ARUP

eThekwini Integrated Resource Plan

Draft | June 2020




Contents

List of Figures

List of Acronyms

CAP	Climate Action Plan
CAPEX	Capital expenditure
CCUS	carbon capture, utilisation and storage
CHP	Combined heat and power
CIA	Climate Impact Atlas
DCCS	Durban Climate Change Strategy
DER	Distributed energy resources
DMRE	Department of Mineral Resources and Energy
DoE	Department of Energy
DST	Department of Science and Technology
EV	Electric vehicles
EIRP	eThekwini Integrated Resource Plan
EO	Energy Office
EPRI	Electric Power Research Institute
ESR	Energy Strategic Roadmap
EWG	Energy Working Group
GHG	Greenhouse gas
GW	Gigawatt
GWh	Gigawatt hour
HELE	High Efficiency Low Emissions technology
IPP	Independent Power Producers
IRP	Integrated Resource Plan
kW	Kilowatt
kWh	Kilowatt hour
kWp	Kilowatt peak
LCOE	Levelised cost of electricity
LNG	Liquefied natural gas
MIPPPP	Municipal Independent Power Producer Procurement Program
MW	Megawatt
MWh	Megawatt hour
OCGT	Open Cycle Gas Turbine
OPEX	Operation expenditure
PGM	Platinum Group Metals
PPA	Power purchase agreement
PV	Photo-voltaic
RE	Renewable Energy
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
SMR	Small Modular Reactors
UN	United Nations
ZAR	South African Rand

Executive Summary

This section summarises the technical aspects of the eThekwini Integrated Resource Plan (EIRP), the first IRP for a local government in South Africa. The Plan sets out a proposal for eThekwini's long-term clean energy strategy up to 2050. It describes the:

- Creation of a resilient integrated energy system, which is diversified in its energy mix.
- Provision of reliable energy supply as a pillar for supporting economic development.
- Development of the energy industry to create jobs and diversify the economy.
- Increase renewable energy supply in the eThekwini municipality as a contribution to global climate action – aiming to achieve at least 40% renewable energy supply by 2030 and 100% by 2050.

The eThekwini energy system has been modelled for several demand and supply scenarios to assess the optimal energy mix scenarios for the Municipality to meet its targets. Various electricity consumption forecasts were made, based on eThekwini and national predictions. A number of renewable energy mix supply options were then selected to match the demand. Local job creation, the levelized cost of electricity production and carbon emissions reduction were among the factors considered when appraising supply options. The methodology is further laid out in Sections 4, 5 and 6.

Context

The Energy Strategic Roadmap (ESR) was developed as a precursor to the EIRP. Published in its entirety as a standalone document, it should be read in conjunction with this report for further detail.

The roadmap explored renewable energy resources available within the Municipal boundary with the aim of stimulating local job creation, increased policy certainty and economic investment. The recommendation from the ESR was for eThekwini to prioritise solar PV generation, alongside contributions from onshore wind generation, biogas-based electricity from landfill and wastewater treatment sites and small-scale hydropower.

The remaining power demands that cannot be met by generation within the municipality would need to be purchased from renewable Independent Power Producers (IPPs) and imported into the area. The assumption there is that there will be sufficient renewable power being generated by IPPs in South Africa to allow eThekwini to purchase what it needs directly from them. In addition to this, the assumption is also made that the IPP power import can meet the hourly demand profile of eThekwini. This will need to be managed accordingly as the Energy Office begins to procure renewable power; sufficient baseload and peaking capacity will be required. It is also recognised that in some cases going forward, these IPPs may operate from within the municipality's jurisdiction.

There are a number of reasons the municipality seeks to make the transition away from Eskom towards generating its own renewable power and purchasing it from other Independent Power Producers (IPPs) outside the municipality:

- The cost of power from Eskom is higher than generating it or purchasing it from other private IPPs. The municipality needs to ensure provision of low cost energy to residents and businesses, in part to reduce risk of losing customers.
- The renewable content of the Eskom supply is not high enough in 2050 for the municipality to meet its 2050 renewable target of 100%.
- Introduction of a carbon tax that puts pressure on the private sector to reduce its carbon emissions, would in turn pressure the municipality to provide a low carbon source of power in order to avoid those customers defecting from the grid.

In order to reduce costs and to meet renewable targets, the municipality will transition to installing renewable power generation assets, as well as purchasing power from renewable IPPs. The extent to which this needs to happen has been modelled and is explored in Section 6.

The aim of the EIRP is to evaluate the optimum integrated-energy mix that can serve eThekwini's aspirations for diversified, reliable and clean energy. Nonetheless certain electricity generation technologies have been excluded from the modelling optimisation for reasons including current low commercial viability and the risk of compromising the achievement of eThekwini's renewable energy target. The most significant of these energy generation technologies are:

- Natural gas
- Nuclear power
- Ocean energy
- Hydrogen related technologies

See Section 5.4 for more detailed description of these technologies and their context in South Africa.

The eThekwini energy system has been modelled for several demand and supply scenarios to assess the optimal energy mix scenarios for the Municipality to meet its targets of 40% renewable energy generation by 2030 and 100% by 2050.

This document presents:

- The description and results from the stakeholder consultation process.
- Findings from integrated-energy mix scenarios modelling.
- The implementation plan for delivery of additional energy capacity through a Ministerial Determination application.
- A Municipal Independent Power Producer Procurement Program (MIPPPP) based on the recommended energy mix scenarios.

Energy mix scenarios modelling

The modelling team developed a series of distinct eThekwini electricity consumption scenarios by indexing the eThekwini current consumption profile five scenarios based on eThekwini's own projections and the South Africa national IRP. These are:

- "Highest" - Indexed against 'High' (Same Sectors) scenario, National IRP, with addition of Electric Vehicle (EV) uptake
- "High" - Indexed against 'High' (Same Sectors) scenario, National IRP
- "Medium" - Inferred from 'High' and 'Low' scenarios
- "Low" - Indexed against 'Low' (Same Sectors) scenario, National IRP
- "Energy Efficient" - Indexed against eThekwini's demand forecast using grid load forecasting software

The supply scenarios previously considered as part of the ESR have been optimised and explored in further detail to create five unique supply scenarios including a range of renewable technologies. These are:

- A: Base case – continued supply from Eskom
- B: All renewables – all the renewable technologies identified in the municipality are included, as well as ability to import renewable power from Independent Power Producers outside the municipality
- C: Solar scaled to meet target – all renewable technologies included and with solar PV scaled up to avoid need to import energy from outside municipality
- D: Renewable technologies, biomass excluded – renewable technologies included as before but excluding the use of biomass, as well as ability to import renewable power from Independent Power Producers outside the municipality
- E: Biomass and imports – biomass and imported energy from the grid or IPPs outside the municipality only

The technology optimisation investigated how each technology interacts with the wider electricity system, providing energy output and usage data for technologies across each of the scenarios. In order to find the least-cost scenario, economic parameters have been developed or gathered through engagement with the municipality. These assumptions are detailed in section 5.7.

As stated, many scenarios include a significant amount of power to be imported from privately owned IPPs. It will be the role of the Energy Office to ensure that this power is renewably generated and will need to be cautious to select a range of generation and storage technologies that meet the demands of the municipality. Alongside wind and solar, these will need to include technologies that enable the base load demand to be met such as energy storage solutions (including hydrogen), demand side response, biomass combustion plants and ocean energy solutions.

Key Results

Using the build-out programmes outlined in section 6.5, the Levelised Cost of Electricity (LCOE, i.e. the cost to generate power, including a 10% cost assumption for distributing it to end users), carbon emissions and job creation over a 30-year period were calculated for the five supply scenarios, shown in Table 4, Figure 1 and Figure 2.

Initial results show that the Base Case, Scenario A, does not meet the renewable target in 2050. Scenario C supply technologies are not able to meet the demand meaning it is not a technically viable solution.

Table 4: LCOE results for supply scenarios.

Supply Scenario		LCOE (ZAR / MWh)
A	Base case	959
B	All renewable technologies	650
C	Solar scaled to meet target	4,648
D	All renewable technologies, biomass excluded	598
E	Biomass and imported energy	617

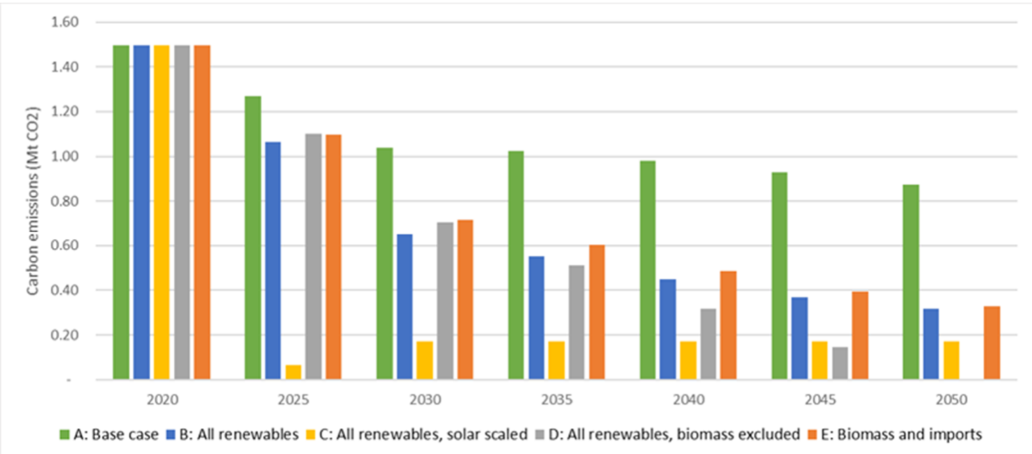

Figure 1: Carbon emissions results for the five supply scenarios

Observations from these modelling results show that each of the supply scenarios considered in more detail have different advantages and disadvantages. However, since the municipality's main priority is the delivery of affordable low-carbon energy (this is the UN's Sustainable Development Goal 7[1]), Scenario D was selected as the recommended scenario since this offers the lowest cost solution. This scenario involves maximising the use of technologies like solar PV, wind, landfill gas, wastewater and hydropower within the municipality through a combination of public ownership and private ownership with Power Purchase Agreement (PPA) contracts. No biomass generation capacity is used in this Scenario. The lower costs of this scenario are in part attributed to high reliance on import of electricity from IPPs. Procurement of so much IPP generation together with uncertainty about the magnitude of its future availability could pose a delivery risk.

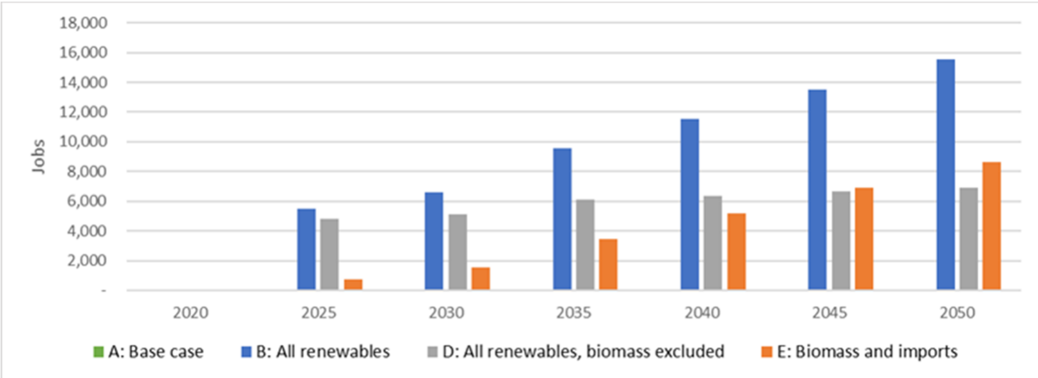

Figure 2: Job creation results for the five supply scenarios

The generation transition programme for Scenario D is shown in Figure 3. Up to 2050, the power imported from Eskom is reduced whilst the municipality procures more energy from renewable IPPs. At the same time, renewable power generation asset construction projects are rolled out within the municipality, as shown in

[1] UN Sustainable development Goals https://sustainabledevelopment.un.org/?menu=1300

Table 5. Through undertaking a programme of construction and operation of its own power generation assets, the municipality would secure future revenues and generate jobs.

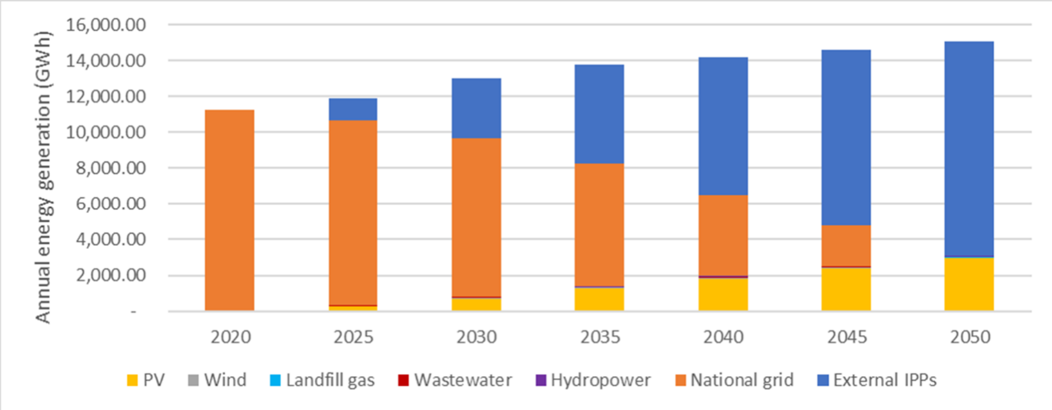

Figure 3: Energy generation mix transition plan, Scenario D

Table 5: Generation capacity build out programme

Year	Energy supply mix capacity building schedule, MW						Imported power, MW	
	Bio-mass	PV	Wind	Land fill gas	Waste-water	Hydro-power	IPPs	Eskom
2020	0	0	0	4.0	0	0	0	10,701
2025	0	176	57	4.0	3.5	4.0	373	6,260
2030	0	470	153	7.5	3.7	10.6	745	1,830
2035	4.0	854	153	7.5	3.8	10.6	1,140	1,370
2040	0	1,239	153	7.5	3.9	10.6	1,530	915
2045	0	1,623	153	7.5	4.0	10.6	1,920	458
2050	0	2,007	153	7.5	4.1	10.6	2,320	0
% Total Capacity, 2050	**0%**	**45%**	**3%**	**<1%**	**<1%**	**<1%**	**52%**	**0%**
% Annual Energy, 2050	**0%**	**20%**	**<1%**	**<1%**	**<1%**	**<1%**	**79%**	**0%**

Implementation

The Energy Working Group (EWG) will review the final recommendation of the EIRP and release the ESR and EIRP for public comments. After responding to comments and making any necessary policy adjustments, the EWG will submit the final ESR and EIRP to the eThekwini Council for final approval. Upon internally approved, eThekwini Energy Office will draft letter to the Department of Mineral Resources and Energy (DMRE) via Mayor's Office.

Following this, eThekwini municipality should apply for specific Ministerial Determination in order to fulfil the broader strategic goals of achieving 40% of renewable energy by 2030 and 100% by 2050. This will be followed by establishment of Municipal Independent Power Producer Procurement Program which is informed by new generation capacity building schedule as outlined in Table 2.

eThekwini municipality plans to meet its future energy and capacity needs through a mix of appropriate technologies which includes intermittent and stable baseload generation. Currently, eThekwini procures 99% of electricity provision from Eskom. To effectively meet the broader strategic goals as set in Durban Climate Change Strategy (DCCS) and Climate Action Plan (CAP), eThekwini requires new generation capacity, taking into consideration the demand forecasts projected towards 2030.

The municipality will achieve their renewable energy targets through a range of policy settings, including:

- Reduce Procurement of Coal Electricity
- Improve Renewable Energy Generation
- Industrial Energy Efficiency Standard
- Private Sector Generation
- The Growth of Revenue Generation
- Decarbonize Transport Sector
- Energy Efficiency Demand Side Management
- Carbon Tax
- Heating and Cooling Systems.

1 Introduction

1.1 eThekwini Municipality Overview

The eThekwini Metropolitan Municipality is a government authority which oversees major services including but not limited to Electricity, Water and Sanitation, Cleaning and Solid Waste across a population of approximately 3.8 million people, making it one of the biggest cities on coast of the African continent. It is located on the East coast of South Africa, and includes the city of Durban as a major urban hub. Roughly 68% of the Municipal area is considered rural and of this approximately 10% comprises of commercial farms and metropolitan open space and ~90% of the rural area is hilly, rugged terrain with dispersed traditional dwellings and communal land holdings. The remainder of the municipal area, approximately 32%, is urban land dominated by residential, commercial/office and industrial land use[2]. The combination of rural and urban communities is unique to the Municipality and presents several challenges particularly with respect to land, planning and urban management.

Within the Municipality, several departments have been assigned responsibilities to lead on the City's clean energy transition. For instance, the Climate Protection Branch and later the Energy Office teams were established to assist in implementing policies and strategies aimed toward achieving cleaner energy use and emissions reduction.

The Energy Office (EO) itself was launched in 2009 to increase awareness around saving electricity and promoting energy efficiency. Since then the mandate of the Energy Office has expanded significantly to include promoting renewable energy, climate change mitigation and sustainable transport. The EO was the first of its kind in South Africa, setting a precedent for local government participation in sustainable and clean energy interventions.

The most recent developments led by the EO was the development of the City's ESR in 2019 in parallel to the Integrated Resource Plan which this document outlines.

1.2 eThekwini Integrated Resource Plan (EIRP)

The follow section provides a summary of the Municipality's Integrated Resource Plan developed to provide an outline for the City's electricity supply mix for the next 30 years. This document consists of the technical aspects of the EIRP.

Like the national IRP, the EIRP is intended to be a living document that will be updated regularly.

[22] 'Integrated Development Plan, eThekwini Municipality, 2019

1.2.1 EIRP Objectives

The eThekwini Integrated Resource Plan (EIRP) is the first IRP for a local government in South Africa. The development of the EIRP was commissioned to respond to four of eThekwini's aspirations for their energy system:

- Creation of a resilient integrated energy system which is diversified in its energy mix.
- Provision of reliable energy supply as a pillar for supporting economic development.
- Development of the energy industry to create jobs and diversify the economy.
- Increase renewable energy supply in the eThekwini municipality as a contribution to global climate action – aiming to achieve at least 40% renewable energy supply by 2030 and 100% by 2050.

The EIRP is a policy document which sets out a proposal for eThekwini's long-term clean energy strategy up to 2050. This report serves to assist the Municipality in planning and policy development specifically targeted toward a clean energy transition. In the short term, three key outcomes anticipated from the development of the EIRP are as follows:

- Creation of an evidence-base for a Ministerial Determination request for the Municipality to procure energy from IPP's, as envisaged in the New Generation Capacity regulations.
- Development of a clear plan for roll-out of municipal owned power generation assets as a way of increasing revenues for the municipality.
- Clarification of the scale of investment (domestic and foreign) needed for eThekwini's clean energy transition.

Long-term energy planning is a continuous process dependent on the speed of development in the energy industry both globally and locally through innovation and commercialisation of technologies. National policies play a critical role in facilitating the deployment of renewable energy technologies and legislative drivers will be required to enable the Municipality to implement plans for a clean energy transition. The EIRP sets out the Municipality's energy plan in the current context and is the first steps towards the Municipality providing its constituents with reliable and clean energy.

1.2.2 EIRP Development

The section below aims to provide a brief background of the ESR which was developed as a precursor to the EIRP. The ESR is published in its entirety as a standalone document and should be read in conjunction with this report for further detail. As the roadmap has served as the foundation of the EIRP it is thus frequently referred to in this document.

1.2.2.1 Energy Strategic Roadmap

The development of the Municipality's renewable energy roadmap was commissioned under C40 Cities Clean Energy Technical Assistance Programme to support the Municipality in achieving their climate action targets for 2030 and 2050. The development of the roadmap was informed by existing clean energy research studies previously commissioned for the Municipality. The aim of the roadmap was broadly to establish a baseline for the Municipality, assess the current and predicted energy demand and supply options, identify barriers to deployment of renewable energy technologies and provide the guidance required by the Municipality to drive implementation. A strong focus was placed on demand reduction and energy efficiency strategies for the Municipality to implement in parallel to pursing clean energy generation.

The roadmap explored renewable energy resources available within the Municipal boundary with the aim of stimulating local job creation and economic investment. The technologies analysed were solar (combination of rooftop and ground-mounted), large scale wind, in-line hydro power, waste to energy (wastewater to energy and landfill gas) and biomass (from forestry and sugar industries near the Municipal bounds). Various scenarios, including the option to purchase clean energy from Independent Power Producers (IPPs) outside the municipal boundary, were appraised at a high level, in order to determine a least cost optimal energy mix for the Municipality.

Overall, the most viable technologies were found to be solar photovoltaic (PV) panels, biomass (including local forestry and bagasse resources), small scale hydro power, gas extraction from landfill and wastewater treatment sites and onshore wind energy. Energy extraction from landfill and wastewater treatment sites were found to be limited due to the low yields expected from these systems. Wind energy generation was found to be limited within the City boundary largely due to environmental sensitivities and scattered dwellings reducing land availability for turbine installations.

Six scenarios were generated to reflect different contributions from locally generated renewable energy with varying cost profiles. The recommendation from the ESR was for eThekwini to prioritise solar PV generation, alongside contributions from onshore wind generation, biogas-based electricity from landfill and wastewater treatment sites and small-scale hydropower. Nonetheless, around 78% of the Municipality's energy demand was anticipated to be met from imported renewable electricity outside the City boundary. These scenarios are further analysed in Section 5 and 6 which have resulted in slight changes to original findings.

In addition to appraising the resource potential and various renewable energy technology options available within the Municipality, the roadmap explored the political, financial and legislative barriers that would need to be addressed in order to drive implementation.

Building on the work done in the roadmap, the next step for the Municipality was to pursue a more detailed analysis of the predicted demand and supply scenarios as described herein. This report describes the methodology and results of that analysis, making up the technical aspects of the EIRP.

1.2.2.2 Municipal participatory process

As part of the Municipality's mandate, a series of public participation sessions were hosted with stakeholders in the energy sector. The ESR key findings were presented and participants were able to provide feedback and suggestions with regards to the findings that emerged through the formulation of the roadmap. Further information regarding the public participation process is presented in Section 3.

1.2.2.3 Ministerial Determination

The National Energy Regulator of South Africa (NERSA) is a regulatory authority established in Terms of Section 3 of the National Energy Regulator Act, 2004. NERSA's mandate includes regulation of the Electricity Supply Industry. In accordance with Section 34 of the Electricity Regulation Act (Act No. 4 of 2006), the Minister of Mineral Resources and Energy may, in consultation with the Energy Regulator:

a) determine that the new generation capacity is needed to ensure the continued uninterrupted supply of electricity;
b) determine the types of energy sources from which electricity must be generated, and the percentages of electricity that must be generated from such sources;
c) determine that the electricity thus produced may only be sold to the persons or in a manner set out in such notice;
d) determine that electricity thus produced must be purchased by the persons set out in such notice;
e) require that new generation capacity must:
    - be established through a tendering procedure which is fair, equitable, transparent, competitive and cost-effective; and
    - provide for private sector participation.

In light of the country's energy supply crisis the Minister is now considering closing the supply gap in the immediate term through the procurement of 2 GW of energy from a range of technologies, in accordance with the short-term risk mitigation capacity allocated for the years 2019 to 2022, in Table 5 of the national Integrated Resource Plan for Electricity 2019-2030.

The country's energy crisis is primarily driven by Eskom's existing plants poor performance. The Eskom's Energy Availability Factor (EAF) sat at 70% for the 2019 financial year and currently sits at ~68%, with the shortfall expected to increase (NERSA, 2020). A fast-tracked consultation process was released on the 18th March 2020 and is set to conclude within the next 3 months.

Prior to the release of this process the eThekwini Municipality has been preparing to apply for Ministerial Determination to allowing purchase of clean energy from IPPs. The Municipality is confident that the likelihood of the application being successful is increasing as pressure grows nationally to reduce load shedding. The implementation pathway and detail on the Ministerial Determination application is discussed further in Section 7.

1.2.3 EIRP Innovation

While there has been movement by other cities in South Africa toward a clean energy transition viz. City of Cape's application for Ministerial Determination to purchase clean energy from IPP's and City Power's IRP Framework for Johannesburg – the eThekwini Municipality is the first city to develop and publish its own IRP. As there has been no precedent set for municipal IRPs effort has been made to ensure that the IRP is future fit by considering the following items including but not limited to:

- The effect of climate change on the heating and cooling needs of the Municipality
- The effect of climate change on the performance of renewable energy technologies
- The impact of the potential uptake of EV's on future energy demand scenarios
- Technological advancements of renewable energy (e.g. bifacial solar PV)
- Emerging and future technologies (e.g. ocean energy technologies)
- Energy efficiency and demand side reduction strategies
- Smart grid technologies
- The impact of data management systems and tools on municipal operations
- The impact of resilience against load shedding through security of supply

1.2.4 EIRP methodology

This study focusses solely on eThekwini's electricity consumption and has excluded other energy sectors such as the transport sector. The eThekwini energy system has been modelled for several demand and supply scenarios to assess the optimal energy mix scenarios for the Municipality to meet its targets of 40% renewable energy generation by 2030 and 100% by 2050. Various constraints were applied to each scenario relating to the forecast electricity consumption. Various renewable energy mix supply options were then selected to match the demand. Local job creation and carbon reduction were among the factors considered when appraising supply options. The methodology is further laid out in Sections 4, 5 and 6.

1.3 Report structure and content

The main aim of this document is to present the developments in eThekwini's energy planning, specifically:

- The description and results from the stakeholder consultation process undertaken
- Findings from integrated-energy mix scenarios modelling
- The implementation plan for delivery of additional energy capacity through a Ministerial Determination application
- Establish Municipal Independent Power Producer Procurement Program (MIPPPP)

As a result, the report has been structured to present these developments in detail. Nonetheless contextual information and updates on eThekwini's energy landscape and climate commitments are provided. For more detailed information on these aspects as well as the evaluation of renewable energy resources, we encourage readers to refer to the roadmap.

2 Energy sector update

A snapshot into the latest developments in the energy sector are outlined below to provide context for the current political climate in which eThekwini's IRP will be released. Timing is crucial to gaining buy in both from public and private sector, and careful consideration needs to be placed on when developments are announced.

2.1 Integrated Resource Plan 2010 (IRP)

The integrated resource plan (IRP) in the South African context is an electricity capacity plan which aims to provide an indication of the country's electricity demand, supply and cost implications. The first IRP, IRP 2010, was released in 2011 outlining South Africa's forecast energy plan for the 20-year period from 2010 to 2030. The IRP 2010 indicated that the plan should be revised by the Department of Energy (DoE) at minimum every two years, however this was not achieved. IRP 2010 contained capacity allocations for electricity generated from renewable technologies, and it is against these allocations that the previous Minister of Energy issued Ministerial Determinations, in line with Section 34 of the Electricity Regulation Act, to allow the procurement of new generation capacity. This included technologies such as solar PV, wind energy, concentrated solar power, landfill gas, biomass, biogas and small-scale hydropower. To date, four bidding rounds have been completed for renewable energy projects under the Government's Renewable Energy IPP Procurement Programme.

