned}$$

Hourly “Electricity Demand (final)” is obtained by applying sector specific hourly profiles, calibrated in the base year, to sector specific annual energy demand projections for “Electricity Demand (final)”.

$$\begin{aligned} \text{Electricity Demand (final)}[y, h, s] \\ = \text{Electricity Demand}[y, s] \times \text{Demand Profile Factor}[h, s]. \end{aligned}$$

Annual energy projections for “Electricity Demand (final)” by Aggregate sectors are obtained either:

- by applying a user-specified/assumed growth rate to base-year “Electricity Demand (final)” by Aggregate sector, or
- by selecting one of the existing projections from SATIMGE (version August 2023).

In Mode 2, the user must also provide a projection for onsite generation or select 1 of the 3 proposed projections.

$$\text{On site generation}[y, h, s] = \text{Onsite Capacity}[y, s] \times \text{Onsite Profile Factor}[h, s].$$

The BaseYear selected for calibration is 2017 as there was almost no load-shedding in that year, it was pre-covid, and there was only a small amount of SSEG in place.

The calibration is done in two steps:

1. Annual “Electricity Demand (final)” by sector is estimated by combining Eskom sales data, municipal data gathered from municipal “State of Energy Reports”/D-forms, Supply and Use tables published by StatsSA, the last (2012) NERSA publication on municipal sales, and historical generation data on large on-site generators collected by NERSA. Sector specific losses are estimated in order to get back to the aggregated hourly “Secondary Electricity (sent out)” from Eskom. Since the losses scale up “sales/purchases” to “sent-out”, the losses also include non-technical losses.

$$\begin{aligned} \text{Electricity Demand (final)}[2017, s] \\ = \text{Eskom Sales}(ex. munic)[2017, s] + \text{Munic Sales}[2017, s] + \text{Onsite}[2017, s]. \end{aligned}$$

2. Hourly “Electricity Demand (final)” sector specific profiles obtained from Eskom, are applied to the annual “Electricity Demand (final)”, adjusted for onsite generators and adjusted for losses to try and match the hourly “Secondary Electricity (sent-out)”. Small adjustments are made to the base profiles received from Eskom until a good match is achieved. Sector profile calibration adjustments are made at two levels:
 - a. At an hourly level (*h*)
 - b. At a monthly level (*m*)

$$\text{Demand Profile Factor}[h, s] = \text{Eskom Profile Factor}[h, s] \times \text{Adjustment Factor}[h_m, s].$$

3.3 PART 2: DATASET USED FOR ANALYSIS PRESENTED IN THIS REPORT

3.3.1 Calibration data

The data sources used for calibration in 2017 demand projections are as follows.

- Eskom monthly sales by SIC code for 2017
- SATIM Energy Balance Calibration spreadsheet that takes into account Supply and Use tables for 2017 (StatsSA), and some NERSA data on municipal sales
- Total Sent out from “RSA Contracted Demand Column” from Eskom data portal.
- NERSA power plant data for 2017

The annual calibration described in more detail in the appendix takes place in a sheet called “AnnualCalibration”.

The data sources used to determine the base year sector profiles were:

- Profiles by Sector from Eskom (2017 Calibration), found in the “DemandProfiles” sheet.
- Hourly sent out from “RSA contracted demand column” from Eskom data porta, found in the “HistSentOutProfiles” sheet.
- PV Profiles for SSEG is based on profile data from renewables.ninja for the major metros which are then weighted and scaled to get an overall SSEG solar PV profile. The way this is done can be found in the “PVProfiles” sheet.

The Calibration of sector profiles takes place in the “ProfileCalibration” sheet.

3.3.2 Annual Energy Demand (Final) Projections

Projections for the annual electricity demand (GWh) by sector are taken from SATIMGE (August 2023 version). The economic sectors which are included in the annual electricity demand projections are Agriculture, Mining, Manufacturing, Commerce, Traction, Residential, and International (exports). Private electrified road transport is accounted for under residential and commerce depending on a user-defined assumption around how much charging is done at home vs at work/public spaces (Commercial sector). Public and freight electrified road transport is accounted for under the Commercial sector.

SATIMGE

SATIMGE combines SATIM: a bottom-up full-sector energy systems model of South Africa (Hughes et al, 2021), and eSAGE: a dynamic recursive, economywide, multisector, computable general equilibrium (CGE) model (Diao and Thurlow, 2012). By combining these detailed models, SATIMGE captures both the technical detail needed for full energy systems modelling and economic detail for assessing the impact of changes in the energy system on various sectors, markets, and agents in the economy. SATIM is used to compute the least-cost energy technology mix, both on the supply side (e.g. power plants) and on the demand side (e.g. boilers and passenger/freight vehicles) given assumptions on technology and fuel costs, and constraints (e.g. demand and emissions constraints). SATIM can respond to cost and constraint assumptions endogenously with investment and operation decisions around technology options available to the model. The technology mix which results from the endogenously computed and exogenously specified assumptions as observed in SATIM results is passed to eSAGE which incorporates the new energy supply and demand

composition. Aggregate investment is determined in eSAGE by assuming a macro adjustment process where any changes in aggregate final demand are shared proportionally across the macro aggregates: consumption, investment, and government spending on goods and services. This process determines the pool of investable funds. Investment in the Exogenous Sectors is first allocated from this pool. Other sectors in the economy then compete for the remaining funds. This arrangement ensures that the opportunity costs of investment between sectors are captured within the modelling framework. eSAGE incorporates all this information and the solution provides a new set of projections of economic indicators of interest to the policy maker (GDP, employment, household welfare, etc).

These updated sector and household income growth projections are then passed back to SATIM which optimises again based on this new information. This iterative process continues until the overall model converges such that energy utilization (and associated CO2 emissions) in both models are aligned and internally consistent in terms of demand, price and technology mix.

SATIMGE was developed and is maintained on an ongoing basis by the Energy Systems Research Group (ESRG), at UCT and colleagues from the Southern Africa Labour and Development Research Unit (SALDRU) also at UCT.

Assumed GDP Projection

The August 2023 version of SATIMGE is calibrated to the 2017 Energy Balance, and a 2019 SAM with adjustments made to capture Covid and near-term GDP outlooks by different institutions such as SARB, National Treasury, IMF, and World Bank, as shown in Figure 2. In the medium to long term, in the scenario considered, GDP growth is projected to reach the 3.8% range in the mid 2030's and maintain this level over the horizon to 2050.

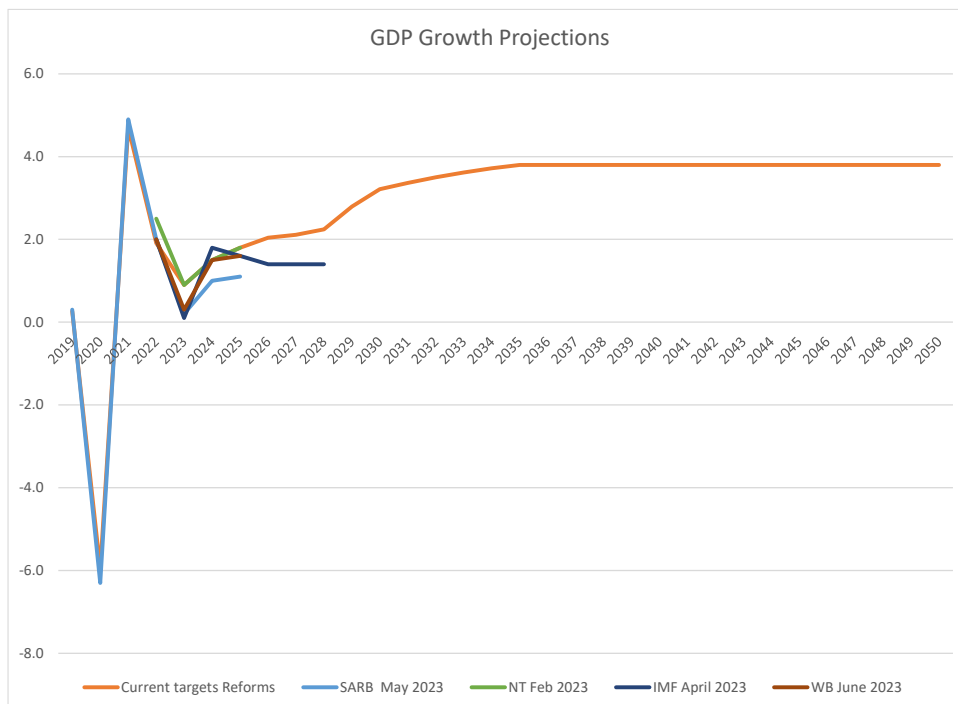


Figure 2: GDP growth rate projections for reference case

The assumed evolution of the GDP composition is given in Table 1.

