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Actions Towards Decarbonization

— Climate Policy Assessment and Emissions Modelling with Case Study for South Africa

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Preface

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Abstract

As a historic turning point in the fight for reducing global warming, the Paris Agreement has a central aim of keeping a global temperature rise by this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. To achieve the targets, governments need to convert their (I)NDCs into tangible mitigation policies. Assessing the potentials of different policies on emission reduction will be of great help for policy makers to design effective policies which are compatible with the goals of the Paris Agreement.

In this research, a spreadsheet-based Excel tool is developed to track and predict overall and sectoral Greenhouse Gas (GHG) emissions of countries/regions. The tool is developed in a sectoral-level bottom-up methodology, which provides detailed information and increased transparency in every sector. It allows users to define different scenarios for emission projections. A case study for South Africa is conducted by applying the Excel tool. Three policy scenarios are constructed based on the policy assessment of two key sectors in South Africa, i.e., electricity generation and transport sectors. Emission projections under each scenario are also obtained and discussed.

This work will contribute towards an improved understanding of decarbonisation trends and an improved transparency of policy assessments regarding to emission reduction.

Key words: climate change, GHG emissions, policy scenarios, South Africa

Contents

Abbreviations

2W	2-wheeler vehicle
3W	3-wheeler vehicle
BOD	Biological Oxygen Demand
BOF	Basic Oxygen Furnace
BRT	Bus Rapid Transit
CAT	Climate Action Tracker
CCS	Carbon Capture and Storage
CTI	Carbon Transparency Initiative
EAF	Electric Arc Furnace
EV	Electric Vehicle
EU	European Union
GDP	Gross Domestic Product
ICE	Internal Combustion Engine
IEA	International Energy Agency
NDCs	Nationally Determined Contributions
LDV	Light Duty Vehicle
LULUCF	Land Use, Land-Use Change and Forestry
pkm	Passenger Kilometre
PROSPECTS	Policy Related Overall and Sectoral Projections of Emission Curves and Time Series
RE	Renewable Energy
T&D	Transmission and Distribution
tkm	Tonne Kilometre
UNFCCC	United Nations Framework Convention on Climate Change
vkm	Vehicle Kilometre
WtE	Waste-to-Energy
WOM	Without Measures

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Chapter 1: Introduction

1.1 Background

Climate change is one of the most urgent global challenges we are facing today, the impacts of which include higher global average temperatures, increased frequency of extreme weather, and rising sea level. It has been estimated that the adverse effects of climate change could drive 100 million people into extreme poverty by 2030 [1]. The threats of climate change have been reinforced by the fact that 2016 was the hottest year since modern record keeping began [2], and 10 of the warmest years on record have occurred since 2000 [3].

Mitigation strategies for emissions are indispensable for managing the risks of climate change. To increase the possibility of effective adaptation and reduce challenges of mitigation in the longer term, substantial emissions reductions need to be achieved over the next few decades. There has been a marked increase in climate policies and legislation on climate change since 1997 [4]; however, more effort is still in need to achieved a substantial deviation in emissions from the past trend [5].

The **Paris Agreement** [6] on 12 December 2015 was seen by many policymakers as a historic turning point in the fight for reducing global warming, as it was adopted among 195 countries. The central aim of the Paris Agreement is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below **2 degrees Celsius** above pre-industrial levels and to pursue efforts to limit the temperature increase even further to **1.5 degrees Celsius**.

To achieve the goals of the Paris Agreement, substantial mitigation actions need to be taken in an efficient way. Assessing how different climate change policies may influence national and sectoral emissions can identify where more or urgent actions are needed and provide better climate transparency, which can support policy-makers in selecting the most appropriate and efficient climate policies.

1.2 Problem description

Climate change-related policies are indispensable and of key importance for GHG emissions reductions. Large reductions are achievable at relatively low costs, if the right policies are put in place [7]. Given the urgent need to significantly reduce GHG emissions, most developed nations and many developing countries have planned and implemented related policies since the early 1990s [8]. When the governments do so, they may seek to assess and communicate the effects of policies on GHG emissions to understand whether the intended objectives are achieved. Especially after the Paris Agreement, governments need to convert their (Intended) Nationally Determined Contributions, or (I)NDCs, into actual mitigation policies together go beyond these targets in order to meet the agreed temperature goals [9]. It is necessary to assess whether policies are compatible with the goals set in the Paris Agreement, as mentioned in the above paragraphs.

Countries that signed the United Nations Framework Convention on Climate Change (UNFCCC) were asked to publish their INDCs for reductions in greenhouse gas emissions in the lead up to the Paris Agreement. After the Paris Agreement, governments are now in the process of converting their (I)NDCs into tangible mitigation policies and programs. Considering that to a large extent, (I)NDCs mainly focus on overall emission reduction goals and do not go down to details on a **sector-level**, governments will now need to look into the emissions on a sectoral level to identify where rapid decarbonization is occurring and where more action can be taken. If the results and impacts of policies on greenhouse gas emission reductions can be verified in an adequately detailed and transparent way, it will be of great help for policy makers to design effective policies which are compatible with the goals of the Paris Agreement.

There is a **"ratchet mechanism"** of the Paris Agreement, which is designed to steadily track and stimulate ambitious over time, as shown in Figure 1. After submitting their first round of climate pledges (INDCs), governments need to communicate and update their pledges, i.e., Nationally Determined Contributions (NDCs), every five years. In the short term, a facilitative dialogue will take place in 2018 to assess the progress in implementing the goals, and inform the preparations in countries of the next round of pledges, which will happen in 2020. Before the facilitative dialogue, assessments on whether **current policies** in countries are sufficient to meet the goals are necessary, which can put pressure on governments to raise their ambitions when preparing for their second-round climate pledges for 2020.

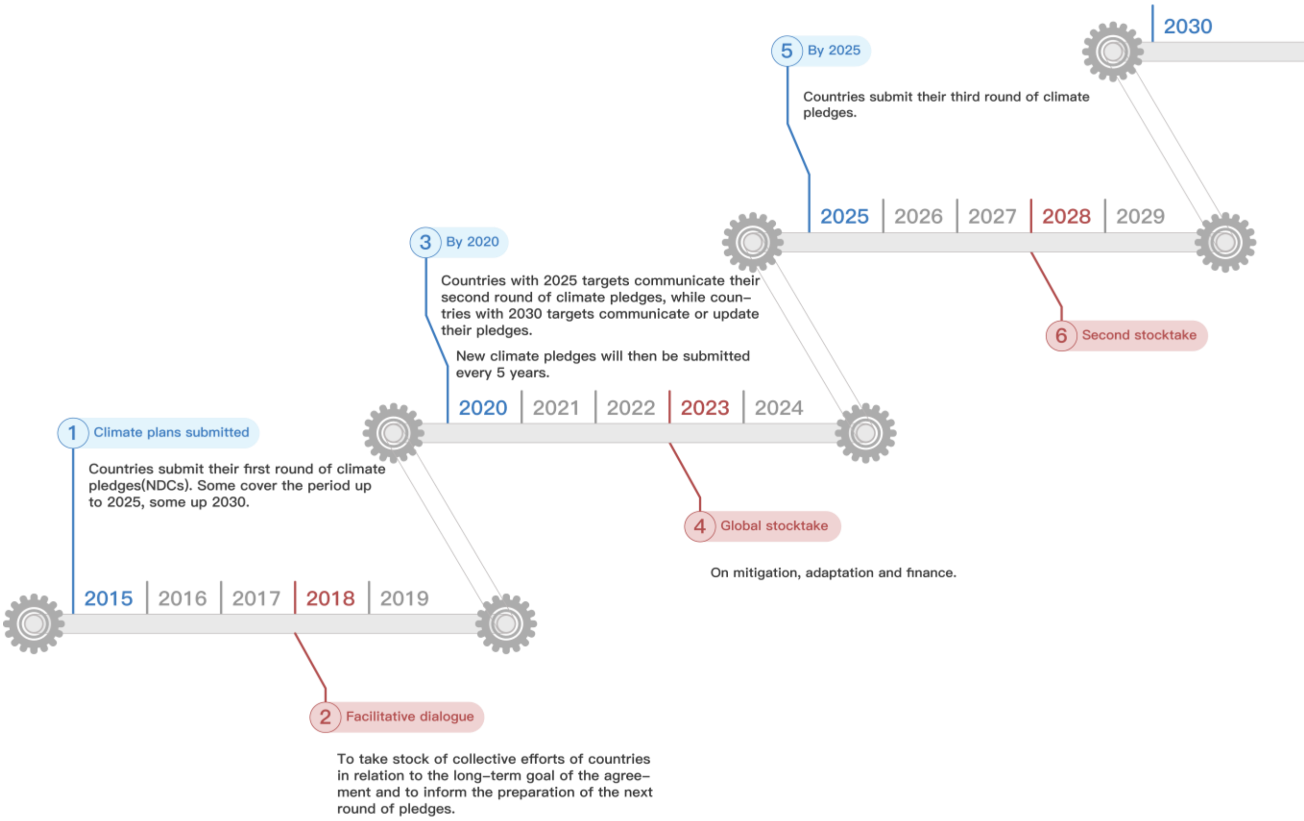


Figure 1. Timeline for the "ratchet mechanism" of the Paris Agreement, adopted from [10]

1.3 Objectives

As mentioned above, actions need to be taken to achieve the goals of the Paris Agreement: governments need to look into sectoral emissions to convert their (I)NDCs into tangible mitigation policies; the mitigation policies also need to be assessed to see if they are sufficient to meet the goals. The **objective** of this research is to: 1) develop an Excel-based modelling tool to calculate sectoral and national emissions in a given country; 2) do a case study for South Africa, where the current actions are deemed to be insufficient in the context of the Paris Agreement [11]; analyse the historical emission trends and identify the mitigation policies in key sectors, i.e., the Power Generation and Transport sectors; 3) construct policy scenarios to quantitatively predict future GHG emissions in South Africa under different policy scenarios.

The Excel tool will be used in the framework of the Climate Action Tracker (CAT) project [12] for analysing emissions pledges and current policies in different countries. The tool will be referred to with the acronym **PROSPECTS (*Policy Related Overall and Sectoral Projections of Emission Curves and Time Series*)** hereafter. The user of the tool should be able to construct one or more scenarios based on the assumed impact of certain external drivers including policies, socio-economic changes, and technology development. The **focus** of this research will be the impacts of policy drivers, but other drivers will also be considered. With historical data and policy scenarios as user input, the tool will **output** sectoral and national GHG emissions corresponding to different policy scenarios.

Considering that substantial historical data is needed as input to the Excel tool, **data availability** is a very important issue for implementing the tool to different countries. In order to be able to apply this tool to as many countries as possible, an adequate balance between simplification and accuracy should be achieved. Simplification generally means better data availability and the possibility to apply the approach to a relatively wide range of countries, but inappropriate or over simplification can make the results less reliable. When developing the tool, data availability should be always taken into consideration, and appropriate simplifications should be made whenever possible.

South Africa was chosen for the case study in this study because of the following reasons: on the one hand, South Africa was the 16th largest emitter of CO_2 in the world in 2013 and the largest emitting country on the continent of Africa [13]. On the other hand, its NDC was rated as inadequate according to the Climate Action Tracker (CAT) [11] which means global warming would exceed 3–4°C if most other countries were to follow South Africa's approach; and under current policies, this target would not even be reached according to the CAT assessment. Thus, it is necessary for South Africa to adjust its target and improve its policy plan such that the target may be reached. Moreover, the availability of needed sector-level data in South Africa is considered reasonable, but not as good as for countries/regions like the European Union (EU), US, and China. Thus, a case study for South Africa can indicate if the Excel tool developed in this research could meet the objective of being applicable to a large number of countries, not only to a few select ones where data availability and detail are excellent.

The **key outcomes** of this research will be the Excel tool, the methodology for constructing policy scenarios in selected sectors and policy areas, and emission projections for South Africa including recent policy trends. The outcomes can be used by climate policy analysts, policy makers or the public to explore future emissions in different policy scenarios. By improving understanding of policy impacts on overall and sectoral GHG emissions in countries, this research can contribute to better transparency in decarbonization and more efficient approach to 2°C or 1.5°C targets.

1.4 Research boundaries

Figure 2 shows the overview of this research. First, the Excel tool for emissions modelling will be developed, for which the functional design and calculation logic design will be detailed in this thesis. After inputting historical data and policy scenarios, the tool will output historical and projected emissions. To validate the emissions results from the Excel tool, they will be compared with authoritative external sources. After the results of the tool are validated, the policy assessment will be conducted outside the Excel tool for South Africa as a case study, and the results of the policy assessment will be policy scenarios which can be input into the tool. The **focus** of this research will be designing calculation logic for emissions in different sectors, developing the Excel tool, and developing a logic for policy assessment with South Africa as a case study, which are emphasized with dark blue in Figure 2. The development of the Excel tool is part of the CAT project, and the designing of emissions calculation logic is conducted in cooperation with several climate analysts within this project. Data collection is not a main focus of this research and will be supported by Climate Action Tracker staff.

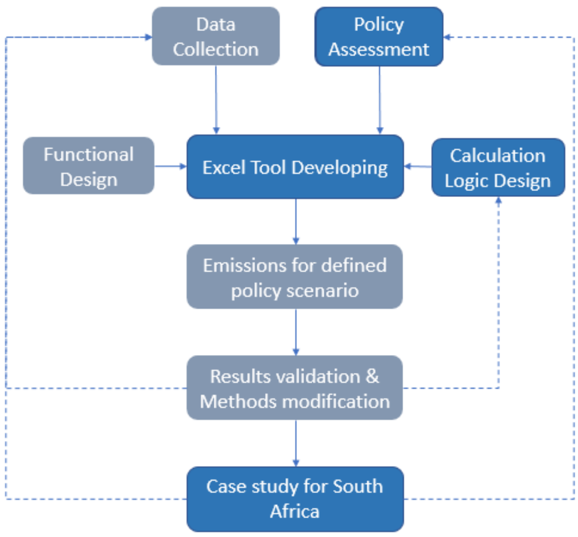


Figure 2. Overview of the contents of this research

The PROSPECTS tool developed in this study covers all economic sectors responsible for GHG emissions except Land Use, Land-Use Change and Forestry (LULUCF), but the policy assessment will only be conducted for key policy areas in two most important sectors in South Africa: **Power Generation** and **Transport** sectors. They are important because they turn out to contribute around 42% and 12% of the total emissions in South Africa respectively and are identified as key sectors to begin major efforts to cut emissions in order to reach the Paris Agreement's goals [14].

"Greenhouse gases" refers to those gaseous constituents of the atmosphere that absorb and emit radiation at specific wavelengths, which causes the greenhouse effect. Anthropogenic greenhouse gases include CO_2, CH_4, N_2O, SF_6, HFCs, PFCs, among which CO_2, CH_4 and N_2O are the most significant ones, sharing around 98% of total greenhouse emissions in 2010 [15]. The emissions of such gases will be converted when needed to CO_2equivalent (CO_2e) by applying the corresponding Global Warming Potentials (GWPs). The GWP for a particular GHG is the ratio of heat trapped by one unit mass of the GHG to that by one unit mass of CO_2 over a specified time period [16]. IPCC provides values of GWPs with different time horizons (20, 100 or 500 years). At present, the 100-year GWPs are used most widely, so the GWP-100 values from IPCC Fourth Assessment Report (AR4) will be used in this research, as given in Table 1.