Since the promulgated IRP 2010, the following capacity developments have taken place:

- A total 6,422MW under the government led Renewable Energy Independent Power Producers Programme (RE IPP Procurement Programme) has been procured, with 3,876MW currently operational and made available to the grid.
- IPPs have commissioned 1,005MW from two Open Cycle Gas Turbine (OCGT) peaking plants.
- Eskom have commissioned a build programme of: 1,332MW of Ingula pumped storage, 1,588MW of Medupi, 800MW of Kusile and 100MW of Sere Wind Farm.

Overall approximately 18,000MW of new generation capacity has been committed to.

2.2 Integrated Resource Plan 2019 (IRP)

The new Presidency saw the release of an updated Draft IRP in August 2018. Following a public participation and consultation process the final IRP 2019 was gazetted by the Minister of Mineral and Energy Resources on 18 October 2019. Please refer to the ESR for a brief overview on the Draft IRP.

Figure 4 below provides an overview of the capacity allocated per technology up to the year 2030 in the IRP 2019, including the current baseline installed to date.

The updated IRP 2019 saw an increase in solar PV and wind energy allocations, and a significant decrease in gas and diesel as well as new inclusions of nuclear energy and energy storage. Embedded generation, previously described as generation for own use allocation, is now effectively replaced with the concept of "distributed generation" which is described as all generation whereby the facility is operated solely to supply electricity to an end-use customer within the same property of the generation facility, and is allocated with other technologies of co-generation such as biomass and landfill gas.

Wind and solar PV being the most mature in terms of technological development, costs and market penetration, dominate the IRP allocations. The annual allocation for wind technology is 1,600MW from 2022 up to 2030 while the annual allocation for solar PV is 1,000MWs per year over the period up to 2030, with no allocation in the years 2024 (Koeberg nuclear extension is expected to be commissioned here) and the years 2026 and 2027 (2,000MW of gas is expected in the year 2027). Although there are annual build limits in the IRP these limits will be reviewed to account for demand and supply requirements (Cliff Dekker Hofmeyr, 2019).

SNAPSHOT OF THE UPDATED ENERGY MIX

	Coal	Coal (Decommissioning)	Nuclear	Hydro	Storage	PV	Wind	CSP	Gas & Diesel	Other (Distributed Generation, CoGen, Biomass, Landfill)
Current Base	37,149		1 860	2,100	2 912	1 474	1 980	300	3 830	499
2019	2,155	-2,373					244	300		Allocation to the extent of the short term capacity and energy gap.
2020	1,433	-557				114	300			
2021	1,433	-1403				300	818			
2022	711	-844			513	400	1,000	1,600			
2023	750	-555				1000	1,600			500
2024			1,860				1,600		1000	500
2025						1000	1,600			500
2026		-1,219					1,600			500
2027	750	-847					1,600		2000	500
2028		-475				1000	1,600			500
2029		-1,694			1575	1000	1,600			500
2030		-1,050		2,500		1000	1,600			500
TOTAL INSTALLED CAPACITY by 2030 (MW)	33,364		1,860	4,600	5,000	8,288	17,742	600	6,380	
% Total Installed Capacity (% of MW)	43		2.36	5.84	6.35	10.52	22.53	0.76	8.1	
% Annual Energy Contribution (% of MWh)	58.8		4.5	8.4	1.2*	6.3	17.8	0.6	1.3	

- Installed Capacity
- Committed/Already Contracted Capacity
- Capacity Decommissioned
- New Additional Capacity
- Extension of Koeberg Plant Design Life
- Includes Distributed Generation Capacity for own use

- 2030 Coal Installed Capacity is less capacity decommissioned between years 2020 and 2030.
- Koeberg power station rated/installed capacity will revert to 1,926MW (original design capacity) following design life extension work.
- Other/ Distributed generation includes all generation facilities in circumstances in which the facility is operated solely to supply electricity to an end-use customer within the same property with the facility.
- Short term capacity gap is estimated at 2,000MW.

Figure 4: Integrated Resource Plan 2019

As shown in Figure 5 below the largest allocation for 2030 has been set for wind energy, followed by solar PV and distributed generation which includes co-generation, biomass and landfill gas. The allocation of storage is complementary to the wind and solar allocations. The current 1.4 GWh battery storage pilot underway by Eskom will drive the development and progress of legislative and regulatory items with regards to utility-scale energy storage.

Coal is reduced to 1,500MW and nuclear energy is maintained at 1,860MW. A further 24,100MW of coal power is expected to be decommissioned in the period beyond 2030 to 2050. The IRP 2019 states that coal will continue to play a significant role in electricity generation in South Africa in the foreseeable future as it is the largest base of the installed generation capacity. New investments will need to be made using more efficient clean coal technologies such as High Efficiency Low Emissions technology (HELE) and power plants with carbon capture, utilisation and storage (CCUS) to comply with climate and environmental requirements. HELE coal technologies include underground coal gasification, integrated gasification combined cycle, carbon capture utilisation, supercritical and ultra-supercritical power plants, and similar technology.

The term ‘Distributed Generation’ refers to small-scale technologies that produce electricity close to the end users of power. There is no specific limitation on the installed capacity of the generation facility, the determining factors are the location of the generation facility and that the technology used is small scale technology. Unfortunately, there is no guidance as to what constitutes ‘small scale technologies’ for the purpose of qualifying as ‘other distributed generation’ and there is no specific reference to the installed capacity of the generation facility. This also excludes generation facilities where the electricity generated is wheeled to an end user not located on the same property or where the electricity is supplied to multiple end users. (Cliff Dekker Hofmeyr, 2019).

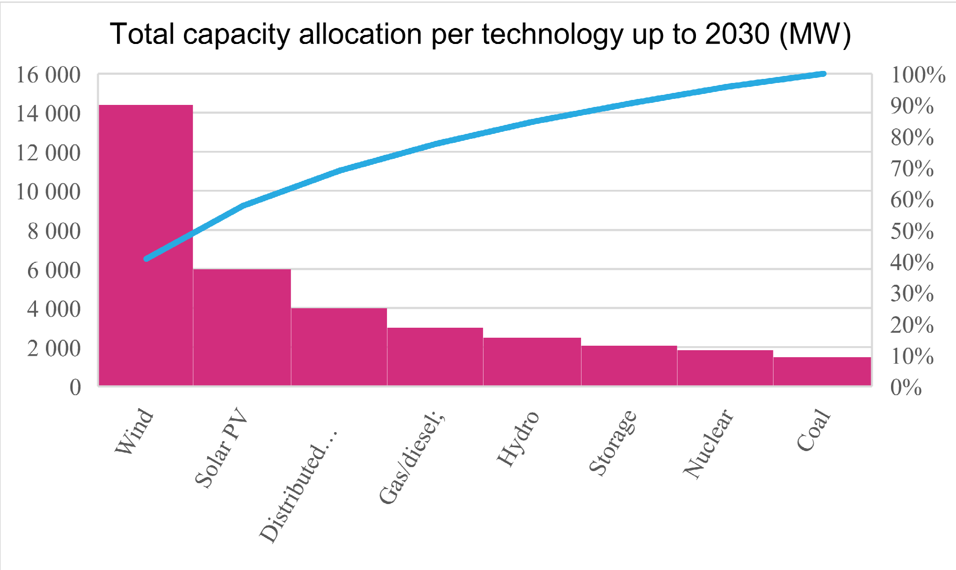

Figure 5: Capacities per technology – IRP 2019

2.3 Climate Action Plan (CAP)

The eThekwini Municipality has been lauded by Mayors attending the C40 World Mayor’s Summit in Copenhagen in 2019 for being the first city in Africa to develop a Climate Action Plan aimed at reducing carbon emissions. The plan seeks to accelerate the action required to limit global temperature increase to 1.5 Degrees Celsius. It comprises of 33 actions and 149 sub-actions aligned to nine thematic areas that provide a pathway for Durban to achieve climate resilience and carbon neutrality. According to the plan by 2030 Durban will have achieved 40% reduction in emissions and 80% reduction by 2050 (eThekwini Municipality, 2019).

2.4 Climate Impact Atlas (CIA)

This Climate Impact Atlas is an interactive website that provides information about eThekwini's changing climate with the aim of bridging the gap between climate science and city level action by translating climate impact information to policy relevant and usable science, embedding that information with the relevant stakeholders. By introducing workshops and an interactive eThekwini climate hazard mapper, the identification of vulnerable areas and indicators are carried out together with the city stakeholders. Tapping into local expert knowledge provides the basis for selecting indicators that can represent the vulnerability of eThekwini in terms of social, environmental and economic factors. The CIA visualizes the most important consequences of climate change in terms of heat, drought, pluvial flood and coastal flood. The themes summarize a broader set of climate change impacts. The potential consequences of climate change on the City's Natural, Social and Economic capital are analysed in line with sectoral responses which are one of the key priorities of South Africa's National Climate Change Response White Paper (eThekwini Municipality, 2020).

3 Public Participation

3.1 Stakeholder Engagement

The stakeholder engagement process is informed by Section 195 (1) (e) and 195 (1) (g) of the Constitution of the Republic of South Africa Act (No 108 of 1996). The Council of eThekwini authorised the direct engagement with key stakeholder groups in the energy sector. Throughout the policy development, eThekwini engaged internal and external stakeholders to understand diverse opinions and to build the required scenario planning that challenge assumptions. eThekwini gathered all the necessities and established the Integrated Resource Plan (IRP) Working Group comprises of eThekwini officials, C40 members and Arup specialists. The IRP Working Group scheduled a bi-monthly meetings to review the progress, input framework required for energy modelling and their respective opinions regarding energy transition towards low carbon economy in eThekwini Municipality. IRP Working Group also presented the policy determinations to the local and international conferences. Details are covered in the following sections.

The stakeholder engagement with key subject matter experts started at University of KwaZulu Natal, Westville Campus on the 26 July 2019 through March 2020. eThekwini Municipality received feedback regarding scenario planning that informs input framework, which helped shape draft IRP and ESR. The IRP Working Group held meetings across the eThekwini Municipality and online platforms such as pre-arranged C40 online webinars, telephonic engagements, email and in-person at the meetings. Getting feedback from diverse views withdrawn from industry experts, commercial businesses, research and development institutions, and government was critical in shaping IRP and to a certain extent informing ESR.

3.1.1 Stakeholder Meetings and Presentations

Understanding the varying needs and priorities of eThekwini Municipality and impact of energy crises in the City’s economy. The IRP process was a transparent and participatory approach in developing a least-cost energy solution for eThekwini Municipality. Stakeholder involvement was a particular focus throughout the IRP process. The presentations of input framework and ESR guidelines were shared with stakeholders during meetings. The stakeholder meetings and plans were revealed in the various stakeholders, investors and government departments.

- KZN Department of Economic Development, Tourism and Environmental Affairs (EDTEA)
- Trade and Investment KZN (TIKZN)
- University of KwaZulu Natal (UKZN)
- Mangosuthu University of Technology (MUT)
- Durban Business Fair (DBF)

- Renewable Energy International Conference in South Korea (KIREC)
- National Energy Regulator of South Africa (NERSA)
- Richards Bay Industrial Development Zone (RBIDZ)
- War Room in Ntuzuma and KwaMashu
- Durban University of Technology (DUT)
- Durban Chamber of Commerce and Industry (DCCI)
- World Urban Forum (WUF) in Abu Dhabi

All the presentations and articles regarding stakeholder engagements of above events were uploaded on the official website of eThekwini Municipality[3].

3.1.2 Stakeholder Comments

eThekwini Municipality released the draft ESR on July 26, 2019. The ESR is a comprehensive framework envisioning, developing, guiding and measuring strategy performance. High level scenarios were presented before the stakeholders and eThekwini received approximately 15 comments coming from industry, government department and academic institutions as presented in Table 6.

Table 6: Summary of stakeholder comments

Stakeholder engagement	Examples of stakeholder comments
Energy Strategic Roadmap (ESR)	✓ Roadmap process and reason for transition towards low carbon economy ✓ Proposed energy resources to meet future demand and timeframes for roadmap execution ✓ Inclusion of relevant stakeholders and approval processes
Integrated Resource Plan (IRP)	✓ IRP process and reasons behind developing a least-cost energy mix ✓ The difference between ESR and IRP scenarios ✓ The methodology used to recommend the least-cost scenario ✓ Recommendations that eThekwini evaluates renewable energy within the jurisdiction and emphasize waste to energy as baseload electricity ✓ Recommendation that eThekwini consider strategies that evaluate energy efficiency and distributed energy resources (DERs) ✓ Considering the risks and uncertainties of energy supply to eThekwini economy and procure from IPPs ✓ The impact of IRP to vulnerable people and those with limited income ✓ Broader scenario outlook in terms of meeting future energy demand with intermittent renewables ✓ Recommendations to consider natural gas as a bridging fuel in support of intermittent renewables ✓ Recommendation to consider rapid urbanisation, population growth and job creation

[3] http://www.durban.gov.za/City_Services/energyoffice/Sustainable%20Energy/Pages/Energy-Seminar-2019.aspx

3.1.3 Composition of Stakeholders

The information collected during the stakeholder engagements period helped shape the initial framework of eThekwini Municipality and was used to determine which least-cost candidate resource should be considered. A number of comments were received via email and follow up questions during stakeholder meetings.

The attendance of stakeholder meetings achieved an average of 80%. The composition is articulated in Figure 6.

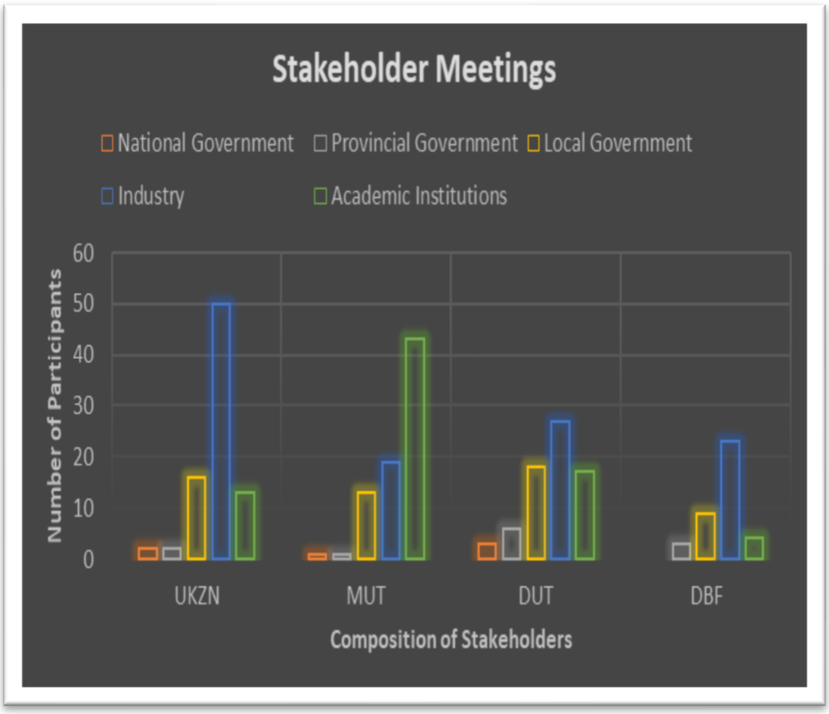

Figure 6: Composition of stakeholders

3.2 EIRP Energy Working Group (EWG)

The diverse educational background of an IRP Energy Working Group helped in developing future scenarios that will ensure eThekwini continues to provide service delivery to the consumers. This was supported by broader view of achieving sustainable development goals (especially goal number 7). The IRP Energy Working Group was responsible for assessing input framework, preliminary results of the energy modelling and providing feedback throughout the process.

3.2.1 EIRP Energy Working Group Members

The IRP Energy Working Group consists of 10 members in total. Four of the members represent the broader view of Durban Climate Change Strategy (DCCS), which provides strategic direction of achieving 40% renewable energy supply by 2030. Three members represent C40 Climate Leadership Group, the C40 Clean Energy Network with interest in decarbonizing energy system and reduction of

GHG emissions. The other three members represent Arup team with incredible experience in the energy modelling systems.

eThekwini Metropolitan was awarded a Technical Assistance Programme by C40 Clean Energy Network on the 4th of May in 2018. The IRP Energy Working Group first met to discuss the draft of ESR, which was approved by eThekwini Council in July 2019. Subsequently after approving the Draft ESR, the IRP Working Group received another Technical Assistance Programme to develop eThekwini Energy Policy, the IRP. As outlined in Section 2.1.1, various stakeholder engagements were held at different locations throughout the metropolitan region.

The stakeholder meetings were designed to encourage discussion on all facets of the process and to communicate the broader strategic direction of eThekwini metropolitan. Information sharing, collaboration and expectations setting for the IRP was discussed robustly with key stakeholders. IRP Energy Working Group members suggested, reviewed, and communicated the proposed demand and supply-side scenarios.

The discussion on energy scenarios and technology options were communicated to the stakeholders. Given the diverse makeup of the stakeholder members, there was a wide range of views on specific issues such the following.

- Base Case – which advocate for business as usual scenario. Sometimes called "Do nothing scenario"
- Economic Downturn – which assess the potential growth of economic outlook for South Africa, KZN Province and eThekwini Municipality
- eThekwini Demand Growth – which represent sustainable energy supply in the face of rapid urbanization, population migration and reindustrialization
- Reduction in GHG emissions – which is driven by a strong push to curb emissions due to concerns over climate change
- Distributed Energy Resources – which is driven by growing consumer awareness and preference for energy choices
- Procurement of energy services from IPPs – which is driven by least-cost scenario and drive to create employment

3.3 Public Outreach and Briefings

The IRP Energy Working Group hosted one webinar during the ESR process to keep other cities informed about the broader strategic vision of eThekwini metropolitan.

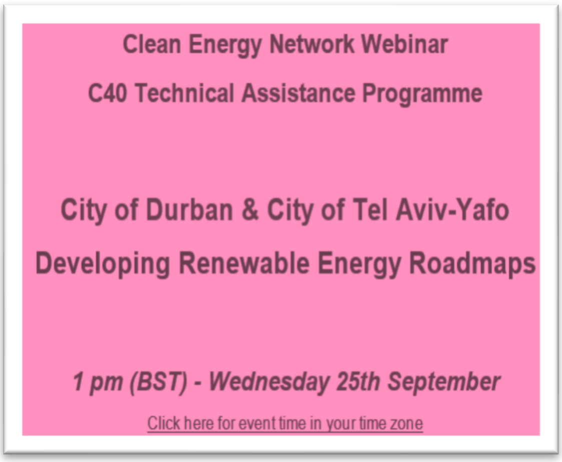

Figure 7: Example of webinar post

eThekwini metropolitan staff made a brief presentation, followed by a moderated questions, comments and answers session. In the topics discussed, eThekwini staff introduced the development of ESR, concept of integrated resource plan (IRP), the planning scenarios and resource options. eThekwini has also briefed other public organizations, NGOs and public representatives.

3.3.1 Social Media

To effectively provide service delivery to the people of eThekwini metropolitan, the IRP Energy Working Group used both eThekwini Facebook, LinkedIn and Twitter pages to communicate strategic vision. During development of the draft ESR and draft IRP, eThekwini used social media communications to inform and educate the public about ESR and IRP, its processes and promote opportunities for public input. Social media communications for the ESR and IRP began in August 2019.

Social media communications objectives for the draft ESR and IRP included:

- Gather public views on the proposed energy plan;
- Provide clear, consistent and accurate information about ESR and IRP

Examples of content posted to social media include announcement for stakeholder consultation, ESR & IRP related events and photos providing basic information about energy resources.

Figure 8: Example of LinkedIn posts

The IRP Energy Working Group worked with eThekwini Communication Department to further share information on LinkedIn. Example of LinkedIn post in Figure 8.

eThekwini municipality plans to post updates throughout the public comment period about reminders to submit comments.

Due to the changing conditions of the energy sector. eThekwini municipality determined and evaluated 50 scenarios for supply-side and demand-side metrics. The recommended portfolio mix of energy resources and annual procurement limit programme was assessed. Stakeholders have opportunity to comment on the resource portfolio of energy resources.

4 Energy consumption scenarios

4.1 Current consumption in eThekwini

Annual current electricity consumption in the municipality has been calculated from Eskom billing data from the last two years for the main primary substation incomers.

Half hourly demand profiles were provided by the eThekwini Electricity department; this gave a baseline annual hourly profile of consumption as well as an indication of the peak demand required on the network. Table 7 shows the demand and consumption values for 2019.

Table 7: Electricity demand / consumption, 2019

Parameter	Value
Electricity consumption	10,700 GWh / annum
Peak electricity demand	1,680 MW

4.1.1 Impact of absorbing Eskom customer base

Currently there are some customers within the municipality that purchase power directly from Eskom, bypassing the municipality altogether. These customers are viewed by the municipality as a loss of potential revenue.

Through engagement with the electricity board, it is understood that the annual consumption of these customers is in the region of around 0.26GWh/annum[4].

In comparison to the overall consumption in the municipality of over 10,700GWh/annum, it can be seen that the consumption of direct Eskom customers is negligible compared to the overall consumption in the municipality.

4.1.2 Load shedding

At some times during the year, national electricity demand can exceed available supply. If these events are anticipated, load curtailment can be used to manage demand and balance the energy system. However, sometimes demand can peak quickly and unexpectedly and there is either insufficient time or resource to mitigate this change using load curtailment. In these situations, Eskom use load shedding – the temporary switching off of sections of the electricity grid – to manage energy demand and avoid a national blackout.

The load shedding schedule for eThekwini over the past 5 years has been analysed as part of this study and has been used to augment historical electricity demand data to create a complete energy demand profile for the municipality. It is

[4] Email, Vasu Chetty 9/12/19

anticipated that load shedding will continue over the next 18-24 months, into 2022.

Using some benchmarks which describe the financial impact load shedding has on eThekwini, shown in Table 8, and based on the assumption that recent load shedding trends might continue over this 18-24 month period, the potential annual revenue loss due to load shedding has been estimated. Historical load shedding data indicated up to 100 and 195 hours of stages 1 and 2 load shedding respectively could be anticipated over the next 18-24 months, which suggests an estimated financial impact of 17 million ZAR.

Table 8: Financial indicators of the impact of load shedding in eThekwini.

Stage	Magnitude	Financial impact
1	70 MVA	0.56 R/kWh
2	140 MVA	0.56 R/kWh
3	210 MVA	1.58 R/kWh
4	280 MVA	1.58 R/kWh
5	350 MVA	1.58 R/kWh
6	420 MVA	1.58 R/kWh

4.2 Future consumption scenarios

The future consumption of electricity in eThekwini depends on a number of demographic, economic and technical factors such as population growth, GDP, tariff structures, the network capacity, the ability for customers to generate their own power, as well as the uptake of new electrical technologies like electric vehicles (EVs).

The National Integrated Resource Plan (IRP), August 2018[5], accounted for many of these factors in developing a number of future consumption scenarios for South Africa. In the report, regression models for different areas of the electricity sector were developed, and five overall scenarios were presented.

Additionally, the effects of EV uptake in the municipality could have a significant effect on electricity demand. This report has therefore investigated the effects of EV uptake on potential future consumption (see Section 4.2.5).

[5] Forecasts for electricity demand in South Africa (2017 – 2050) using the CSIR sectoral regression model for the Integrated Resource Plan of South Africa, CSIR, May 2017

In addition to the National IRP, eThekwini Municipality has its own grid load forecasting software, which was used to inform the power consumption growth projections in the ESR (the work which precedes this study).

The modelling undertaken as part of this study has developed a series of distinct eThekwini electricity consumption scenarios for the years 2030 and 2050, by indexing the eThekwini current consumption profile against three of the five scenarios provided in the National IRP, as well as presenting two additional scenarios to account for eThekwini's own projections, and the potential effects of EV uptake. The five future consumption scenarios investigated are summarised in Table 9.

Table 9: Consumption scenarios and demand profiling

Consumption scenario (kWh/MWh/GWh)	
EIRP Scenario Name	**Source**
Highest	Indexed against 'High' (Same Sectors) scenario, (National IRP) with addition of EV uptake
High	Indexed against 'High' (Same Sectors) scenario, National IRP
Medium	Inferred from 'High' and 'Low' scenarios
Low	Indexed against 'Low' (Same Sectors) scenario, National IRP
Energy Efficient	Indexed against eThekwini's demand forecast using grid load forecasting software*.

4.2.1 Energy Efficient Scenario

The Energy Efficient demand scenario represents maximum ambition in terms of reducing energy demand. A graph of the annual energy demand under this scenario is shown in Figure 9.

Driving energy efficiency initiatives and policies in order to suppress as far as possible the increases to the demand for power in eThekwini is by far the easiest / quickest win in terms of meeting renewable energy targets for the future. Reducing demand (or at least limiting its increase) will serve to reduce the requirements for generation and distribution infrastructure. As such, in all cases, the municipality should be targeting the lowest future consumption scenario only.

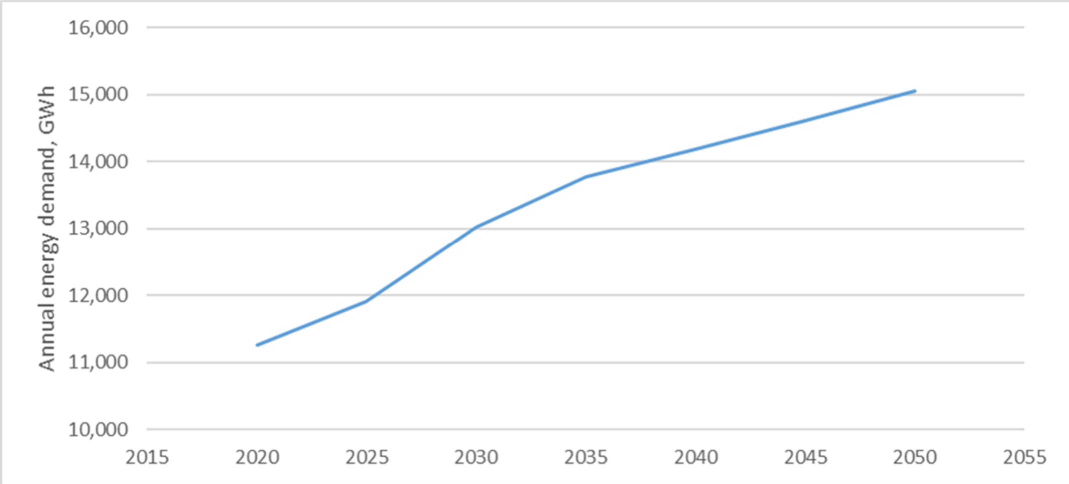

Figure 9: Annual energy demand for the Energy Efficient demand scenario.

4.2.2 Low Scenario

The Low Scenario is characterised by the corresponding ‘Low’ scenario from the National IRP. This forecast uses historic demand data for eThekwini with the national demand trends from the National IRP to create a 30-year annual energy demand forecast, shown in Figure 10.