Table 1 Assumed evolution of GDP composition

	2021	2030	2040	2050
Overall GDP Growth		3.2%	3.8%	3.8%
Tertiary Share of GDP (ex. Freight and logistics)	62%	64%	67%	70%
Agriculture Growth	4.7%	3.2%	3.8%	3.8%
Coal mining Growth	-0.5%	0.7%	-2.1%	-1.2%
Other Mining Growth	4.7%	3.2%	3.8%	3.8%
Population ('000)	59,392	64,659	69,714	73,530
Population Growth	1.0%	0.9%	0.7%	0.4%
GDP/capita ('000 2019 R/capita)	73.5	81.1	108.1	148.8

Residential Electricity Demand Projections

The South African population is assumed to follow the trajectory projected by the United Nations population model (United Nations, 2022). The households are split into three income groups with a roughly 50-30-20% split in 2019 between low-, middle- and high-income groups. The evolution of the household groups split is consistent with the projected GDP growth and is shown in Figure 3.

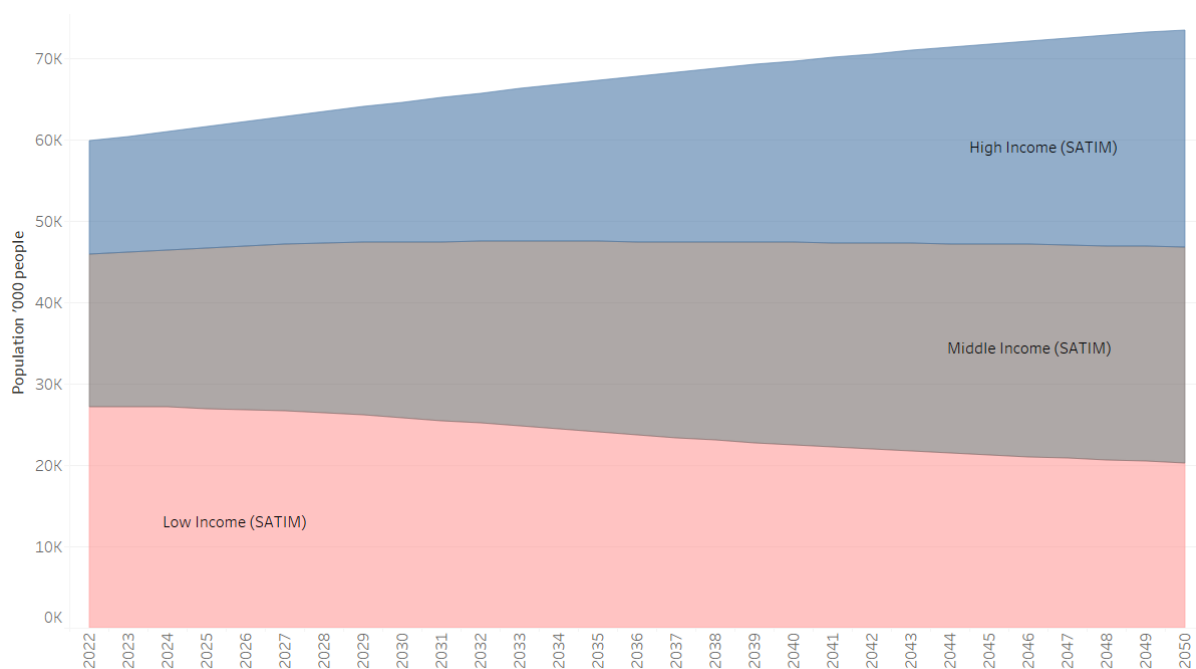


Figure 3: Population projections by income category

Population growth is an important factor driving changes in residential energy demand. High-income households have a higher electricity demand compared to middle and low-income households. Figure 4 shows the electricity demand projected for households by income group and by end-use. Note that in this particular scenario, quite a high proportion of high-income

households (~2/3) have switched to solar water heaters/heat pumps for water heating, which explains the low projected growth in that tranche. The extent to which this could materialise is highly uncertain and should be explored further (as is currently being done in another SANEDI commissioned project with UCT).

Households (elc)

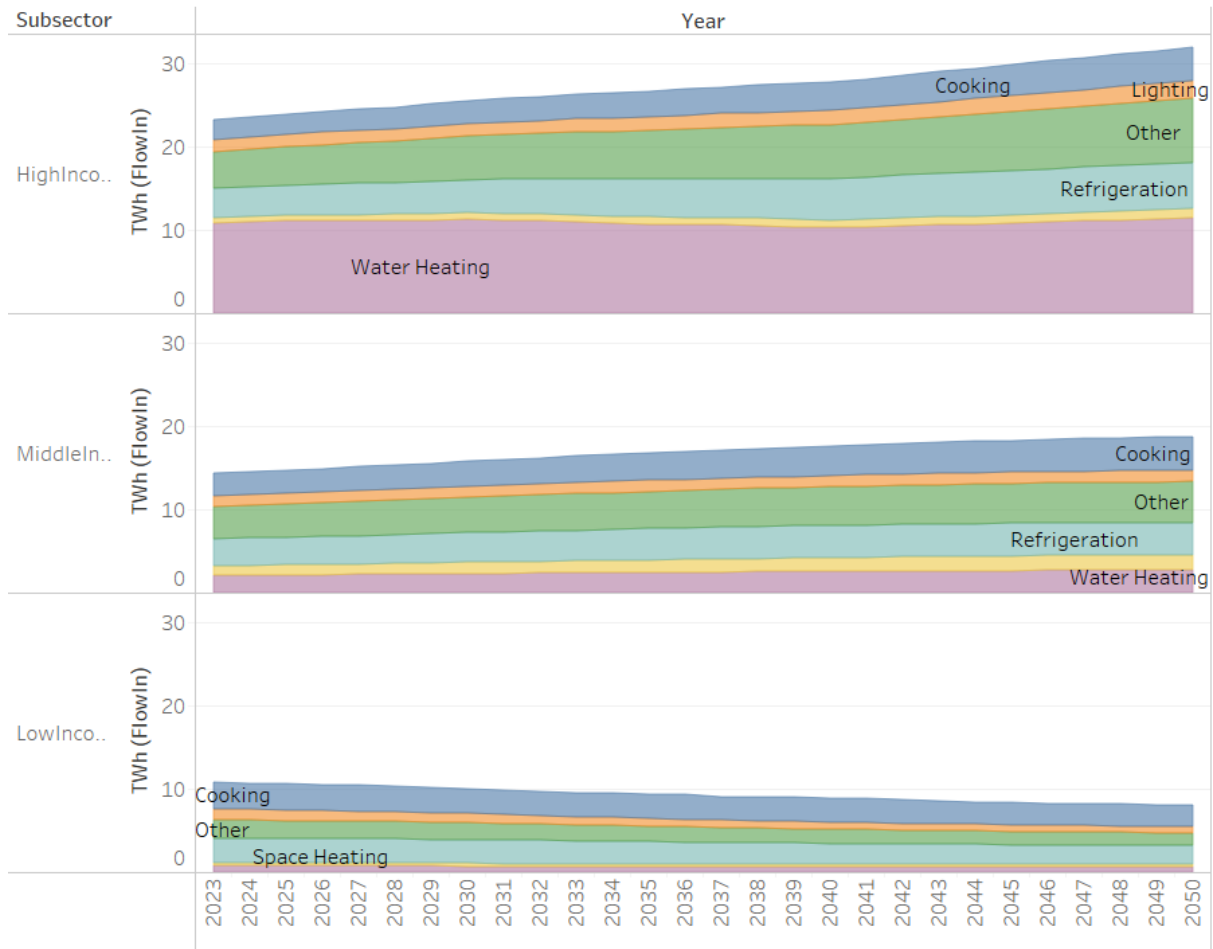


Figure 4: Residential electricity demand projections by end-use and income category

Commercial Buildings Electricity Demand Projections

Commercial buildings are split into Existing- and New-buildings, where New-buildings are assumed to meet proposed new building regulations such as SANS10400 XA2. The New-buildings add to overall building stock and also replace some of the ageing and retiring existing stock at a pace that is consistent with the growth of the service sector component of GDP. SATIM also considers the demand for the commercial buildings at and end-use level. The projected final electricity demand for existing/new buildings and by end-use are shown in Figure 5.