Table 1. Factors for converting greenhouse gases to their equivalent in carbon dioxide, adopted from IPCC Fourth Assessment Report, [15]

Industrial designation	Chemical formula	Global warming potential for 100-year time horizon (relative to CO_2)
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298

The term "policies" can refer to interventions taken or mandated by a government, institutions, or other entities [17]. Many policy measures can affect GHG emissions, both mitigation-specific policies such as carbon taxes and general policies not necessarily related to climate change, such as fuel taxes or subsidies [18]. Policies in this paper refer to actions that can be taken or mandated by a **national government** which have effects of accelerating the application and use of measures that curb GHG emissions [19]; subnational policies will only be studied when they have pivotal impacts on the implementation of national policies; non-state actions will not be studied.

Although policy assessments are the focus of this research, socio-economic and technology drivers will also be considered. For example, population and Gross Domestic Product (GDP) may influence activities in certain sectors, such as the total floor space of buildings and the amount of municipal solid waste produced; and energy efficiency and emission intensity may have physical limits.

Nine economic sectors will be covered in this research, including **Power & Heat Generation**, **Transport**, **Buildings**, **Iron & Steel**, **Cement**, **Other Industry**, **Oil & Gas**, **Waste**, and **Agriculture**. Definitions of each sector are given in Table 2. Power & Heat Generation is a **supply-side** sector, since it supplies power and heat to other sectors; other sectors are **demand-side** sectors as they receive power and heat from the Power & Heat Generation sector. In the PROSPECTS tool, emissions from power and heat generation are counted in the Power & Heat Generation sector but can also be allocated to demand-side sectors to show the emissions profile in each sector. When calculating national emissions, emissions from power consumption will be counted once either in the Power & Heat Generation sector or in the demand sectors to avoid double-counting. More specific emissions source categories included in each sector is given in *Appendix 1*. The time period covered in the tool runs from **1990** to **2030**. The **base year**, in which historical data series end and data series based on user projections start, can be chosen by the user in PROSPECTS; in this study, the base year was taken as 2015 throughout.

Table 2. Sectors included in this research

Sectors	Definition of emissions included
1. Power & heat generation	Total GHG emission from main-producer plants for power and heat generation (Emissions from auto-producers are assigned to the sector where they are generated and not in here).
2. Transport	Total GHG emissions associated with fuel use and electricity use for domestic transport, including air, road, and rail transport, as well as international aviation
3. Buildings	Total direct (on-site fuel use) and indirect (electricity) greenhouse gas emissions from residential and commercial buildings related to water heating, space heating, space cooling, cooking, lighting, appliances and other miscellaneous equipment.
4. Iron & Steel	Total direct (on-site fuel use), indirect (electricity) and process greenhouse gas emissions from iron and steel production.
5. Cement	Total direct (on-site fuel use), indirect (electricity) and process greenhouse gas emissions from cement production.
6. Other industry	Total greenhouse gas emissions from other industry (excluding iron & steel and cement).
7. Oil & Gas	Upstream & midstream greenhouse gas emissions from oil and natural gas production, including flaring emissions and fugitive emissions.
8. Waste	Total greenhouse gas emissions from solid waste and wastewater management (excluding emissions related to waste-to-energy facilities).
9. Agriculture	Total anthropogenic greenhouse gas emissions from agriculture activities.

1.5 Thesis outline

In the following content, a literature review will be given in *Chapter 2*: previous studies about emissions modelling and policy assessment will be introduced and summarized; characteristics of this study will be identified; challenges and limitations in this study will also be analysed. In *Chapter 3*, how the PROSPECTS tool is developed will be explained with details for each sector and how the case study for South Africa is conducted will be introduced, with a focus on how to construct policy scenarios. In *Chapter 4*, the results from the PROSPECTS tool and the case study will be presented. In the following chapter, the results will be commented and other open questions will be discussed. In the end, conclusions will be given in *Chapter 6*, and recommendations for future researches will be made in *Chapter 7*.

Chapter 2: Literature review

Dozens of studies have been conducted to provide insights into possible future decarbonization scenarios by emissions modelling. In general, two approaches to developing those scenarios are the top-down method and the bottom-up method [20]: the top-down method begins by setting a decarbonization target or constraint, a portfolio of feasible technologies is then selected to achieve the target or constraint; the bottom-up method first analyses the potential for development of the energy system and of various technologies and/or other opportunities, and the analyses are then developed to form a decarbonization scenario.

The main advantage of the top-down method lies in data availability: it is much easier to obtain aggregated emission data than sector-level activity and intensity indicators from third parties. Compared with the top-down method, however, the bottom-up approach increases transparency on decarbonization in each sector and allows comparisons among regions at multiple levels of the economy in a time series. For example, when one wants to track the decarbonization trend in the transport sector, he/she can get trends in penetration rates of electric vehicles (EVs), fuel mix of internal combustion engines (ICEs), or emission intensity of ICEs, via decarbonization indicators, rather than just the total emissions trend. Also, if one wants to compare the decarbonization performances in transport sector between China and Japan, it is not reasonable to compare the total emissions, considering the huge differences in population and economy. Instead, it is much easier to compare penetration rates of EVs and emission intensity of ICEs among countries. Moreover, when one wants to predict the effect of a policy which stimulates the penetration of EVs, it is generally not clear how this policy will directly influence the total emissions. But with a decarbonization indicators approach, one can first analyse how this policy will influence the penetration rates of EVs and then scale it up to the influence on whole sector emissions.

Also considering that, as explained in *Chapter 1*, the objective of this study is to project future emissions based on the analysis of policies, the bottom-up method is used in this study.

2.1 Emissions modelling

Table 3 summarises existing key models/ tools for constructing decarbonization scenarios with bottom-up methods. They have different scopes and characteristics.

The ClimateWorks Foundation has developed an Excel-based bookkeeping tool, Carbon Transparency Initiative (CTI) [21], which is used to predict emissions until 2030 in six major emitting countries so far. This tool covers all economic sectors and gives default numbers for projections, which means that users are not allowed to construct their own scenarios. Because this tool needs very detailed sectoral input data, such as activity and intensity data for 14 types of products in chemical industry, data availability can be a bottleneck when applying this tool.

The Department of Energy & Climate Change (DECC) in the UK developed a 2050 Calculator [22], an Excel-based tool which can model possible emissions in the UK until 2050. Users of this calculator are able to construct their own policy scenarios by choosing ranks of certain indicators, after which emissions can be calculated. The Calculator only covers energy-related emissions in electricity, transport, industry and part of the buildings sectors, and the data is only applicable for the UK.

The International Energy Agency (IEA) has developed a World Energy Model [23], which supports the projections in the IEA's World Energy Outlooks. This model simulates how energy markets function at large-scale. It can generate detailed sector-by-sector and region-by-region projections on energy-related emissions mainly based on economic analysis instead of policy impacts. Moreover, the model only looks at energy sector and the methodology of how the projections are made is not public.

The World Bank has developed an Energy Forecasting Framework and Emissions Consensus Tool (EFFECT), which is a spreadsheet-based modelling tool used to assess impacts of policies on GHG emissions and development scenarios.

Although this tool focuses on policy scenarios, users can only choose default scenarios but cannot make their own scenarios.

The LEAP (Long-Range Energy Alternatives Planning) model by SEI is a widely-used software tool for analysis of energy policies and climate change mitigation assessment. It is an integrated, scenario-based model used to track energy consumption, production and resource extraction in all sectors of an economy. It can be applied on a wide range of scales, from the global to the country-level and even city-level scales, and its training materials and documentation are available free of charge to academic, governmental and non-profit organizations in the developing world [24].

Based on existing models/tools, the modelling in this study aims to provide an open-source tool that can track historical GHG emissions and estimate future emissions under various policy scenarios. The PROSPRCTS tool in this study uses a fixed list of decarbonisation indicators similar to those used by the CTI tool. Like DECC and LEAP, it allows user-defined policy scenarios, but with a much simpler methodology and parameter space as compared to LEAP. By combining some of the strengths of the above-mentioned models, the approach in this study has an objective to remove as many as possible constraints, such as technical applicability and data availability, and enable fast roll-out to a wide range of countries/regions.

Table 3. Models/ Tools for estimating GHG emissions

Model/ Tool	Author	Scope	Characteristic	Link
Carbon Transparency Initiative	ClimateWorks Foundation	Cross-sector (all GHG emissions)	Calculate GHG emissions until 2030, across all sectors of the economy for selected countries (Mexico, China, India, EU, US and Brazil), with default numbers for projection.	http://www.climateworks.org/portfolios/global-view/
2050 Energy Calculator	DECC	Cross-sector (only energy emissions)	Model possible GHG emissions in UK until 2050 based on scientific and engineering data. Allow users to choose ranks of indicators, which will be converted to values of indicators to calculate emissions.	http://2050-calculator-tool.decc.gov.uk/#/home
World Energy Model	IEA - World Energy Outlook analysis	Energy (only energy emissions)	Large-scale simulation for replicating how energy markets function. The principal tool used to generate detailed sector-by-sector and region-by-region projections for the World Energy Outlook (WEO) scenarios. Not available for public.	http://www.worldenergyoutlook.org/media/weowebsite/2015/WEM_Documentation_WEO2015.pdf

Table 3. Models/ Tools for estimating GHG emissions (continued)

Model/ Tool	Author	Scope	Characteristic	Link
Energy Forecasting Framework and Emissions Consensus Tool (EFFECT)	World Bank (ESMAP)	Energy	Spreadsheet-based modelling tool used to assess impacts of policies on GHG emissions and development scenarios. Users can choose given scenarios but cannot make own scenarios.	http://esmap.org/EFFECT
LEAP	Stockholm Environment Institute (SEI)	Cross-sector (all GHG emissions)	An integrated modeling tool for tracking GHG emissions and analyzing policy scenarios. Training materials and documentation are available free of charge to academic, governmental and non-profit organizations in the developing world.	http://sei-us.org/software/leap http://www.energycommunity.org/

2.2 Policy assessment

Although the detailed methodology of how to project the impact of policies is not given for the above models/tools, studies specifically on evaluations of policies' impacts have received increasing attention since the start of the 2000s [8], because they have the potential to assist governments in selecting the most appropriate and effective policies for their countries.

A range of efforts have been made to evaluate the impacts of policies related to decarbonization. Depending on the objectives, they can be divided into ex-ante evaluation and ex-post evaluation. The ex-ante evaluation estimates the impacts of policies before they are implemented, i.e., using available data and forecasting methods to determine the likely impacts of policies; the ex-post evaluation estimates the impacts of policies after they have been implemented, i.e., using to the extent possible observed data on estimating policies' actual impacts [25]. Considering that the aim of this research is to predict future emissions corresponding to certain policy scenarios, the ex-ante policy evaluation is of interest in this research.

The Dutch government performed the first ex-ante assessments of domestic GHG mitigation policies during the early 1990s [8]. However, the evaluation is more about cost effectiveness and equity, rather than emissions reductions.

P. G. M. Boonekamp [26] studied policies' interaction effects for household energy efficiency in the Netherlands for 1990-2003, including overlapping, reinforcing, or mutually independent policies. A matrix rating method was developed for qualitative analysis and a bottom-up model was used to quantify the changes in household energy use.

The World Resources Institute published a standard in 2014 [17], which aims to provide a standardized approach for estimating GHG emissions and removals resulting from policies and actions. As supplementary for the standard, sector-specific guidance for the energy supply sector [27], road transport sector [28], commercial and residential buildings sector [29], and agricultural, forestry, and other land use sector [30] were provided in 2015. This standard focuses on GHG emissions reduction effects of policies. But it only provides a general process of conducting policies assessments, rather than giving methodologies for quantifying policy impacts.

The IPCC report on mitigation of climate change [5] assessed the strengths and weaknesses of various national and sub-national mitigation policy instruments and policy packages. Classification and characteristics of different policy instruments and packages were introduced; sector-specific policies were analysed; how different policies may interact either positively or negatively was also indicated. Projections on emissions in different policy scenarios were made towards 2050, but detailed data and methodologies for projections are not available.

The International Energy Agency (IEA) has conducted medium to long-term energy projections from 1993 [23], in which projections on energy related emissions is a very important part. In the IEA's World Energy Outlook for 2016 [31], projections are made until 2040 based on three policy scenarios: new policies scenario, current policies scenario and decarbonization scenario (450 scenario). For each scenario, recent developments and predictions of emissions trends in different energy sectors are given. Although key policy areas and trends regarding to fossil fuel consumption, energy efficiency and renewable energy uptake are documented, details of how the policies are assessed and how the emissions are calculated are not given. Similarly, many studies have also been conducted to estimate emissions under different policy scenarios by applying LEAP [32]. However, such reports mainly focus on presenting results of projections but typically do not explain details of policy assessments.

It can be noticed from above introduction that most of the previous studies about policy assessment are qualitative instead of quantitative. Researches such as the World Energy Outlook do quantify the impacts of energy policies, but the detailed methodology for the projections are not available.

2.3 Emissions studies of South Africa

Apart from the above-mentioned researches on emissions modelling and policy assessment, there are also emission studies specifically for South Africa which provide valuable information about South Africa related to decarbonization.

The Department of Environmental Affairs in South Africa published the GHG National Inventory Report for South Africa [33] for the period 2000-2010 in 2014. In the inventory report, methodologies of data collection and emissions calculations are described and emission trends in different sectors are given. It is reflected in the report that the primary energy supply in South African energy is dominated by coal (65.7%), meaning that there is huge potential in emissions reduction in the energy supply sector.

The IEA provided an Energy Efficiency Outlook specifically for South Africa [34], which quantifies the potential energy savings in South Africa and related emission reductions of policies aimed at exploiting that potential. This report reviews energy intensity indicators and energy efficiency potential by sector. It highlights where the largest opportunities and potentials exist for energy efficiency improvement in South Africa.

The Mitigation Action Plans & Scenarios (MAPS) Programme [35] has conducted a series of researches to provide information in long term development and mitigation policy for some developing countries, including South Africa. Dobson, B. [36] observed several energy and thermal efficiency policies in South Africa and analysed key considerations when implementing them. B. Merven et al. [37] derived baseline forecasts of GHG emissions for South Africa until 2050 by implementing the TIMES model [38] developed by IEA-ETSAP; values of key drivers including population, GDP, fuel mix of electricity generation were projected. B. Merven et al. [39] modelled the possible fuel mix and emission reduction when introducing carbon taxes in the power sector in South Africa, in which the TIMES model, which does not quantify economy-wide implications, was linked with an economy-wide model to make emissions projections. Moreover, J. Burton [40] did backwards projections for the energy sector, i.e., modelled effects on the energy sector of meeting various carbon constrains by implementing the same models as in [39].

2.4 Key characteristics of this research

As discussed above, most of the existing models/ tools for constructing decarbonization scenarios focus on energy systems and mainly consider economic and technological impacts on emissions instead of political impacts. Although there are studies specifically on evaluating the impacts of policies, no generally accepted method is available in a detailed and transparent way. Comparing with previous studies, this research has the following characteristics:

1) It is **comprehensive** and covers different aspects of emission projections: methodologies for both policy assessment and emissions calculations are developed; an Excel tool is also developed to apply the methodologies and to realise calculations; a case study for South Africa is conducted as well to apply the methodologies and the Excel tool.

2) **All economic sectors** are covered exclude LULUCF. Apart from energy-related emissions, non-energy emissions, such as emissions from waste landfill, agricultural livestock, and industry processes are also included.
3) With a bottom-up approach and detailed sectoral information, this research conducted **independent** and **transparent** analyses on GHG emissions. Not only overall national or sectoral emission trends are revealed, trends on sectoral activity and intensity metrics are also revealed.
4) A balance between **accuracy** and **data availability** is achieved in the Excel tool: it should be applicable for a relatively large number of countries as far as data availability is concerned, and can provide sufficient sectoral details at the same time.
5) The Excel tool can **interact with users**: users are allowed to construct their own scenarios and the Excel tool will give corresponding emission projections.
6) The historical data and policies information collected for the case study in this research are **up to date** and can reflect the latest trend in GHG emissions.
7) **Policy scenarios** will be constructed for South Africa to quantify the emission reduction impacts of policies in key sectors. Detailed methodology will be documented in this research to provide **transparency** in policy assessment.