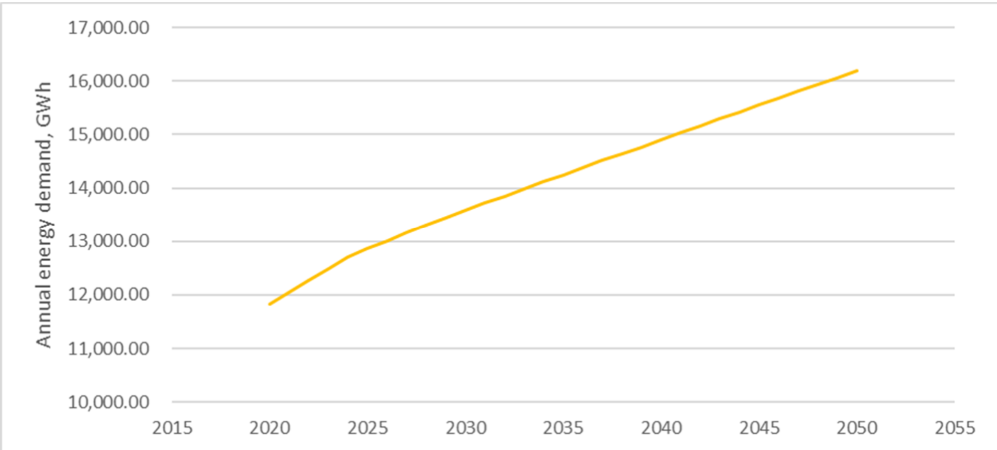

Figure 10: Annual energy demand for the Low demand scenario.

4.2.3 Medium Scenario

The Medium Scenario is characterised by inferring a trend midway between the ‘Low’ and ‘High’ scenarios from the National IRP. This forecast uses historic demand data for eThekwini with the national demand trends from the National IRP to create a 30-year annual energy demand forecast, shown in Figure 11.

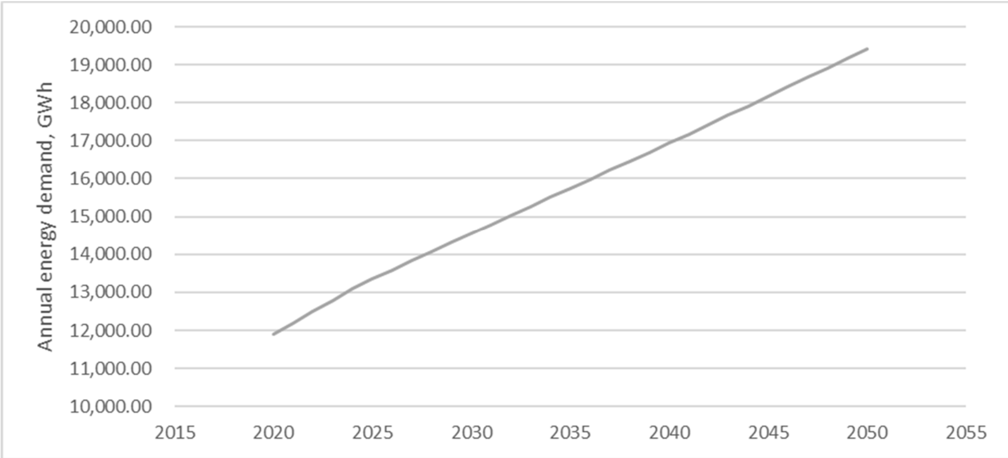

Figure 11: Annual energy demand for the Medium demand scenario.

4.2.4 High Scenario

The High Scenario is characterised by the corresponding 'High' scenario from the National IRP. This forecast uses historic demand data for eThekwini with the national demand trends from the National IRP to create a 30-year annual energy demand forecast, shown in Figure 12.

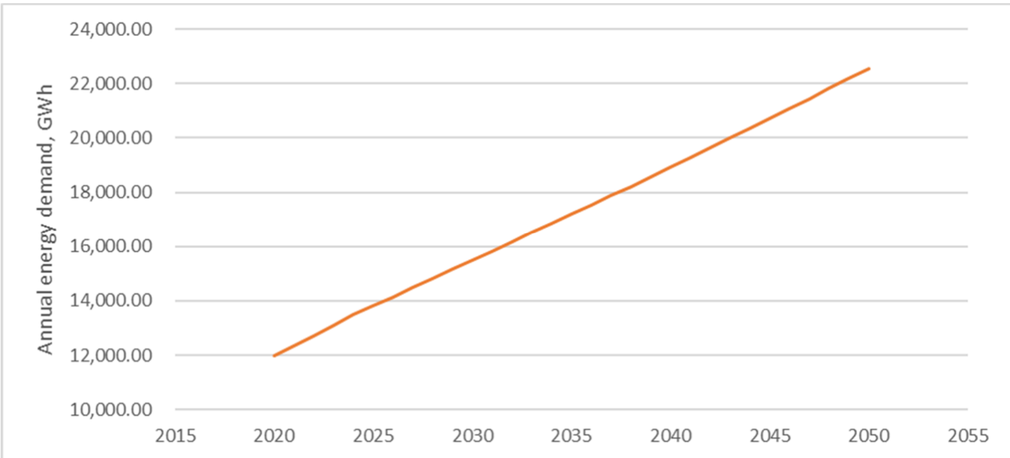

Figure 12: Annual energy demand for the High demand scenario.

4.2.5 Highest Scenario

The Highest Scenario for demand is calculated using the data for the High Scenario with the addition of demand arising from electric vehicles. The rate of EV penetration will be dependent on a number of factors; from the Durban Climate Action Plan (CAP), the following targets have been committed to:

- shift 20% vehicles to low-emission vehicles by 2030 and 70% by 2050
- 50% reduction in private vehicle usage in city by 2050 due to mode shift towards more sustainable transportation modes (walking, cycling, public transport)

On account of these targets, the following assumptions have been used to estimate the future usage of electric chargers in eThekwini:

- Assume that low emission vehicles are electric vehicles i.e. there will be a shift of 20% of all vehicles to electric by 2030 and 70% by 2050
- This will be combined with an assumed reduction in vehicles (or regular usage) on account of the shift to more sustainable transport modes of 50%
- The starting number of vehicles will be based on the current 565,190 value provided by the Transport department of the Municipality.
- 80% of vehicles that are regularly in usage are recharged each day in private car parking space with their own slow charger, the remaining 20% will require public fast chargers (note the assumption of 80% with private charging is drawn from work by KPMG and LEK & Arup on charging infrastructure in the state of Victoria in Australia, which estimates that between 80% and 90% of charging will occur at home).
- Use an hourly electric charging profile drawn from modelling work from the UK National Grid Future Energy Scenarios.
- Average journey length is 23 km.

From these assumptions, the additional power consumption requirements for EVs has been calculated to be in the region of 225GWh annually, a 2% uplift in consumption on today's consumption in the municipality. The results for this scenario are shown in Figure 13.

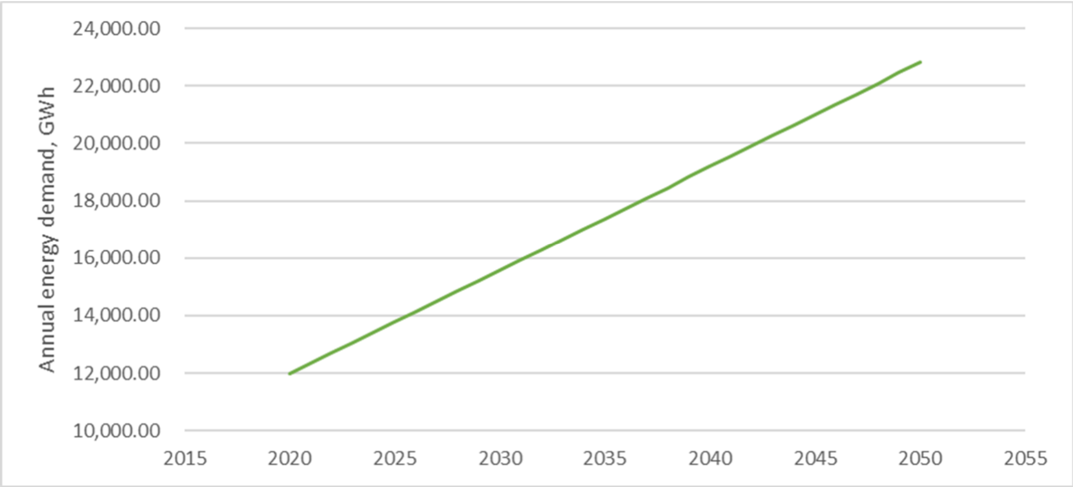

Figure 13: Annual energy demand for the Highest demand scenario.

4.2.6 Demand forecasts results

The results of the demand forecasts as described above are shown in Figure 14. As it can be seen, the most conservative estimate of power consumption increase is the Energy Efficient projection scenario. Results for technology supply scenarios are presented in Section 6 for all demand scenarios developed.

Highest, High, Medium and Low scenarios are based on the real 2019 data against trends from the National IRP. The Energy Efficient scenario is based on a forecast undertaken in 2016 using a different methodology, hence has a slightly different starting point to the other curves.

As it can be seen, the inclusion of EVs in the 'Highest' scenario, has a limited impact on the consumption of power in the municipality.

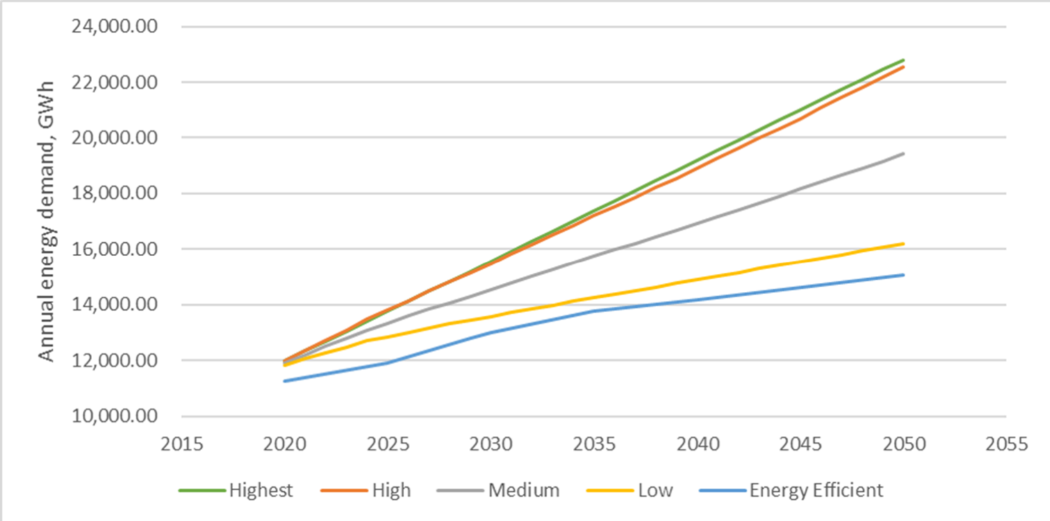

Figure 14: Annual energy demand for the five demand scenarios.

4.3 Annual demand profiles

For each consumption scenario, a relevant hourly demand profile has been applied to reflect what the consumption scenario captures. This has been based on data provided by the City, with the exception of profiles for EV charging, which has been estimated from a literature search. This section presents the demand profile forecasts for 2030 and 2050.

Demand for electricity in eThekwini is monitored closely by the municipality; data was collected on a half hourly basis and converted to an hourly profile as per Figure 15.

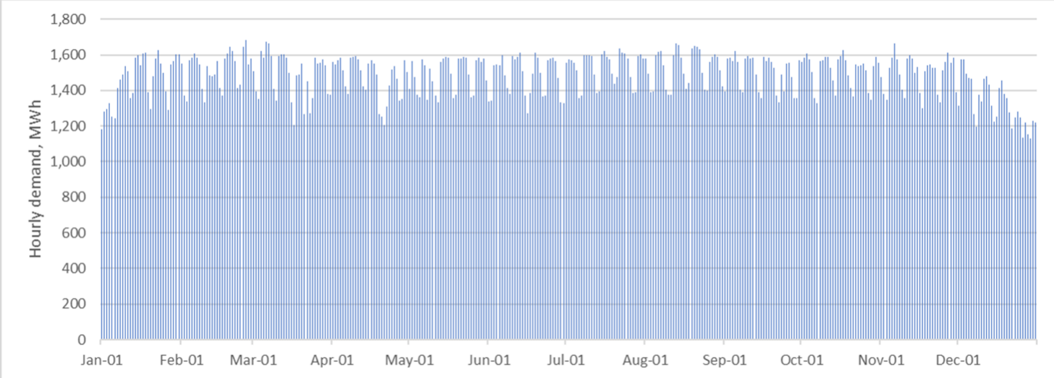

Figure 15: Existing annual electricity demand profile in eThekwini for 2019.

As can be seen from this data, electricity demand is fairly consistent throughout the year, with a slight decrease over the holiday period in December/January. Durban's unique climate means that temperature does not vary as much as in other parts of South Africa. The result is that demand is less weather dependent as there is less of a need for heating or cooling technologies.

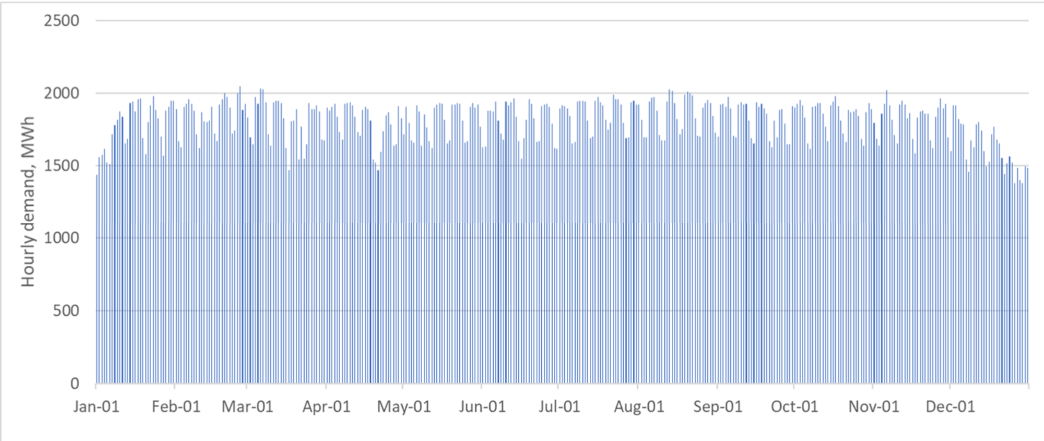

Figure 16: Forecast annual electricity demand profile in eThekwini for 2030.

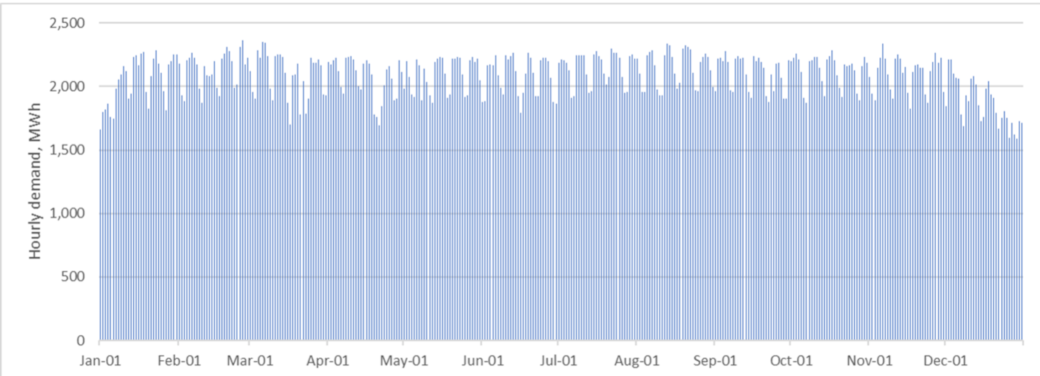

Figure 17: Forecast annual electricity demand profile in eThekwini for 2050.

The data for 2019 was used together with the demand scenarios to create forecasted demand profiles. Figure 16Figure 10: Annual energy demand for the Low demand scenario. and Figure 17 show the forecast hourly electricity demand for 2030 and 2050 under the Energy Efficient demand scenario.

5 Supply scenarios

5.1 Current energy supply

Currently, the municipality buys all power from Eskom and sells on to residents and businesses within its jurisdiction. Profits from this sale cover the costs of operating the distribution network.

Under the current arrangement, it is expected that by 2030, the Eskom supply will be made up of 40% renewable power (National IRP). Based on forecasting of annual greenhouse gas emissions for South Africa (National IRP) as well as the projected use of fuels such as coal, gas and diesel shown in Figure 18, our projections show that by 2050 the renewable power penetration of the Eskom supply will be around 56%.

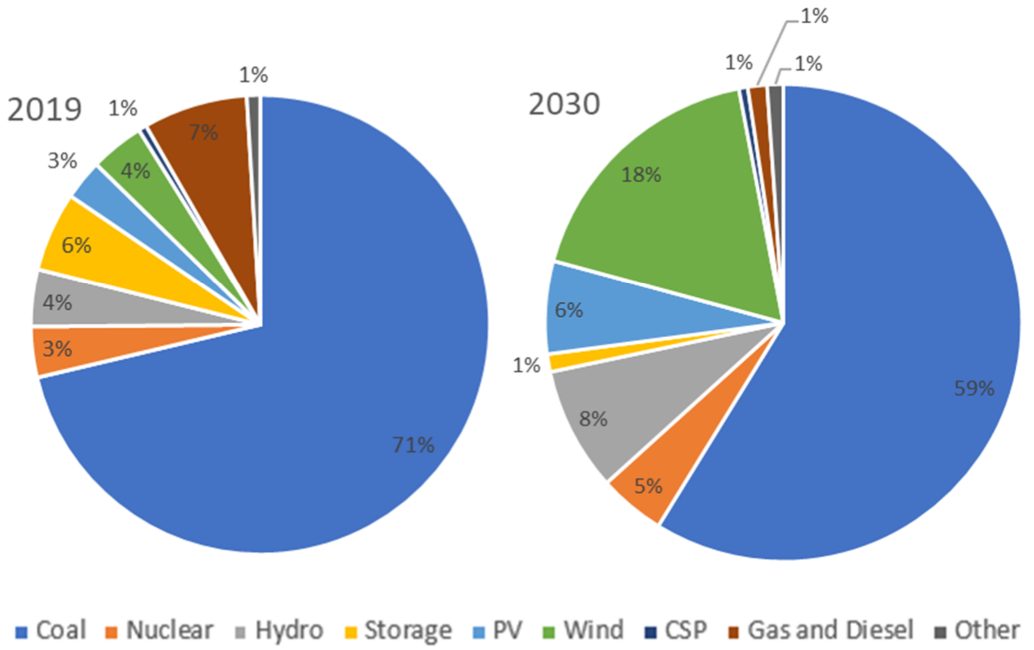

Figure 18: National energy mix for 2019 (left) and 2030 (right) according to data from the National IRP.

There are a number of reasons the municipality seeks to make the transition away from Eskom towards generating its own renewable power and purchasing it from other Independent Power Producers (IPPs) outside the municipality:

- The cost of power from Eskom is higher than generating it or purchasing it from other private IPPs. The municipality needs to ensure provision of low cost energy to residents and businesses, in part to reduce risk of losing customers.
- The renewable content of the Eskom supply is not high enough in 2050 for the municipality to meet its 2050 renewable target of 100%.
- Introduction of a carbon tax that puts pressure on the private sector to reduce its carbon emissions would in turn pressure the municipality to provide a low

carbon source of power in order to avoid those customers defecting from the grid.

In order to reduce costs and to meet renewable targets, the municipality will transition to installing renewable power generation assets, as well as purchasing power from renewable IPPs. The extent to which this needs to happen has been modelled and is explored in Section 6.

5.1.1 Independent power producers (IPPs)

Currently, the municipality buys no power from IPPs since legislation has only recently changed that enables them to do so. With the new legislation, it is predicted that the availability of power produced independently will increase, and that eThekwini will purchase that power where it is renewable (e.g. wind/solar etc).

The cost of purchasing independently produced renewable power has reduced significantly in recent years. In 2011, the bidding tariff for solar power was 3.84 ZAR/kWh and wind power was 1.60 ZAR/kWh.

More recently, bidding tariffs for both solar and wind were down at around 0.65 ZAR/kWh; learning in the market about these new technologies has driven costs down significantly since 2011. See Figure 19 for how the trend has changed with the various bidding windows since 2011.

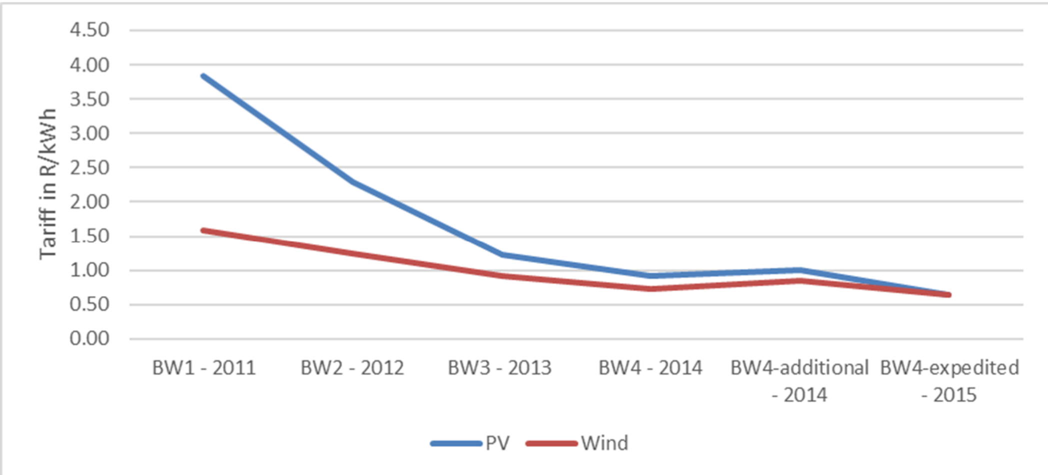

Figure 19: Bidding window tariffs for solar and wind

Now that the municipality is able to purchase directly from IPPs, it is expected that this will be how, in part, renewable targets are met. The city shall need to negotiate Power Purchase Agreements with the IPPs which would typically last around 15 - 20 years. In some cases, the ownership of the generation assets may transfer to the municipality after the duration of the purchase agreement contract.

0.65 ZAR/kWh has been used as the PPA cost assumption from IPPs in the modelling. It is assumed this cost of the power purchased includes an allowance for the costs of distribution, payable to whomever is operating that transmission infrastructure (currently Eskom).

The type of IPPs that come forward in South Africa will affect the municipality's ability to procure power, it's supply profile and carbon emissions associated with it. Broadly, we expect that the type of IPPs eThekwini will start to procure power from over the next 30 years will be made up of solar PV, wind (on- and off-shore), biomass / biogas production and large-scale hydropower. If the ocean energy industry develops further, this may also play a role.

5.2 Future supply scenarios

In eThekwini, the renewable power supply targets are as follows:

- 2030: 40% renewable power supply
- 2050: 100% renewable power supply

The Municipality, together with C40, has already undertaken significant work in the eThekwini ESR to understand how these targets could be met, and which technologies might be used to do so. Please refer to that study to understand how plant capacities were developed, and various scenarios for meeting demand were suggested.

The supply scenarios previously considered as part of the eThekwini ESR (see Table 22 and 23 in that report) have been slightly tailored and optimised and explored in further detail (see Table 10). Plant capacity constraints and technical details will be used to show how hourly demand profiles would be met (See Section 6).

Table 10: eThekwini IRP Supply scenario summary

		Generated within Durban						
Scenarios		Solar	Wind	Landfill	Wastewater	Biomass	Hydropower	Imported
A	Base case	×	×	×	×	×	×	✓
B	All RE technologies included	✓	✓	✓	✓	✓	✓	✓
C	Solar scaled to meet 100% RE target	✓	✓	✓	✓	✓	✓	×
D	Biomass excluded	✓	✓	✓	✓	×	✓	✓
E	Biomass and imported renewables	×	×	×	×	✓	×	✓

Of the six scenarios presented in the initial report, only the first three will be explored and optimised, as the others are less achievable or are variations of the first three. Future supply scenarios will be compared against the Business as Usual scenario of continuing to purchase electricity from Eskom – the Base Case.

Table 10 summarises the scenarios and technologies modelled, with further description below. See the ESR document for further information on each of the technologies considered. Please see Section 6.4 for results relating to scenarios and technologies described in this section.

5.2.1 A: Base Case

This is the 'Do nothing' scenario, assuming imported electricity from Eskom, and using the National IRP scenario characterised by the lowest renewable and highest coal supply mix (called IRP 5 Market Linked Gas Price in the National IRP document).

Under the base case, and assuming Eskom meets its own renewable energy targets Durban would meet its renewable energy target of 40% in 2030, but not the 2050 target. However, it is important to model this scenario for comparison with the others.

5.2.2 B: All renewable energy technologies included

This scenario (also 'Scenario 1' from the ESR report), includes all renewable technologies identified for use in the municipality. This scenario maximises the use and rollout of these technologies, making up the rest of the demand that cannot be met within the municipality by importing renewable power from IPPs from outside the municipality.

5.2.3 C: Solar scaled to meet 100% RE target

This scenario ('Scenario 2' from the ESR report) assumes that no power can be imported into the municipality. Under this case, the potential for solar penetration is scaled up in an attempt to meet all demand and operate in 'Island mode'.

5.2.4 D: Biomass excluded

This scenario ('Scenario 3' from the ESR report), investigates the implications of excluding biomass power generation from the supply mix within the municipality. Otherwise, this scenario is the same as Scenario B.

5.2.5 E: Biomass and imported renewables

This is a new scenario assuming biomass generation is installed within the municipality, and remaining power demand is met by offsite imported renewable generation (i.e. IPPs). This scenario is chosen due to the fact that biomass has the highest potential to deliver renewable power within the municipality and its inclusion (or exclusion) has the highest potential to alter results. Furthermore, it is the most expensive technology, as well as the highest carbon emitter.

5.3 Role of Distributed Energy Resources

Distributed energy resources (DERs) refer to energy generation, storage and demand management systems that are used in conjunction with the larger generation assets to meet and manage electricity demand on a more local scale.

They can include smaller capacity generation assets like private solar PV panels, micro-CHP, wind turbines, biomass generators and fuel cells which may be owned and operated by residential, commercial and industrial users, offsetting power they would usually purchase from the grid. In many networks around the world, excess power generated by these assets can be fed back into the grid and used elsewhere, i.e. the power is sold on the wholesale power market.

For the purposes of this report, generation assets are covered under 'Supply scenarios' and are not considered as DERs. In addition to generation assets, DERs can include inverters, storage or demand side response technologies that are used to shift demand away from peak times, hence reducing peak demand and the associated need for infrastructure upgrades.

Of the non-power generating DERs available, those that have been modelled as part of this study are:

- Battery power storage
- Demand side response

Both technologies have been modelled as load shifting technologies. The overall consumption remains the same, but the model chooses to move consumption away from peak times to reduce peak demand.

The amount of power that can be shifted is dependent on the scale and rate of penetration of these technologies in the municipality.

5.3.1 Demand side management

Demand side management is a load shifting mechanism whereby certain processes are switched off or postponed to limit demand during peak times. Often these are industrial processes (for example using large furnaces) for which switching off for short periods of time will have very limited effect on their overall output.

For this study we have used the assumption that demand side response could be used to shift up to 0.5% of peak demand and that this demand shifting would cost 5% of the price of importing electricity into the municipality from IPPs. To more accurately quantify the potential capacity and expense of demand side response in eThekwini, a more bespoke and in depth study dedicated to this subject would be needed.

5.3.2 Energy storage

There is a swiftly growing global market for Lithium-Ion (Li-Ion) batteries, which can be used for storing electricity during times of abundant supply.