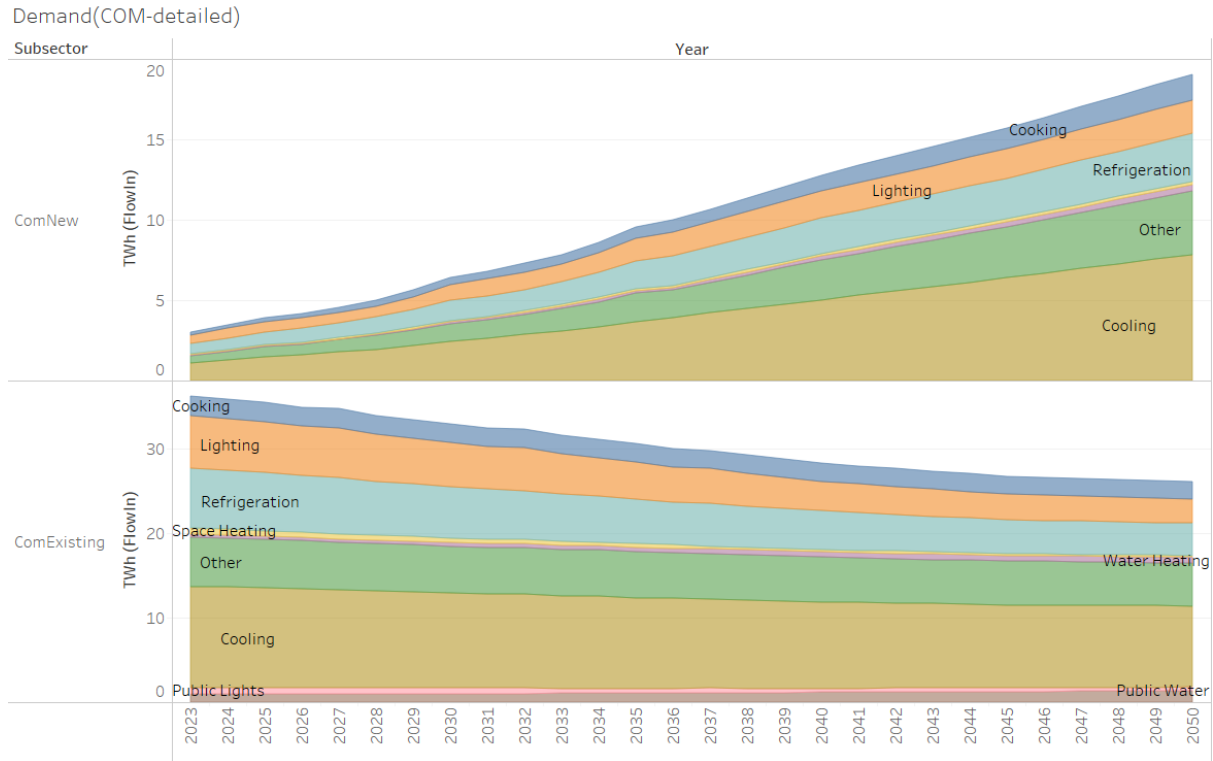


Figure 5: Electricity demand projections for Commercial Sector

Industry Electricity Demand Projections

As described in (Hughes et al 2021), SATIM splits industry into different sub-sectors, with some sectors modelled in more detail than others. The demand for electricity in industry is mainly driven by economic activity in the different sub-sectors, assumptions around energy efficiency and fuel switching. In the scenario presented here (see Figure 6), it is assumed that there is little energy efficiency gains (relative to 2017) and fuel switching taking place, and so demand is mainly driven by economic growth.

Demand(IND)

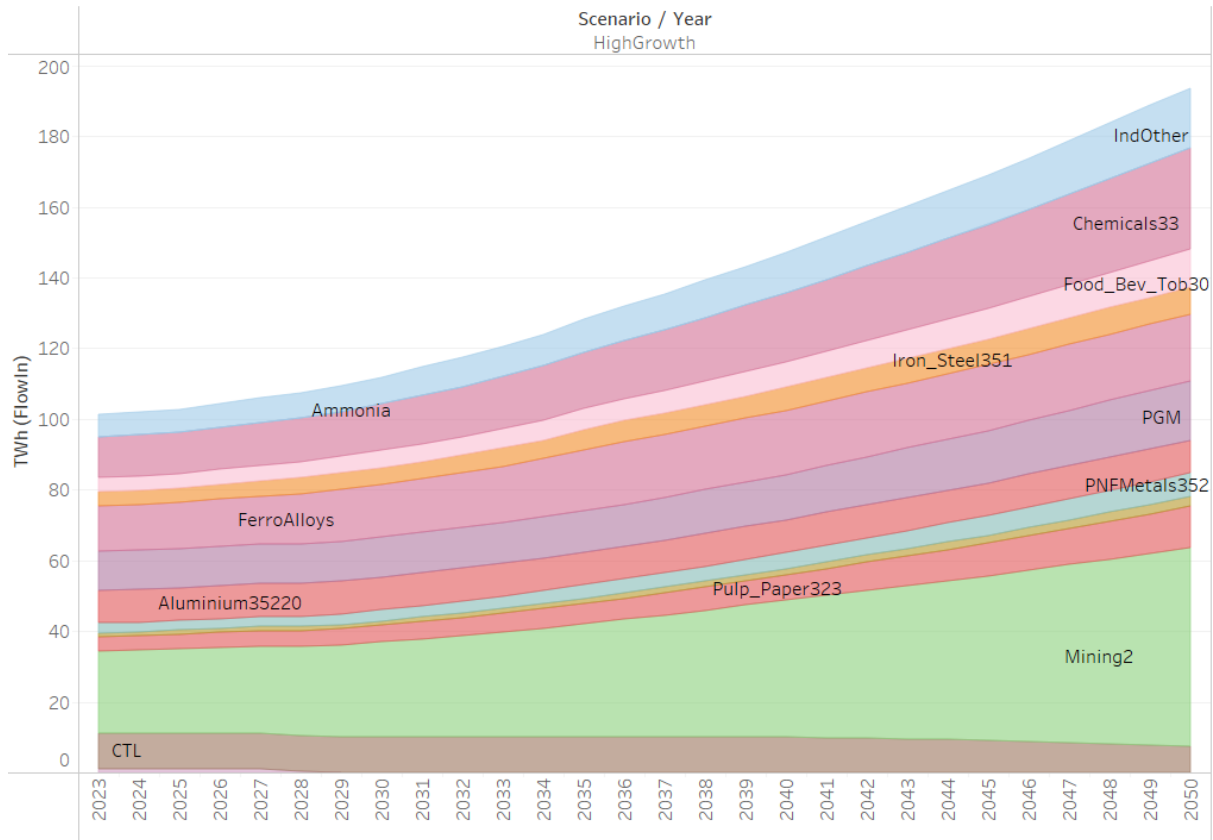


Figure 6 Demand Projection for Industry Sector

Transport

In SATIM, energy for transport is split into Freight and Passenger. Passenger demand in bpkm (billion passenger-km) is mainly driven by population and household income, driving car ownership, which also sets the private/public share. The share of private that is done by car vs SUV/moto is set exogenously. The share of public that is done by minibus vs bus/rail is also set exogenously. The technology mix between ICEVs, EVs and Hydrogen-based, is determined endogenously by the model based on assumptions around costs/prices (vehicles and fuels incl. supply chain costs) and other constraints such as upper limits on sales shares. Freight demand in btonkm (billion ton-km) is driven by GDP. In freight, the modal share between rail and different freight truck classes is specified exogenously. The technology mix is done in the same way as for passenger transport. Figure 7 shows the projected demand for transport and the assumed/resulting technology mix for Passenger and Freight. Figure 8 shows the implied electricity demand. Note that this would exclude the demand for electricity to make hydrogen, which is used to meet some of the freight demand. The demand for electricity for hydrogen is included in Figure 9.