2.5 Challenges in this research

This research applies ex-ante policy assessment method to forecast future emissions in a sufficiently detailed way, which is a very challenging task, and uncertainty may exist in many different aspects [41] [25] :

1) Strategies or policies can often be adjusted as new information and understanding develops during implementation.
2) Policies can have **feedback or unintended effects**, e.g., policies increasing vehicle efficiency can make travel cheaper, which will in turn increase transport demand.
3) The impacts of certain policies may occur with a considerable **time lag**, e.g., investment in public transport may have influence on modal shift a few years later.
4) Some general indicators are changing during the projection period, e.g. income growth, fuel prices.
5) Rapid growth or breakthrough of technologies makes it difficult to accurately estimate future emissions.
6) Impact of policies depend on design factors but also external aspects, e.g. cultural aspects or structure of the economy. The impact of exactly the same feed in tariff will likely have different outcomes in different countries. Having one standard approach to cover all countries is thus challenging.

Apart from uncertainties in policy assessments, there exist other challenges as well:

1) The bottom-up method for sectoral emissions calculations needs detailed sectoral historical data; data availability can be a problem in certain sectors. Data gaps can be filled with interpolation, extrapolation and/or combination/harmonisation to other data sources, but this can introduce additional elements of uncertainty and/or inconsistency.
2) The Excel tool is designed to be applicable to as many countries as possible, but significant differences may exist among different countries, e.g., steel production in EU mainly applies Blast Furnace with Basic Oxygen Furnace (BOF) method and the scrap-based Electric Arc Furnace (EAF-scrap) method, while India mainly applies the direct reduced iron-based Electric Arc Furnace (EAF-DRI) method. Thus, despite this study’s attempt to construct a model logic allowing for fast roll-out to a wide range of countries, a comprehensive insight into different sectors are needed and situations in different countries/regions around the world need to be considered.

When accurate historical data are not available for certain indicators, data from scientific literature or neighbour countries/regions with similar geographical, cultural and/or socio-economical situations will be used. To make sure that current situation and future trends at the global scale are considered in each sector, sector-specific expert consultations are conducted to increase the applicability of this research.

Considering that the global environment of climate change is complex and changing all the time, and the real function mechanism of policies is like a black box, effective and accurate policy assessments and emissions projections may be an **iterative process**. This research is a start of this process. With further case studies for more countries and new information and understanding provided by other researches, methods proposed in this research can be improved and better projections can be made.

Chapter 3: Methodology and data

This section will introduce the methods applied in this research and the data needed for the emission analysis.

3.1 Overall method

The research will be conducted in an **indicator-led approach**, which measures key decarbonization indicators that shape emission trends on sectoral level in a country/region.

All the decarbonization indicators in the research can be classified into 3 groups: **activity metrics**, **intensity metrics** and **aggregate metrics**.

- Activity metrics refer to the level of emission-related activities: they include quantities such as electricity generation, steel production, and cement production.
- Intensity metrics are measures of the amount of energy consumption or emissions resulting from one unit of activity.
- Aggregate metrics refer to electricity and direct energy demand and the corresponding emissions.

Activity metrics and intensity metrics are classified as **driver metrics**, because they are the drivers for aggregate metrics. Taking the steel sector as an example, total steel production and the share of each production method describe the activity of steel production, so they are activity metrics. Emission intensities (electricity related and non-electricity related) measure the amount of emissions resulting from one unit of steel production, so they are intensity metrics. Total emissions of the steel sector are a result of emission calculations based on activity and intensity metrics, so they are aggregate metrics.

The GHG emissions in each sector will be modelled based on the following basic principle indicated in IPCC 2006 Guidelines for National GHG Inventories (IPCC 2006 Guidelines) [42]:

Emission = activity data x emission factor

Activity data refers to activity metrics mentioned above; an emission factor can be individual, or (a) combination(s) of, intensity metric(s).

Based on the indicator-led approach, the PROSPECTS tool for emissions modelling is developed and a case study for South Africa is conducted to project emissions under different policy scenarios.

3.2 PROSPECTS tool for emissions modelling

The methods described in this section and their documentation are the joint work of the author of this thesis and various analysts working for the Climate Action Tracker, and may be published in another format in the future as part of a PROSPECTS documentation.

The general objective of this study is to create a sector-level bottom-up Excel tool which can track and predict overall and sectoral GHG emissions trends of a country/region, based on the historic and future development of relevant indicators for decarbonization. The users of the tool should be able to construct (one or more) emission scenarios, based on the assumed impact of certain external drivers—policies, socio-economic changes, technology developments—on sector-level activity and intensity data.

The PROSPECTS framework is developed under an indicator-led methodology, which measures key indicators that shape emission trends on sectoral level for each country (e.g. emission intensity of electricity generation for the power sector or passenger km travelled per person for the transport sector). By breaking down macro-level emissions into sectoral-level indicators, the approach increases transparency on decarbonization in each sector and allows comparisons among countries/regions and over time at multiple levels of the economy. An aggregation of all sectoral trends in the model then leads to an overall emissions profile of a country/region.

By providing details at sector level and allowing users to define different scenarios, this model can potentially provide better transparency on GHG emission in a country/region and provide ideas of how to achieve the goals of the Paris Agreement more efficiently compared to models developed with top-down methods. The approaches in this work can also be useful in the medium term for improved policy analysis in advance of the 2018 Global Stocktake. Furthermore, the developed model will be usable in general to assess a country's/region's emission profile under various types of policy scenarios and enhanced-ambition scenarios, with relatively low levels of technical and time resources investment.

3.2.1 Functional and technical design

This section describes considerations of the overall abilities of the tool and how the user will interact with it.

OVERALL STRUCTURE

The PROSPECTS tool will contain a *Cover* sheet, a *Country Summary* sheet, a *Data Validation* sheet, a *Policy Scenarios* sheet, a *Data Input* sheet, *Calculation* sheets for every sector, a *References* sheet and an *Admin* sheet.

- The *Cover* sheet gives an introduction of the tool, and lists contents of every sheet. It is interconnected with other sectors to enable easy navigation among sheets. This sheet also contains a version log.
- The *Country Summary* sheet displays values of main global indicators and key outputs from the calculation sheets.
    - The sheet draws all energy and emission data from the different sectors' *Calculation* sheets, summarizes, and adds them up to get total energy demand and emissions profiles of a country/region.
    - This sheet will contain buttons with which the user can run different scenarios and update the corresponding global indicators, key outputs, as well as graphs.
- The *Data Validation* sheet contains tables in which the user can enter time series of economy-wide and sectoral emissions from external sources, which will be shown together in graphs. The emission curves calculated in PROSPECTS will also be shown in those graphs, allowing the user an easy check on consistency of values and trends.
- The *Policy Scenarios* sheet is for the user to define up to four separate policy scenarios based on the evaluation of energy- and emission-related policies in a country/region (and of other drivers, such as socio-economic and technology-related ones).
- The *Data Input* sheet contains primary historical data for every sector and "macro" data such as population size. Data requirements are described in more detail in the following *Sectoral Logic* section.
- Every sector has a *Calculation* sheet with a uniform structure for all sectors, as shown in Figure 3 and explained in the following bullets:
    - Assumptions for each sector are listed.
    - Historical indicators in each sector are calculated based on primary historical data (*1990-2015*) in *Data Input* sheet. For example, historical data of electricity generation by fuel is drawn from the Data Input sheet, with which historical total generation and fuel mix are calculated in this part.
    - Projections of certain indicators (2016-2030) are made based on the input from the *Policy Scenarios* sheet and the historical value of indicators.
    - With historical and predicted data for activity and intensity indicators, emissions from each sector can then be calculated. In the electricity sector, for instance, total emissions are the product of total electricity generation (activity indicator) and average emission intensity (intensity indicator).
    - The calculations per sector are discussed in detail in the following *Sectoral Logic* section.
- The *References* sheet contains a list of all sources of the historical data collected in the tool.
- The *Admin* sheet contains a number of standard values, conversion factors, and lists of symbols.

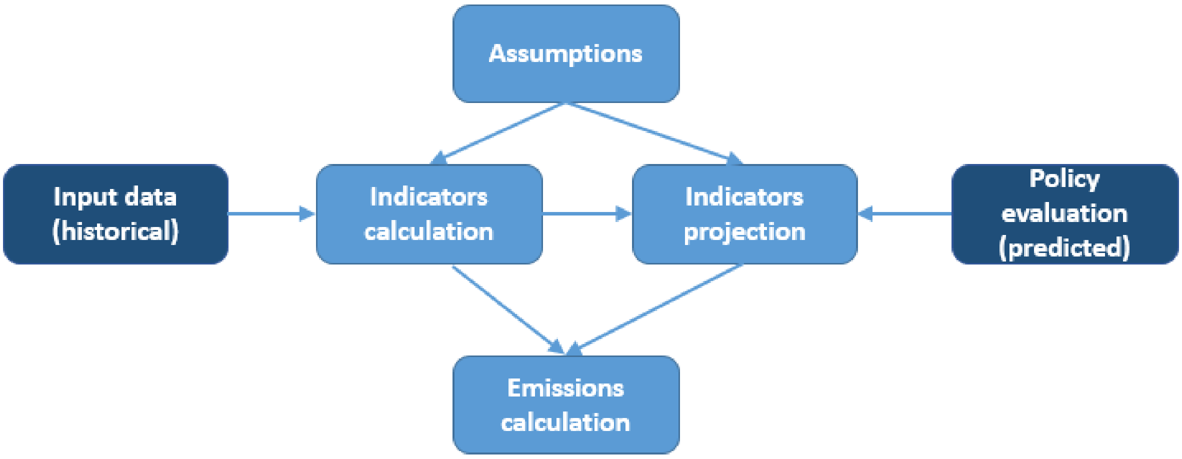


Figure 3. Structure of calculation sheets

POLICY SCENARIOS

The tool will allow the user to enter assumptions corresponding to different input scenarios, as mentioned above. This section describes the *Policy Scenarios* sheet in more detail.

In this sheet, the user is presented with a list of indicators, grouped by the different sectors, for which a projection, mainly expressed as one of the following two metrics, need to be entered for each year in the period 2016-2030:

- A percentage share (%) if the indicator is itself a percentage, such as the share of every type of energy source in electricity generation, and the share of a certain steel-making technology in overall steel production.
- A growth rate (%) if the indicator is an activity- or intensity-related metric in absolute units, such as the emissions intensity of coal, and the overall steel production.

Those numerical data should be entered for each future year, because some policies may only have an impact on the short term before their effect flattens off, while others might only start showing an impact after a number of years' implementation.

One of the main challenges lies in selecting the most relevant indicators when it comes to assessing how the impact of a policy could be quantified:

- In some cases, the indicators used for policy assessment could be the same as those required as input data—e.g. total housing space in the residential buildings sector;
- In other cases, an "intermediate indicator" may be needed for increased policy-relevance—e.g. having *energy use* in buildings as input data (1990-2015), but converting it to the intermediate indicator *energy intensity per unit floor area* (TJ/m^2) for the policy scenarios, defining the latter's growth rate (2016-2030), and then using the corresponding projected energy intensity and the projected growth in housing space to determine the projection of energy use in the period 2016-2030.

Certain indicators need not to be defined for each specific scenario. For instance, population projections (needed for per-capita indicators) exist from authoritative sources (e.g. UN population projections) and are not related to climate policies, so these need not be re-entered for each of the up to 4 scenarios but are instead determined once for the entire tool.

DATA REQUIREMENTS, AVAILABILITY AND VALIDATION

This section describes the requirements and constraints on data needed to construct an emissions scenario in PROSPECTS tool. It also discusses how the sectoral and overall emissions scenarios generated by PROSPECTS can be validated against external (third-party) scenarios.

Input data

A variety of input data are needed to use the PROSPECTS approach to construct an emission projection for a country:

- Historical data for a list of indicators in each sector is needed, from which the historical GHG emission time series of each sector can be calculated.
- Historical and projected data for economy-wide indicators is needed, such as population size and GDP.
- The user needs to define the scope of the scenario(s) that they wish to develop. For instance, for a "current policy scenario", the user would need to define which currently existing policies they wish to explicitly include in the modelling approach.
- The user needs to input numerical data on the assumed development of the relevant sector-level indicators in each sector under the specific policy scenario under development.

Data availability

Whenever explicit data for required input is not available, the user needs to resort to a number of possibilities for estimation:

- "Proxy" variables can be used where a known correlation exists to the required data. For instance, in the CTI tools [21], this approach is used for some countries to estimate the waste generation per capita from data on GDP/capita.
- It can be assumed that the value of a certain required input data is the same, or similar, as in another country, where the data is known. An example could be to assume that energy intensity in buildings (TJ/m^2) and floor space per capita (m^2/cap) in country A is the same as in neighbouring country B with similar climate and level of development, and using this assumption to estimate overall floor space and energy demand in buildings in country A.

Output data

The tool will output a variety of sector-level and economy-wide data for the country in question. This will cover historical and projected data series of the following:

- Emissions from each sector with electricity-related emissions allocated to the power sector;
- Emissions from each sector with electricity-related emissions allocated to the respective end-use sectors.
- Aggregated country-wide emissions under the scenarios defined in the tool.
- Different categorisations of these emissions, such as electricity-related, other energy-related, and non-CO_2 emissions.
- An overview of the most relevant sector-level activity and intensity indicators calculated in the model.

3.2.2 Sectoral logic

In the following sections, the calculations performed in each sectoral module of PROSPECTS will be described and main possible data sources for each sector will be listed. The first section deals with indicators that are defined across all sectors. The second section describes the approaches used in all specific sectors. The logic trees for each sector can be found in Appendix 2.

GLOBALLY-DEFINED INDICATORS

A number of indicators in PROSPECTS are not defined on a sectoral level, but taken as the same throughout the tool and feeding into the calculations of various end-use sectors. These indicators are discussed first, before the logic of each sector is introduced in the sections hereafter. It concerns the emissions intensity of electricity production, the emissions intensity of direct energy use, and the emissions potentially captured with CCS.

Emissions intensity of electricity production

Buildings, industry, transport and agricultural activities require electricity. If the electricity grid is fed with higher shares of low-carbon power, this reduction of carbon intensity (an output of the *Calculations - Power & Heat Generation* sheet) has the same relative effect on electricity-related emissions in every end-use sector.

Emissions intensity of direct energy use

The emissions intensity of direct energy use—which in PROSPECTS is categorised into coal, oil, gas, waste, heat, and others—must be treated with more caution. The reason is that different sectors may have different direct energy use patterns.