When planning for a renewable energy system, distributed batteries can be used in conjunction with technologies like solar PV and wind energy to capture surplus energy and store this for use during peak times. The most effective way to determine the capacity of these batteries is to size them according to the scale of the surplus energy available for storage.

Using the eThekwini solar resource data, model results showed that the optimal size for battery storage was 10 GWh, due to the great potential for generation from solar energy. This however is incredibly ambitious in the current market, and would require very large amounts of space. For eThekwini, peak potential output for solar PV is 1.12 GW. Accounting for an efficiency of 88% and some losses, storing 3 hours of this energy would require around 4 GWh storage. While lower, this is still a very ambitious figure. Distributed storage engineers have estimated 500 MWh to be a reasonable maximum limit on battery capacity for eThekwini based on current technologies. This has been taken forward as an upper limit for optimisation in the modelling.

5.4 Additional energy supply technologies excluded from modelling

The aim of the EIRP is to evaluate the optimum integrated-energy mix that can serve eThekwini's aspirations for diversified, reliable and clean energy. Nonetheless certain electricity generation technologies have been excluded from the modelling optimisation for reasons including current low commercial viability and the risk of compromising the achievement of eThekwini's renewable energy target. The most significant of these energy generation technologies are described below

It should be noted that long-term energy planning is a continuous process depending on the speed of development of the energy industry globally and locally through innovation and commercialisation of technologies. The technologies excluded today may therefore factor in future energy plans.

5.4.1 Natural Gas

Natural gas can be utilised for power generation, typically in Combined Cycle Gas Turbines (CCGT) or Open Cycle Gas Turbines (OCGT). Gas power stations are promoted by the industry as a source of cleaner fuel than coal and for the provision of more flexible energy supply than can respond more quickly than other baseload technologies (e.g. nuclear or coal) to balance supply and demand.

In South Africa, natural gas is sourced from existing off-shore fields, however it is believed these are nearing depletion. In order to offset this reduction, importation of liquefied natural gas (LNG) is being considered by entities such as the Petroleum, Oil and Gas Corporation of South Africa. This would require development of new infrastructure such as coastal LNG terminals on the coast.[6]

[6] Electric Power Research Institute, "Power Generation and Technology Data for Integrated Resource Plan of South Africa",2017. Retrieved from: http://www.energy.gov.za/IRP/irp-update-draft-report2018/EPRI-Report-2017.pdf

According to South Africa's IRP, natural gas-based power station deployment is forecast based on a low-gas utilisation scenario "taking into account the locational issues like ports, environment, transmission etc"[7]. The resulting capacity of 1000 MW in 2023 and 2000 MW in 2027 is based on prioritising conversion of diesel-powered generators on the east coast of South Africa.

In addition to the national constraints, in the context of eThekwini, investment in new power plants fed by natural gas could compromise eThekwini's ambitions to achieve 100% renewable energy by 2050. Gas power stations typically have a lifetime of 30 years, meaning that any investment should allow for this operational lifetime. Assuming that a gas power station is switched on from 2023, this could mean that the plant would be operational until 2053 and temporarily 'lock' eThekwini into a high carbon infrastructure in 2050 or risk having a 'stranded' asset.

The worldwide growth of the gas market is expected[8] to slow in the coming years: 0.7% in the years 2023 – 2035 in comparison to 1.3% per year from 2018 – 2023, indicating that the world is recognising the implications the fossil fuel has on countries meeting their carbon and climate change commitments.

This risk is in combination with the fact that gas power plants are reaching grid parity with renewables, notably wind and solar power in the United States.[9][10] According to the Electric Power Research Institute (EPRI) study, the 2017 levelised cost of electricity of gas power plants ranges between 900 and 2,000 ZAR/MWh. The cost of renewables and energy storage, the latter which can replace the flexibility of supply provided by a gas power plant, continue to decline. As a result, gas-based generation was not included in the modelling analysis of this study.

5.4.2 Nuclear

Nuclear power is a well-established baseload technology which provides near zero carbon energy fuelled by uranium. Although nuclear generation is a low carbon generation technology, it presents many risks from a safety and environmental perspective. The safety risks have notably led to countries decisions for early decommissioning of their nuclear fleet, for instance Germany and Japan.

South Africa currently has 1940 MW of installed nuclear capacity in one site, Koeburg in Cape Town, which is expected to be decommissioned in the mid-2040s. According to South Africa's IRP, the future role of nuclear energy is yet to be determined and further studies are required to understand "the implications of nuclear energy, including its costs; financing options; institutional arrangements; safety; environmental costs and benefits; localisation and employment opportunities; and uranium-enrichment and fuel-fabrication possibilities". In the short term, however, there are no plans to increase capacity.

---

[7] Department of Mineral Resources and Energy, "Integrated Resource Plan 2019", 2019. Retrieved from: http://www.energy.gov.za/files/docs/IRP%202019.pdf
[8] https://www.mckinsey.com/industries/oil-and-gas/our-insights/global-gas-and-lng-outlook-to-2035
[9] https://www2.deloitte.com/insights/us/en/industry/power-and-utilities/global-renewable-energy-trends.html
[10] https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf

Nuclear facilities are highly complex to procure and build and as a result, their build rate is often delayed as observed in France recently[11]. In terms of cost, nuclear power stations have very high capital costs[12] and their operational and decommissioning costs mean that the lifecycle costs are already higher than renewable energy options in the United States.[13] According to the EPRI study, the levelised cost of nuclear generation was estimated at between 1,852 and 2,523 ZAR / MWh.

In the context of eThekwini, given that the power demand is between 2-3 GW and currently nuclear power stations are in the order of 1 GW, investment in nuclear power would mean committing eThekwini to this energy system for at least a third of electricity demand and a correspondingly high (if not higher) proportion of annual electricity consumption. Finally, nuclear power stations have an operational lifetime of 50 or more years, with several plants extended to operate longer than their original design life. These two points specifically compromise eThekwini's aim to supply electricity exclusively from renewable energy by 2050 and as a result, nuclear generation was not included in the modelling analysis of this study.

If the nuclear situation in South Africa changes, it may be appropriate for eThekwini to look again at procuring nuclear power; the International Energy Agency (IEA) states that a doubling of nuclear capacity additions is required to be on track with the Sustainable Development Scenario[14].

5.4.3 Ocean Energy

Ocean energy can be broadly divided into technologies which harvest the energy from currents, waves or the tide. A review of the feasibility of ocean energy along eThekwini's coast was undertaken as part of the ESR. It was found that the resources are not sufficient to be viable using currently commercial technologies[15].

Technologies that are nearing commercialisation were identified such as the Toshiba type tethered tidal generator or more novel systems based on ocean temperature energy conversion. The development of these technologies should be monitored and where possible, eThekwini could facilitate pilot projects and thereby support innovation and commercialisation of this technology.

5.4.4 Hydrogen Economy

Hydrogen is a versatile energy carrier that is gaining attention for its multiple applications in energy storage, distribution and transformation to useable forms such as electricity, heat and mobility. Hydrogen is converted into electricity by using as an input to fuel cells. Hydrogen must be produced in the first place from

---

[11] https://www.energylivenews.com/2019/07/29/edf-confirms-further-delay-at-flamanville-nuclear-plant/
[12] Highest overnight costs according to the draft South Africa Integrated Resource Plan
[13] LAZARD report is for US context but considered comparable - https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf
[14] https://www.iea.org/fuels-and-technologies/nuclear
[15] For more information see eThekwini Energy Strategic Roadmap

hydrocarbons (commonly natural gas) using steam or water using heat (thermolysis) or electricity (electrolysis)

Although hydrogen production and its uses are currently limited, globally, interest is growing in its role to support the clean energy transition in the following areas:

- Widespread adoption of renewable energy by acting as a flexible energy storage for short and long periods
- An alternative to fossil fuels for heat or combined heat and power (CHP) in buildings and industry
- Portable clean energy supply in remote areas
- Clean energy in vehicles particularly Heavy Duty Vehicles

In South Africa, hydrogen has become a strategic industry because of the abundance of local natural resources in Platinum Group Metals (PGM) which could be leveraged to develop an export industry and support South Africa's clean energy transition. South Africa's north eastern provinces (Limpopo, Gauteng and Mpumalanga) are host to nearly 75% of known platinum reserves, which are the key catalytic materials used in fuel cells.[16]

In May 2007, The Hydrogen and Fuel Cell Technologies Research, Development and Innovation Strategy (or also known as Hydrogen South Africa -HySA) was approved by the Department of Science and Technology (DST) with the goal of establishing a South African Hydrogen Fuel Cell Technology industry. One of the initiatives, known as Hydrogen Infrastructure, has been developed to support research and development of hydrogen-based energy systems coupled with variable renewable electricity generation. A pilot off-grid energy system was launched in 2018 in a rural school consisting in 17kW of PV, lead-acid batteries, an electrolyser, bulk hydrogen storage tubes, and a 2.5 kW fuel cell system. The components work together to provide the school with uninterrupted electricity.

The exact role of hydrogen in the future economy continues to be debated. IRENA, in a study published in 2018, indicated that hydrogen produced from renewable energy may only be commercially viable from high production and low-cost renewable electricity supply, e.g. remote solar or wind farms supplying exclusively to a large hydrogen production facility, or otherwise through high utilisation e.g. as a grid-balancing service.[17]

Currently there remain three key areas where cost reductions are needed to make hydrogen more viable:

- Production of hydrogen from renewable electricity power powered electrolysis.
- Capital costs of fuel cells. This may be obtained through technological innovation and economies of scale in production

[16] 'Hydrogen Fuel Cell Technologies', DST. Retrieved from https://www.hysa-padep.co.za/wp-content/uploads/2015/06/HFCT-FAQ-Booklet.pdf
[17] 'Hydrogen from Renewable Power', IRENA, 2018. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf

- Distribution and storage of hydrogen. Research and development areas include how to improve the energy density of hydrogen.

Within this context, eThekwini's role in developing South Africa's hydrogen economy and the role it can play in energy supply remains to be investigated further. Technology innovation advancements should be monitored by the City and where possible, facilitate pilot projects and support innovation and commercialisation of this technology.

5.5 Supply technology assumptions

Based on the findings of the ESR report, renewable energy generation assets that could be located within the city boundaries are limited by space requirements, topological and weather aspects, as well as the availability of fuel and resources necessary to maintain their supply output.

Table 11 shows the peak output capacity from each technology investigated within the municipality.

Table 11: Total installed capacities, renewable technologies in eThekwini.

Technology	Total 2050 maximum installed generation capacity availability	Source
Solar	2GW	Calculation for ESR analysis - rooftop and ground-mounted PV based on 1400 kWh/kWp/Year
Wind	150MW	Calculation for ESR analysis based on land availability. Assuming 25% capacity factor based on median capacity factor for a 3MW turbine, 100m hub height from inhouse tool.
Landfill gas	7.5MW	Calculation based on: What a Waste 2.0: A global Snapshot of Solid Waste Management to 2050 Figure 3.32 Waste Generation Rates: Sub-Saharan Africa Region, data from Loganathan Moodley May 2019
Wastewater gas	4MW	Calculation based on: National Waste Information Baseline Report 2012 and information from Loganathan Moodley - Deputy Head of Cleansing and Solid Waste, Durban
Biomass	1.5GW	Based on CSIR Bio-energy deep dive presentation and Marbek consultants 2007 report

Hydropower	11MW	Calculation based on Sustainable Energy Africa report and Entura report 2016 - Process Manual for Mini-Hydro Development on existing water supply networks
Imported	Assumed limitless	Assumption that the market will rise to meet demand for renewable power

5.6 Supply profiles

Meeting the peak demand for power demand in Durban requires enough generation capacity to meet that peak demand. However, in a renewable led future, if the sun is not shining or the wind isn't blowing when this demand occurs, back up generation/supply or stored electricity will be necessary to meet demand.

This report has undertaken hourly demand and supply modelling to optimise the future electricity grid performance and to understand how the technologies of the future will interact and be used to meet demand in the municipality. This section describes how the hourly generation profiles of the various input technologies have been developed.

5.6.1 Solar generation profile and assumptions

Assuming PV panels are aligned optimally, the generation of power from solar is predominantly based on when the sun is shining and to what extent. Cloud cover and climate will affect the output of solar PV panels; understanding how and when power is generated from these assets will ensure that the correct back-up generation allowances are made.

Global weather modelling by the National Centre for Atmospheric Research (NCAR) Climate Forecast System has been used to estimate the solar PV output annual supply profile from solar radiation and temperature data. By using the Photovoltaic Geographical Information System (PVGIS) an optimal plate inclination and orientation was identified for Durban's unique geography. This was used with industry benchmark assumptions about PV performance and yield to create an hourly profile of expected electricity generation per unit of installed PV capacity. Figure 20 shows how the output of solar power varies throughout the year. Figure 21 to Figure 24 show how this output can vary on an hourly basis during two days in different months of the year.

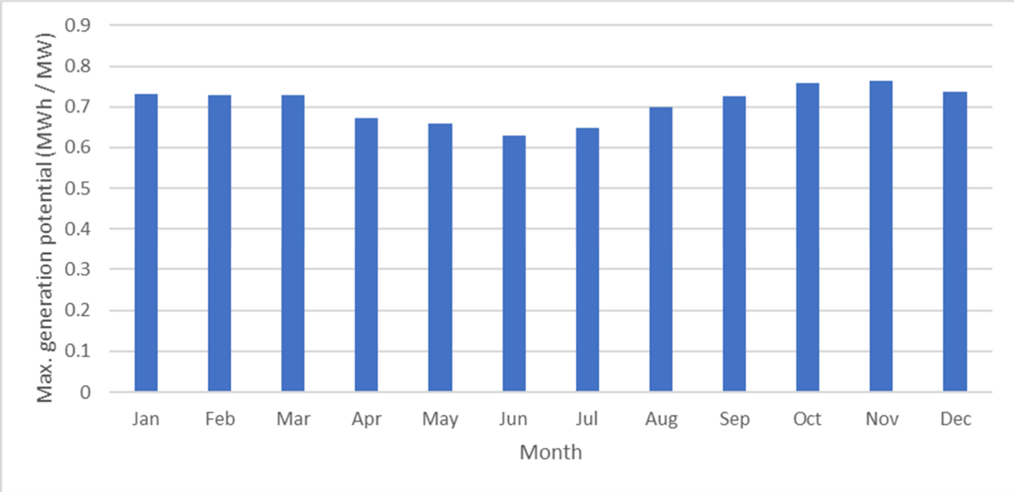

Figure 20: Peak monthly electricity generation potential per unit of installed PV capacity.

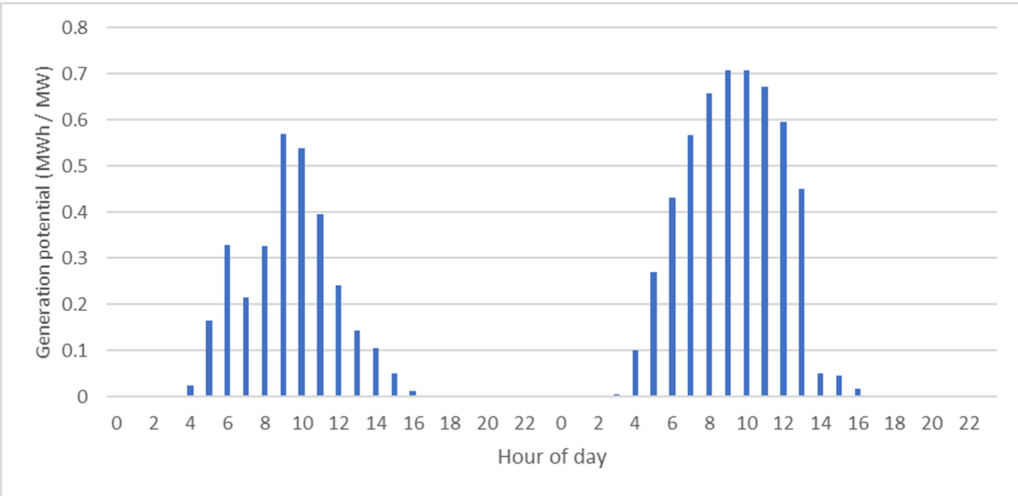

Figure 21: Hourly electricity generation potential from solar PV for two typical days in February.

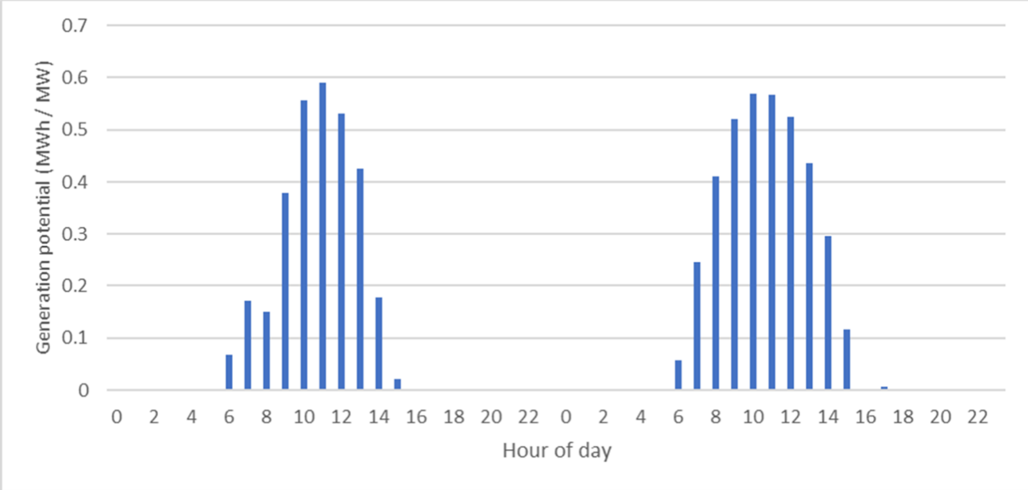

Figure 22: Hourly electricity generation potential from solar PV for two typical days in May.

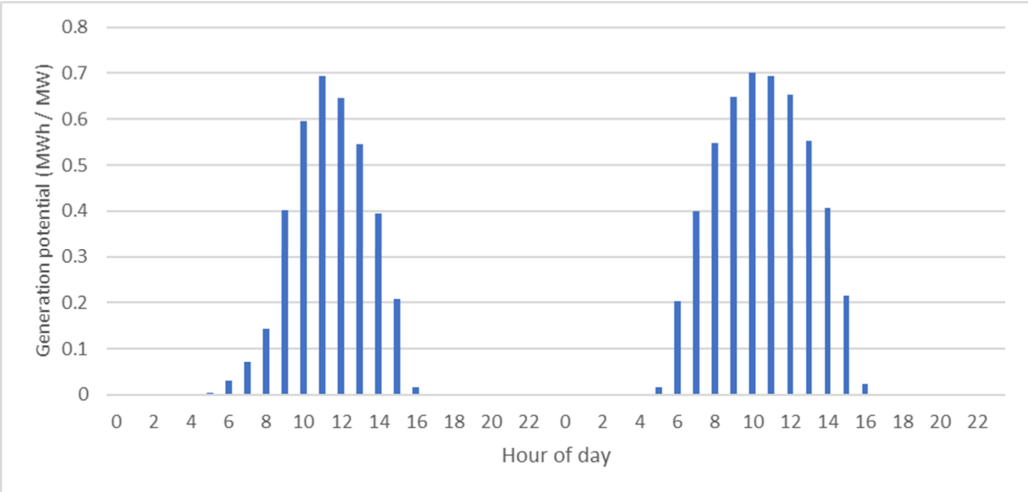

Figure 23: Hourly electricity generation potential from solar PV for two typical days in August.

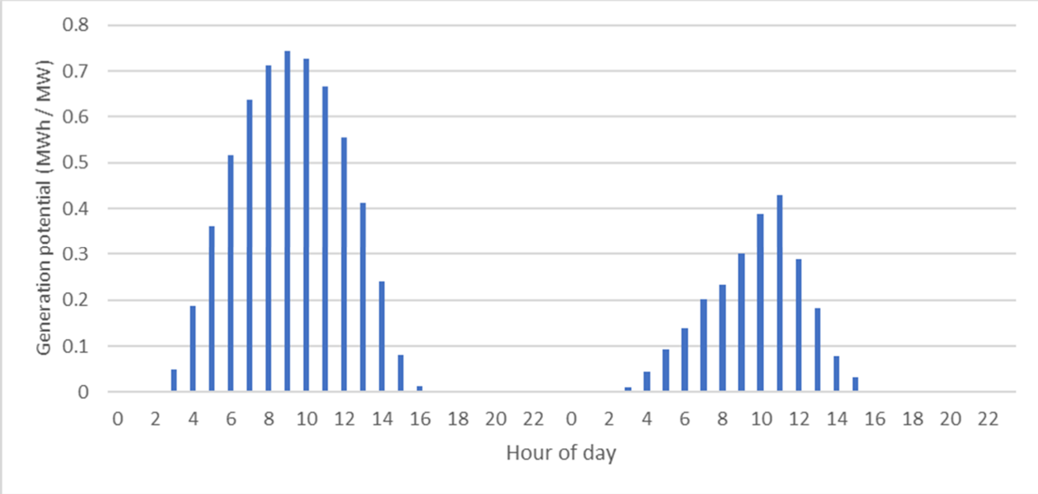

Figure 24: Hourly electricity generation potential from solar PV for two typical days in November.

For eThekwini, a potential for 2.0 GW of PV was identified. With these resource profiles this capacity delivers a peak generation of 1.5 GW in November when solar radiation is at its maximum.

5.6.2 Wind generation profile and assumptions

In the same way that solar power generation is affected by the weather, so too is generating power from wind turbines. Additionally, the above ground height of the turbine can affect power output as well as the size of each turbine and how it is positioned.

No detailed analysis has been undertaken as to the exact location of wind turbines within the municipality, although the following assumptions have been made based on industry standards seen elsewhere for onshore wind generation:

- Arrays would be predominantly made up of 3MW turbines (similar to the Vestas V90)
- Turbine hub height of 100m (consistent with 3MW turbine)
- Aggregated efficiency of 87% - this includes electrical efficiency, terrain effects, blade degradation and other technical factors

Wind specialists created a turbine power curve based on these assumptions. Durban wind speed profiles from the NCAR Climate Forecast System were used with this curve to create estimated hourly wind energy resource profiles. Figure 25 shows how the potential output of electricity from wind turbines changes through the year, and Figure 26 demonstrates the way this can vary on an hourly basis for two days in February. Since wind speeds do not follow a pattern throughout the day in the same way solar radiation does, potential for generating energy from the wind is much more variable as shown by Figure 26.

Detailed analysis was not completed studying the impact of using offshore wind turbines of larger sizes such as the General Electric Haliade-X 12 MW turbine, however larger turbines such as this have rated operating wind speeds which still greatly exceed typical wind speeds in Durban, which means that using these turbines in Durban's unique climate would result in low energy output per unit installed capacity.

Notably, the potential for energy generated by wind turbines per unit installed capacity in eThekwini is considerably lower than the potential from solar PV. This is because average wind speeds are low in eThekwini when compared with the rated operating speeds for wind turbines, whereas there is an abundant solar resource.

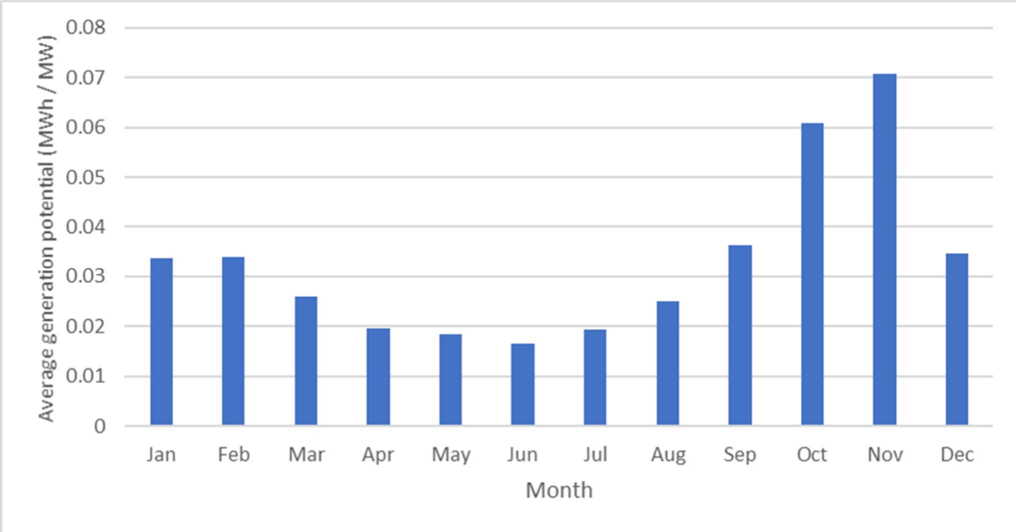

Figure 25: Average monthly electricity generation potential per unit of installed wind capacity.

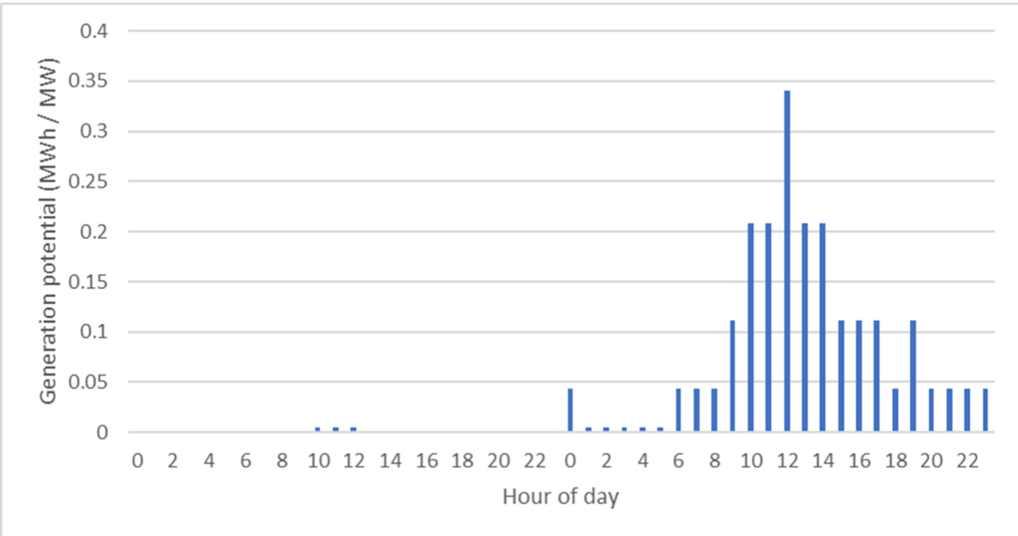

Figure 26: Hourly electricity generation potential from wind turbines for two days in February.

5.6.3 Other profiles and assumptions

For technologies like biomass, landfill gas and wastewater gas combustion, output is less dependent on the weather. When generation units are in operation, output is steady and consistent. Such plant should be operated at peak output as much as is possible, allowing only for temporary shut down for maintenance. The amount the plant is used when compared to its theoretical maximum output is known as the capacity factor.

The supply profile of these generation technologies is a flat line sitting at the installed capacity, assuming uninterrupted fuel supply chains. However, at times throughout the year, planned maintenance is undertaken and hence a capacity factor has been assumed across all such technologies to account for this, see Table 12.