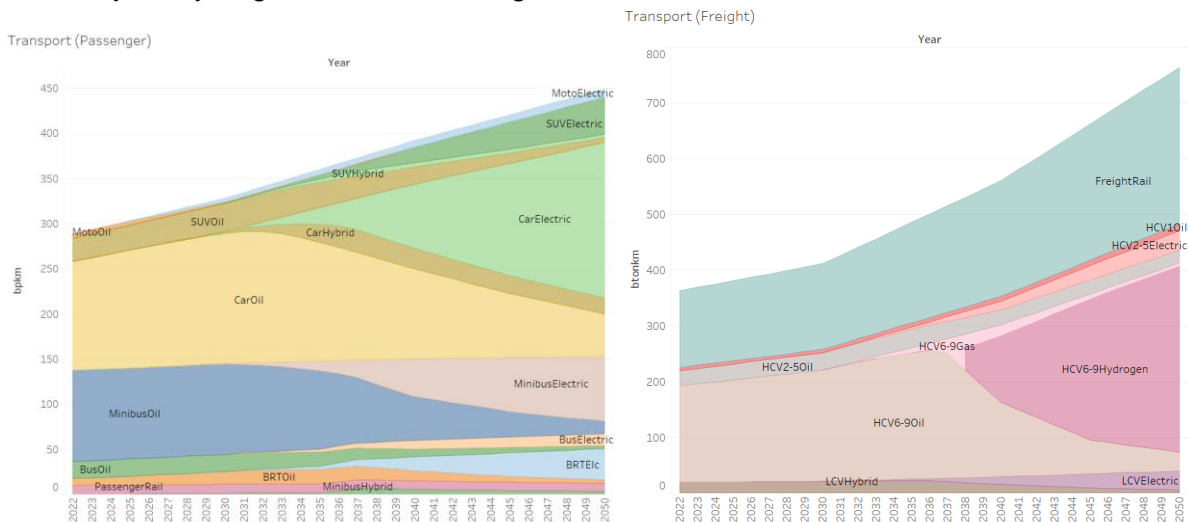


Figure 7 Projected Technology mix to meet Passenger and Freight Demand

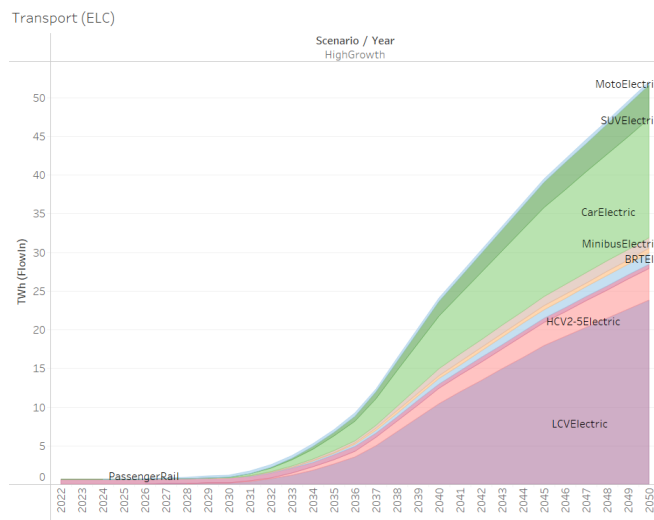


Figure 8 Electricity Demand for Transport

SATIMGE Final Demand Projections

The combined final electricity demand projection is shown in Figure 9. This can be found in the sheet: "SATIMDemand" (High Growth Scenario). A few things to note:

1. The electricity for Hydrogen is not included in the total electricity demand. This is because hydrogen can be produced in a flexible way (in terms of seasonal and diurnal profiles), and so it is better to include the demand for hydrogen (in PJ/yr or tons/yr) in the supply model and include hydrogen production options in the supply model.
2. As mentioned in the SATIMGE-Transport section above, the electricity demand for freight and public transport is allocated to the "Commercial" sector (in terms of distribution losses). The electricity demand for private transport is split between "Residential" and "Commercial" sectors assuming a user specified split (row 48 of the "AnnualDashboard" sheet, which is currently quite uncertain. A 50/50 split is currently assumed.
3. The Passenger Public category includes both road and rail. The rail part is included in the "Traction" sector.
4. The PGM subsector in SATIM includes both aspects of mining and processing, so this sector is split into "Mining" and "Other Manufacturing" assuming a constant split of 55%/45% as per calibration data.

The calculations for 3. and 4. and the resulting sector projections can be found in the sheet "EnergyDemand".

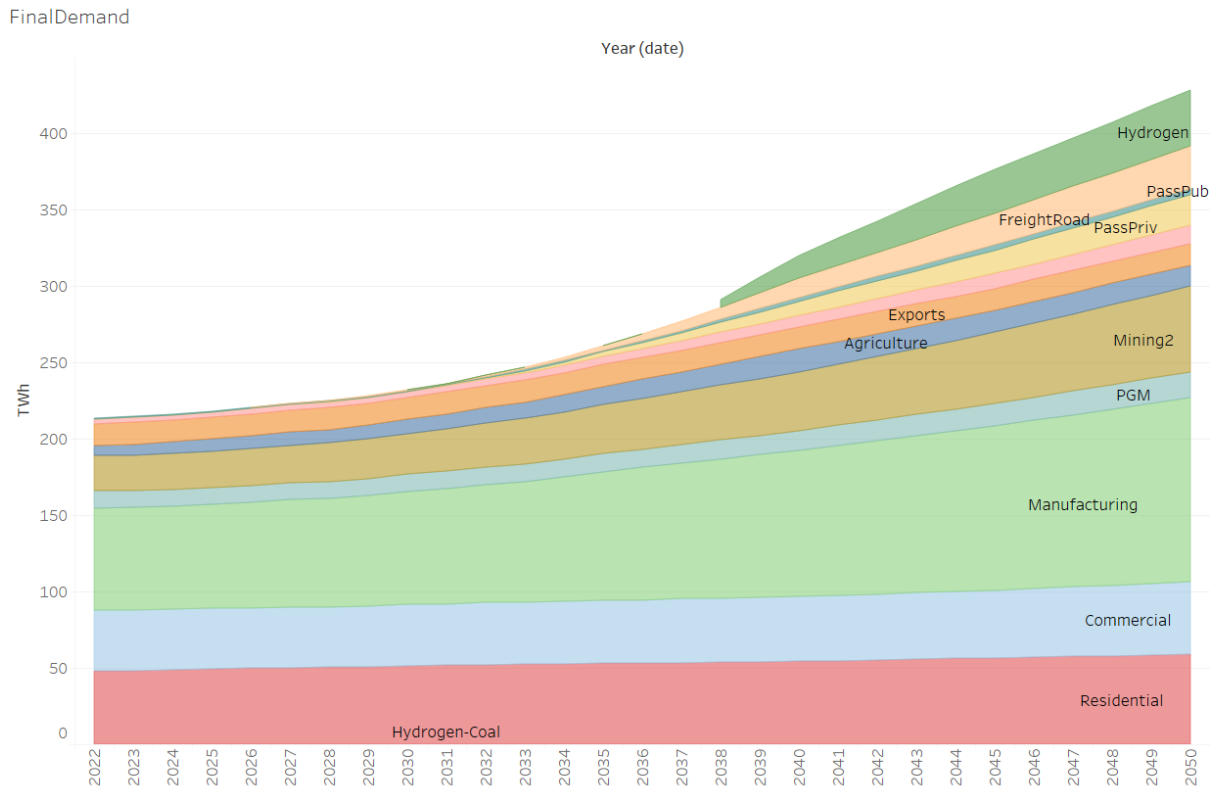


Figure 9: Final Demand by Sector

3.3.3 Loss Factor

Sector distribution losses (including non-technical losses) are estimated for 2017 in the calibration and shown in Table 2, and Transmission losses are assumed to be 3.9% as per (NERSA, 2006). The evolution of projected Distribution and Transmission losses can be adjusted by the user in the sheet: “AnnualDashboard”. In the scenario presented here, it is assumed that the losses are constant over the planning horizon. Note that a decline in non-technical losses would not necessarily result in a lowering of the demand, as the demand is “there”, so this parameter must be adjusted with care, but it is something that should be carefully considered when looking at the tariff trajectory, as well as future calibration exercises now that a lot more SSEG is in place.

Table 2 Estimated Distribution Losses

Sector	Estimated Distribution Losses
Mining	5.0%
Manufacturing	6.0%
Commercial	12.0%
Traction	5.0%
Agriculture	13.0%
Residential	18.0%
Redistributors	3.2%

3.3.4 On-site Generation

In Mode 2 of operation, the user needs to specify for each sector projected installed capacity of PV and other on-site generators. This can be done directly in the sheet: “AnnualDashboard”. Alternatively, we also provided some possible trajectories given available data in August 2023. The historical and proposed projected trajectories can be found in the sheet: “OnSitePV”, and in Figure 10 below, noting that these projections are not used in the version used by the IRP, since the demand projection there was generated in Mode 1.

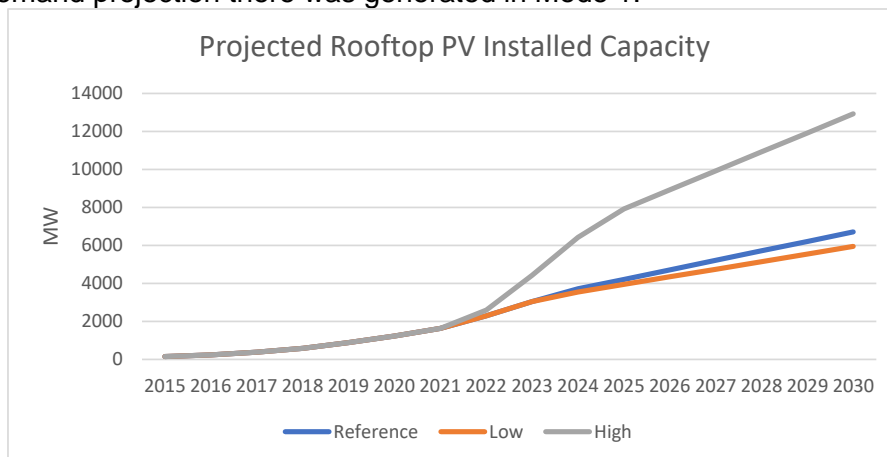


Figure 10 Historical and Projected Rooftop PV Capacity

3.3.5 Sectoral Demand Profiles and Calibration

Hourly sector profile estimates (normalised) were obtained from Eskom and can be found in the sheet: "DemandProfiles". The sector profiles for each hour of an average day, and monthly averages before calibration adjustments, weighted by Sectoral Final Energy, minus onsite generation and adjusted for losses are shown in Figure 11 and Figure 12. The figures on the right are cumulative and the graph is overlaid with the "Sent Out" profile, shown in red. With no adjustments made, we can see that there is not enough energy allocated to the morning and evening hours, and during the winter months in the original profiles. Table 3 shows the adjustment parameters and Figure 13 and Figure 14 show the same profile charts after the calibration adjustment was made. The calibration work is found in the sheet: "ProfileCalibration".