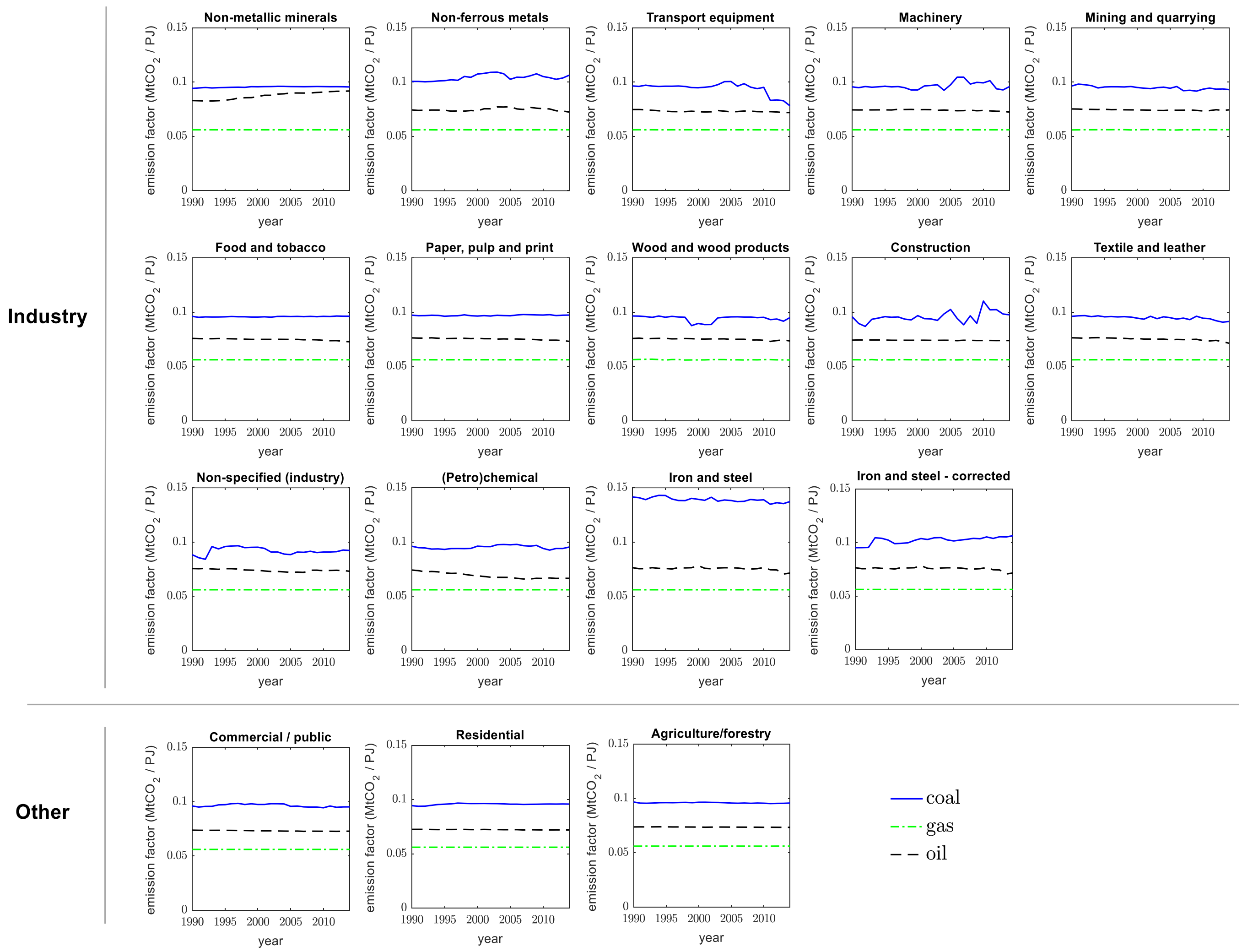


Figure 4: Implied energy intensities of direct energy use, EU-28, from [43]

A good example is the steel sector, whose direct energy mix typically has relatively high shares of coal, due to the use of coke, which has a very high relative carbon content as compared to other products that can be categorised as "coal". Thus, taking the same average emissions intensity of "coal" indiscriminately in the steel sector as in other industrial sectors would systematically underestimate the emissions from steelmaking.

An analysis of the IEA Energy Statistics and Balances data [43] reveals that, on an aggregated level, the emissions intensities of direct energy are generally comparable across different industrial sectors and others (buildings, agriculture)[1]. The one strong exception is the steel sector, where—due to the use of coke-related products for coke ovens—the weighted average emission factor of all coal products aggregated is much higher than in other sectors. Example data corresponding to the EU-28 are shown in Figure 4. However, when removing the coke-related products from the fuel mix in the iron and steel sector, numbers match much better (graph labelled "iron and steel – corrected"). For this reason, the calculations in the iron and steel sector will be done based on the adapted fuel mix, so that the same direct energy emission factor can be applied across all sectors. Emissions from coke-related products are then accounted for separately with a corresponding high emissions intensity.

While the fuel mix of the power sector is globally defined across the PROSPECTS logic, the fuel mix of direct energy needs to be distinguished per sector. Figure 5 illustrates how the industrial sectors in PROSPECTS (steel, cement, and "other")

[1] Note: the value for gas is the same throughout, because there is only one type of "natural gas" considered in the IEA Energy Statistics and Balances, as compared to 19 different types of energy carrier that fall under "coal".

have different direct energy use profiles (example for EU-28)[2]. Not distinguishing between these would introduce considerable systematic errors.

The emissions intensities as shown in Figure 4 are in $MtCO_2/PJ$ of *final energy demand* per sector. The primary energy supply needed to cater to this demand is higher, and the difference needs to be accounted for when calculating emissions. This is done in PROSPECTS by adapting the emission factors of fossil fuels upwards with a factor that expresses the ratio between total primary energy supply and total final consumption.

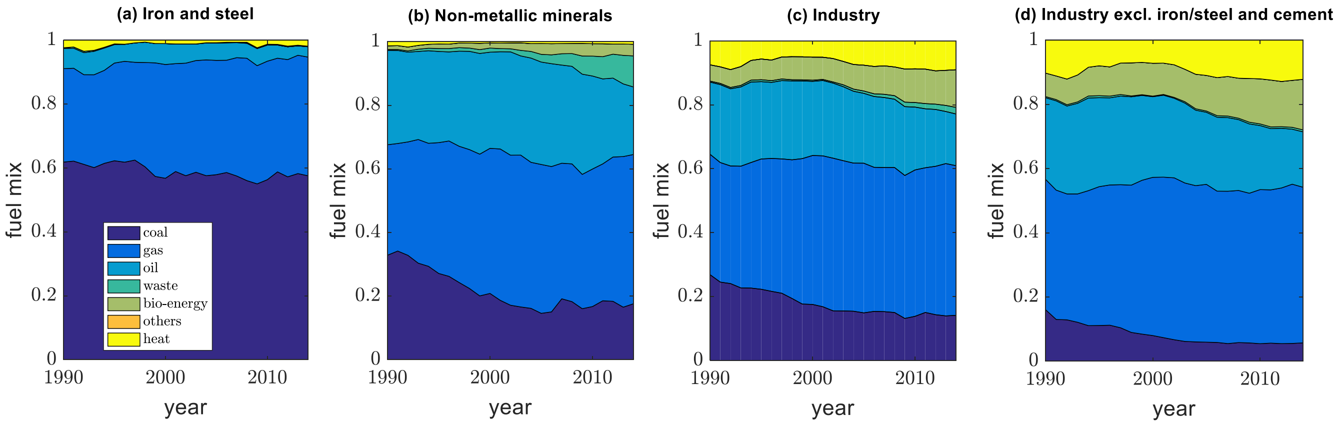


Figure 5: Fuel mixes of direct energy use in various industrial categories for the EU-28, [43]

Emissions captured with CCS in industry

The PROSPECTS logic contains the option to specify the share of process-related and direct energy-related emissions from industrial installations captured using CCS. This indicator is applicable to all industry across the PROSPECTS logic, but still needs to be specified separately by the user for i.e. steel an cement, as there may be different feasibilities with respect to CCS deployment depending on the specific industry.

POWER & HEAT GENERATION SECTOR

Power supply

The power supply module analyses emissions related to electricity generation and consumption. It plays a crucial role in PROSPECTS tool, since it is closely connected to any other sectors where electricity is consumed. It receives electricity demand from other sectors as input for **total demand**. At the same time, it calculates the **average emission intensity** (GHG emissions produced per unit of electricity generation) of electricity generation as an output, which is again used as input in other sectors.

Table 4 shows required historical data input for the power supply sector in PROSPECTS tool, with the first column listing indicators whose historical data is needed, the second column giving the units of the indicators, and the third column providing suggested data sources of the indicators, which are usable for many countries. Table 5 shows the indicators in the power supply sector required as input for policy scenarios. As mentioned in *section 3.2.1*, most of them should be input in the form of percentage share (%) or annual growth rate (%), which is shown in the third column of Table 5. Tables show historical data input and policy scenario input for other sectors in the following sections will have the same format. The fuel types considered in this sector include coal, gas, oil, nuclear, hydro, geothermal, biomass, wind, solar, marine, waste and "others". One of the functionalities of PROSPECTS is that the user can allocate electricity-related emissions either to the end-use sectors or to the power sector. The only emissions that are always counted in the electricity sector are those from exported electricity, from own use of the energy industry, and from losses. The ratio of the energy industries' own use of electricity, and of losses (e.g. in T&D), to total electricity generation are calculated and used as an indicator in the policy scenarios.

[2] The iron and steel fuel mix here includes coke-related products.

As the import of electricity adds to the supply of electricity in a country without increasing the emissions—as those are counted in the producing country—PROSPECTS calculates the ratio of imported power to total generated power, and uses this factor to correct the aggregate emissions intensity of electricity downwards. This ensures that no systematic error towards too high emissions is included in the tool. This correction applies to all emissions on the demand side (i.e. from the end-use sectors), but not to emissions allocated only to the energy supply sector, such as those from exported electricity.

As indicator in the policy scenarios to quantify future imports of electricity, the ratio of imported electricity to total electricity demand is used, which is deemed a more intuitive indicator than the ratio of imported electricity to total electricity production (the former is 100% in case all power is imported, whereas the latter would be infinity). As indicator to quantify future exports of electricity, the ratio of exported electricity to total electricity generation (equal to total electricity demand, plus losses, own use needs, and exports, minus imports) is used.

It should be noted that several fuel types in the electricity sector (nuclear, hydro, geothermal, wind, solar and marine) could be combined as "non-fossil fuel" type if the data availability on individual types were to be poor in certain countries, since emission intensities of these fuel types could all be considered zero at present.

Table 4. Historical input data for the power supply sector

Indicators	Units	Suggested data sources
Emissions intensity by fuel type	$MtCO_2e$ / TWh	[43]
Electricity generation by fuel type	TWh	
Electricity needed for energy industries own use		
Losses (T&D)		
Imports		
Exports		

Table 5. Policy scenario input for the power supply sector

Indicators	Units	Input required
Fuel mix	%	% share
Emissions intensity of electricity by fuel type	$MtCO_2e$ / TWh	% growth rate
Share of own use in total electricity generation	%	% share
Share of losses in total electricity generation	%	% share
Share of exported power in total electricity generation	%	% share
Share of imported power in total electricity demand	%	% share

Heat supply

The PROSPECTS logic contains a small module on the commercial heat sector. The purpose of this module is to estimate the average emission factor of commercial heat, which is counted among the types of "direct energy" that the demand-side sectors receive in the IEA Energy Statistics and Balances, as shown in Figure 5 with the yellow area (legend "heat").

The module requires a historical data series on heat generation by fuel, from which the fuel mix of heat generation can be inferred. The weighted average of the emissions intensities of direct energy with the fuel mix then gives the average emissions intensity of commercial heat. The fuel mix serves as an indicator for the policy projections.

While in theory the precise same logic as for electricity generation could be employed, this is further simplified here by neglecting imports and exports (which are in the order of 0.01% of electricity imports and exports worldwide) [43]. Thus, it is assumed that total heat generation and total heat supply are equivalent. However, losses and own use of heat in the energy industry need to be taken along and their emissions are accounted for on the supply side. These can be expressed in an indicator showing their ratio to the total heat generation, similar to the electricity sector logic.

Table 6. Historical input data for heat supply sector

Indicators	Units	Suggested data sources
Heat generation by fuel type	TJ	[43]
Heat needed for energy industries own use		
Losses (T&D)		

Table 7. Policy scenario input for heat supply sector

Indicators	Units	Input required
Fuel mix	%	% share
Share of own use in total heat generation	%	% share
Share of losses in total heat generation	%	% share

TRANSPORT SECTOR

Calculations in the transport sector can be divided into three parts: passenger transport, freight transport, and aviation. PROSPECTS considers different modes of transport and different types of fuels in passenger and freight transport, while international aviation follows a much more simplified approach.

Passenger transport

The historical input data and policy scenario data of passenger transport is listed in Table 8 and Table 9, respectively. In the passenger transport part, vehicles are grouped under four types: *personal vehicle*, *bus*, *train,* and *plane*. The vehicle type "personal vehicle" includes light duty vehicles (LDVs), 2-wheelers (2Ws), and 3-wheelers (3Ws). The mode "plane" includes only *domestic* aviation. Considered fuel types (depending on the mode) include gasoline, diesel, compressed natural gas (CNG)/ liquefied petroleum gas (LPG), jet fuel and biofuel. Historical data on passenger transport activity can be obtained for a number of regions from the ICCT Global Transportation Roadmap Model [44].

Passenger transport emissions are driven by the passenger transport activity, which is input as the total amount of passenger-kilometres (pkm), and converted to vehicle-kilometres (vkm) using a load factor (in the unit of pkm/vkm). With passenger transport activity and modal split as inputs, distances travelled by every vehicle type (car, bus, train, plane) can be calculated. Then, with the share of electrified transport, distances travelled by different types of electrified vehicles[3] and distances travelled by different types of internal combustion engine (ICE) vehicles can be calculated.

Multiplying electrified vehicle kilometres with electricity intensity gives the electricity demand. Electricity emissions from passenger transport can then be obtained as the product of electricity demand and electricity emission intensity (an output from the electricity sector).

For ICE vehicles, the sum-product of the fuel mix and the fuel emission intensity for a certain type of vehicles is the average emission intensity for this type of vehicles. Multiplying the distances travelled by ICEs with the average emission intensities results in direct energy emissions. Adding up electricity emissions and direct energy emissions from different types of vehicles then gives emissions from passenger transport.

[3] For the category "personal vehicles" and "buses", this means electric personal vehicles/buses; for "trains" this refers to electrified railway lines.

Table 8. Historical input data for passenger transport

Indicators	Units	Suggested data sources
Passenger transport activity	pkm	[45] and [46]
Modal split	% of pkm with personal vehicle, bus, train, airplane	
Load factor for each mode (for personal vehicles, buses, trains, airplanes)	pkm / vkm	
Share of electrified passenger transport activity (for personal vehicles, buses, trains)	%	For cars: [47] For trains: [45]
Electricity intensity of electrified transport (for personal vehicles, buses, trains)	kWh / vkm	[45]
Fuel mix for non-electrified transport (for personal vehicles, buses, trains, airplanes)	% gasoline, diesel, CNG/LPG, biofuels (for personal vehicle, bus) % diesel, CNG/LPG, biofuel (for train) % jet fuel, biofuels (for plane)	
Energy intensity by fuel type (for personal vehicles, buses, trains, airplanes)	MJ/ vkm	
Emission intensity by fuel type	tCO_2e / MJ for gasoline, diesel, CNG/LPG, biofuel, jet fuel	

Table 9. Policy scenario input for passenger transport

Indicators	Units	Input required
Passenger transport activity per capita	pkm / cap	% growth rate
Modal split	% personal vehicle, bus, train, plane	% car, bus, train, plane
Load factor	pkm / vkm	Exact value
Share of electrified passenger transport activity (for personal vehicles, buses, trains)	% share	% share
Electricity intensity of electrified transport (for personal vehicles, buses, trains)	kWh / vkm	% growth rate
Fuel mix for non-electrified transport (for personal vehicles, buses, trains, airplanes)	% gasoline, diesel, CNG/LPG, biofuels (for personal vehicle, buses) % diesel, CNG/LPG, biofuel (for trains) % jet fuel, biofuels (for planes)	% share
Energy intensity by fuel type (for personal vehicles, buses, trains, airplanes)	MJ/ vkm	% growth rate
Emission intensity by fuel type (for personal vehicles, buses, trains, airplanes)	tCO_2e / vkm for gasoline, diesel, CNG/LPG, biofuels (for personal vehicle, buses, trains) tCO_2e / vkm for jet fuel, biofuels (for planes)	% growth rate

Freight transport

The historical input data and policy scenario data for freight transport are listed in Table 10 and Table 11, respectively. In the freight transport part, vehicles are grouped under two types: *trucks* and *trains*. This module will neglect any amount of freight that would be transported through domestic aviation or domestic shipping. Apart from this, the approach is identical to that for passenger transport.