Table 12: Capacity and efficiency factors for other renewable technologies

Technology	Capacity Factor	Turbine/ engine efficiency	Source
Landfill gas	80%	40%	Developed from investigation into existing Landfill gas CHP plant installations
Wastewater gas	80%	40%	As above
Biomass	66%	40%	IRENA biomass capacity factors
Hydropower	60%	85%	Assumptions developed through engaging with specialist providers of hydro technologies. Blended average across different sizes of plant.

5.7 Economic assumptions

The modelling undertaken optimises technology capacity and performance based on the lowest cost method of power production. In order to do so, a number of economic parameters have been developed or gathered through engagement with the municipality. These assumptions are detailed in this section.

5.7.1 Capital expenditure (CAPEX) assumptions

The following capital cost assumptions were used in relation to the energy supply and storage technologies included in the scenario modelling. Whilst estimates are very high-level, they are based on research into the local environment and market, as well as through comparison with the context globally. Actual costs may vary in reality; as learning is applied to new technologies, costs tend to come down.

Table 13: CAPEX assumptions summary

Technology	Cost	Units	Comments
Biomass	51m	ZAR / MW	Developed as part of ESR calculations

Solar PV	19.7m	ZAR / MW	Developed as part of ESR calculations and developed as a weighted average between rooftop and ground mounted figures, assuming 44:56 rooftop:ground PV ratio
Wind turbines	21.5m	ZAR / MW	Based on 3MW turbines, 100m hub height. Costs developed under ESR calculations
Landfill energy	11m	ZAR / MW	Cost only allows for the generation assets, assumes purchasing landfill gas on site and converting to power.
Wastewater energy	9.5m	ZAR / MW	Cost only allows for the generation assets, assumes purchasing biogas on site and converting to power.
Batteries	6.8m	ZAR / MWh	Engagement with manufacturers Samsung and SMA

5.7.2 Operating expenditure (OPEX) assumptions

As above, Operating cost assumptions have also been developed (through the same means) for the various technologies being explored. Table 14 summarises the inputs used. Actual costs may vary between projects; costs detailed are aimed to capture average values across the sector.

Table 14: OPEX assumptions summary

Technology	Value	Units	Source of assumptions
Biomass (fixed)	3.5	% of CAPEX	Developed through engagement with a number of in-house specialists in their field. Such specialists have undertaken research into the costs of their specific technologies through engagement with the market and undertaking research on local implications
Biomass (variable)	97	ZAR / MWh	
Solar PV	152.8k	ZAR / MW	
Wind	250	ZAR / MWh	
Wastewater	2.6m	ZAR / MW	
Hydro	0.8m	ZAR / MW	
Landfill energy	1.0m	ZAR / MW	Loganathan Moodley - Deputy Head of Cleansing and Solid Waste, Durban

5.7.3 Cost assumptions for imported energy

All tariff assumptions for power imported from Eskom are based on current Eskom Megaflex tariff rates from 2019. The modelling accounts for fixed charge as well as the variable Peak, Standard and Off-peak rates that are applied through this tariff structure; rates for electricity are lower when demand is lower. It is expected that Eskom tariff rates will continue to rise as they have over recent years, as plant efficiencies deteriorate further. For the purposes of the modelling, they are assumed to remain at current levels.

0.65 ZAR/kWh[18] has been used as the PPA cost assumption from renewable IPPs from outside the municipality in the modelling, with the addition of a 10% uplift to account for distribution costs as the IPP may not be close to the municipality. In such instances, the cost of the power purchased would need to include an allowance for the costs of distribution, payable to whomever is operating that distribution infrastructure (currently Eskom).

[18] As instructed by the eThekwini Electricity board

6 Modelling results

6.1 Modelling methodology

Demand and supply scenarios have been modelled in Calliope, an energy systems modelling tool which uses linear optimisation. The tool takes a range of cost, carbon and technical inputs (as detailed in this report) and models the supply and storage of power in the municipality on an hourly basis in order to optimise the system for lowest cost and other user-defined goals. The model outputs detail how and when each technology should operate in the optimised system.

6.2 Model flow diagram

Figure 27 overleaf shows the model process flow diagram. The diagram shows the inputs the model takes, the calculations undertaken and the outputs provided.

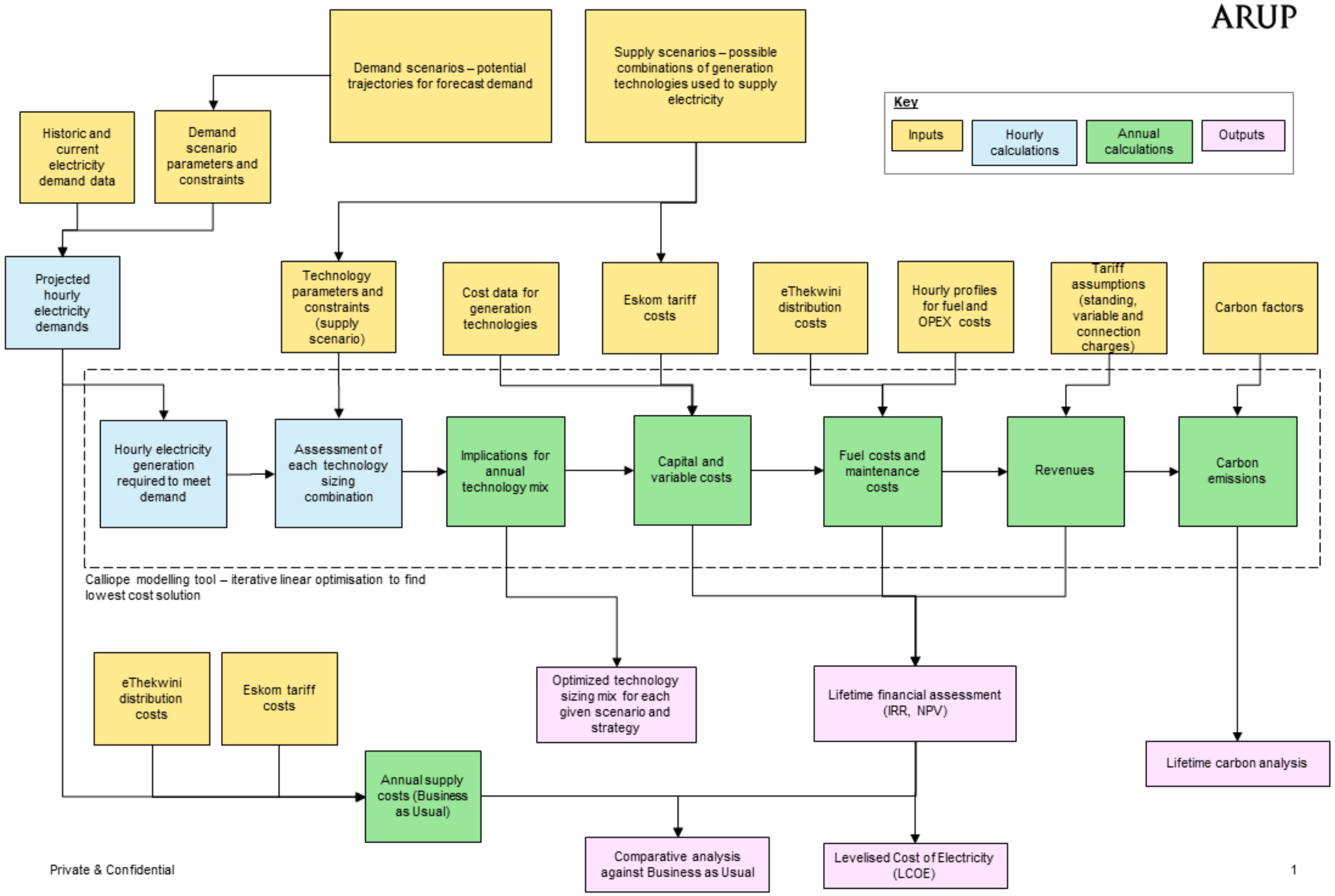

Figure 27: Model process flow diagram

6.3 Renewable energy targets

The eThekwini municipal targets for renewable energy supply are as follows:

- 40% renewables penetration by 2030
- 100% renewables penetration by 2050

The model has taken account of these targets and assesses whether each scenario will enable the municipality to meet the target or not.

6.3.1 Renewable energy scorecard results

The proportion of renewable energy supplied for the demand scenarios explored under each supply scenario is presented in Table 15. Cells in red show scenarios where it is not possible to meet the demand with the technologies included in that supply scenario.

Table 15: Renewable energy supply results against all demand scenarios

Year	Supply scenario		Demand scenario				
			Highest	High	Medium	Low	Energy Eff
2030 Target: 40%	A	Base case	40%	40%	40%	40%	40%
	B	All renewable technologies	66%	65%	65%	64%	64%
	C	All renewable technologies, no imported energy, solar scaled to meet demand	100%*	100%*	100%*	100%*	100%*
	D	All renewable technologies, biomass excluded	59%	59%	59%	59%	59%
	E	Biomass and imported energy	62%	61%	61%	61%	61%
2050 Target: 100%	A	Base case	56%†	56%†	56%†	56%†	56%†
	B	All renewable technologies	100%	100%	100%	100%	100%
	C	All renewable technologies, no imported energy, solar scaled to meet demand	100%*	100%*	100%*	100%*	100%*
	D	All renewable technologies, biomass excluded	100%	100%	100%	100%	100%
	E	Biomass and imported energy	100%	100%	100%	100%	100%

*includes demand that is not met by the generation capacity available

† denotes where renewable targets of the municipality are not achieved

The results show that the Base Case Scenario A does not meet the renewable target in 2050. In all other cases, renewable targets are met.

In Scenario C, supply technologies are not able to meet the demand without significant storage capacity that the city would be likely unable to implement. This is due to the hourly profile of solar generation not matching the demand profile of the municipality. In other words, it is necessary for the municipality to import power.

As such, Scenarios A and C are excluded from further analysis, since they would not meet either the targets for renewable energy nor the demand for power in the municipality. In all other scenarios, demand and renewable energy targets are met.

6.3.2 Energy supply scorecard results

The percentage of electricity generated by each of the technologies is shown in Table 16 for each of the supply scenarios in 2030 and 2050, with the Energy Efficient demand scenario.

Table 16 – Electricity generation results for each supply scenario, Energy Efficient demand scenario. 'Imported' refers to IPP and Eskom imported power.

Year	Supply scenario		eThekwini local generation						Imported
			Solar	Wind	Landfill	Wastewater	Biomass	Hydropower	
2030	A	Base case							100 %
	B	All renewable technologies	5%	<1%	<1%	<1%	10%	<1%	83%
	C	All renewable technologies, no imported energy, solar scaled to meet demand	55%	<1%	<1%	<1%	34%	<1%	
	D	All renewable technologies, biomass excluded	5%	<1%	<1%	<1%		<1%	94%
	E	Biomass and imported energy					10%		90%
2050	A	Base case							100 %
	B	All renewable technologies	20%	<1%	<1%	<1%	55%	<1%	25%
	C	All renewable technologies, no imported energy, solar scaled to meet demand	55%	<1%	<1%	<1%	30%	<1%	
	D	All renewable technologies, biomass excluded	20%	<1%	<1%	<1%		<1%	79%
	E	Biomass and imported energy					57%		43%

As mentioned in section 6.3.1 Scenario C leaves some demand unmet, which is why the percentages for this scenario do not add to 100%.

As can be seen from the results, wind, landfill, wastewater and hydropower technologies do not contribute significantly to the overall energy consumption. Solar, biomass and imported energy are the more significant technologies in terms of their contribution to the overall energy consumption.

6.4 Technology optimisation results

The Calliope energy optimisation tool has modelled how each of the technologies interact and are used to meet the demand profile based on their availability within each supply scenario. Results here are presented for the Energy Efficient demand scenario only, to reduce the number of results presented.

Detailed results are not shown here for Scenario A: Base Case, or Scenario C: Solar Scaled – See Section 6.3.1 for why these scenarios are discounted.

6.4.1 A: Base case

Figure 28 and Figure 29 show how demand is met in supply Scenario A on a typical day and month in 2030 and 2050.

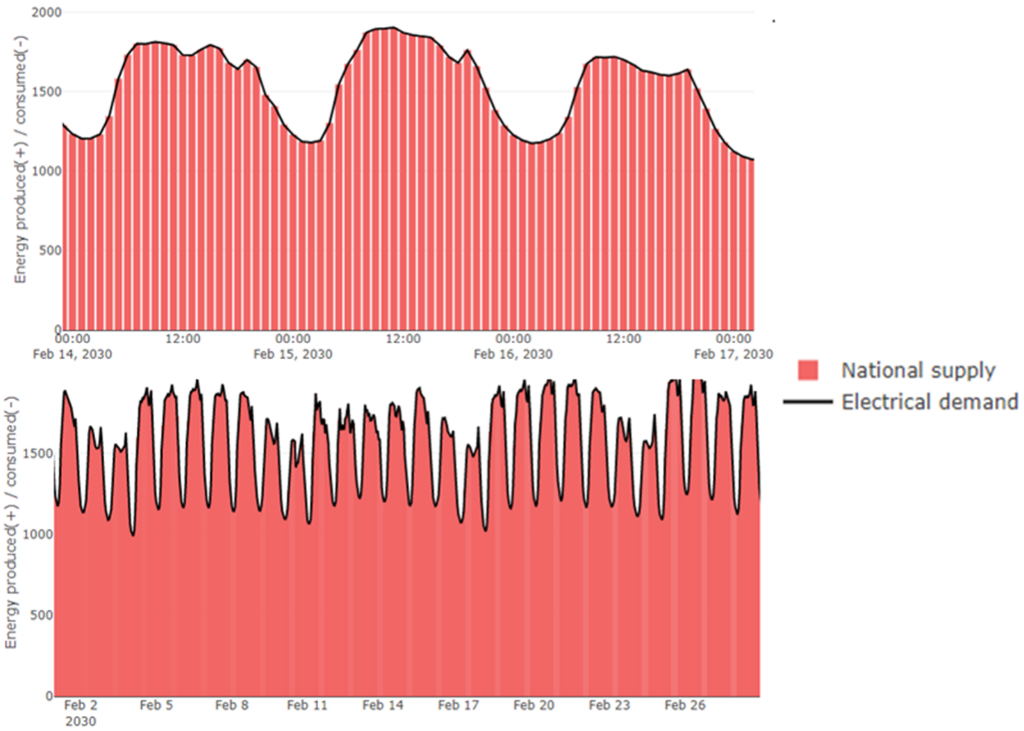

Figure 28: Scenario A 2030 results, typical day (top), typical month (bottom)

This scenario represents the base case, in which the municipality is still fully dependent on supply from Eskom, so 100% of electricity is supplied from Eskom in each graph.

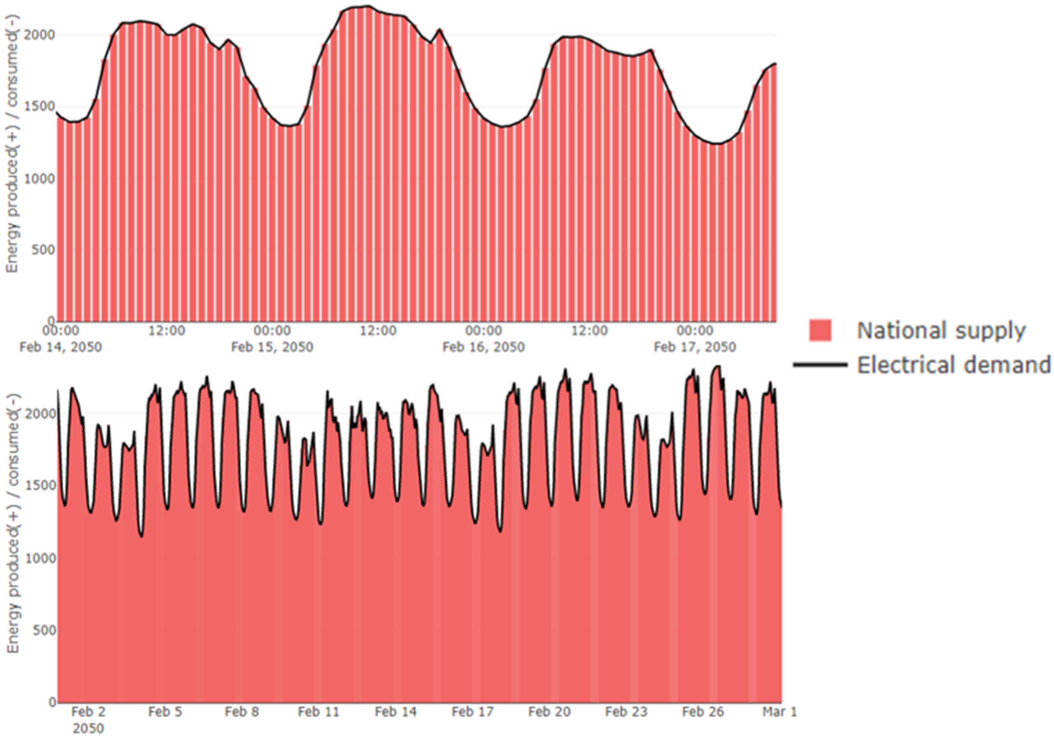

Figure 29: Scenario A 2050 results, typical day (top), typical month (bottom)

This scenario does not include deployment of demand side response or battery technologies, meaning that all demand is met through Eskom. Using batteries as part of this scenario could reduce overall costs by charging the batteries during less expensive off-peak demand periods and discharging during peak times.

6.4.2 B: All renewable energy technologies included

Figure 30 and Figure 31 Figure 30show how demand is met in supply Scenario B on a typical day and month in 2030 and 2050.

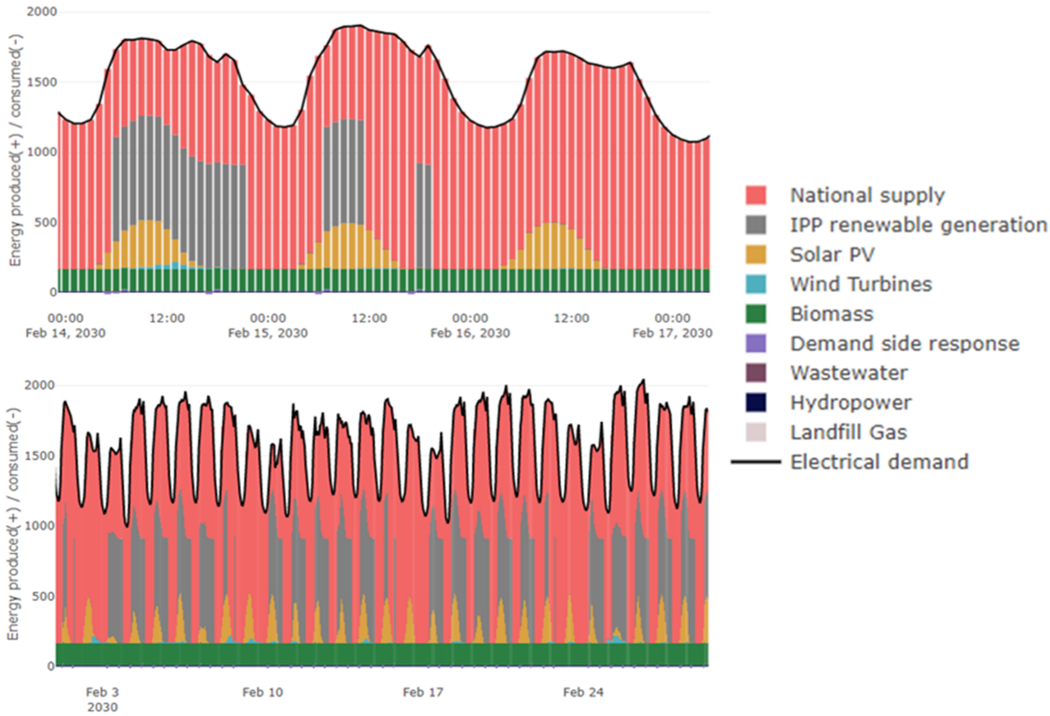

Figure 30: Scenario B 2030 results, typical day (top), typical month (bottom)

It can be seen that in 2030, the municipality is still heavily reliant on importing power from Eskom, but is making the transition over to generating power and buying from IPPs external to the municipality instead of Eskom.

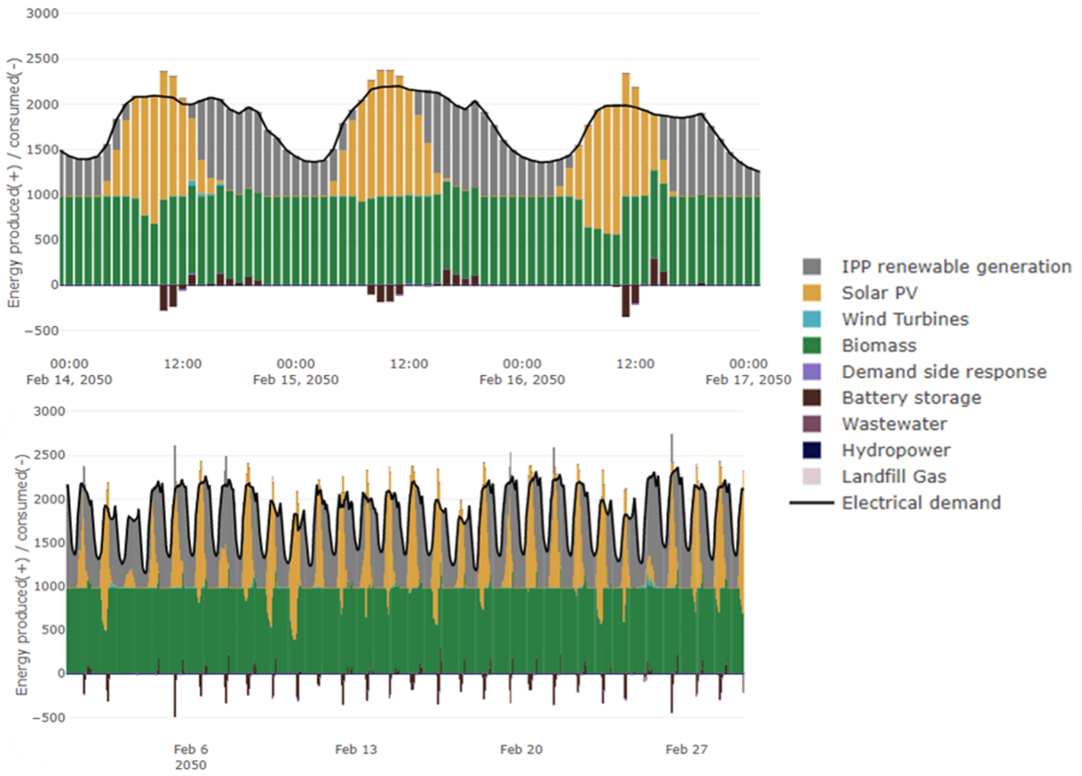

Figure 31:Scenario B 2050 results, typical day (top), typical month (bottom)

In 2050, the municipality has transitioned completely away from the Eskom supply as it has fully installed its own generation capacity and is purchasing all remaining power from IPPs. Input from hydropower, wastewater and landfill gas is minimal and cannot be seen in the outputs.

It can be seen that additional solar power is stored and discharged later through use of the batteries.

6.4.3 C: Solar scaled to meet demand

Figure 32 and Figure 33 show how demand is met in supply Scenario C on a typical day and month in 2030 and 2050. In this scenario, the municipality does not import any energy but aims to generate all energy from within the municipality. In order to do this, the upper limit on potential solar PV installation capacity is removed so that the amount of PV required can be optimised.

As can be seen from the graphs, there are large amounts of demand that remain unmet in this scenario despite the fact that solar PV generation has been accelerated far beyond the maximum capacity limit identified. This is on account of the times during each day when there is no solar resource, which means that solar electricity generation is not possible. To try to mitigate against this the model deploys the installed batteries to their maximum capacity, however these are fully utilised without offsetting the unmet demand in even a single hour of low solar resource.

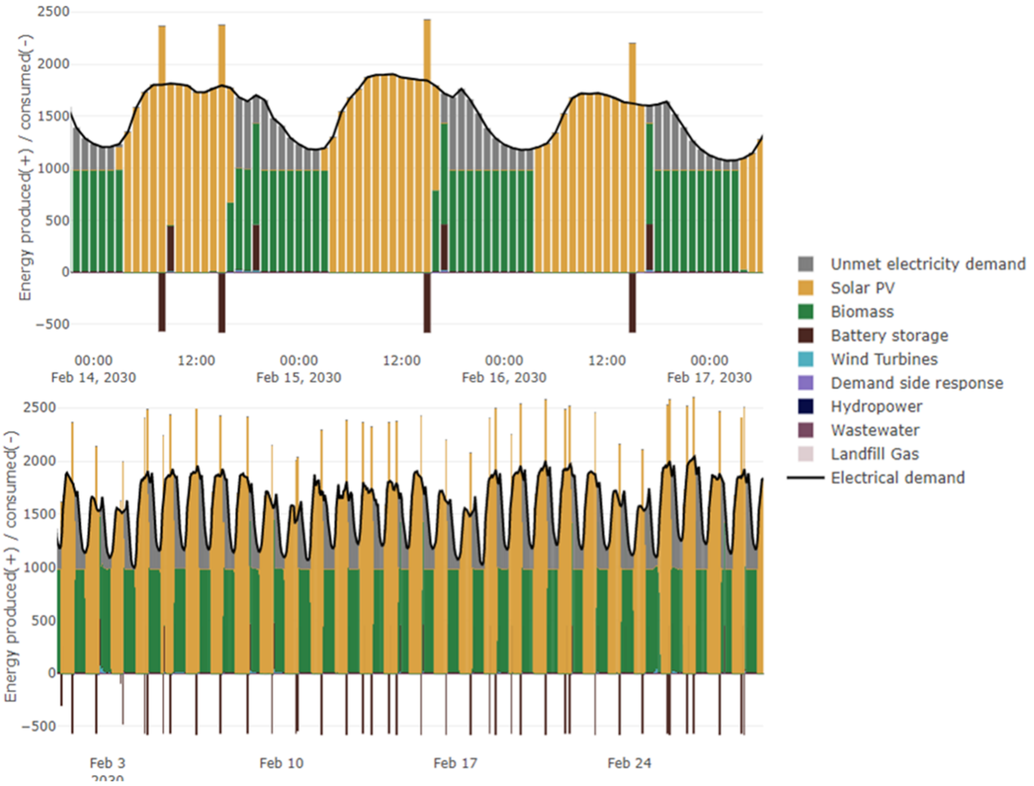

Figure 32: Scenario C 2030 results, typical day (top), typical month (bottom)

In 2030 the municipality maximises its use of renewable energy, however technologies such as biomass do not operate during periods when the solar energy is available. This is because the operational cost of solar PV is linked to its capacity rather than its output, whereas biomass energy depends on the purchase of biomass fuel, therefore this is a more expensive option.