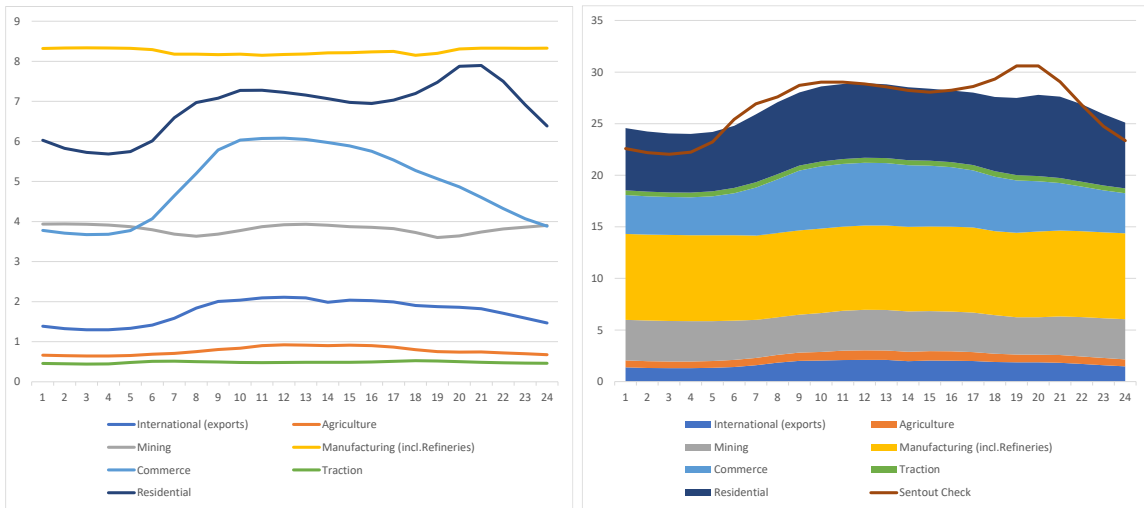


Figure 11 Sector profiles weighted by Final Energy scaled by losses, in GW (hourly)

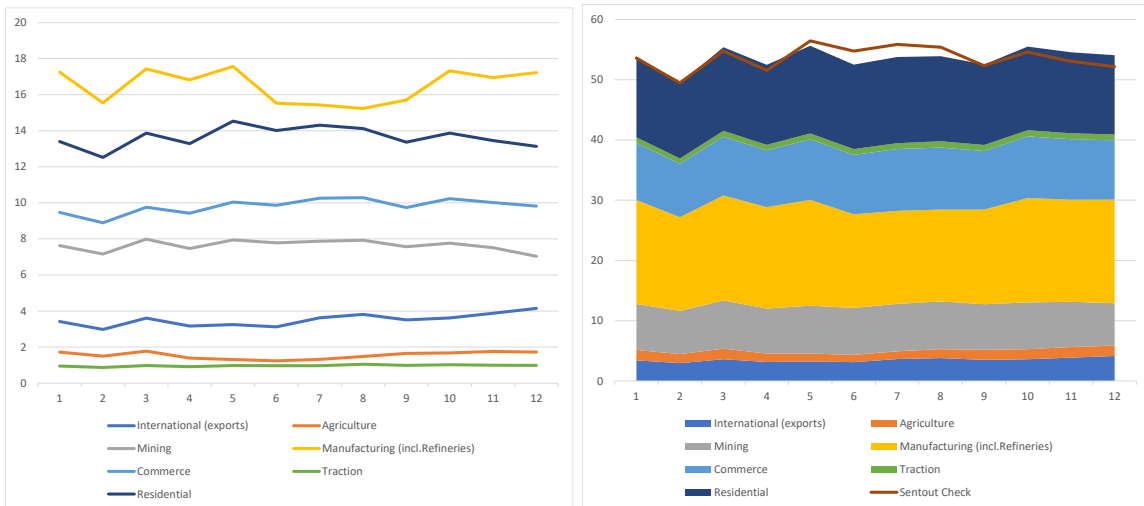


Figure 12 Sector profiles weighted by Final Energy scaled by losses, in GW (monthly)

Table 3 Profile Adjustment Parameters

Adjustment parameter (hourly)							
	International (exports)	Agriculture	Mining	Manufacturing (incl. Refineries)	Commerce	Traction	Residential
1	1	1	0.9	0.9	0.9	1	0.9
2	1	1	0.9	0.9	0.9	1	0.9
3	1	1	0.9	0.9	0.9	1	0.9
4	1	1	0.95	0.95	0.9	1	0.9
5	1	1	0.95	0.95	0.9	1	1
6	1	1	1	1	1	1	1.1
7	1	1	1	1	1	1	1.2
8	1	1	1	1	1	1	1.1
9	1	1	1	1	1	1	1.1
10	1	1	1	1	1.05	1	1.05
11	1	1	1	1	1.05	1	1
12	1	1	1	1	1.05	1	1
13	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1.1
18	1	1	1	1	1	1	1.3
19	1	1	1	1	1	1	1.5
20	1	1	1	1	1	1	1.4
21	1	1	1	1	0.9	1	1.3
22	1	1	0.95	0.95	0.9	1	1.2
23	1	1	0.9	0.9	0.9	1	1.1
24	1	1	0.9	0.9	0.9	1	0.95
Adjustment parameter (monthly)							
1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1
5	1	1	1	1	1.03	1	1.04
6	1	1	1	1.1	1.05	1	1.03
7	1	1	1	1.15	1	1	1
8	1	1	1	1.1	1	1	1
9	1	1	1	1	1	1	1
10	1	1	1	0.98	1	1	1
11	1	1	1	0.95	1	1	1
12	1	1	1	0.9	1	1	1

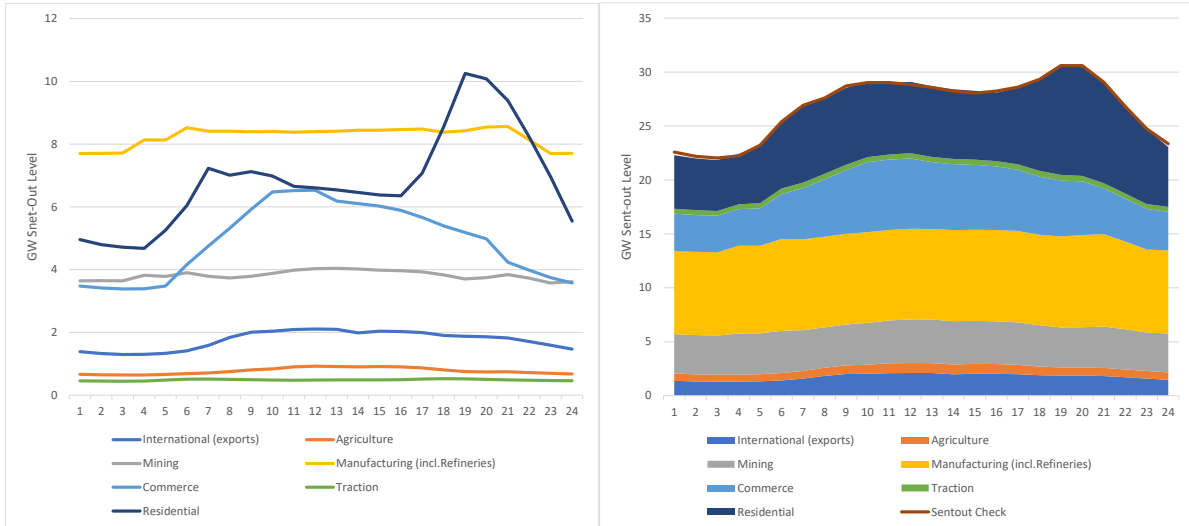


Figure 13 Sector profiles after calibration (hourly)