Table 10. Historical input data for freight transport

Indicators	Units	Suggested data sources
Freight transport activity	tkm	[45]
Modal split	% truck, train	
Load factor for each mode (for trucks, trains)	tkm / vkm	
Share of electrified transport activity (for trucks, trains)	%	
Electricity intensity of electrified transport (for trucks, trains)	kWh / vkm	
Fuel mix for non-electrified transport (for trucks, trains)	%	
Emission intensity by fuel type (for trucks, trains)	tCO_2e / vkm	

Table 11. Policy scenario input for freight transport

Indicators	Units	Input required
Freight transport activity per capita	tkm / cap	% growth rate
Modal split	% truck, train	% truck, train
Load factor for each mode (for trucks, trains, airplanes)	tkm / vkm	Exact value
Share of electrified transport activity (for trucks, trains)	% share	% share
Electricity intensity of electrified transport (for trucks, trains)	kWh / vkm	% growth rate
Fuel mix for non-electrified transport (for trucks, trains)	% gasoline, diesel, CNG/LPG, biofuels (for trucks) % diesel, CNG/LPG, biofuel (for trains)	% share
Emission intensity by fuel type (for trucks, trains)	tCO_2e/vkm for gasoline, diesel, CNG/LPG, biofuels (for trucks, trains)	% growth rate

International aviation

The approach on international aviation will be a simplified version of the calculations under passenger transport. No different vehicle types are considered, only the amount of activity (pkm in international aviation), the type of fuels (biofuel and jet fuel) and the fuel emissions intensity are needed as input. Historical input data and policy scenario input are given in Table 12 and Table 13, respectively.

Table 12. Historical input data for international aviation passenger transport

Indicators	Units	Suggested data sources
International aviation activity	pkm	[48]
Fuel mix (jet fuel vs. biofuel)	%	Assumption: share of biofuel near zero today
Emission intensity by fuel type	tCO_2e / pkm	[45]

Table 13. Policy scenario input for international aviation passenger transport

Indicators	Units	Input required
International aviation activity	pkm	% growth rate
Fuel mix (jet fuel vs. biofuel)	%	% jet fuel, biofuel
Emission intensity by fuel type	tCO_2e / pkm for jet fuel, biofuels	% growth rate

Shipping

Maritime emissions are not modelled in the country-level approach in PROSPECTS. This is due to the challenges involved in attributing emissions from fuel use to specific countries, chiefly because of the practice of tankering – shipping additional fuel along in order to avoid refuelling at ports where fuel prices are higher, thus potentially avoiding fuel taxes and other costs [49]. If the PROSPECTS methodology were to be applied on a global level or country-level results were to be aggregated to a global level, a global time series of shipping emissions should be added.

BUILDINGS SECTOR

Table 14 and Table 15 show the historical input data and policy scenario input indicators needed for the buildings module in PROSPECTS.

As input, historical data on energy demand (both direct energy and electricity) is needed, which (along with the fuel mix) is available from the IEA Energy Statistics and Balances [43]. To distinguish between different types of energy use, the logic requires a split into energy demand for heating (for space & water), space cooling, and cooking & appliances (incl. lighting). This could be estimated from the split in the IEA ETP [50] (for instance for OECD vs. non-OECD countries).

Data on floor space will not be available from a single source for all countries. Wherever it is not directly available, it is proposed to estimate it by assuming the floor space intensity (m^2/capita) is the same or close to that of another country with comparable cultural/climatic/economy factors affecting the building stock. Important for this mapping are factors such as same climatic zones, similar building type compositions (e.g. single family vs. multifamily) and rural/urban split.

These data are converted into several indicators that are used in defining the policy scenarios: the total intensity per square metre of energy (direct energy and electricity together) for heating, cooling, and cooking and appliances, respectively; and the electrification rate in heating and in cooking/appliances (it is assumed to be 100% in cooling).

The building stock of the future is divided into two categories in PROSPECTS – “old” and “new/renovated” buildings – with a simple stock turnover calculation. Here, “old” refers to buildings constructed before the base year of the calculations (i.e. the year until which the historical data runs). The stock turnover is based on the renovation/renewal rate of buildings (the percentage of the building stock being either reconstructed or undergoing deep renovation). This new/renovated stock can then be assigned a lower energy intensity for heating/cooling than the old buildings stock.

Table 14. Historical input data for buildings sector (separately needed for residential and commercial buildings)

Indicators	Units	Suggested data sources
Total floor space	million m^2	IEA Buildings [51] and/or estimates from countries with similar climatic zones, cultural settings, building types and rural/urban split.
Direct energy demand for heating	PJ	[43] + estimate from [50]
Direct energy demand for cooking/appliances	PJ	[43] + estimate from [50]
Fuel mix direct energy use	%	[43]
Electricity demand for water / space heating	TWh	[43] + estimate from [50]
Electricity demand for cooling	TWh	[43] + estimate from [50]
Electricity demand for cooking / lighting / appliances	TWh	[43] + estimate from [50]

Table 15. Policy scenario input for buildings sector (separately needed for residential and commercial buildings)

Indicators	Units	Input required
Total floor space per capita	m^2/cap	% growth rate
Renovation / renewal rate	%	% rate
Improvement in energy intensity for heating/cooling for new/renovated buildings	%	% rate of energy intensity reduction (relative to old stock)
Total energy intensity for water / space heating	GJ/m^2	% growth rate
Total energy intensity for cooling	MWh/m^2	% growth rate
Total energy intensity for cooking/appliances	GJ/m^2	% growth rate
Electrification rate in water / space heating	%	% share
Electrification rate in cooking / lighting / appliances	%	% share
Fuel mix of direct energy use	%	% share

IRON & STEEL SECTOR

Table 16 and Table 17 show the historical input data and policy scenario input, respectively, needed for the steel sector in PROSPECTS. The emissions of the cement industry come mainly from two sources: **electricity use** and **direct energy use**. *Electricity use* refers to electricity consumption from the grid in the steel industry. *Direct energy use* mainly refers to traditional fuels and renewables that are burned or directly used onsite. The contemporary steel industry mainly relies on three types of furnaces to produce steel: The **Blast Furnace with Basic Oxygen Furnace (BF-BOF)** route, the **scrap-based Electric Arc Furnace (EAF-scrap)** route**,** and the **direct reduced iron-based Electric Arc Furnace (EAF-DRI)** route. These routes have significant differences in electricity intensity and direct energy intensity. Thus, the three types of steel production are distinguished throughout the calculation. Potential future steelmaking routes may be summarised under the denominator “other” with user-defined intensities.

Data on steel production and shares of steel production routes can be obtained from the WSA [52]. Data on the electricity and direct energy intensities will have to be taken/inspired from scientific literature, such as [53]–[55].

The fuel mix in the steel sector, when taken directly from the IEA Energy Statistics and Balances [43], is significantly affected by the high demand for coke products in blast furnaces. Thus, this fuel mix cannot be indiscriminately taken for all three production routes. Instead, in the PROSPECTS methodology, coke-related products for use in blast furnaces - coke oven coke, coke oven gas and blast furnace gas – are separated out from the fuel mix (Figure 6), according to the guidelines in [56]. This fuel mix without coke is used as overall direct energy mix for all steelmaking routes. The use of coke is accounted for with the coke intensity (in PJ / t steel), which, together with a separate emission factor for coke, is used to calculate emissions from coke (with the steel production from the BF-BOF route as activity driver).

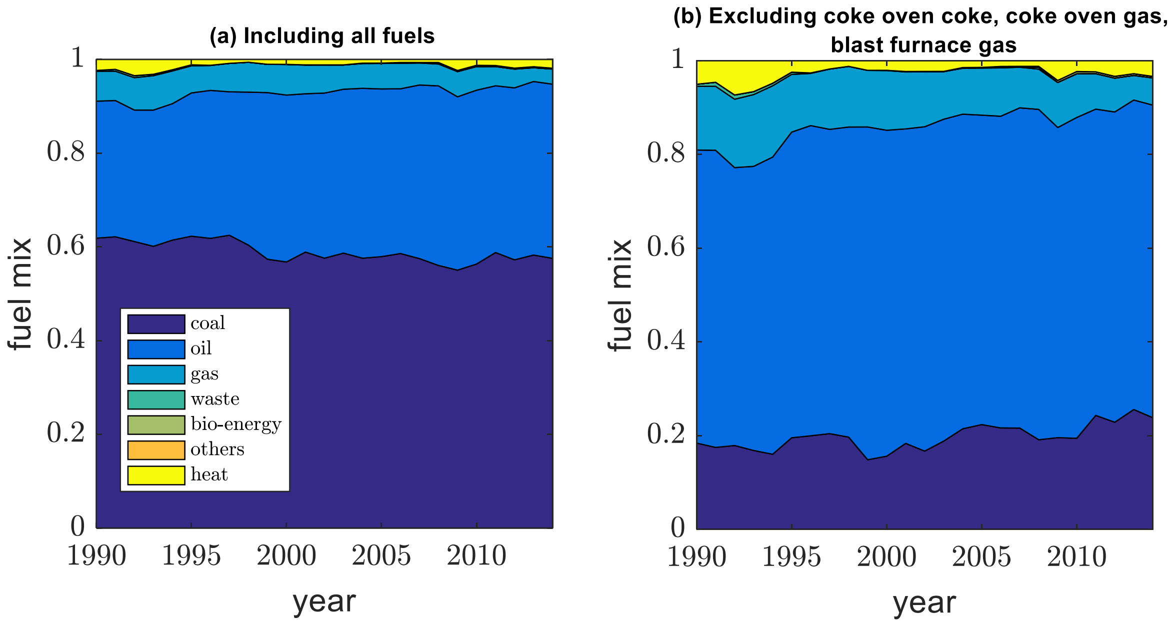


Figure 6: The fuel mix for the iron and steel sector in the EU-28, with (a) and without (b) coke oven coke (including that converted into coke oven gas and blast furnace gas) [43].

As in all other sectors, the direct energy emissions intensity is not a specific input to the steel sector, as it is globally defined in the model. The only exception to this is formed by the direct energy emissions intensity of **coke products** in the steel sector. This is because of the significantly higher average emissions intensity in the steel sector as compared to other sectors, owing to the high share of coke necessary for coke ovens, as shown in Figure 2. For this reason, it must be separately specified for steelmaking in blast furnaces.

Note that emissions resulting from combustion of blast furnace gas would be counted under emissions from direct energy use in the relevant end-use sectors in the IEA Energy Statistics and Balances [43], so these need not be explicitly incorporated in the steel sector in PROSPECTS. Also, while emissions from coke use in coke ovens are sometimes categorised as process emissions, the PROSPECTS tool counts them under direct energy-related emissions, as coke is an energy carrier that is counted as one of several coal products in, for instance, the IEA Energy Statistics and Balances.

Table 16. Historical input data for steel sector

Indicators	Units	Suggested data sources
Steel production	Mt steel	[52]
Share of production methods (BF-BOF, EAF-scrap, EAF-DRI, "other")	%	
Electricity intensity of steel production (BF-BOF, EAF-scrap, EAF-DRI, "other")	TWh / Mt steel	[53], [54], [55]
Direct energy intensity of steel production (BF-BOF, EAF-scrap, EAF-DRI, "other")	PJ / Mt steel	
Coke intensity of steel production (BF-BOF)	PJ / Mt steel	
Direct energy fuel mix	%	[43] (category "iron and steel")
Direct energy emissions intensity of coke	$MtCO_2e$ / PJ	
Emissions captured with CCS	% of direct energy-related emissions (incl. from coke)	

Table 17. Policy scenario input for steel sector

Indicators	Units	Input required
Steel production	Mt steel	% growth rate
Share of production methods (BF-BOF, EAF-scrap, EAF-DRI, “other”)	% share	% share
Electricity intensity of steel production	TWh / Mt steel	% growth rate
Direct energy fuel mix	%	% share
Direct energy intensity of steel production	PJ / Mt steel	% growth rate
Emissions captured with CCS	% of direct energy-related emissions (incl. from coke)	% captured

CEMENT SECTOR

Table 18 and Table 19 show the historical data and policy scenario inputs, respectively, needed for the cement sector in this prototype of PROSPECTS. The emissions of the cement industry come mainly from three sources: **electricity use**, **direct energy use** and **process emissions**. In the cement industry, process emissions come mainly from a chemical process called calcination. Calcination occurs when limestone, which is made of calcium carbonate, is heated, breaking down into calcium oxide and CO_2. The simplified stoichiometric relationship is as follows [57]:

$$CaCO_3 + heat \rightarrow CaO + CO_2$$

Data on cement production can be obtained from sources such as the United States Geological Survey [58]. A separate data series on clinker production is necessary to ensure that cement produced from imported clinker does not result in additional process or direct energy-related emissions, since those should be counted in the clinker-producing country (and similarly for clinker for export).

Data on energy and electricity intensity of cement making can be estimated from WBCSD time series [61], whereas data on the fuel mix can be obtained from the IEA Balances [43].

Most of these indicators are retained for the policy analysis (requiring a future percentage or growth rate value as input). An exception is that the link between total cement and total clinker production is made more explicit by calculating another indicator: the ratio of locally *processed* clinker to locally *produced* clinker. (If this indicator is >100%, this indicates that the country, to some extent, uses imported clinker in its cement production; conversely, a number <100% indicates that not all clinker produced in the country is used for cement production in that country, and most likely used for exports.) This prevents potentially inconsistent projection time series of cement and clinker production.

Table 18. Historical input data for cement sector

Indicators	Units	Suggested data sources
Cement production	Mt cement	[60] or [61]
Clinker / cement ratio	%	
Total clinker production	Mt clinker	
Electricity intensity of cement production	TWh / Mt cement	[61]
Direct energy intensity of clinker production	PJ / Mt clinker	
Direct energy fuel mix	% share	[43] (category “non-metallic minerals”)
Process emission intensity	$MtCO_2e$ / Mt clinker	Global value of 0.507 tCO_2 / t clinker from the IPCC guidelines [60]
Emissions captured with CCS	% of process and direct energy emissions	-

Table 19. Policy scenario input for cement sector

Indicators	Units	Input required
Cement production	Mt cement	% growth rate
Clinker / cement ratio	%	% ratio
Ratio of locally processed clinker to locally produced clinker	%	% ratio
Electricity intensity of cement production	TWh / Mt cement	% growth rate
Direct energy intensity of clinker production	PJ / Mt clinker	% growth rate
Direct energy fuel mix	% share	% share
Emissions captured with CCS	% of process and direct energy emissions	% captured

“OTHER” INDUSTRY SECTOR

Due to low data availability in industry sectors outside of cement and steel, the other industrial sectors are lumped together in PROSPECTS to form a simplified representation of a range of diverse activities. In the context of the IEA Energy Statistics and Balances [43], the “other” industry is divided into *Heavy industry* and *Light industry*.

The *Heavy industry* includes the following categories in the IEA Energy Statistics and Balances: Chemicals and petrochemicals, Non-ferrous metals, Transport equipment, Machinery, Mining and quarrying. The *Light industry* includes: Food and tobacco, Paper, pulp, and print, Wood and wood products, Construction, Textile and leather, Non-specified (industry)[4].