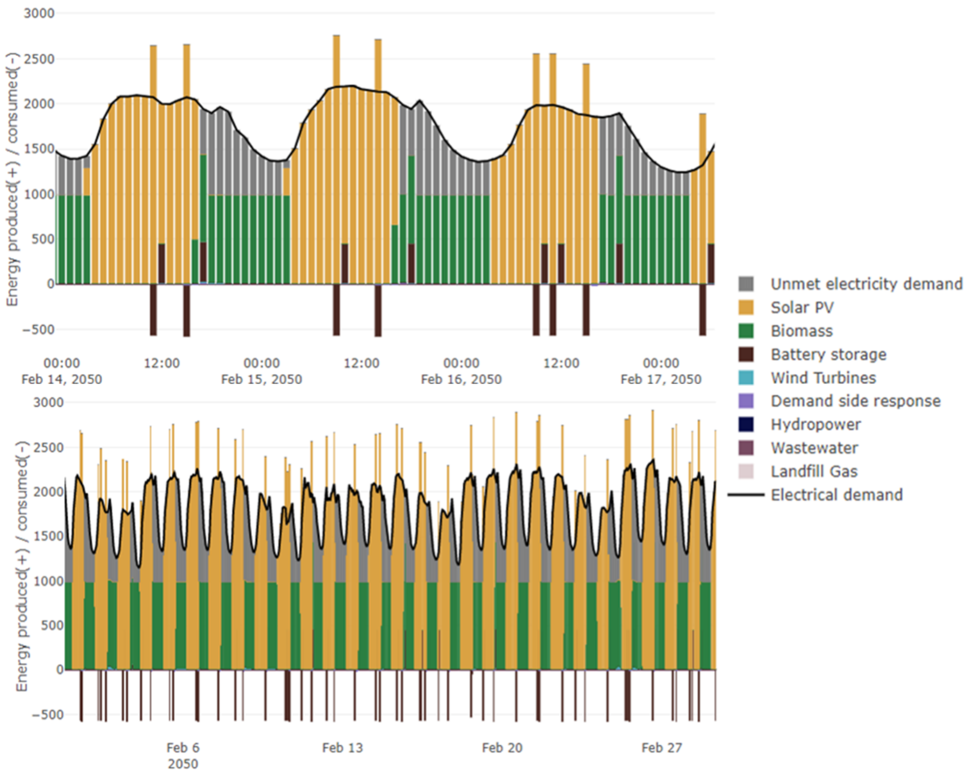

Figure 33: Scenario C 2050 results, typical day (top), typical month (bottom)

As for 2030, during 2050 the model maximises its use of renewable energy technologies, which rise to their full potential capacities in this year. Despite this, there is still unmet demand during the timesteps when solar energy is unavailable, deeming this scenario infeasible as a supply solution.

6.4.4 D: Biomass excluded

Without biomass, Scenario D relies much more heavily on imported power (see Figure 34 and Figure 35). There is still the transition away from Eskom, i.e. purchasing more power from IPPs instead. There is slightly lower use of storage / DSR technologies than for Scenario B as the municipality is assumed to take what is needed from the imported technologies (Eskom/IPP).

In the case of importing renewable power from IPPs, the Energy Office shall need to procure a mix of generation types to ensure its demand profile can be met through renewable power generation. This will require a range of technologies and include those that are weather dependent and those that the city can rely on when the sun is not shining, or the wind is not blowing (for example biomass or large-scale hydropower).

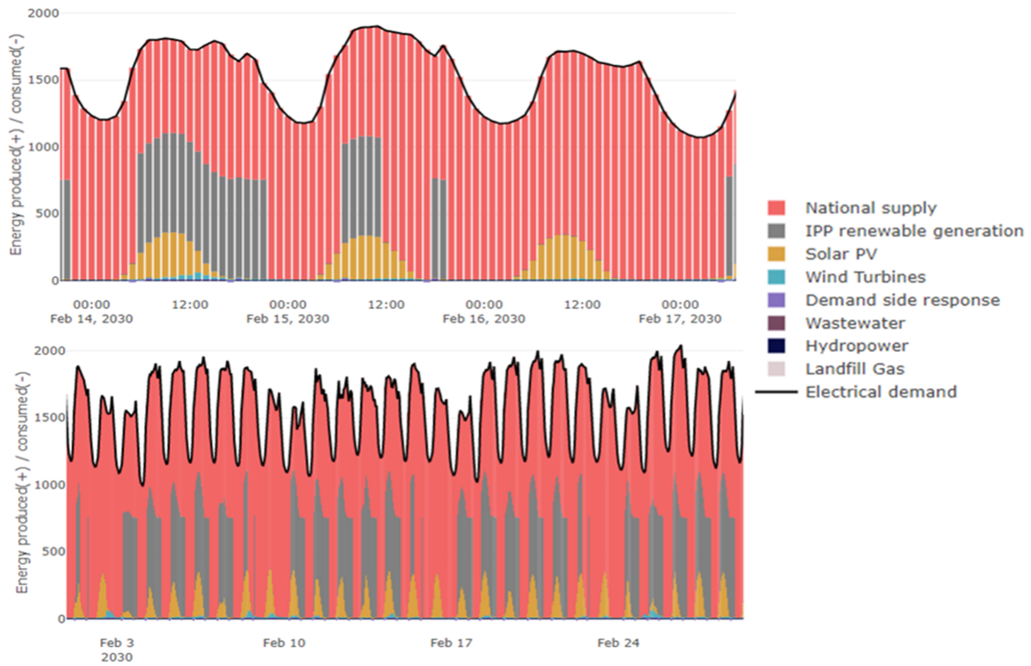

Figure 34: Scenario D 2030 results, typical day (top), typical month (bottom)

As in all results, the contribution from wind generation is minimal, predominantly due to low wind speeds in the area not enabling high generation potential. In 2050, power is heavily reliant on imports still, with the largest other contributor being solar. Other technologies are generating and being used, but only contribute a small amount and are therefore not visible.

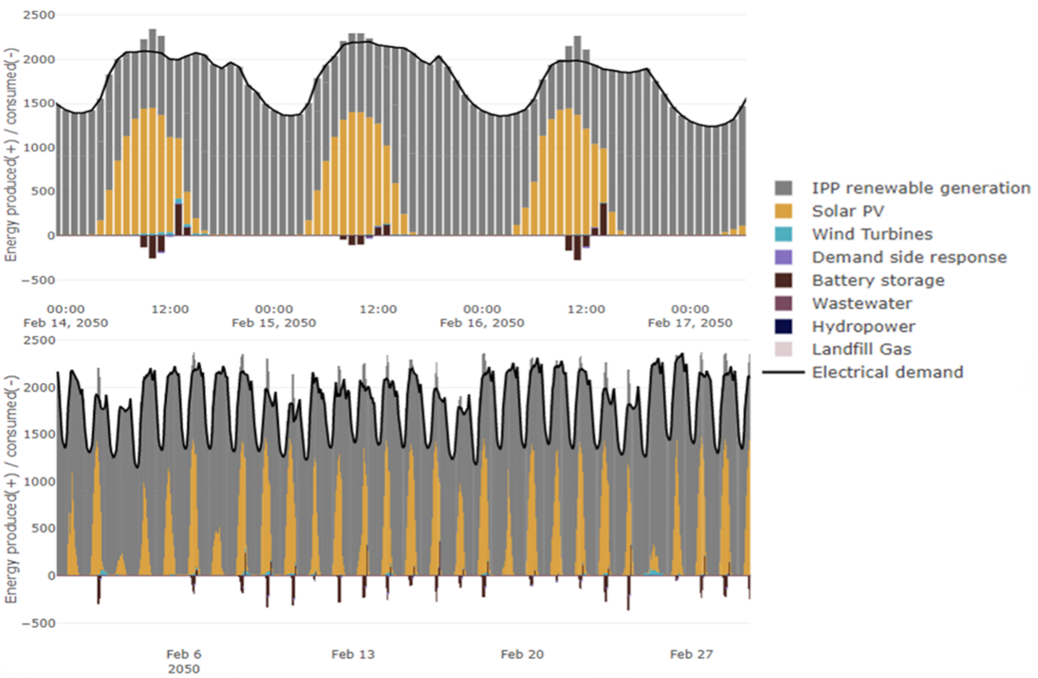

Figure 35: Scenario D 2050 results, typical day (top), typical month (bottom)

6.4.5 E: Biomass and imported power only

In Scenario E, all renewable generation technologies within the municipality are excluded with the exception of Biomass. In 2030 (Figure 36) there is still heavy reliance on the Eskom supply with some transition towards buying from IPPs already beginning. The biomass input is low as the full build out of the technology has not yet been realised.

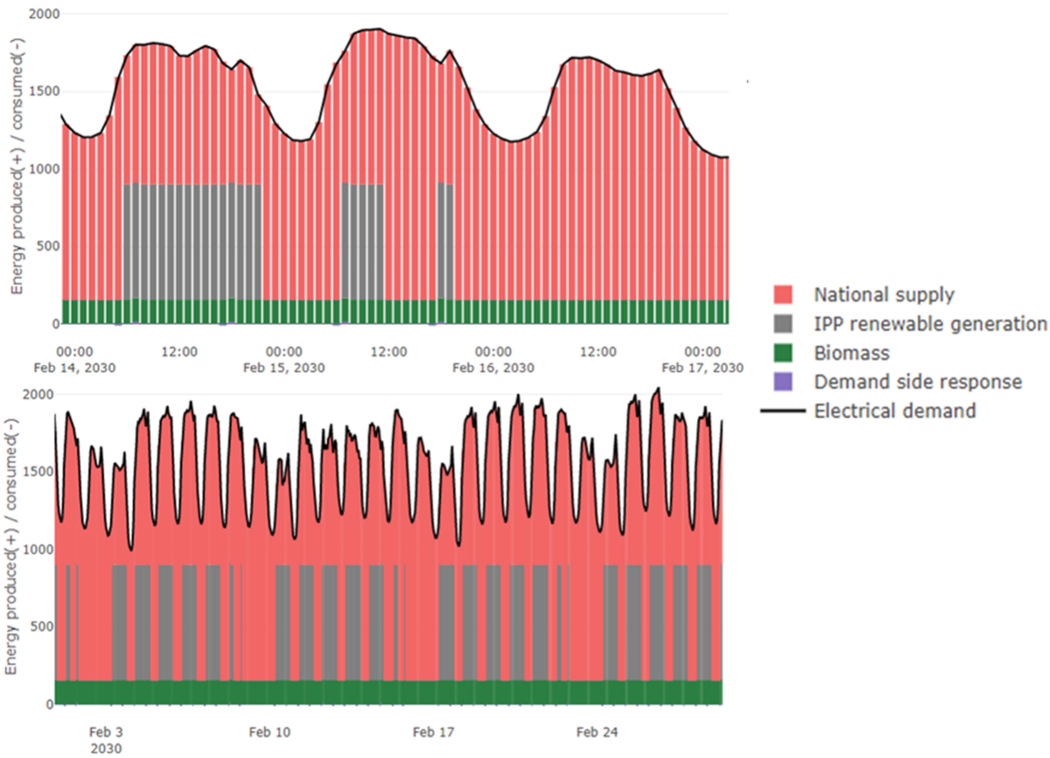

Figure 36: Scenario E 2030 results, typical day (top), typical month(bottom)

By 2050 (Figure 37) the biomass capacity has been built out in full, and it is able to contribute to a large proportion of the electricity demand. Energy storage technology is used to help reduce peak demand.

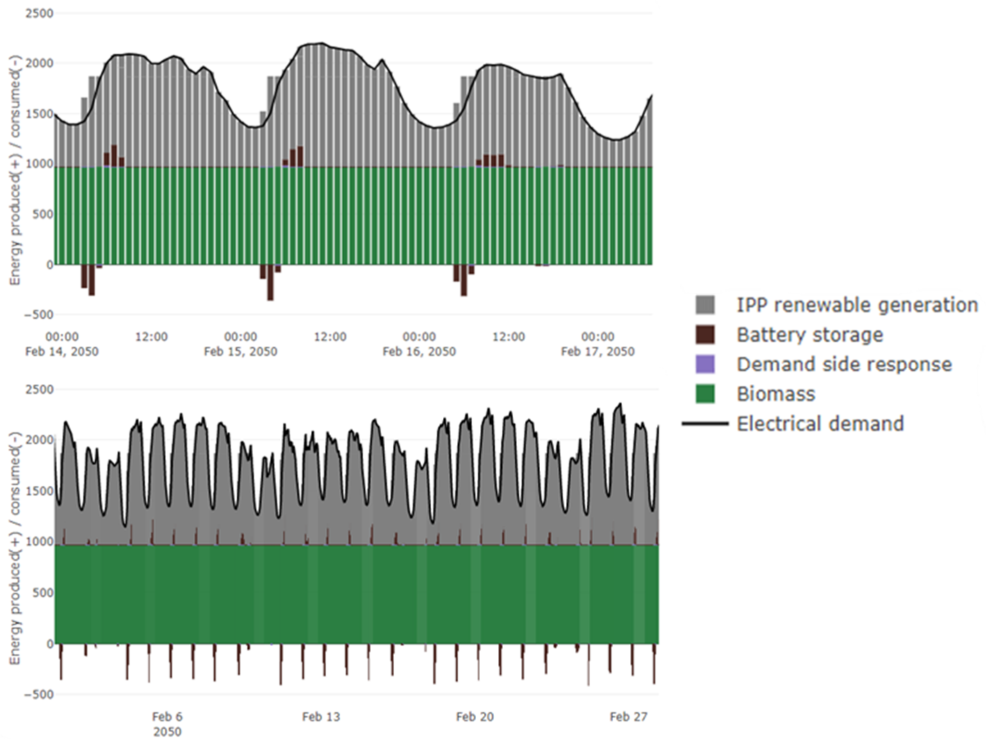

Figure 37: Scenario E 2050 results, typical day (top), typical month (bottom)

6.5 Energy generation share

In the next stage of analysis the share of energy generation through time has been calculated. For each of the supply scenarios, the results for the key target years (see section 6.3) have been used to formulate a guideline phased build-out schedule for eThekwini municipality, demonstrating how each technology can be developed to meet energy demand and facilitate achieving municipal renewable energy targets.

It has been assumed in this stage of the modelling that construction of any new technologies would not be completed until 2023 at the earliest.

6.5.1 Scenario A: Base case

Scenario A represents the base case and as such all demand is met by Eskom electricity supply.

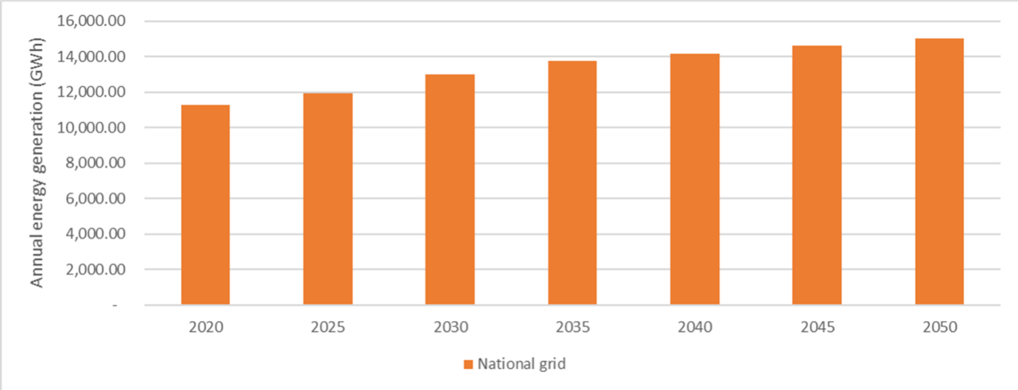

Figure 38: Generation share in supply Scenario A (Energy Efficient demand scenario)

In this scenario, the use of energy from Eskom follows the steady increase of demand over time. In this scenario dependence on Eskom increases as municipal demand rises, and the municipality would be subject to Eskom's rising energy tariffs. It may be that in the future some customers would choose to source private energy from elsewhere rather than continue to pay these rising energy prices.

6.5.2 Scenario B: All renewable technologies included

Scenario B is driven by maximising the potential for local renewable energy generation, however the rate at which it is possible to build the new technology limits the development to a steady incremental increase. An accelerated build-out programme for technologies such as hydropower, landfill gas and energy from wastewater would be possible and these could be developed to their maximum capacities in a matter of years, however for the sake of this analysis it has been assumed that this would be done gradually. It should be noted that for landfill gas and wastewater technologies, while it would be possible to front-load the construction of these their output is linked with eThekwini population and the generation of waste as fuel.

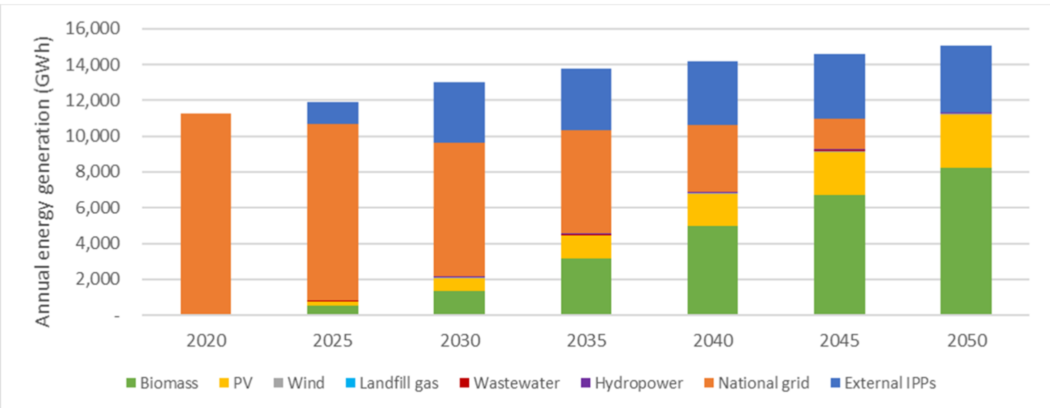

Figure 39: Generation share of technologies in Scenario B (Energy Efficient demand scenario)

The results for this scenario show that most procurement for IPPs outside of the municipality would happen in the first 10 years. After this the main focus is on continuing to develop renewable technologies inside the municipality; primarily solar PV and biomass. Together these lead to a steadily decreasing dependence on the Eskom national electricity supply, with the requirement for this imported energy halving shortly after 2030.

6.5.3 Scenario C: Solar scaled

Scenario C sees the municipality move away from dependence on Eskom after the first year and develop a solar generation capacity larger than that which was identified as possible. Despite this accelerated solar PV generation, there is not enough supply in this scenario to meet energy demand. Figure 40 shows how the technologies in this scenario are used to generate electricity, and it is clear that there is insufficient supply to meet demand.

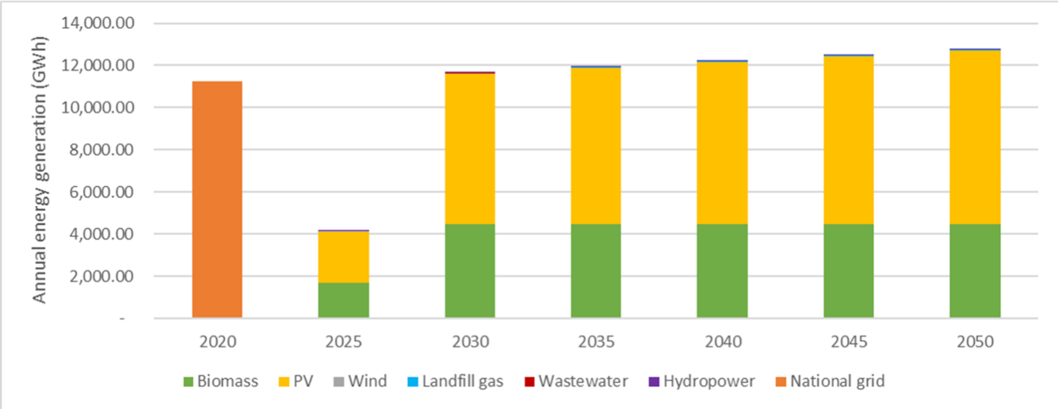

Figure 40: Generation share of technologies in Scenario C (Energy Efficient demand scenario)

To try to achieve the optimal PV capacity by 2030, this scenario requires a highly accelerated build-out of PV plant between 2020 and 2030, which far exceeds the benchmark build-out rate identified for PV. Other renewable technologies are deployed similarly to in Scenario B and use the same capacities, although due to the maximised utility of solar generation at certain times of day these technologies are operated for fewer hours throughout the year and so contribute less to overall supply.

From 2030 onwards this scenario has a shortfall of around 2,000 GWh of electricity supply annually and in 2025 this figure is over 10,000 GWh. In practice this shortfall would be met through importing energy from outside the municipality, either from Eskom or through IPP procurement, however doing so would not achieve the main goal of this scenario which is to operate independently of external supply. It is clear that this scenario is not a feasible supply choice.

6.5.4 Scenario D: Biomass excluded

In Scenario D, owing to the lack of biomass technology, the municipality would become heavily dependent on procuring renewable energy from outside of the municipality through IPP agreements. The renewable technologies available inside the municipality have a limited capacity and account for only 20% of energy generation by 2050. This means that the other 80% must be sourced from outside the municipality.

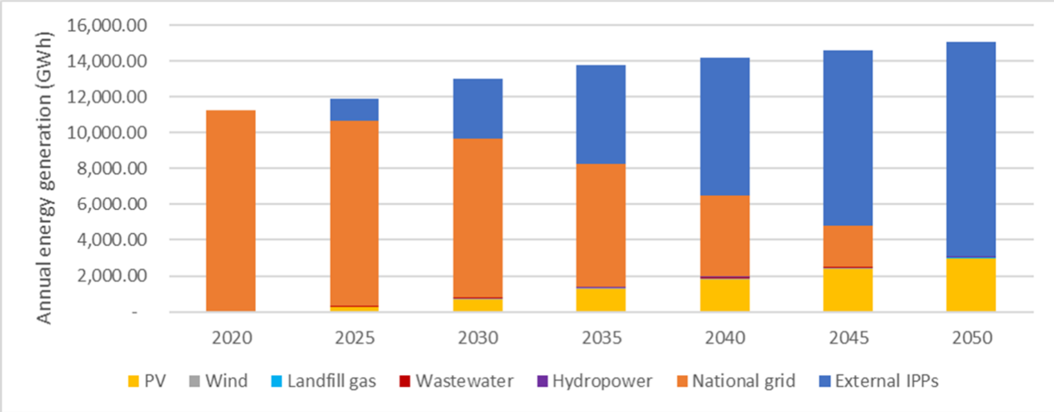

Figure 41: Generation share of technologies in Scenario D (Energy Efficient demand scenario)

As for Scenario B, an accelerated programme could be used for technologies like hydropower, landfill gas and energy from wastewater but this would have a very limited impact on the demand for imported energy. As a result of this, Eskom supply continues an important part of the energy mix, and the need for new procurement of renewable energy outside the municipality increases each year.

6.5.5 Scenario E: Biomass and imported only

In Scenario E demand is met by only biomass and imported energy. The capacity of biomass technology is steadily increased through time until it reaches its maximum capacity in 2050. At the same time, dependence on the national Eskom supply is steadily phased out and replaced by this new biomass generation as well as renewable energy from outside the municipality, procured through IPP agreements. Most establishment of new IPP agreements occurs in the first 10 years in this scenario, although there is a small increase in the demand for this year on year in order to completely phase out Eskom dependence by 2050.

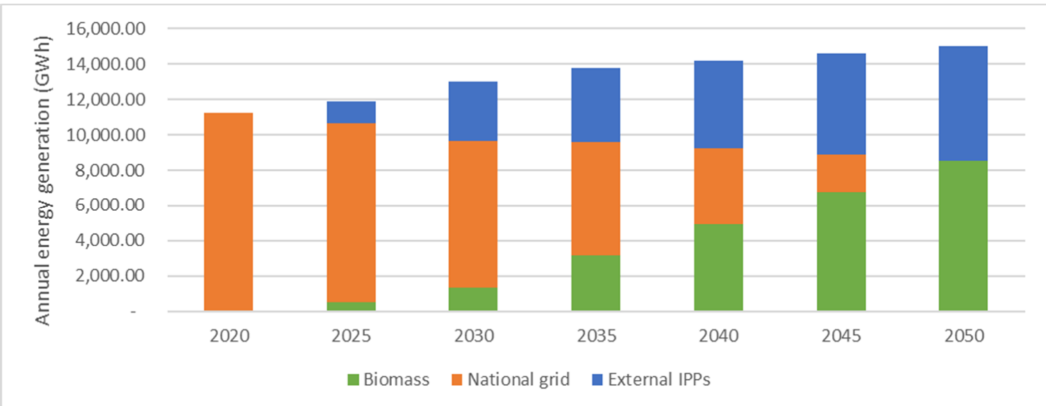

Figure 42: Generation share of technologies in Scenario E (Energy Efficient demand scenario)

6.6 Levelised cost of electricity

Using the build-out programmes outlined in section 6.5 the cumulative costs were calculated for the shortlisted supply scenarios. These are shown in Figure 43. A municipal discount rate of 3.5% has been assumed (following discussion with the City). Using this and total energy generation, the levelised cost of electricity was calculated.

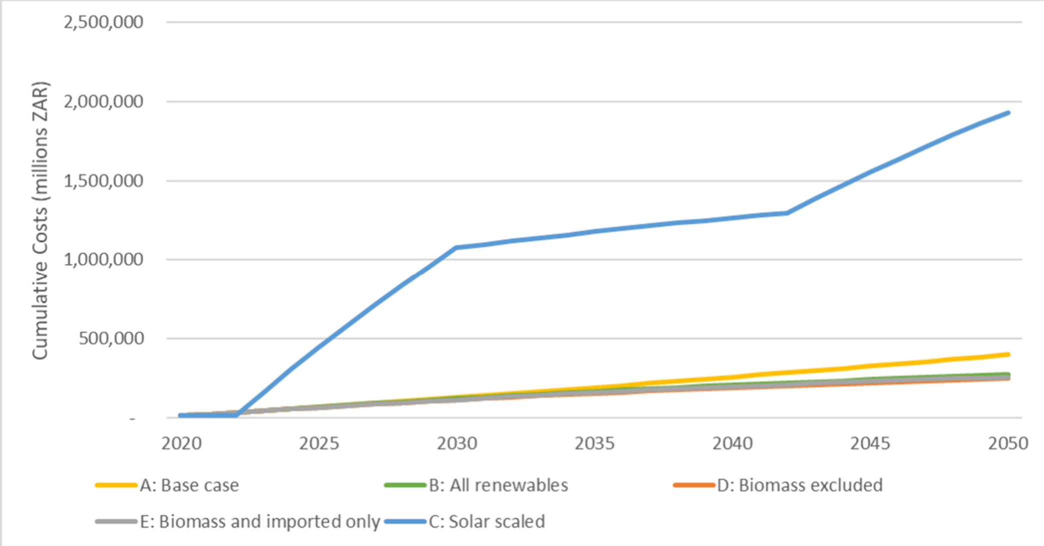

Figure 43: Cumulative costs graph for the five supply scenarios.

This graph shows high cumulative costs for Scenario C, with some step changes from 2023 to 2030 and 2043 to 2050. These are due to the high capital costs associated with the accelerated build-out of PV for 2023-2030, followed by replacement costs from 2043 onwards by which time parts of the original plant are 20 years old.

Table 17 shows the results for levelised cost of electricity for each of the supply scenarios with the Energy Efficient demand scenario. Comparing the calculated results against the Base Case shows that all scenarios except Scenario C offer cost reduction for eThekwini residents. According to the national IRP, the cost of energy bought from Eskom is also anticipated to increase over time. For all the scenarios analysed here lower costs for the development of local renewable energy technologies are balanced against the higher cost of imported energy.

Table 17 - Levelised cost of electricity over a 30-year period for the Energy Efficient demand scenario and the five supply scenarios for comparison.