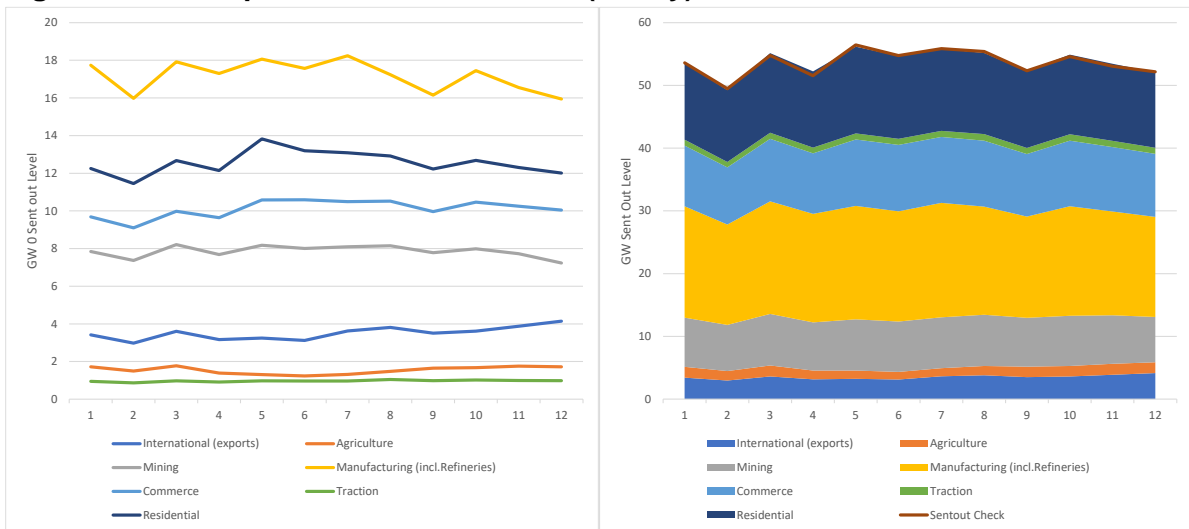


Figure 14 Sector profiles after calibration (monthly)

Even though the calibration is done at hourly and monthly level, we achieve quite a good match at an hourly level throughout the year for 2017 as shown in Figure 15.

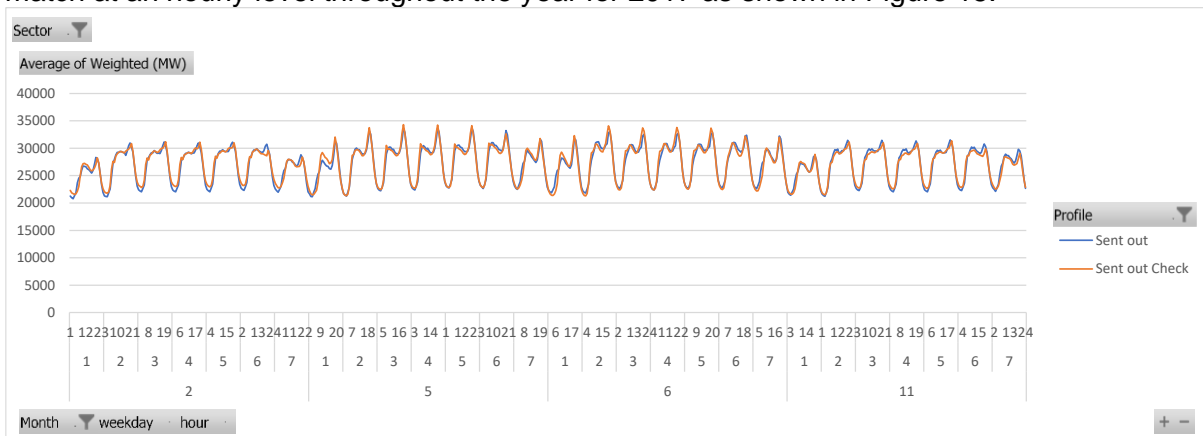


Figure 15 Profile Calibration Check for an average week in months 2, 5, 6 and 11

3.3.6 Vehicle Charging Profiles

Since we have very few EVs in our current system, we rely on international data for charging profiles. This is a relatively new area and there is a lot of new material becoming available. In this version of the model, two sources were considered:

1. NW Council power plan (NW, 2021)
2. A new online tool recently published by the IEA (IEA, 2023) (using mostly default assumptions).

Four categories were considered:

1. Home charging (for user specified share – currently set to 50%, of demand for electricity from private transport), which is then combined with “Residential Demand”.
2. Office charging (for the balance of private transport), combined with “Commercial Demand”.
3. Buses (for public transport), combined with “Commercial Demand”.
4. Freight, combined with “Commercial Demand”.

The profiles adopted in this report, in all 4 categories are the “IEA_Managed” profiles. The managed profiles in “Home Charging” shifts a lot of charging to night-time, to avoid exacerbating evening peak effects, and the IEA profiles in “Office Charging” align with time at the office with most of the charging taking place during the day, as shown in Figure 16.

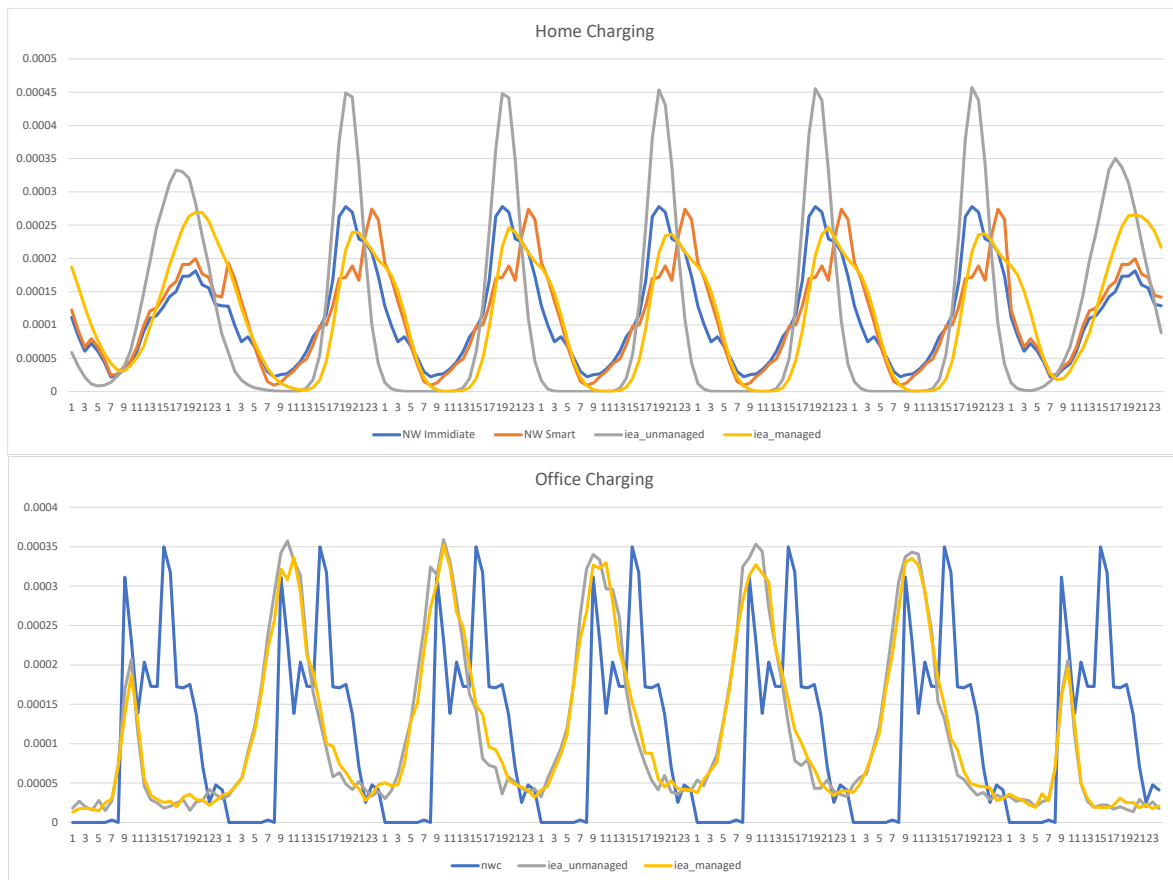


Figure 16 Home and Office Charging for Private Vehicles (average week)

The “IEA_managed” profiles for “Bus” (public road transport) assume most of the charging is taking place at night with some daytime charging, and that for freight, some of the charging is done on the weekends, as shown in Figure 17. Given South Africa’s good solar resource one should perhaps, for future versions of the model, consider profiles with larger share during day-time hours. Another possibility is to adopt a similar approach to hydrogen and include the vehicle charging in the supply model, with some of the charging being flexible, and responsive to scarcity/abundance signals provided by time of use tariffs or other mechanisms.