In the PROSPECTS approach, light and heavy industry are separated because of potential substantial differences in fuel mix (shown for the EU-28 in Figure 7), as well as in measures and opportunities for energy efficiency improvement

[4] This could theoretically be either heavy or light industry. It is counted under “light industry” in PROSPECTS.

between heavy and light industry types, which would influence future emissions pathways differently. For instance, the "light" industry types in the EU-28 had significantly higher shares of e.g. biofuels and renewables than heavy industry types.

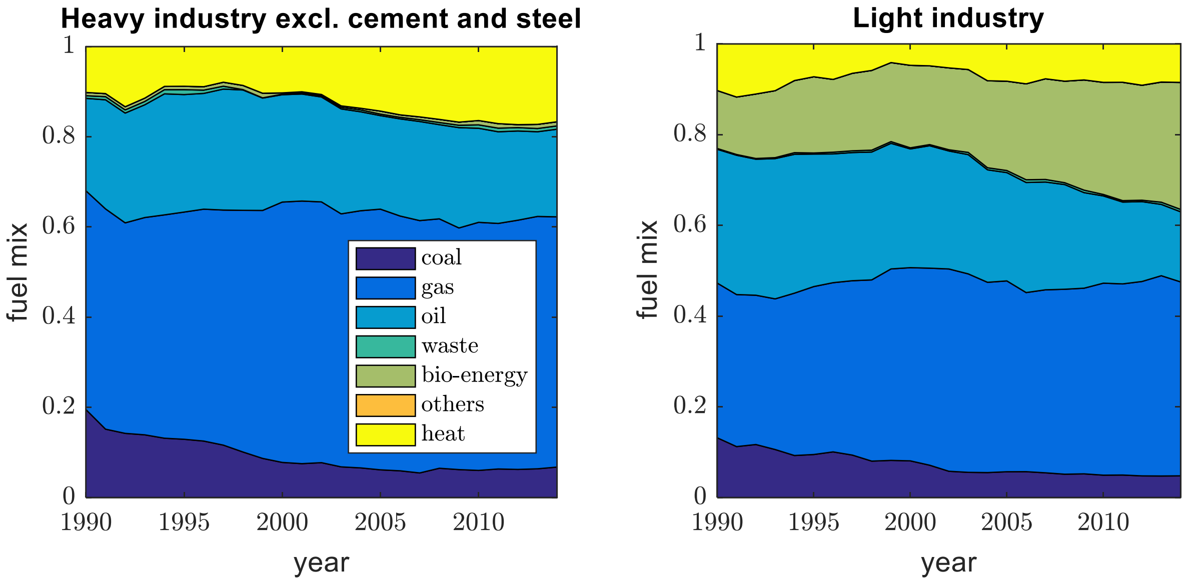


Figure 7: Fuel mix in heavy industry excl. cement and steel, as well as in light industry, for the EU-28, from [43].

Table 20 and Table 21 show the historical input data and policy scenario input needed for the "other" industry sector in the PROSPECTS tool.

The simplified approach distinguishes between direct energy and electricity demand in "other" heavy and light industry, which can be obtained from the IEA Energy Statistics and Balances [43]. The activity indicator is the gross value added (GVA) in the "other" industry. If data is not available for precisely the range of items listed above, the total value added in industry could be used as a proxy.

Process emissions in the "other" industry consist of a wide variety of categories, including limestone and dolomite use, road paving with asphalt, and emissions of halocarbons. These are available for all Annex I countries from the UNFCCC [62]. These emissions will not be explicitly modeled in PROSPECTS. For the policy projection, they will get the same growth rate as overall GVA of the "other" industry.

Table 20. Historical input data for "other" industry

Indicators	**Units**	**Suggested data sources**
Value added in "other" industry	million USD 2012	[63]
Direct energy demand in "other" industry (heavy / light industry)	PJ	[43] (category "industry" minus "iron and steel" and "non-metallic minerals")
Electricity demand in "other" industry (heavy / light industry)	TWh	
Direct energy fuel mix (heavy / light industry)	%	
Process emissions	$MtCO_2e$	UNFCCC for Annex I countries; national sources and/or rough estimates for other countries
Emissions captured with CCS (heavy / light industry)	% of process and direct energy emissions	

Table 21. Policy scenario input for "other" industry

Indicators	Units	Input required
Value added in "other" industry	million USD 2012	% growth rate
Total energy intensity of GVA (heavy / light industry)	PJ / million USD 2012	% growth rate
Electrification rate in "other" industry (heavy / light industry)	% electricity in energy demand	%
Direct energy fuel mix (heavy / light industry)	% share	% share
Emissions captured with CCS (heavy / light industry)	% of process and direct energy emissions	% captured

OIL & GAS SECTOR

The oil and gas sector in PROSPECTS refers to upstream and midstream emissions from oil and gas extraction, i.e. from gas flaring and fugitive methane emissions.

Input data (Table 22) partly consists of fugitive emissions, which can be obtained from the EDGAR database [64]. This includes fugitive emissions of CH_4, CO_2 and N_2O that may occur as a result of oil and gas extraction [65]. Other data series needed are the total amount of flared gas [66] and the total production volumes of oil and gas. The conversion from gas flaring to emissions is done via a constant value representing the emission factor of flared gas (tCO_2 / Gm^3 gas). In reality, this factor differs per country and indeed per installation [65], but this level of detail is outside the scope of this research.

These data series are converted to two other indicators for the policy scenarios (Table 23): the flaring ratio (defined as % share of gas flared) and the fugitive emissions intensity (tCH_4 / Mtoe). The first is dependent on flaring practices; the second is a rather volatile indicator when looking at historical data series, so while it might not be directly relevant to policy analysis, taking it by default as a constant value is reasonable. It is to be noted that such values always represent average emission factors at country/region level and can thus not be applied to individual or small numbers of installations [65].

Table 22. Historical input data for oil and gas sector

Indicators	Units	Suggested data sources
Fugitive emissions	tCH_4	[64]
Amount of gas flared	Gm^3	[66]
Total production of oil & gas	Mtoe	[43]

Table 23. Policy scenario input for oil and gas sector

Indicators	Units	Input required
Total production of oil & gas	Mtoe	% growth rate
Fugitive emissions intensity	tCH_4 / Mtoe	% growth rate
Flaring ratio	%	%

WASTE SECTOR

Emissions in waste sectors can come from municipal solid waste and wastewater treatment.

Municipal solid waste

Emissions from municipal solid waste (MSW) are primarily due to the release of landfill gas from anaerobic decomposition of waste material in landfills. This means that there is no simple link between the yearly waste production and the total emissions from waste, since waste from previous years on landfills is still contributing to the production of landfill gas.

The waste module in PROSPECTS does not attempt to calculate these emissions using the method taking into account the first order decay as presented by the IPCC [67]. The simplified approach is based on data on MSW generation [68] and emissions time series from solid waste [62], [69].

The model needs an estimation of the amount of MSW sent to landfills and of historical emissions from landfills, which are used to calculate the landfill emissions intensity indicator. This indicator can reflect better landfill management practices in the policy scenarios. The amount of MSW sent to landfills in the future and the landfill emissions intensity then gives the emissions pathway.

The waste generation pathway for the policy scenarios is constructed using the waste generation per capita as indicator, which can be related to e.g. socio-economic indicators such as GDP per capita.

To ensure that waste-to-energy (WtE) generation in the power and heat supply sector is consistent with the waste module, a consistency check will be made in the model to assess whether, for instance, the estimated amount of waste sent to landfill is compatible with the implied amount of WtE generation in the power and heat supply sectors (using estimations of the average energy content of waste used for energy generation).

Wastewater

The PROSPECTS approach also contains a small module dealing with wastewater. The input needed for the module is the total production of wastewater and the wastewater treatment rate, which also serve as indicators for the policy scenario. An estimation of the emissions intensity of wastewater is used to calculate overall emissions.

Data on many countries can be obtained for instance from the AQUASTAT database of the FAO [70]. Data on emissions could be cross-checked with the approach advocated by the IPCC on wastewater [71].

Table 24. Historical input data for the waste module

Indicators	Units	Suggested data sources
Amount of MSW generated	kt	[68]
Share of MSW sent to landfill	%	National statistics; estimations from recycling rate, composting rate.
Emissions from landfills	tCH_4	[62], [69]
Amount of wastewater generated	t BOD	[70]
Wastewater treatment rate	%	

Table 25. Policy scenario input for the waste module

Indicators	Units	Input required
Waste generation per capita	t / cap	% growth rate
Share of MSW sent to landfill	% share	% share
Landfill emissions intensity	tCO_2e/t waste landfilled	% growth rate
Amount of wastewater generated	t BOD	% growth rate
Wastewater treatment rate	%	% share

AGRICULTURE SECTOR

In the agriculture sectors, PROSPECTS distinguishes between energy-related emissions and non-energy-related emissions from various agricultural sources. The former category is treated in the same way as the energy-related emissions in e.g. the buildings and industry sectors: with input data on direct energy and electricity use based on the IEA Energy Statistics and Balances [43], and using total agricultural GVA as activity indicator.

The non-energy-related emissions from agriculture are split into three overall emission types in PROSPECTS, as follows:

Animal-related emissions: Emissions from enteric fermentation; Emissions from manure management, manure applied to soils, manure left on pasture. **Rice-related** emissions: Emissions from rice cultivation. **Other land-related**[5] emissions: Emissions from synthetic fertiliser usage; Emissions from crop residues; Emissions from cultivation of organic soils.

While the agricultural emissions profile in each country will be dominated by a few of these types of emissions, these profiles differ significantly between countries and thus none of these categories can be left out of an explicit activity/intensity indicator calculation in PROSPECTS, to ensure applicability across all countries. Input data for these categories is needed directly in terms of emissions, unlike in most other sectors (except the oil & gas upstream emissions, solid waste emissions, and process emissions in other industry, where a similar approach is used).

Table 26. Historical input data for agriculture

Indicators	Units	Suggested data sources
Energy-related		
Direct energy use in agriculture	PJ	[43]
Electricity use in agriculture	GWh	
Direct energy fuel mix	%	
Total GVA of agriculture	USD 2012	[72]
Animal-related		
Emissions from enteric fermentation	$MtCO_2e$	[73]
Stock of animals responsible for enteric fermentation (i.e., total amount of mammal livestock)	#	
Stock of animals (total mammal livestock + total poultry livestock)	#	
Emissions from manure management / manure applied to soils / manure left on pasture	$MtCO_2e$	

5 According to IPCC guidelines, the categories "burning of crop residues" and "savanna burning" are not to be included in inventory totals but only "noted for information" [115].

Table 26. Historical input data for agriculture (Continued)

Indicators	Units	Suggested data sources
Rice-related		
Emissions from rice cultivation	$MtCO_2e$	[73]
Area harvested for rice paddy	ha	
Other land-related		
Emissions from synthetic fertilizer, crop residues and cultivation of organic soils	$MtCO_2e$	[73]
Total area of grassland and cropland organic soils	ha	

Table 27. Policy scenario input for agriculture

Indicators	Units	Input required
Energy related		
GVA of agriculture	USD	% growth rate
Total energy demand per GVA in agriculture	PJ / USD GVA	% growth rate
Electrification rate in agriculture	%	% share
Direct energy fuel mix	%	% share
Animal-related		
Emissions from enteric fermentation per animal	$MtCO_2e$ / animal	% growth rate
Emissions from manure per animal	$MtCO_2e$ / animal	% growth rate
Total mammal livestock	#	% growth rate
Total poultry livestock	#	% growth rate
Rice-related		
Emissions from rice cultivation per hectare	$MtCO_2e$ / ha	% growth rate
Area harvested for rice paddy	ha	% growth rate
Other land-related		
Emissions from synthetic fertilizer, crop residues and organic soil cultivation use per hectare of grass/cropland	$MtCO_2e$ / ha	% growth rate
Total area of grassland and cropland organic soils	ha	% growth rate

3.2.3 Validation

Since the PROSPECTS tool will construct an overall emissions scenario based on sector-level indicators data which would be collected from different sources, the resulting emissions time series will deviate to some extent from authoritative emissions time series from the country's own projections or other external sources. In order to make sure that the user can check and calibrate the PROSPECTS outputs against other emissions scenarios, a *Data Validation* sheet has been designed in the tool, as mentioned in the previous content.

The important questions that needs to be considered is whether or not such deviations are acceptable considering the particular simplifications, assumptions and data sources used in PROSPECTS as compared to other scenarios. If considered inacceptable, the following reasons for the deviation will need to be considered:

- **Coincidental errors**: Can the deviation be (partly) attributed to input data that is faulty? I.e. are the wrong numbers being fed into the calculations? This could include data whose value is inaccurate, or data whose definition deviates from what is actually needed in the tool.
- **Systematic errors**: Are all sources of emissions being considered or have any elements been left out in the calculations? This may include elements that are of no importance in one country but more significant in another. Similarly, are any sources of emissions being double-counted?

After the reasons for the deviation have been identified, corresponding modifications in the tool should be made until acceptable results can be obtained.

3.3 Situation in South Africa

To do a case study for South Africa, the current situation in this country regarding emissions and decarbonization should be first analysed. In this section, the historical emission trends in this country will be analysed to identify the key emitting sectors. Key overarching policies will also be introduced to provide an overview of the policy situation. Then historical trends and policies in the identified key sectors will be studied to prepare for the policy assessment, which will be described in the next section.

3.3.1 General introduction

As mentioned in *Chapter 1*, South Africa was the 16th largest emitter of CO_2 in the world in 2013 and the largest emitting country on the continent of Africa. Given the important role of mining and energy-intensive industries in the country, South Africa has an energy-intensive economy. And given the reliance on coal-based electricity, it is also emissions-intensive: coal supplies 93% of its electricity generation, with 90% of the total electricity produced by the state-owned electricity utility, Eskom [74].

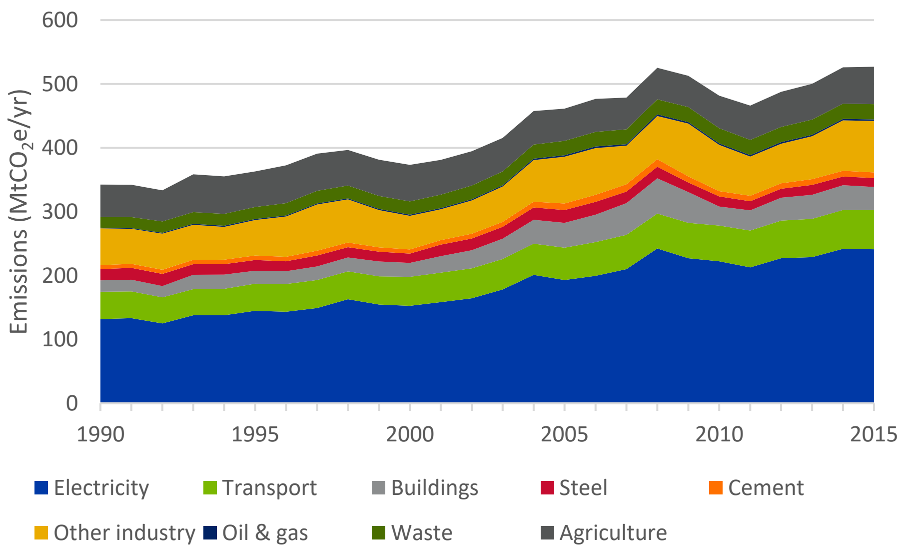


Figure 8. Historical emissions in South Africa, with electricity related emissions allocated to the electricity sector, from PROSPECTS

Figure 8 shows the historical emission trends in South Africa generated by the PROSPECTS tool developed in this research. Data sources used to reconstruct this emission trend are listed in Appendix 3. The total national emissions in South Africa are currently around 530 Mt CO_2e per year (excluding emissions from LULUCF). When attributing electricity use related emissions to the electricity sector, the electricity generation sector accounts for 42% of the total emissions and the transport sector accounts for 12% of the total emissions. Moreover, emissions have increased by 83% in the electricity sector and 43% in the transport sector in the period 1990-2015. Thus, those two sectors should be main focal points of the future decarbonization.