Supply Scenario		LCOE (ZAR / MWh)
A	Base case	959
B	All renewable technologies	650
C	All renewable technologies, solar scaled	4,648
D	All renewable technologies, biomass excluded	598
E	Biomass and imported energy	618

These results show that Scenario D would offer the lowest cost of electricity over the 30-year period. In this analysis the price for IPP tariffs has been assumed to remain constant. In practice, this energy generation is currently dominated by wind and solar PV, the capital and operational costs for which have seen steady decreases over recent years. The assumption therefore that IPP charges would remain constant at today's value despite inflation is a conservative one, since they could potential be subject to further decrease. The lack of biomass in this scenario leads to a very high dependence on import of energy from these IPPs outside the municipality, which is cheap by comparison with other sources of energy. Local energy generation is dominated by PV for this scenario, which has low operational costs. The combination of these two factors means that net costs are low and remain low despite inflation, particularly in later years once construction of new generation technology is mostly completed.

The next best scenario for LCOE is Scenario E. In this scenario, low IPP costs are balanced against higher operation and fuel costs for biomass. Scenario E has a lower dependence on the lower costing IPPs outside the municipality than Scenario D, leading to a higher overall LCOE than for Scenario D but lower still than B. This is because in Scenario B some of the external IPP generation is replaced by more costly generation from other renewable technologies. It should be noted that this scenario's financial results are heavily dependent on the way IPP tariffs outside of eThekwini evolve in the future.

As briefly mentioned above, the higher LCOE for Scenario B derives from the low dependence this scenario has on IPP procurement from outside eThekwini municipality. This scenario focuses on developing more costly local renewable energy generation, which means a lesser requirement for importing lower cost renewable energy than the other two shortlisted scenarios.

Scenario C has a much higher LCOE than all other scenarios, including the base case. This is due to the high capital cost associated with installing solar PV, which significantly dominates energy generation in this scenario, dwarfing the capital costs associated with other technologies.

6.7 Carbon

The carbon emissions created for each of the five scenarios was calculated using carbon emissions factors for each of the technologies and by using data on Eskom's projected emissions (National IRP) to calculate how the national grid carbon emissions factor is expected to change over time.

Figure 44 shows how annual carbon emissions change for the scenarios as each increases the share of renewable energy. Biomass has the highest carbon emissions factor of the renewable technologies considered in this analysis, so it follows logically that Scenario E demonstrates the highest carbon emissions excluding the base case throughout.

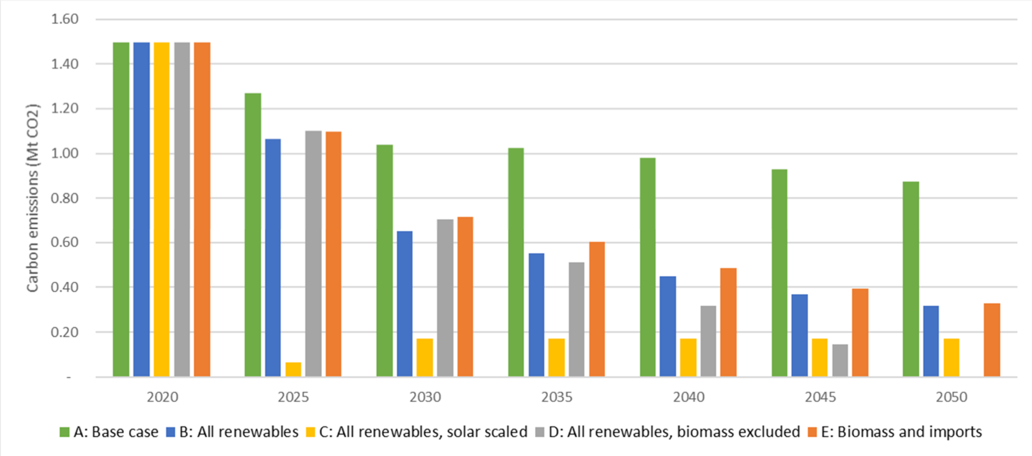

Figure 44: Annual carbon emissions for the Energy Efficient demand scenario and the five supply scenarios.

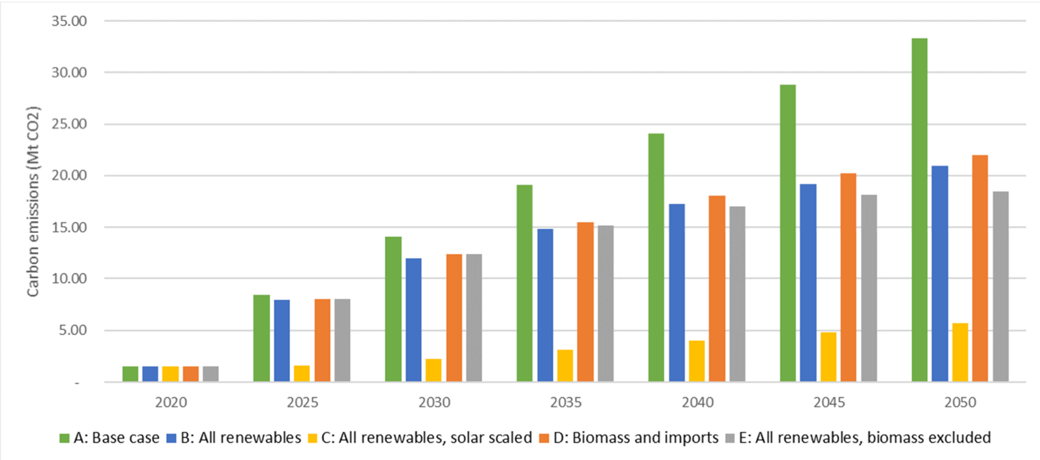

Figure 45: Cumulative carbon emissions for the Energy Efficient demand scenario and the five supply scenarios.

For the same reason, the scenario with the lowest carbon emissions by 2050 is Scenario D, which excludes biomass. By 2050 in this scenario eThekwini depends entirely on low and zero carbon technologies. There are still some emissions arising from the use of landfill gas and wastewater energy, however these technologies contribute little to the overall energy mix and therefore have almost negligible carbon emissions which are too small to be seen on the graph.

The small discrepancy between carbon emission for Scenarios B and E in 2050 is due to the fact that solar PV can be used to meet the demand in Scenario B. This means that although the biomass plant has the same capacity in both scenarios it is used to meet more of the demand in Scenario E.

The scenario offering the lowest cumulative carbon emissions is Scenario C, since this does not use any imported energy. This scenario does still include biomass however, which means that in 2050 it has higher carbon emissions than Scenario D. The carbon emissions results for this scenario cannot be compared directly against those for the other scenarios, since this scenario lacks sufficient generation to meet demand and so is not a feasible energy supply solution.

6.8 Job Creation

The number of new jobs created through the construction and operation of renewable energy technologies has been calculated for each of the three shortlisted supply scenarios – B, D and E. Figure 46 shows how these scenarios compare against each other and vary over a 30-year period. No new jobs are shown against 2020, since it is assumed the construction of technologies could not begin until around 2023. It is assumed that in the base case, the number of new jobs created is zero.

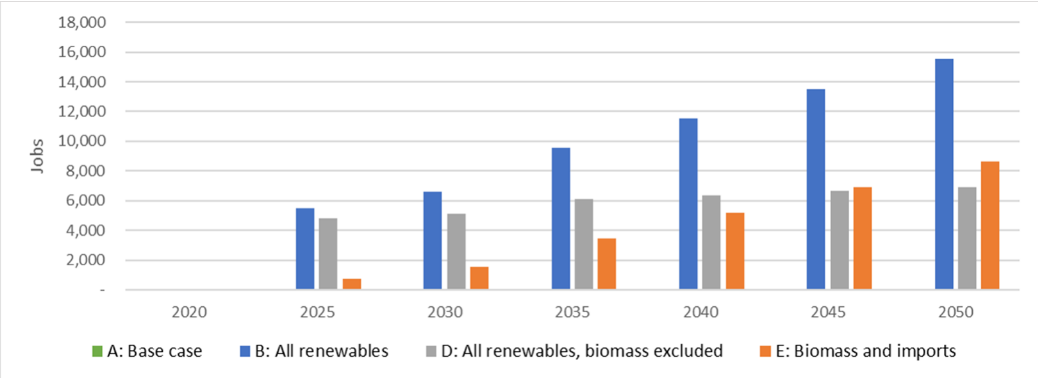

Figure 46: Cumulative job creation in eThekwini municipality from the construction and operation of renewable energy technologies.

The breakdown of these jobs between construction and operation of the technologies is also shown in Figure 47 and Figure 48.

Jobs in the construction of new technologies only exist during the phases in which new capacity is being built, which means that once construction is completed these jobs are no longer available. For all the scenarios there is a consistent growth of new technology capacity building up until 2050, however after this construction would be completed and the jobs arising from construction would fall to zero.

In contrast, jobs in the operation of renewable technologies depend on the capacity of existing generation technologies. As can be seen in Figure 48, the existence of jobs in this area grows steadily as the technology capacities grow for each scenario. The jobs figures seen in 2050 for this figure represent permanent jobs which will continue to exist after this date.

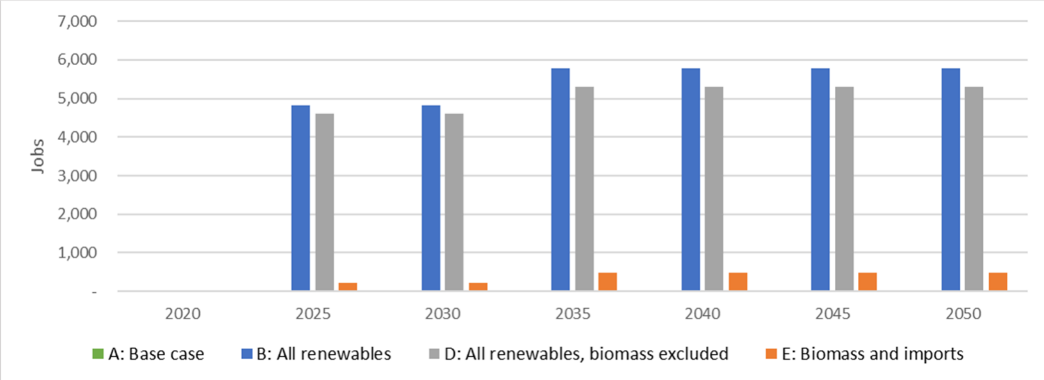

Figure 47: Cumulative job creation in eThekwini arising from the construction of renewable energy technologies.

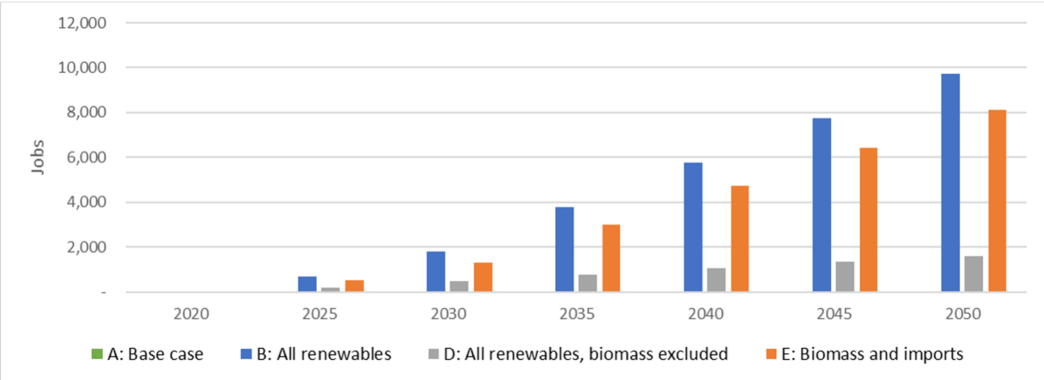

Figure 48: Cumulative job creation in eThekwini arising from the operation of renewable energy technologies.

It is clear from these results that the scenario which would most benefit eThekwini citizens is Scenario B: All renewables, in which the municipality maximises the potential for local renewable technologies through both public and private development. This scenario would result in around 6,500 jobs in renewable energy in 2030 rising to 15,500 jobs in 2050, of which 8,000 would be permanent. In 2030 the majority of these jobs (around 5,000) are in the construction of PV, although by 2050 a similar number are in the operation of biomass plants.

The scenario with the next highest job creation is Scenario E: Biomass and imports, indicating a larger number of jobs from 2045 onwards than Scenario D. This is due to the comparatively large number of people employed in the operation of biomass plants. There are however fewer jobs available in the construction of biomass technology, which means this scenario offers low job creation in earlier years. This gives the result of only 1,500 jobs in 2030, growing to 8,600 by 2050. Due to the fact that most of the 2050 jobs are in the operation of biomass, the majority of these (8,100) are permanent jobs.

Scenario D: All renewables, biomass excluded, provides the lowest jobs in the municipality with the exception of Scenario A. Without biomass, job creation in this scenario is dominated by PV construction throughout, with jobs rising only to 5,000 by 2030 and 7,000 by 2050. With low job requirement for the operation of PV technology, only 1,600 of the jobs in 2050 are permanent.

The results for Scenario A: Base case are shown in this graph, however since this scenario does not involve the construction or operation of any local renewable technology, the job creation for this scenario is zero throughout.

Analysis for Scenario C has not been included in the figures above because this scenario results in such a large job creation deriving from jobs in the construction of PV that it is no longer possible to compare the scenarios against each other. Job creation analysis for this scenario suggested 620,000 and 170,000 jobs for 2030 and 2050 respectively, however these figures and other results for this scenario cannot be compared against the other scenarios due to the fact that supply in Scenario C does not meet demand and the indicative PV capacity exceeds its physical limit.

6.9 Results summary

A summary of key results figures is provided in Table 18. See section 6.11 for observations on the results, and Section 7 for our recommendations based on these findings.

Table 18: Results summary for all scenarios

Year	Supply scenario		LCOE, ZAR/kWh	Number of jobs	% renewable	Carbon emissions, MtCO2
2050	A	Base case	959	0	56%	33.3
	B	All renewable technologies	611	15,524	100%	20.9
	C	Renewable energy, no imported energy, solar scaled to meet demand	4,620*	169,387*	100%*	5.72*
	D	All renewable technologies, biomass excluded	559	6,919	100%	18.4
	E	Biomass and imported energy	578	8,605	100%	22.0

*includes demand that is not met by the generation capacity available – hence scenario discounted

6.10 Sensitivity analyses

Sensitivity analysis has been performed for the Energy Efficient demand scenario on all supply scenarios investigated. Results are presented only for Scenario B to avoid repetition.

Four variables have been tested to determine their impact on the overall LCOE. These are:

- Operational cost
- Capital costs for energy generation technologies
- Capital costs for storage technologies
- Eskom tariff charges

Each of the variables was adjusted by -20%, -10%, -5%, +5%, +10% and +20% and the overall LCOE recalculated for each case.

Figure 49 to Figure 52 show the results for the four sensitivities including the LCOE for the base scheme without any adjustments. Graphs shown here correspond to Scenario B.

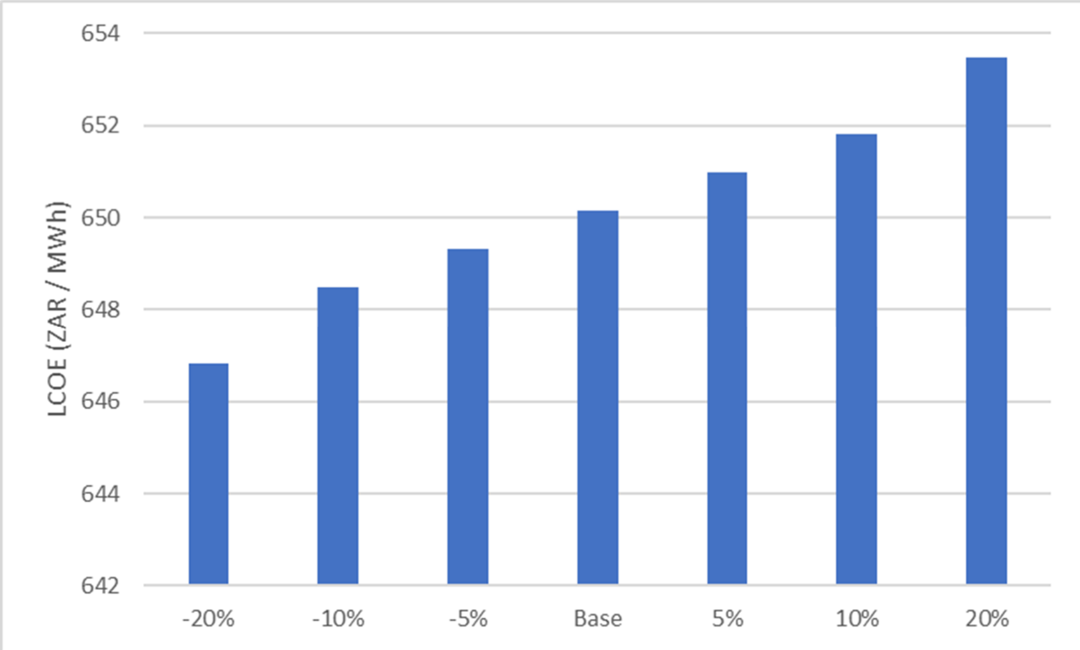

Figure 49: Sensitivity analysis on operational cost for supply Scenario B: All renewables and Energy Efficient demand scenario.

Figure 49 shows that varying operational costs has a marginal impact on overall LCOE. This is due to the fact that for all scenarios, capital costs have a greater impact on overall financial results and operational costs are low by comparison.

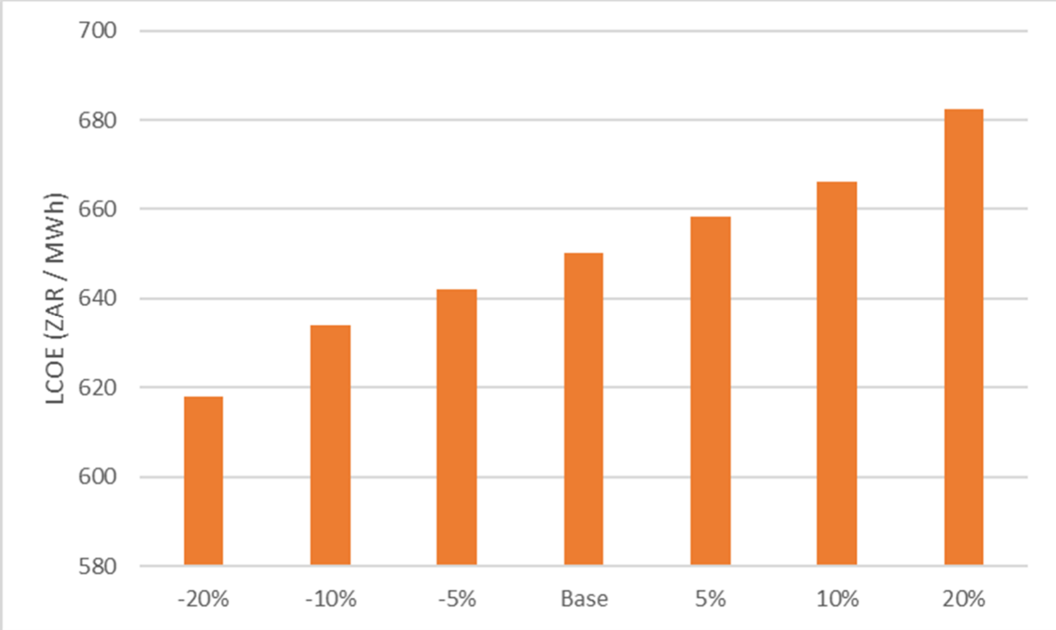

Figure 50: Sensitivity analysis on **generation capital costs** for supply Scenario B: All renewables and Energy Efficient demand scenario.

In Figure 50 the sensitivity analysis for capital costs association with generation technologies is shown. Varying this metric has a significant impact on overall financial performance, with LCOE rising or falling by over 30 ZAR / MWh for the +/-20% sensitivities.

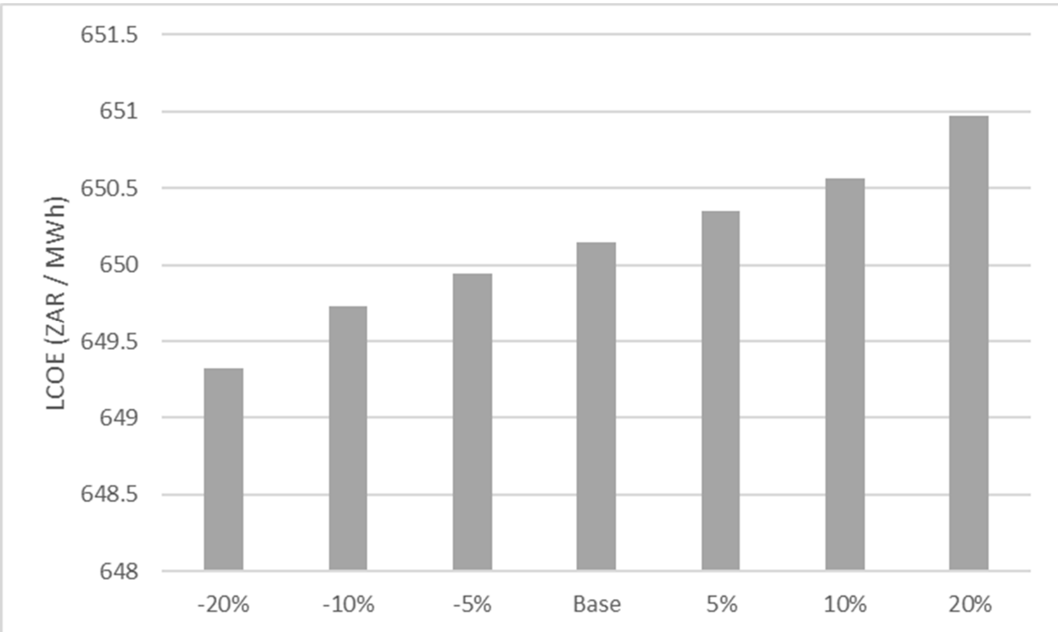

Figure 51: Sensitivity analysis on **storage capital costs** for supply Scenario B: All renewables and Energy Efficient demand scenario.

The variable with the smallest impact on overall LCOE is capital costs for storage technologies. As a proportion of overall costs the capital cost of storage technologies is very small since storage technology makes up a small part of the municipal energy scenarios when compared with the generation technologies and importation of energy.

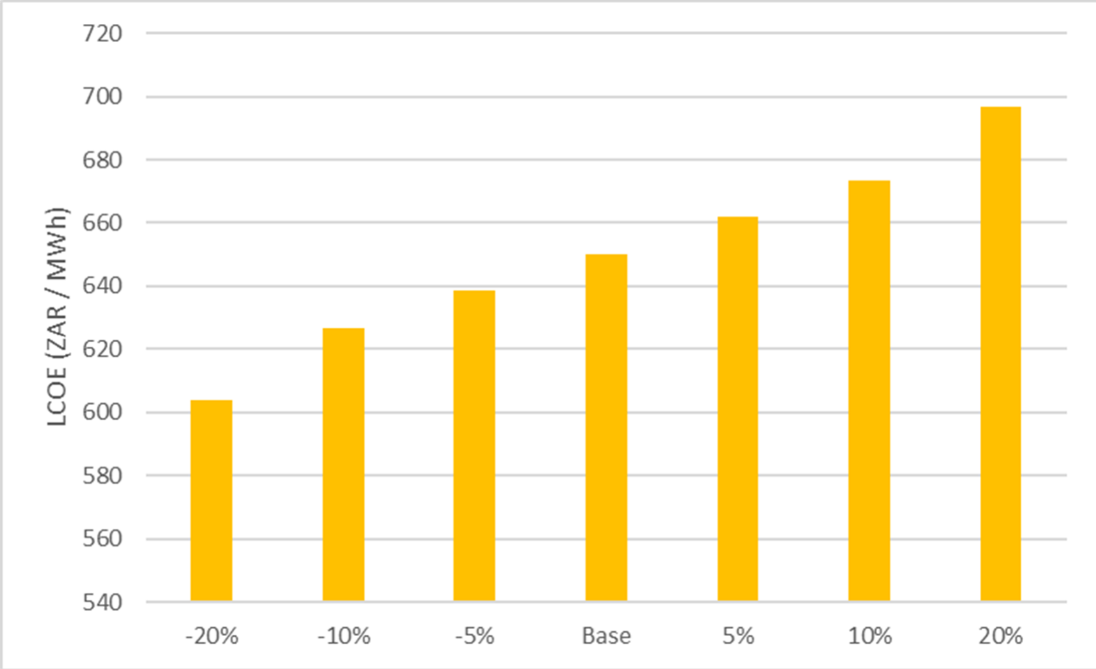

Figure 52: Sensitivity analysis on Eskom tariff prices for supply Scenario B: All renewables and Energy Efficient demand scenario.

These graphs demonstrate that variation in the Eskom tariff would have the largest impact on the overall scheme. Increasing or decreasing this tariff by 20% results in a change of approximately 8% to LCOE. In the earlier phases of building new renewable technologies there is still considerable dependence on Eskom and the importation of electricity from South Africa's national grid, which explains the large impact this variable has on the overall result.

6.11 Observation from Modelling Results

The modelling results for the three shortlisted scenarios reveal that each of the scenarios has some strengths and weaknesses. The results for LCOE, energy mix, carbon emissions and job creation have been used to create Table 19, which ranks the scenarios for each of 4 key metrics. The scenario with the most favourable outcome (e.g. highest jobs, lowest carbon emissions or highest municipal autonomy) is shown with a 1. Conversely the scenario with the least favourable outcome is shown with a 5.

It is clear from these results that the ideal scenario is not clear-cut. However, the municipality has a mandate to provide low cost energy to residents and businesses as a priority, and as such, it is recommended that Scenario D be pursued. It should be noted that while Scenario C performs well for the other metrics this scenario should be discounted from consideration on the grounds of not achieving the municipality's targets.

Table 19 - Key metric comparison for the five supply scenarios.

Metric	A: Base case	B: All renewables	C: Solar scaled	D: All renewables, no biomass	E: Biomass and imports
LCOE	4	3	5	1	2
Cumulative carbon (2050)	5	3	1	2	4
Jobs (2050)	5	2	1	4	3
Municipal autonomy	5	2	1	3	4

7 Implementation

This chapter outlines some challenges and next steps eThekwini municipality faces in implementing the recommended scenario of the least-cost energy mix. Key policy settings and consideration to the energy modelling are outlined.

7.1 Overview of Next Steps

Section 195 (1) (e) of the Constitution of the Republic of South Africa requires public engagement in the policy decision. The input framework of the IRP considered the comments received from stakeholders during engagement period. The Energy Working Group (EWG) will review the final recommendation of the EIRP and release ESR and EIRP for public comments. The commenting period is no earlier than 30 days after publication. After publication for comments, the EWG will then consolidate the comments received during the 30 days period and respond accordingly. After responding to comments and make some policy adjustments, the EWG will submit the final ESR and EIRP to the eThekwini Council for final approval. Upon finalizing the internal approvals, eThekwini Energy Office will draft letter to the Department of Mineral Resources and Energy (DMRE) via Mayor's Office. The framework of the next steps are outlined in the following section.