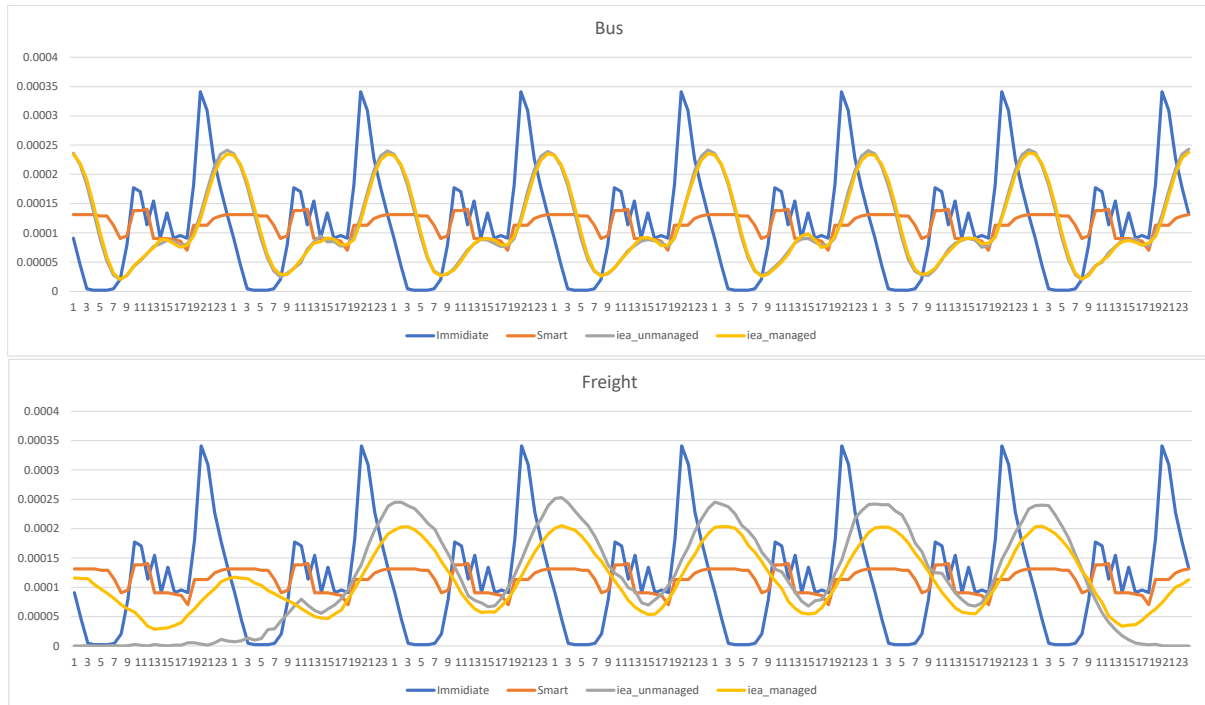


Figure 17 Bus and Freight Vehicle Charging profiles (average week)

4 RESULTS

Annual, hourly results can be extracted from the sheet: “ProfileDashboard” using the “Export Profiles to csv” button, having specified a valid path for the csv file, and having selected “High Growth Scenario”, “Dist.PV Excluded” and “Excluded” for other onsite generation.

The MWh (in millions or TWh) and MW peak projected demand at secondary/sent-out level, having excluded on-site generation is shown in Figure 18. This can be plotted by using a pivot table on the data in the csv file by taking annual sums and maximums. In this scenario the energy demand is projected to increase by around 200 TWh between 2023 and 2050. The peak demand is projected to grow from around 35 000 MW to around 62 000 MW. This implies a slight increase in demand load factor, which results from a slightly faster growth in industrial electricity demand relative to demand from commercial buildings and households. As mentioned in the household section this assumes quite a high penetration of heat-pumps or solar water heaters. We also assume a well-managed electrification of road transport, where the vehicle charging takes place outside of peak demand times. The projected pace of electricity growth after the mid-2030’s is higher than in the period before, both because of the assumed GDP growth trajectory, and the timing of electrification of transport, which is expected to accelerate from that point on. The calibrated profile for 2017 and the resulting profile for 2050 (vehicle charging taking place in commercial and residential) are shown in Figure 19 and Figure 20.