Table 28 lists key overarching policies, plans and targets in South Africa. The National Development Plan released in 2011 is the first national development plan for South Africa, which underpins policies and frameworks going forward [75]. It targeted an annual GDP growth rate of 5.4% and proposed to install at least 20 GW of electricity generation capacity from renewable sources by 2030.

The National Climate Change Response White Paper (NCCRWP) of 2011 presents a vision for an effective climate change response and the long-term transition to a climate-resilient low-carbon economy and society, which is very comprehensive. It proposed a set of mitigation policies including carbon tax, carbon budgets, along with a number of other.

As part of the implementation of the NCCRWP, the national treasury of South Africa announced in the budget speech in 2013 to start the carbon tax from January of 2015 [76]. Then in 2014, the start date was delayed to January of 2016 [77]. However, the carbon tax bill remains at draft phase as of July 2017. Since it has been delayed for several times, there is a huge uncertainty of when the carbon tax may come into force. The carbon budget, which is also proposed by the NCCRWP, has been implemented on a very small scale, with 18 companies participating voluntarily until 2020. The voluntary scheme is not expected to achieve emissions reductions, rather its primary goal is to inform the design of the mandatory process which is planned to be effective from 2020 [78].

Moreover, in 2015, South Arica pledged in its INDC to follow a Peak, Plateau and Decline (PPD) emissions trajectory by 2020 and manage to keep national emissions in the range between 398 and 614 Mt CO_2e by 2025 and 2030.

Table 28. Key overarching policies, plans and targets in South Africa

Name of policy, plan or target	Time	Description
National Development Plan (NDP)	2011	A comprehensive national development plan until 2030. With an assumption of 5.4% annual GDP growth rate and a proposal to install at least 20 GW of electricity generation capacity from renewable sources by 2030.
National Climate Change Response White Paper (NCCRWP)	2011	Key components include carbon tax, carbon budgets, Peak, plateau and decline (PPD) trajectory and Renewable energy flagship program (REIPPPP), a National GHG Emissions Reporting System and Inventory, sectoral mitigation strategies.
Carbon Tax	2013	R120 per ton of carbon dioxide equivalent (CO_2e) on direct emissions and will increase by 10% p.a. until 2020. All sectors are covered except for agriculture, forestry and land use (AFOLU) and waste.
INDC target South Africa 2015	2015	Promised to start a Peak, Plateau and Decline (PPD) trajectory in 2020. Emissions by 2025 and 2030 will be in a range between 398 and 614 Mt CO_2e.

3.3.2 Power generation

As shown in Figure 9, coal has dominated the fuel mix for electricity generation over the period 1990-2015 in South Africa with a share larger than 90%. Because of its significantly larger emission intensity than other fuels, coal accounts for nearly 100% of the emissions from electricity generation. Apart from coal, nuclear and hydro have generated around 6% of the electricity over the period. In recent years, wind and solar have been added to the fuel mix to meet the increased electricity demand. However, the current share of wind and solar power is only around 1%.

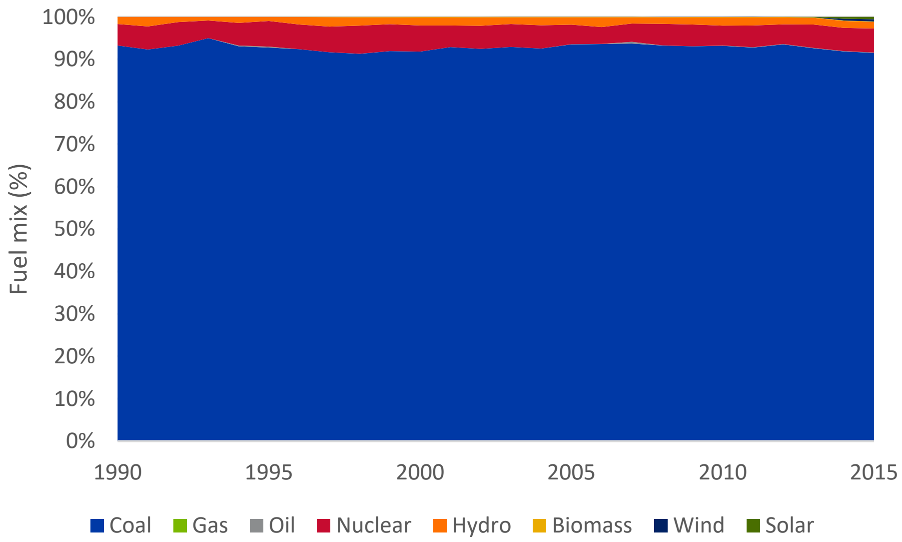


Figure 9. Historical fuel mix for electricity generation, South Africa, from [43]

Table 29 summaries key policies in the electricity sector. The Integrated Resource Electricity Plan 2010-2013 (IRP 2010) released in 2011 is a key policy in the electricity sector. It estimates the demand profile for electricity until 2030 and plans in detail how this demand can be met from different sources such as coal, nuclear, and renewables. It has been updated in 2013 and 2016[6] respectively, but the first version is still the official IRP. The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), replacing the originally proposed feed-in-tariff scheme to incentivise RE growth, is a competitive bid public procurement programme aiming to increase the share of renewable energy in electricity generation and to achieve the targets set in the IRP. REIPPPP has been a quite successful policy: more than 6327 MW electric capacity from 102 renewable energy projects have been awarded through this programme since 2011 [79].

Table 29. Key policies in the electricity sector, South Africa

Policy name	Time	Description
Integrated Resource Electricity Plan 2010 – 2030 (IRP)	2011	Provision for 9.6 GW of nuclear power, 6.3 GW of coal power, 11.4 GW from renewable energy sources and 11.0 GW from other generation sources by 2030. Proposed an emissions constraint of 275 million tons per year on electricity industry throughout the period 2010-2030.
Renewable Energy Independent Power Producer Procurement Programme (REIPPPP)	2011	A competitive bid public procurement programme aiming for an initial target of 3,725 MW installed renewable energy in five different rounds by 2015. Determined a further 3,200MW of renewable generation capacity by 2020.

3.3.3 Transport

The transport sector currently accounts for around 16% of the total emissions in South Africa, while passenger transport accounts for around 80% of the transport emissions. In the period 1990-2015, emissions from passenger transport have increased 56%, while the emissions for freight transport have increased 26%, according to the calculations in this study.

For passenger transport, personal vehicles cover around 63% in the modal split but contribute to 83% of the emissions. Minibus-taxies also have a large share in the modal split (27%) and account for 8% of the emissions. Although energy efficiency for vehicles has improved, the personal vehicles still depend largely on gasoline and the buses (including minibus-taxis) still depend largely on diesel. Little has happened regarding electric vehicles or biofuel blending.

[6] The 2016 IRP update is still undergoing public comments. It is expected to be finalised in early 2018.

For freight transport, trucks have a share of around 56% in the modal share and contribute to 86% of the emissions, which reflects the fact that trucks are more emission-intensive per tonne-kilometre than trains.

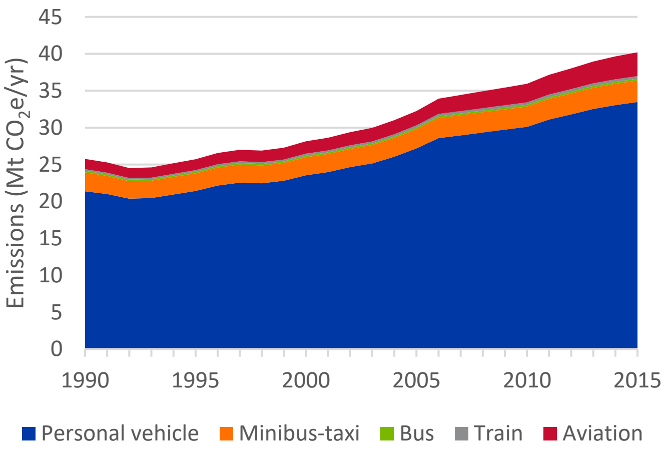


Figure 10. Historical emissions of passenger transport, South Africa, from PROSPECTS

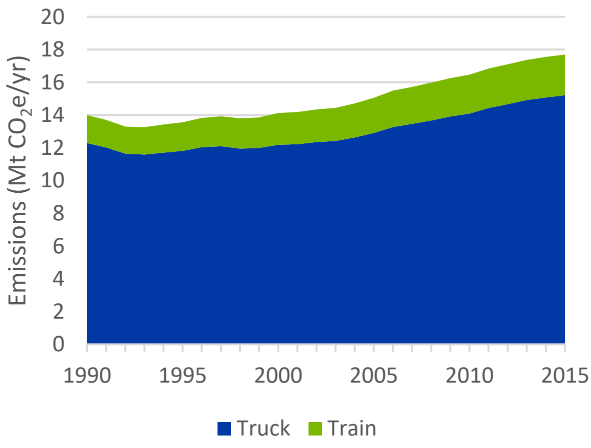


Figure 11. Historical emissions of freight transport, South Africa, from PROSPECTS

Key policies in the transport sector in South Africa are listed in Table 30. The public transport strategy in 2007 has proposed two targets in public transport: accelerated modal upgrading and integrated rapid public transport networks [80]. Accelerated modal upgrading refers to upgrading bus, taxi and rail service delivery in the short to medium term; integrated rapid public transport networks refer to implementing high quality networks of Rail Priority Corridors and Bus Rapid Transit (BRT) Corridors in especially metro cities. Since then, substantial progress has been made on the Bus Rapid Transit policy. BRT systems started operation in 2010 in three large cities of South Africa for the World Cup, which have been expended to more cities afterwards. As of July 2017, there has been eight cities with BRT systems in operation or under construction. The South Africa government has also announced a regulation in 2012 regarding mandatory blending of biofuels with petrol and diesel. The regulation should have come into effect in October 2015, but in fact it has not been implemented as of July 2017. Moreover, there has been a strategy to switch freight transport from road to rail, with a target of increasing the share of rail in freight transport by 2% per annum over a period to 2019. However, not much has been done yet to implement this target [81].

Table 30. Key policies in transport sector, South Africa

Policy name	Time	Description
Public Transport Strategy	2007	Two key thrusts: Accelerated Modal Upgrading and Integrated Rapid Public Transport Networks. A further goal for the metropolitan cities by 2020 is to achieve a mode shift of 20% of car work trips to public transport networks.
Bus Rapid Transit (BRT)	2010	BRT systems, MyCiTi in Cape Town, the Rea Vaya in Johannesburg and Libhongolethu in Nelson Mandela Bay, started operation for 2010 World Cup. Expanded in more cities in recent years.
Regulations Regarding the Mandatory Blending of Biofuels with Petrol and Diesel	2012	Government announced a minimum concentration of 5% for biodiesel and 2% for bioethanol to come into effect in October 2015, but not implemented yet.
Strategic Plan 2015/16-2019/20	2015	Department of transport will develop a Road Freight Strategy and target to increase the share of rail in freight transport by 2% per annum over a period to 2019.

3.4 Policy scenarios for South Africa

With the PROSPECTS tool developed and the policy situation in South Africa analysed at national level and in the electricity and transport sectors, how to construct policy scenarios for South Africa will be analysed in this section. Figure 12 reveals how the policy assessment and the modelling tool are connected in this study.

As explained before, in order to get emission projections from the modelling tool, policy scenarios are needed as input. The aim of the policy assessment is to get the policy scenarios. In the process of policy assessment, policies in the country of question will be first collected to identify the key policies. Then, decarbonization indictors which will be influenced by the key policies will be identified, after which the impacts will be quantified. Projected future values of influenced indicators are obtained as the results of the policy assessment, which constitute the policy scenarios in the modelling tool.

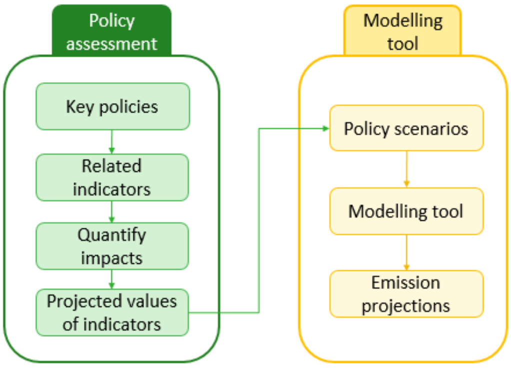


Figure 12. Connection between policy assessment and modelling tool

Based on the introduction in *section 3.3*, three scenarios will be constructed in this research: a **"business-as-usual" (BAU) scenario**, a **current policy scenario**, and a **new policy scenario**. The **BAU scenario** serves as a baseline scenario in this study. According to IPCC [82], it is assumed in the BAU scenario that future development trends follow those of the past and no changes in policies will take place. The **Current policy scenario** represents the most possible emission trends considering current policies and their implementations. The **New policy scenario** assumes several more policies will be taken in the future to further reduce emissions. The details of the three scenarios will be given in the following paragraphs.

3.4.1 BAU scenario

It is assumed no policy measures will be implemented in the future to reduce emissions in the BAU scenario, but social-economic indicators such as population and GDP can still have broad influence on future emissions and thus should be taken into consideration. Projections of them until 2030 are taken from external sources: the future population is taken from UN projections [83]; the average annual growth rate of GDP is assumed to be the same as in the IEA ETP 2016 [84]**.** It should be noticed that although a 5.4% annual GDP growth rate is expected in the National Development Plan of South Africa, the actual annual growth rates have been only around 1% in recent years. Moreover, South Africa has slipped into a recession after its GDP declined 0.7% during the first quarter of 2017 [85], before which the GDP had slow growth rates of roughly 1% for most of 2016 [86]. Since inappropriate assumptions about GDP can have a significant influence on emissions trajectories, it is important to draw attention to the recession. Thus, lower values of GDP growth rate as assumed in [84] are used in this scenario (Table 31).

Table 31. Assumption of population (million capita) [83] *and GDP annual growth rate (%)* [84] *in South Africa*

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Population	54.98	55.44	55.87	56.28	56.67	57.05	57.41	57.76	58.10	58.44	58.76	59.09	59.41	59.72	60.03
GDP growth rate	2.3%	2.3%	2.3%	2.3%	2.3%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%

Based on historical trends and literature [87], the following indicators are assumed to be influenced by GDP and have the same annual growth rate as GDP: cement production, steel production, transport activity, GVA in “other” industry, and GVA in agriculture. The wastewater generation is assumed to have the same annual growth rate as population according to historical trend. Other indicators which constitute the policy scenario are assumed to follow their own historical trends, which basically means the extrapolation of their recent historical data.

Since different indicators have different historical trends, the future values of a certain indicator will follow the trend of which exact time period is the judgement of the author based on the analysis of historical data in the period 1990-2015. For example, Figure 13 shows the emission intensities by fuel type for minibus-taxis in South Africa. It can be found that emission intensities for both fuel types decreased fast in the period 1990-2005 and flattened since 2005. It is reasonable to assume, in the context of a BAU scenario, that the trend in the period 2005-2015 can better represent the current situation than that in the period 1990-2005. Thus, it is assumed in this study that the emission intensity of minibus-taxis in South Africa will follow its trend in the period 2005-2015 under the BAU scenario.