7.1.1 Ministerial Determination

According to Section 34 (1)(a) of the Electricity Regulation Act (No 4 of 2006) and Electricity Regulations on New Generation Capacity (published as GNR.399 in Government Gazette No 34262 dates 4 May 2011, as amended on 19 May 2015. This allows Minister of Energy in consultation with National Energy Regulator of South Africa (NERSA), to make Ministerial Determination for new generation capacity to secure the continued uninterrupted supply of electricity. eThekwini municipality should apply for specific Ministerial Determination in order to fulfil the broader strategic goals of achieving 40% of renewable energy by 2030 and 100% by 2050.

7.1.2 Establishment of MIPPPP

The Municipal Independent Power Producer Procurement Programme (MIPPPP) is similar to Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) in terms of responsibilities as assigned by Electricity Regulations on New Generation Capacity (published as GNR.399 in Government Gazette No 34262 dates 4 May 2011, as amended on 19 May 2015. In the MIPPPP, the procurer in respect of the procurement programmes will be the eThekwini Energy Office.

The role of the procurer will be to conceptualize and conduct the procurement programmes, including preparing any request for proposals, request for information, and all related associated documentation, negotiating the power purchase agreements (PPA), facilitating the conclusion of the other project agreements, and optimizing the conditions to help reach financial close.

The off-taker (buyer) of the procured energy services will be eThekwini Electricity Unit, with a valid distribution licence.

The MIPPPP is the subset of the annual build limit which advocate for a series of bidding windows according to the recommended scenario in the least-cost energy mix.

The aim of the MIPPPP:

- To secure a diversified energy supply from independent power producers (IPPs)
- To promote the least-cost scenario across all service providers
- To simplify procurement of energy services based on annual build limit and eThekwini supply chain management policies.
- To support local content and organizations that contributes to job creation, social upliftment and broadening economic ownership.

7.2 Implementation Strategy

eThekwini municipality plans to meet its future energy and capacity needs through a mix of appropriate technologies which includes intermittent and stable baseload generation. Currently, eThekwini procures 99% of electricity provision from Eskom. To effectively meet the broader strategic goals as set in Durban Climate Change Strategy (DCCS) and Climate Action Plan (CAP), eThekwini requires new renewable generation capacity, and procurement of renewable power from private producers, taking into consideration the demand forecasts projected towards 2030.

7.3 Policy Settings

The following policy themes may be useful in assisting the municipality in realising the recommendations set out in this report:

Reduce Procurement of Coal Electricity

eThekwini municipality adopted a Climate Action Plan (CAP) in November 2019. In eThekwini's GHG inventory, the electricity sector contributes 46% of city-wide GHG emissions. Decarbonizing the grid infrastructure through appropriate interventions that reduce reliance from Eskom supply and promote local generation closer to load consumption areas.

Improve Renewable Energy Generation

Maximizing the deployment of distributed energy resources (DERs) and small scale embedded generation in the greater eThekwini metropolitan area. This will increase energy security, provides a low-cost solution, support environmental stewardship, and foster economic development.

Industrial Energy Efficiency Standards

Partnering with the private sector to reduce electricity consumption and industrial emissions is the easiest way of meeting energy efficiency targets. The energy use patterns of the South African industry by means of energy management systems (EMS) requires fast-changing energy policies. This can be achieved through energy efficiency demand-side management (EEDSM), which is currently being rolled out in eThekwini.

Private Sector Generation

In the State of National Address (SONA 2020), the President of South Africa took a decision to rapidly and significantly increase generation capacity outside of Eskom. The commercial and industrial users of electricity are now allowed to produce electricity for own use above 1MW. There is no limit to the installed capacity of 1MW.

The Growth of Revenue Generation

The paradigm shift towards renewable energy presents a good opportunity for the eThekwini municipality to generate revenue from renewables. According to the economic policy on inclusive growth from the National Treasury (2019). Grid defection has implications for Eskom and municipalities who rely on electricity sales as a revenue source. The Municipalities are encouraged to consider alternative sources of revenue. This can be achieved through the deployment of distributed energy resources (DERs) in the form of mini-grids.

Decarbonize Transport Sector

The transport sector contributes more than 30% of the city-wide GHG emissions. A shift towards electric vehicle adoption has been considered in this policy. This has been included in the consumption scenarios and will require eThekwini municipality to lead by example. Gradual deployment of electric charging infrastructure needs to be deployed across the city.

Energy Efficiency Demand Side Management

The EEDSM programme is managed by the Department of Energy (DoE). This programme supports municipalities in their efforts to reduce electricity consumption by optimizing their use of energy infrastructure. The activities include optimizing traffic and street lighting, retrofitting existing buildings, and offering water service infrastructure. This programme is conducted annually with funding from DoE. A number of buildings in the eThekwini municipality have been optimized through energy efficiency interventions.

Carbon Tax

The President has signed the Carbon Tax Act into law on the 1st of June 2019. This is done to reduce GHG emissions and promote cleaner means of producing electricity. Emitters are required to license their activities liable for the carbon tax and necessary environmental levy which is due in July for each year. The introduction of carbon tax is likely to increase corporate investment in renewable energy.

Heating and Cooling Systems.

A greater aspect of Energy Efficiency Demand Side Management has been covered in this policy. The demand response strategy has been modelled as a catalyst that curtails peak demand in the morning and afternoon. Further policy settings are required to implement demand response on municipal infrastructure.

8 Conclusions and recommendations

8.1 Summary

This report summarises the findings of a study that makes up the technical aspects of the eThekwini Integrated Resource Plan, the strategy for energy supply in eThekwini over the next 30 years.

Currently (with the exception of some small, private generation assets), the municipality imports all power from Eskom, the primary South African National electricity utility and generation company. At the moment, coal fired power generation makes up the vast majority of Eskom's generation capacity and as such, the electricity supply in eThekwini has low penetration of renewable power. Despite Eskom having its own targets for higher renewable generation capacity, targets are not ambitious enough to enable the eThekwini Municipality to realise their own internal targets: 40% renewable generation by 2030 and 100% by 2050.

Furthermore, costs of purchasing power from Eskom have been rising and are predicted to continue doing so; increased costs of power are being passed on to residents and businesses within the municipality. Until recently, legislation did not permit eThekwini Municipality to purchase power privately from Independent Power Producers (IPPs). Now that this is possible, the Municipality has the opportunity to transition its energy supply to one that is both renewable and lower cost. This will help ensure renewable generation targets are met whilst additionally reducing the costs of electricity for the municipality and, in turn, residents and businesses within its jurisdiction.

In addition to transitioning to a more renewable supply of imported electricity, the municipality also has an ambition to reduce the costs of energy for residents and businesses through the generation of renewable power within the municipal jurisdiction.

The report builds on findings of the Energy Strategic Roadmap (ESR), a study commissioned under C40 Cities Clean Energy Technical Assistance Programme to support the Municipality in achieving their climate action targets for 2030 and 2050. The roadmap study established a baseline for the municipality, investigated the future energy requirements and identified the best renewable technologies for implementation in eThekwini.

Overall, the most viable technologies for use within the municipality were found to be solar photovoltaic (PV) panels, biomass (including local forestry and bagasse resources), small scale hydro power, gas extraction from landfill and wastewater treatment sites and onsite wind energy. Energy extraction from landfill and wastewater treatment sites were found to be limited due to the low yields expected from these systems. Wind energy generation was found to be limited within the City boundary largely due to environmental sensitivities and scattered dwellings reducing land availability for turbine installations.

Building on the work done in the roadmap, this report presents the findings of more detailed analysis of electricity supply and demand in the municipality up to 2050:

- data collection, cleaning and analysis on the current use and demand for electricity in eThekwini on an hourly basis;
- predictions on the future use of power, including investigation into the effects of electric vehicles on electricity consumption;
- identification of 5 distinct 'demand scenarios' that capture a range of possible future power consumption scenarios;
- development of area-specific power generation profiles for wind and solar based on local weather data;
- production of 5 distinct 'supply scenarios' based on renewable technologies as identified in the ESR (Table 20);
- calculation of the likely costs to build and operate each supply scenario; and
- linear optimisation of supply, storage and demand shifting of power use in the municipality to understand how targets could be met under all demand and supply scenarios.

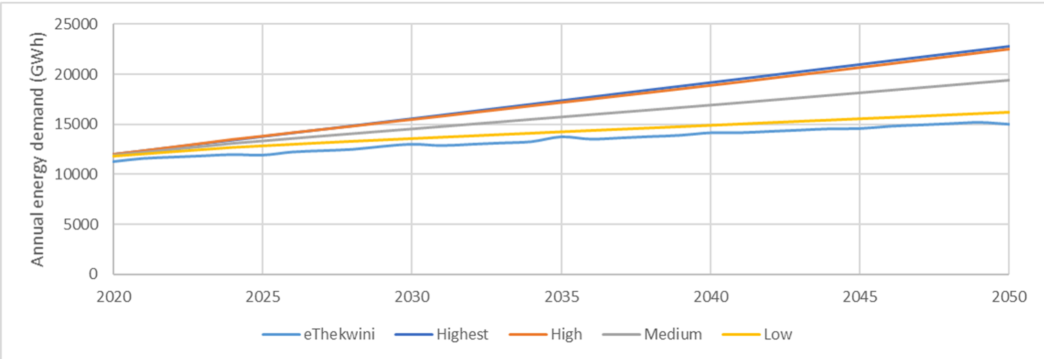

Figure 53: Annual consumption forecasting results

Table 20: Supply scenarios and included technologies

		Generated within Durban						
Scenarios		Solar	Wind	Landfill	Wastewater	Biomass	Hydropower	Imported
A	Base case	×	×	×	×	×	×	✓
B	All RE technologies included	✓	✓	✓	✓	✓	✓	✓
C	Solar scaled to meet 100% RE target	✓	✓	✓	✓	✓	✓	×
D	Biomass excluded	✓	✓	✓	✓	×	✓	✓
E	Biomass and imported renewables	×	×	×	×	✓	×	✓

8.2 Key Findings

The analysis undertaken has enabled a series of results to be presented for the different scenarios. Initially, scenarios were tested as to their ability to meet the renewable energy targets (40% in 2030, 100% in 2050). It was found that:

- Maintaining the current status quo, i.e. importing all power from Eskom, would meet the eThekwini 2030 target, but not that of 2050.
- Moving to a supply scenario where no power is imported at all, is not feasible as it results in a system that is not capable of meeting the full demand.

As such, Scenario A (the base case) and Scenario C (with solar scaled to meet demand) were discounted as viable solutions for the municipality to pursue.

The technology optimisation investigated how each technology interacts with the wider electricity system, providing energy output and usage data for technologies across each of the scenarios. This shows how technologies contribute to the overall demand and gives an indication of how they would be built out over the next 30 years.

Results were presented for the lowest future consumption projection, the Energy Efficient projection (see Section 4.2.6). This is because – as the lowest projection of electricity consumption – this is the scenario that the municipality should pursue achieving. In order to do so, implementing energy efficiency will be paramount.

In all results, contribution from wind is minimal. This is due to the relatively poor conditions for on-shore wind which do not enable high generation potential. Solar generation plays an important role in meeting renewables targets but needs integration with storage technologies like batteries, in order to maximise the output potential. By far the greatest contribution to generation within the municipality would be the implementation of biomass power stations. Without biomass, eThekwini would still rely on imported power for the majority of energy consumption.

Technology implementation requirements were presented for the three remaining viable scenarios, showing how the contribution from generated or imported renewable power grows with time. Where all possible renewable technologies are implemented within the municipality (Scenario B), eThekwini reduces its reliance on imported power to only 25% by 2050. In Scenario C, where biomass is excluded, the municipality must import 80% of power from IPPs.

The levelized cost of electricity (LCOE) production was calculated for the three viable supply scenarios, under the Energy Efficient consumption scenario. It was found that the cheapest scenario, D, is the one that excludes biomass, due to its high capital and operating costs. Scenario B, which includes all possible technologies, has an LCOE of 598 ZAR/MWh, 11% higher than Scenario D. Scenario E lies between the two. In terms of absolute carbon emissions (for which the municipality does not have any specific targets), the scenario where biomass is excluded (Scenario D) achieves the lowest carbon emissions by 2050. However, this is also the scenario which creates the least jobs in eThekwini.

8.3 Recommendations

Based on the findings detailed above, a number of recommendations can be made to the Municipality for implementation up to 2050.

Firstly, it is recommended that the Municipality strives to achieve the lowest possible increase to future electricity consumption. By minimising the increase to consumption in the Municipality over the coming 30 years, this will maximise the chances of being able to reach the renewable energy targets.

Of the supply scenarios investigated, it was found that the current status quo, i.e. importing power from Eskom, will not enable the city to meet its renewable energy targets. Furthermore, the cost of electricity under this scenario is particularly high and the city would run the risk of losing significant proportions of revenue to private power producers within the municipality as it would not be able to offer price competitive power to businesses and residents.

Since the city cannot be self-sufficient (Scenario C, i.e. meeting all demand from generation capacity within the city's jurisdiction), it shall need to make the transition away from the Eskom imported power towards procuring renewable power from Independent Power Producers as well as generating what is possible within the municipality.

Based on the analysis summarised in this report, the recommended, lowest cost supply option for the City is Scenario D. This scenario includes all the renewable technologies identified for use within the municipality, with the exception of biomass generation as it is the most costly generation technology.

The resulting energy generation share of the recommended scenario implies around 79% of power to be imported into the municipality, with the rest generated within it; around 20% by solar PV and the remaining by wind, wastewater, landfill gas and hydropower.

The Energy Office will have a significant role to play in procuring this 79% power from renewable IPPs and assumes that the market in South Africa will rise to meet this demand. There may be competition from other consumers within South Africa for new renewable generation Power Purchase Agreements; the Energy Office shall need to engage as best and early as possible with the market to understand where new projects are being proposed and when they are likely to come online.

Furthermore, the Energy Office will have a role to play in enabling the renewable energy projects within eThekwini as set out in Section 8.4. This may require changes to policy, investment and stakeholder engagement to ensure that projects come to fruition successfully.

8.4 Supply Power Mix

In order for eThekwini to achieve its renewable energy targets for the lowest possible cost, there shall need to be some significant power generation and storage projects undertaken within the municipality as well as procurement of renewable power from IPPs.

The recommended programme of implementation of technologies up to 2050 is set out in Table 21. Results are shown for the Energy Efficient consumption projection. Should the increase in power consumption be greater, the city would need to either import more renewable power or install greater generation capacity.

It is recommended that the city continues to monitor energy use, renewable mix and technology maturity/costs against those set out in this report such that the implementation plan can be updated accordingly. As it can be seen, there already exists a small amount of landfill gas and wastewater power generation capacity. The municipality shall need to start implementing battery storage in 2035 as penetration of solar power increases.

Table 21: The energy supply mix programme for the recommended scenario.

Year	Energy supply mix capacity building schedule, MW						Imported power, MW	
	Bio-mass	PV	Wind	Land fill gas	Waste-water	Hydro-power	IPPs	Eskom
2020	0	0	0	4.0	0	0	0	10,701
2025	0	176	57	4.0	3.5	4.0	373	6,260
2030	0	470	153	7.5	3.7	10.6	745	1,830
2035	4.0	854	153	7.5	3.8	10.6	1,140	1,370
2040	0	1,239	153	7.5	3.9	10.6	1,530	915
2045	0	1,623	153	7.5	4.0	10.6	1,920	458
2050	0	2,007	153	7.5	4.1	10.6	2,320	0
% Total Capacity, 2050	**0%**	**45%**	**3%**	**<1%**	**<1%**	**<1%**	**52%**	**0%**
% Annual Energy, 2050	**0%**	**20%**	**<1%**	**<1%**	**<1%**	**<1%**	**79%**	**0%**

Appendix

Table 22 - IRENA employment factors.

From Table 2.2 of IRENA Renewable Energy and Jobs (2013). Sources: 1) Rutovitz and Harris (2012); 2) Rutovitz (2010); 3) Maia et al. (2011); 4) National Renewable Energy Laboratory NREL (2010); 5) Tourkolias and Mirasgedis (2011); 6) NREL.

IRENA Renewable Energy and Jobs (2013)

Table 2.2 - Employment factor estimates for different RETs

	MCI (Jobs per newly installed MW)	O&M (Jobs per MW)	Region	Year of estimation	Source
Wind, onshore	8.6	0.2	OECD countries (Average values)	Various (2006-2011)	Source 1
	27	0.72	South Africa	2007	Source 2
	6	0.5	South Africa	NA	Source 3
	12.1	0.1	United States	2010	Source 4
	8.8	0.4	Greece	2011	Source 5
Wind, offshore	18.1	0.2	OECD countries (Average values)	2010	Source 1
Solar PV	17.9	0.3	OECD countries (Average values)	Various (2007-2011)	Source 1
	69.1	0.73	South Africa	2007	Source 2
	25.8	0.7	South Africa	NA	Source 3
	20	0.2	United States	2011	Source 4
CSP	18	1.33	South Africa	2007	Source 2
	36	0.54	South Africa	NA	Source 3
	7	0.6	Spain	2010	Source 6
	19	0.9	Spain	2010	Source 7
Hydro, large	7.5	0.3	OECD countries (Average values)	Various	Source 1
Hydro, small	20.5	2.4	OECD countries (Average values)	Various	Source 1
	20.3	0.04	South Africa	2009	Source 2
Geothermal	10.7	0.4	OECD countries (Average values)	Various (2009-2012)	Source 1
	5.9	1.33	South Africa	2004	Source 2
Biomass	7.7	5.51	South Africa	2000	Source 2

Table 23 - Eskom variable and fixed tariff rates for 2030 and 2050.

Fixed charge 2018/19 (excluding VAT)			
Total fixed charge	1,455,863,715	ZAR	Eskom eThekwini 2018/19 bill documents
Weighted variable tariffs 2018/19 (excluding VAT)			
Low Standard charge (R /kWh)	0.61	ZAR / kWh	Eskom eThekwini 2018/19 bill documents
Low Peak charge (R /kWh)	0.89	ZAR / kWh	Eskom eThekwini 2018/19 bill documents
Low off charge (R /kWh)	0.39	ZAR / kWh	Eskom eThekwini 2018/19 bill documents
High Standard charge (R /kWh)	0.82	ZAR / kWh	Eskom eThekwini 2018/19 bill documents
High Peak charge (R /kWh)	2.73	ZAR / kWh	Eskom eThekwini 2018/19 bill documents
High off charge (R /kWh)	0.45	ZAR / kWh	Eskom eThekwini 2018/19 bill documents
Forecast Fixed Charge (excluding VAT)			
Fixed charge (2030)	1,563,240,809	ZAR	
Fixed charge (2050)	1,600,897,478	ZAR	
Forecast Variable Tariffs (excluding VAT)			**Tariff Code**
Estimated Low Standard charge (2030)	0.66	ZAR / kWh	Std-Low
Estimated Low Peak charge (2030)	0.95	ZAR / kWh	Peak-Low
Estimated Low Off charge (2030)	0.42	ZAR / kWh	Off-Low
Estimated High Standard charge (2030)	0.88	ZAR / kWh	Std-High
Estimated High Peak charge (2030)	2.93	ZAR / kWh	Peak-High
Estimated High Off charge (2030)	0.48	ZAR / kWh	Off-High
Estimated Low Standard charge (2050)	0.67	ZAR / kWh	Std-Low
Estimated Low Peak charge (2050)	0.98	ZAR / kWh	Peak-Low
Estimated Low Off charge (2050)	0.43	ZAR / kWh	Off-Low
Estimated High Standard charge (2050)	0.90	ZAR / kWh	Std-High
Estimated High Peak charge (2050)	3.00	ZAR / kWh	Peak-High
Estimated High Off charge (2050)	0.49	ZAR / kWh	Off-High
VAT	15%	%	

Table 24 - Model input parameters with calculations.

Durban C40 TA - model parameters

Exchange rates	
15.14	ZAR/USD
19.52	ZAR/GBP
16.98	ZAR/EUR

Conversion factors	
1,000	MW / kW
3,600	MJ / MWh
1,000	kg / tonne

Parameter	Value	Unit	Source
Capacity			
IPP generation potential	Variable	MWh	Arup industry knowledge
Biomass plant energy cap	1,475	MW	Based on CSIR Bio-energy deep dive presentation and Marbek consultants 2007 report
PV resource size limit	2,007	MW	Arup calculation for strategic roadmap analysis - rooftop and ground-mounted PV based on 1400 kWh/kWp/Year
Wind resource size limit	153	MW	Arup calculation for strategic roadmap analysis based on land availability. Assuming 25% capacity factor based on median capacity factor for a 3MW turbine, 100m hub height from inhouse tool.
Landfill energy cap	1.5, 1.7, 1.9	MW	Arup calculation based on: What a Waste 2.0: A global Snapshot of Solid Waste Managment to 2050Figure 3.32 Waste Generation Rates: Sub-Saharan Africa Region, data from Loganathan Moodley May 2019
Wastewater energy cap	3.3, 3.7, 4.1	MW	Arup calculation based on: National Waste Information Baseline Report 2012 and information from Loganathan Moodley - Deputy Head of Cleansing and Solid Waste, Durban
Hydro cap	10.56	MW	Arup calculation based no Sustainable Energy Africa report and Entura report 2016 - Process Manual for Mini-Hydro Development on existing water supply networks
Battery cap (Storage or energy)	500	MWh	Figure iteratively optimised and determined using Arup industry knowledge
DSR maximum size	~5% of demand		Arup industry knowledge
Fuel / supply costs			
Grid connection cost	Variable tariff	ZAR / kWh	SA IRP and Eskom energy bills/tariffs calculation
IPP cost	0.65	ZAR / kWh	Data provided by Vasu Chetty based on REIPPP bidding window 4.5 results: 0.65 ZAR / kWh, added 10% charge for use of grid infrastructure
IPP infrastructure costs	10%	% of charge	Arup industry knowledge
IPP cost (including infrastructure charge)	0.72	ZAR / kWh	
Demand side response cost	5%	% of IPP tariff	Arup industry knowledge
Demand side response cost	35.75	ZAR / MWh	
Biomass fuel cost	30	USD / tonne	IRENA Renewable Energy Technologies: Cost Analysis Series - Biomass for Power Generation (2012)
Biomass fuel cost	454	ZAR / tonne	Conversion to ZAR/tonne
Biomass fuel cost	142	ZAR / MWh	Conversion to ZAR / MWh
CAPEX			
Biomass plant capex	51,000,000	ZAR / MW	Arup industry knowledge
PV rooftop capex	18,000,000	ZAR / MW	Arup industry knowledge
PV ground capex	21,000,000	ZAR / MW	Arup industry knowledge
PV effective capex	19,680,000	ZAR / MW	Calculation based on strategic roadmap findings of 44:56% rooftop:ground ratio
Wind capex	21,500,000	ZAR / MW	Arup industry knowledge
Landfill capex	11,000,000	ZAR / MW	eThekwini DSW, DNA CDM workshop: Durban's gas to electricity project 2011
Wastewater capex	9,500,000	ZAR / MW	Arup industry knowledge
Hydro capex	37,000,000	ZAR / MW	Entura report rounded up - also in line with Arup benchmark for SA of around $2,500/KW
Battery capex	350	£/kWh	Manufacturer's quotes (SMA and Samsung)
Battery capex	6,832,000	ZAR / MWh	Conversion to ZAR / MWh

Table 21 continued

OPEX	6,929,600		
Biomass plant opex (fixed)	3.5%	% of capex	Arup industry knowledge
Biomass plant opex (variable)	0.005	USD / kWh	Arup industry knowledge
Biomass plant opex (variable)	97.60	ZAR / MWh	Conversion to ZAR / MWh
PV opex	9,000.00	£ / MW	Arup industry knowledge
PV opex	152,820.00	ZAR / MW	Conversion to ZAR / MW
Wind opex	15.00	£ / MWh	Arup industry knowledge
Wind opex	254.70	ZAR / MWh	Conversion to ZAR / MWh
Landfill opex	1,000,000	ZAR / MW / year	Loganathan Moodley - Deputy Head of Cleansing and Solid Waste, Durban
Wastewater opex	132,000	£ /MW	ARUP / DECC "Review of the generation costs anddeployment potential of renewableelectricity technologies in the UK 2011"
Wastewater opex	2,576,640	ZAR / MW	Conversion to ZAR / MW
Hydro opex	800,000	ZAR / MW / year	Arup SA industry knowledge - Auret Basson
Battery opex	5	£/kWh	Manufacturer's quotes (SMA and Samsung)
Battery opex	97,600	ZAR / MWh	Conversion to ZAR / MWh
Efficiency			
Biomass plant capacity factor	66%	%	IRENA Biomass Capacity Factors
Landfill capacity factor	80%	%	Arup industry knowledge
Wastewater capacity factor	80%	%	Arup industry knowledge
Hydro capacity factor	60%	%	Arup industry knowledge
Battery efficiency	88%	%	Manufacturer's quotes & Lazard's Levelised Cost of Storage
Lifetime			
Biomass plant lifetime	20	years	Arup industry knowledge
PV lifetime	20	years	Arup industry knowledge
Wind turbine lifetime	20	years	Arup industry knowledge
Landfill tech lifetime	20	years	Arup industry knowledge
Wastewater tech lifetime	20	years	Arup industry knowledge
Hydro tech lifetime	20	years	Arup industry knowledge
Battery lifetime	8	years	Arup modelling
Carbon			
Grid connection carbon	Variable	kg CO2 / MWh	SA IRP gives high level indication of this
South Africa electricity grid T&D carbon factor	13.28	kg CO2 / MWh	BEIS Greenhouse gas reporting: conversion factors 2019 - advanced users WTT overseas electricity (T&D)
South Africa electricity WTT carbon factor	119.65	kg CO2 / MWh	
Effective South Africa carbon factor	132.93	kg CO2 / MWh	
WTT Biomass (wood pellets) carbon factor	37.44	kg CO2 / MWh	BEIS Greenhouse gas reporting: conversion factors 2019 - advanced users WTT - bioenergy
WTT Biomass (wood logs) carbon factor	12.77	kg CO2 / MWh	BEIS Greenhouse gas reporting: conversion factors 2019 - advanced users WTT - bioenergy
WTT Biogas carbon factor	24.05	kg CO2 / MWh	BEIS Greenhouse gas reporting: conversion factors 2019 - advanced users WTT - bioenergy
WTT Landfill gas carbon factor	-	kg CO2 / MWh	BEIS Greenhouse gas reporting: conversion factors 2019 - advanced users WTT - bioenergy
Biomass carbon factor	38.38	kg CO2 / MWh	Calculation using averaged value for wood pellets and wood logs and adding on T&D factor
Wastewater carbon factor	37.33	kg CO2 / MWh	Calculation adding biogas and T&D factors
Landfill gas carbon factor	13.28	kg CO2 / MWh	Calculation adding landfill gas and T&D factors
Biomass calorific value	11.50	MJ / kg	IRENA Renewable Energy Technologies: Cost Analysis Series - Biomass for Power Generation. "Forest residues" value used
Biomass calorific value	3.19	MWh / tonne	Conversion to MWh / tonne
Build out rates			
Biomass	33.5	MW / year	Based on IRP
PV	67.0	MW / year	Based on IRP
Wind	107.0	MW / year	Based on IRP
Landfill	33.5	MW / year	Based on IRP
Wastewater	33.5	MW / year	Based on IRP
Hydro	33.5	MW / year	Based on IRP
Potential 2030 capacities			
Biomass	235	MW	
PV	469	MW	
Wind	749	MW	