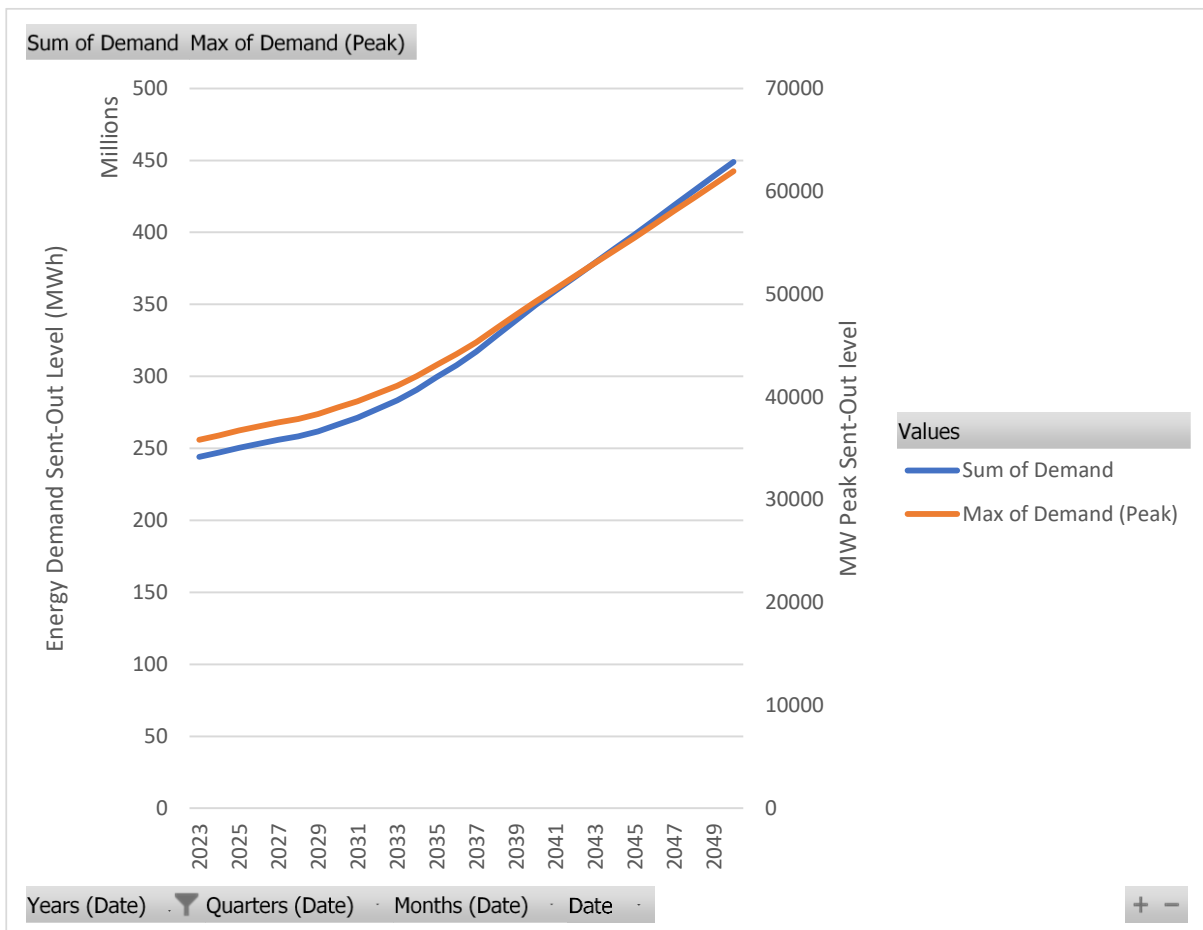


Figure 18 Projected Electricity Demand Secondary/Sent-Out level

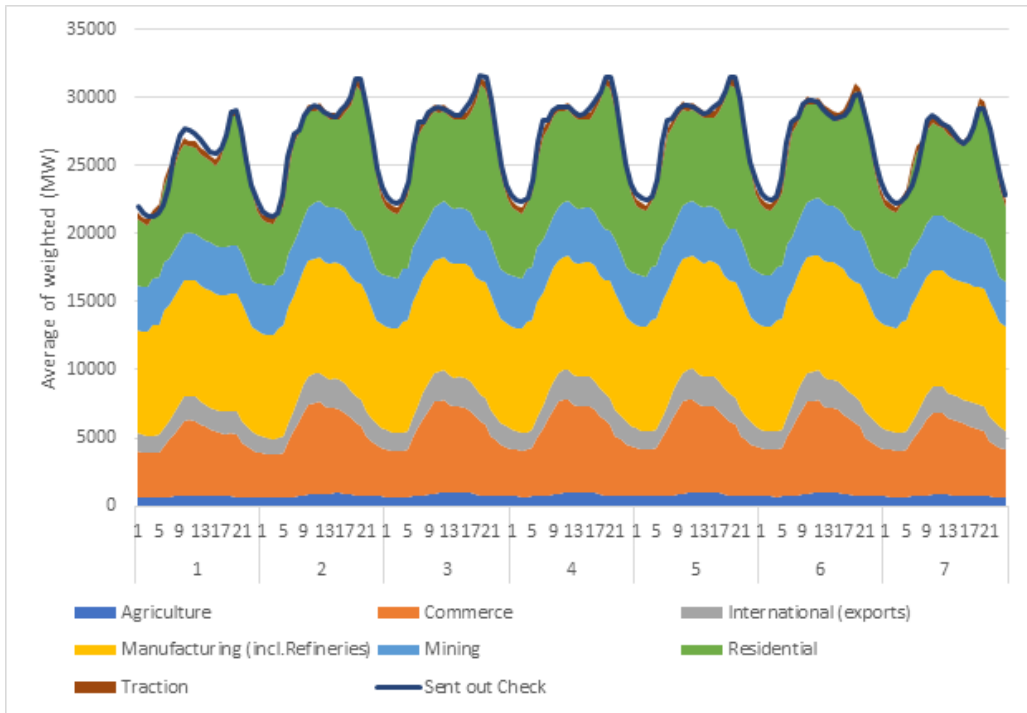


Figure 19: Average daily and hourly weighted sector profiles (2017 calibration)

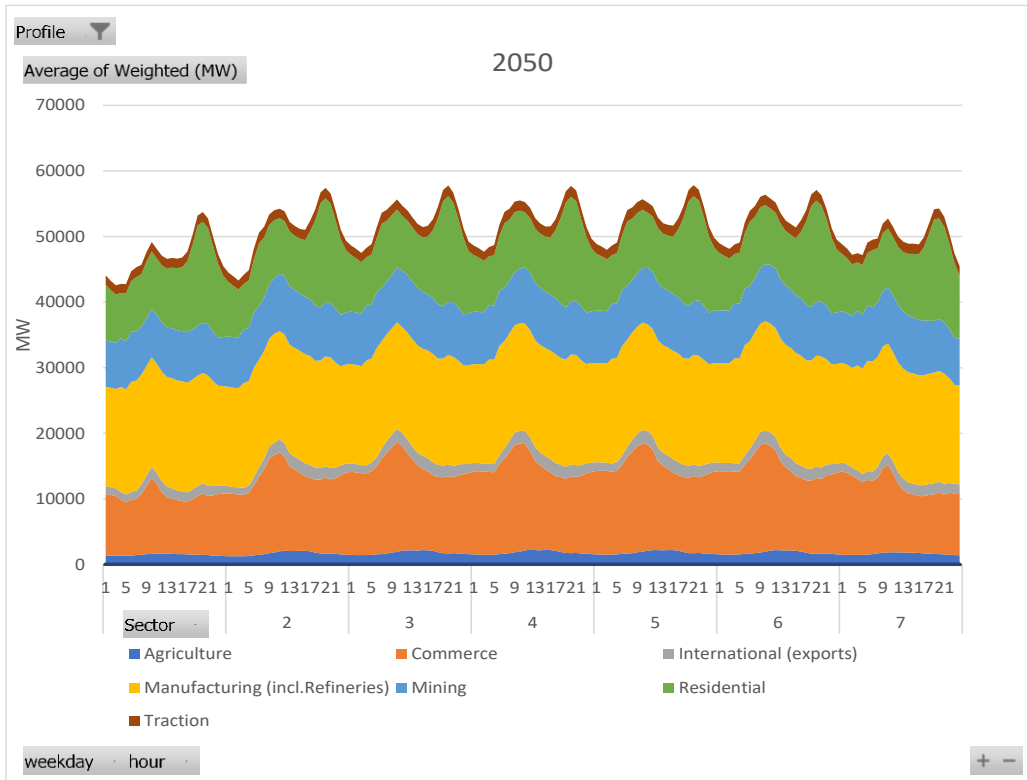


Figure 20 Sent-Out Profile in 2050 for an average week

5 CONCLUSION

A first pass at a high temporal resolution (hourly) bottom-up calibrated spreadsheet-based demand model was described in detail, as well as the dataset used for the Reference scenario for the IRP update for 2023. The tool presented is hopefully an improvement on how long term projections were done previously, in that it provides the user to explore different scenarios, where the GDP structure is evolving, allowing for different sectors to grow at different pace, new sectors (such as electrified road transport), to come in, and capturing the effect of this not only on the energy demand but also on the demand profile, which is required for the expansion planning/supply model.

The tool was calibrated with available data in August 2023, and populated using scenario projections done using SATIMGE 2023 (August version), with a GDP projection reaching 3.8% in the mid-2030s, assuming the continuing trend of an increasing share of the tertiary sector but maintaining constant shares of mining and agriculture. New building standards are assumed to be implemented in the commercial sector and residential sector, but no major efficiency gains or fuel switching from 2017 is assumed in the industrial sectors (including agriculture). Should South Africa aim to increase climate mitigation ambition, it is expected that there would be some changes in the industry sector. Road transport electrification takes place at an accelerating pace from the mid-2030's in passenger transport, and in the light commercial vehicle tranche of freight, but it is assumed that charging is well-managed in terms of time of use. This results in an energy demand that grows by around 200 TWh between 2023 and 2050 and a peak demand at the Secondary/sent-out level, that grows by around 27GW, though much of this may be met by onsite generation, the effect of which on demand is excluded.

The bottom-up model requires many user-defined assumptions, many of which are highly uncertain. Using a model such as SATIMGE can help making internally consistent assumptions but there are still many uncertainties to be explored. The model in its current form provides demand projections at a high temporal resolution (hourly), but for a single node model. Given current bottlenecks on the transmission network, ideally one would want to do the planning in a spatially disaggregated way to be able to take this into account. Also, the non-homogeneity in how different sectors may evolve in different geographic locations given assumptions around growth and, in the long run climate impacts, require future demand forecasts to be spatially disaggregated. The spatial disaggregation, price responsiveness, as well as a thorough exploration of the uncertainty space is left for future work.

6 RECOMMENDATIONS

There are several axes of development that would improve the model from its current form, as well as the demand analysis required for medium to long term IRP-type exercises.

As mentioned, the model presented has high temporal resolution, but low sectoral resolution, in that it only disaggregates by sector, and ideally one would want to disaggregate down to the end-use level. It also has low spatial resolution, and ideally one would like to model with more than one node. It also considers one scenario at a time (low uncertainty resolution). Spreadsheet based models are great in that many people know how to use spreadsheets, and so it is accessible for many to “look under the hood” to see how it works. However, at 8760 data points per end-use per region, the spreadsheet (which is already quite slow and large at 50+Mb), will quickly become un-usable if we were to increase the resolution along the other 3 axes (sectoral, spatial, uncertainty). Possible workarounds would be:

- Keep a low temporal resolution version of the model, say using a few representative days, and increase sectoral, spatial, uncertainty resolution in the workbook. When the user has finished making the assumptions then “extract” the high-resolution version using code.
- Keep a separate workbook for each spatial area or sector. The disadvantage of this approach is that such an approach will be difficult to maintain and will require linking of multiple workbooks for the user to be able to have an overview perspective.
- Keep calibration separately. It will be hard to come up with a better tool for doing calibration in an interactive way, than in Excel.
- Do the demand projections using other platforms example, LEAP, MAED and MAED-EL.

In terms of improving the analysis, at this point, the most important would be to explore the uncertainty space more thoroughly. One should not plan with just one demand but a range and find a least-regret, robust plan, with adequate contingencies should demand evolve at a higher or lower pace than expected.

Another important improvement would be to include a price reactive component. Models such as MAED and LEAP would allow for high resolution on sectoral, spatial and scenarios, but do not have price responsiveness. Price is a function of what’s happening on the supply side of electricity (but also of other competing fuels).

SATIMGE in its August 2023 version does include a higher sectoral resolution (by end-use), has some price responsiveness via the CGE link, as well as consideration for competing fuels, but is also running at a low spatial resolution and low temporal resolution. Efforts are currently being made to increase the temporal resolution of SATIMGE, which should be available in coming weeks, but a spatially disaggregated SATIMGE is still quite a few months away.

It would also be worth exploring the role of demand-side flexibility (as could be done in transport and hydrogen production), instead of assuming constant profiles across all end-uses and sectors. This would be another advantage of using SATIMGE as this framework includes supply modelling and it would be possible to include demand flexibility as was done in (Ireland et al, 2019).

Other aspects which would be interesting to explore in more detail and would require more experimentation and data collection include behavioural responses of households and firms to different tariff trajectories and time of use profiles.

An update base year/calibration when 2024 data becomes available (hopefully with lower levels of load-shedding than observed in 2022-2023), would also help ground the analysis a bit more firmly in a post-covid world.

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