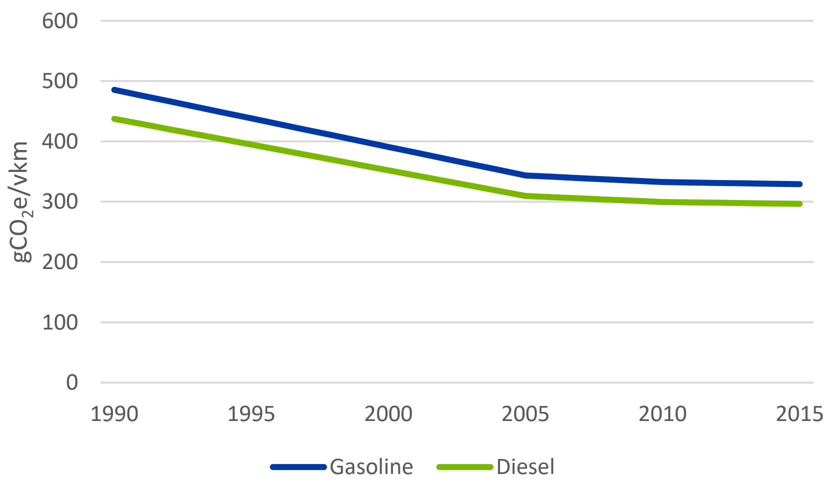


Figure 13. Emission intensity by fuel type for minibus-taxi, South Africa, data sources see Appendix 3

3.4.2 Current policy scenario

The current policy scenario is based on the BAU scenario and considers additionally the impacts of current policies. As introduced in section 3.3, there are mainly two policy areas that are being implemented to reduce emissions: one is to promote the uptake of renewable energy (RE), i.e., solar and wind, in electricity generation and the other is to develop BRT systems in transport sector. Their impacts will be assessed as following:

RE (WIND AND SOLAR) UPTAKE

The IRP 2010 and REIPPPP policies in South Africa focus on increasing the capacity of wind and solar energy in electricity generation. Those policies will influence future emissions by directly influencing the fuel mix in the electricity sector. Thus, how to predict the future share of wind and solar energy in the fuel mix will be analysed here. The methods described in this section are the joint work of the author of this thesis and various analysts in NewClimate Institute.

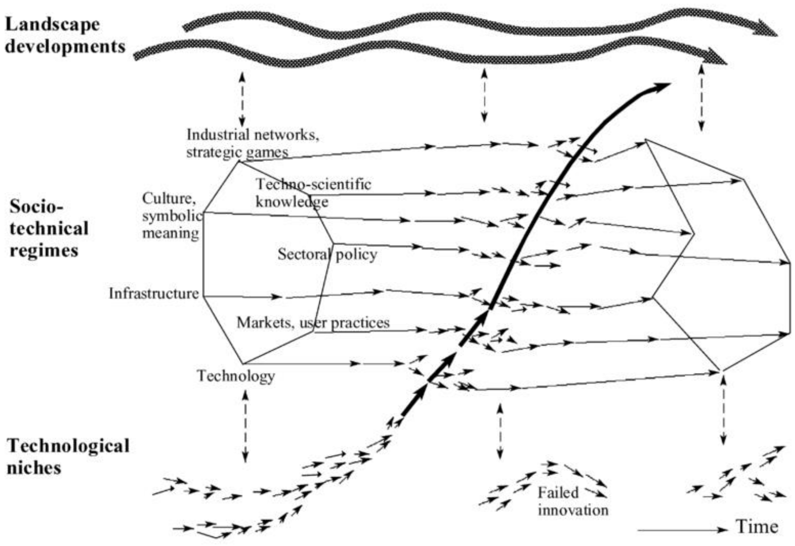


Figure 14. A dynamic multi-level perspective on technology uptake, taken from [88].

Figure 14 shows a schematic depicting a dynamic multi-level perspective on technology uptake [88]. The development of a technology innovation is influenced by several factors including user practices, markets, and policies. When a technology innovations first appears, the uptake process is generally slow due to lock-in of traditional technologies. Along with their development and commercialization, the performance improves and the cost reduces, which can accelerate the uptake processes [89]. This will lead to a regular ongoing incremental period, represented with relatively long upgoing arrows in Figure 14. As the technology further develops and mainstreams, the markets near saturation, and the uptake speed will slow down again. In general, the technology uptake process can be conceptualized in terms of a logistic curve or "**S-curve"**, which is for instance demonstrated by the historical adoption trends of many technologies in the U.S. shown in Figure 15.

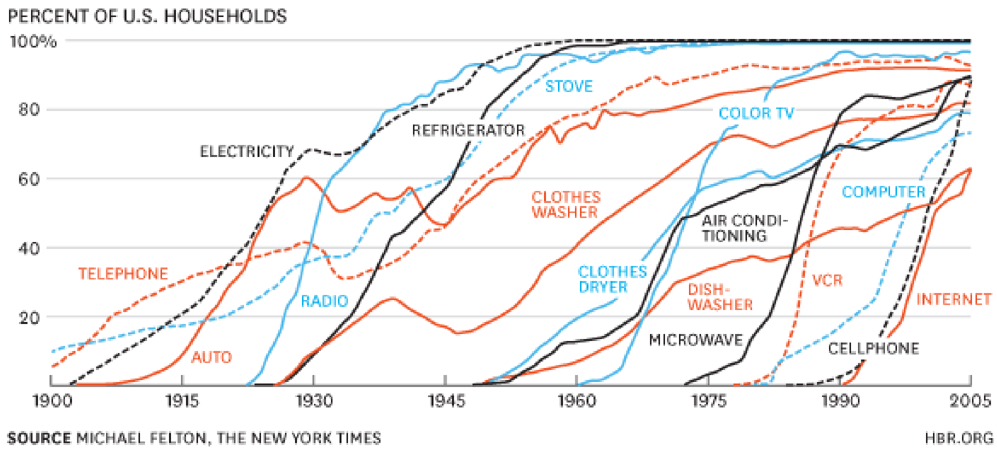


Figure 15. Technology adoption trend in U.S., from [90]

In this research, it is assumed that uptake processes of wind and solar power technologies will follow S-curves. Policies are assumed to influence their upper limit of penetration (saturation level) and uptake speed in time, as shown in Figure 16. Historical data will determine the initial part of the S-curve. From the base year, which is 2015 in this research, three scenarios will be analysed: a good practice scenario, a no-policy scenario, and a current policy scenario, among which the **good practice scenario** and **no-policy scenario** are **benchmark scenarios**. The good practice scenario assumes that currently implemented best-practice policies will be implemented in the future, which determines the upper limits of the penetration rate and the penetration speed. The no-policy scenario assumes that in the future, no policy will exist to support renewable energy, which determines the lower limits of the penetration rate and the penetration speed. It is assumed that any policy scenario will result in uptake curves in between these two extremes.

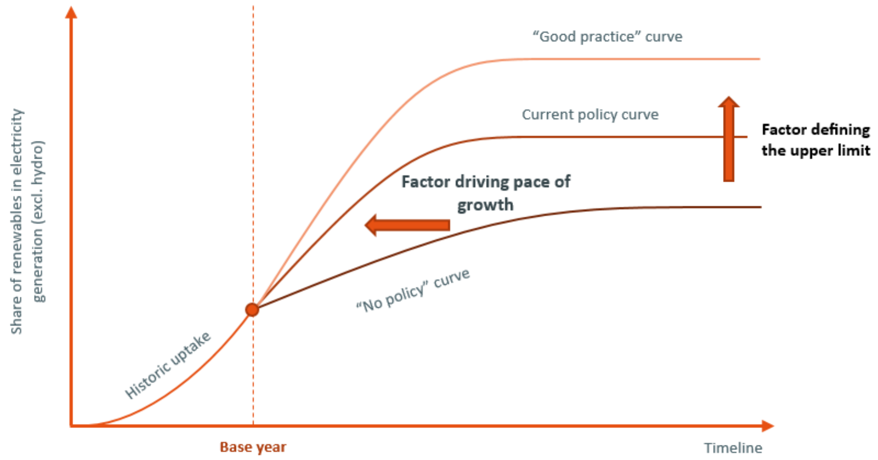


Figure 16. Schematic diagram of assessing policy impacts on RE uptake with S-curve [91].

With upper and lower limits of the S-curved determined, the current policy curve can be analysed. The **current policy curve** here depicts a path in which policies and measures that are already in place by early 2017 will be considered, but aims, targets and intentions that have been announced without having led to additional policy measures cannot be taken for granted. By comparing situations in the current policy scenario with those in the good practice scenario and in the no-policy scenario, factors which drive growth speed and define the saturation level of the S-curve will be quantified, and projections for the current policy curve for share of wind and solar power will be obtained. In this research, Denmark is taken as a good practice model for RE uptake to get the "good practice" curve, as it has the best framework conditions in the world when it comes to access to energy, energy efficiency and renewable energy according to the World Bank [92], with the share of electricity generated by renewable energy in Denmark increasing from 28.1% in 2007 to 57.4% in 2014 [92]. The "no policy" curve is constructed based on expert judgement.

To determine the current policy curve of RE uptake in South Africa, the impact of policies and drivers are modelled by shifting the S-curve between the "no policy" and "good practice" curves using a *factor defining the upper limit* and a *factor driving the pace of growth*, each of which is a number between 0% and 100%. The *factor defining the upper limit* determines the upper maximum penetration rate (i.e., saturation level of share in fuel mix) of wind and solar that can be achieved in the long-run. A value of 0% means that the saturation level is equal to the "no policy" case, whereas 100% means that the saturation level is equal to the "good practice" case. The *factor driving the pace of growth* determines the growth rate of the share of wind and solar in total electricity generation, i.e. the time to reach 99% of saturation level. A value of 0% means that the growth rate is equal to the "no policy" case, whereas 100% means that the growth rate is equal to the "good practice" case.

Each of the two factors is a number that represents the aggregated quantification of a set of metrics theorized to be important drivers for the speed of uptake and saturation level of wind and solar in total electricity generation. The selection of metrics for both factors are listed in Table 32 and Table 33. The aggregated quantification for both factors will be explained in the following.

Table 32. Metrics for the factor driving pace of growth, based on [93] [94] [95]

Metric (M)	Measured in	Lower boundary value (M_l)	Upper boundary value (M_u)	Weighting (w)
Level of support from support scheme(s)	Ratio of RE provided by incentive schemes to total additional RE generation according to "best practice" case	0% - No or very unambitious incentive	100% - RE support schemes totally aligned with best practice development	90%
Long term target	Ratio of targeted share of RE to share of RE in target year according to "best practice" case	0 - No or very unambitious long term target	100% - Long-term target totally aligned with best practice development	10%
Permit granting procedure	Existence of One-Stop-Shop, Online application, Maximum time limit for procedures, Automatic permission after deadline and Facilitated procedures for small-scale producers	0 - None of administrative services exists	2 - All administrative services exist in country	-15%
Siting/Zoning	Administrative identification of geographical sites	0 - No administrative identification of geographical sites	2 - Existing administrative identification of geographical sites [96]	-15%

Taking the *factor driving pace of growth* as an example, it is quantified by four metrics, as shown in Table 32. Each metric M is compared to a lower bound M_l and upper bound M_u of this metric, after which a ratio R is calculated. For metrics with positive weightings, their existence will be incentives of the uptake of RE, and their ratio R_i will be calculated with the following formula:

$$R_i = \frac{M - M_l}{M_u - M_l}$$

For the metrics with negative weightings, their absence will be barriers of the uptake of RE, and their ratio R_b will be calculated with the following formula:

$$R_b = \frac{M_u - M}{M_u - M_l}$$

In cases where $M \leq M_l$ or $M \geq M_u$, the value of R remains 0% and 100%, respectively.

The value of the *factor driving pace of growth*, represented with *F,* will be then obtained with the following formula:

$$F = \sum_{n=1}^{N} R_i \cdot w_n * (1 + \sum_{m=1}^{M} R_b \cdot w_m)$$

where $N = 2$ is the number of incentive metrics, and $M = 2$ is the number of barrier metrics.

The value of the *factor defining upper limits* can be obtained with the four metrics listed in Table 33 by using the same method. The only difference is there is no R_b for the *factor defining upper limits.*

Table 33. Metrics for the factor defining upper limits

Metric (M)	Measured in	Lower boundary value (M_l)	Upper boundary value (M_u)	Weighting (w)
Grid transmission and distribution and interconnection	Total connection capacity as share of electricity generation capacity (based on data in [97])	0% - No transmission and interconnection	100% - Full transmission and interconnection	25%
Markets supporting integration of variable RE sources [98]	Level of market support for the integration of RE sources	0 - No efforts around markets to increase flexibility	2 –Both measures to increase flexibility of markets and capacity markets are introduced	40%
Demand-side management (DSM) [99]	Extent to which DSM is enabled	0 - No serious engagement with Demand-side Response reforms	2 – Enables both Demand-side Response and independent aggregation	25%
Storage capacities	Storage capacity (existing/planned) as share of total installed capacity (based on Eskom data[100])	0% - No storage capacity	18% - Good practice storage capacity of Germany	10%

BRT DEVELOPMENT

The potentials of BRT to reduce emissions are mainly reflected in the following aspects:

1) Larger load factor than traditional buses. The capacity of traditional buses is typically 80 passengers in South Africa [101], while that for BRT is up to 160 passengers [102]. The Rea Vaya BRT, South Africa's first BRT system, has a capacity of 112 passengers [101], so it is assumed in this study that the average capacity for BRT systems in South Africa is 112 passengers. The average occupation rate for traditional buses is around 24%, while BRT systems have a higher occupancy rate, generally ranging from 20% to 90% [101]. This study assumes 50% as an average occupation rate for South Africa. Thus, the assumed load factor for BRT is calculated from the following equation:

$$\text{Load factor} = \text{Capacity} * \text{Occupation rate} = 112 * 50\% = 56\ (\text{pkm/vkm})$$

2) Lower emission intensity. Compared with traditional buses, BRT has new and cleaner vehicles and thus has lower emission intensity. According to [103], the emission intensity of BRT is assumed to be 301 gCO_2e/vkm, which is around 20% lower than the current emission intensity of traditional buses in South Africa.
3) Induced modal shift from more emissions-intensive modes to BRT. Currently, nearly 64% of minibus-taxis and 50% of buses in South Africa are older than their expected lifespan [104], BRT systems can gain ridership from minibus-taxis, buses, and also personal vehicles.

Assumptions on the BRT-induced modal shift are more complex than that for load factor and emission intensity, since it is largely influenced by the characteristics of BRT projects and the BRT projects are implemented at a city level. Different cities have different plans for BRT systems. Thus, the analysis of the BRT induced modal shift starts from city level in this study, as shown in Figure 17. It is assumed that the share in modal split which BRT gains in a city mainly depends on the status of the BRT project. A study about the MyCiti BRT in Cape Town, South Africa , has modelled that BRT will have a share of 20% in modal split of Cape Town in peak hours [101]. Thus, it is assumed in this study that the maximum yearly average share of BRT in modal split on a city level is 15% until 2030. The share of BRT in the modal split of a city at each year in the period 2015-2030 is assumed based on the project status. For example, the Rea Vaya BRT project in

Johannesburg is currently planned to have three parts: phase 1A, phase 1B and phase 1C. The first two parts have been in operation, and the third part is planned to be completed in 2018. Thus, is it assumed that the maximum share of BRT in modal split in Johannesburg, which is 15% in this study, can be achieved from 2018 onwards. After deciding the share of BRT in the modal split, the new modal split in a city can be estimated by applying the prior transportation mode, as listed in Table 34. Then, the assumed national modal split can be obtained by aggregating modal split in different cities, using city population as weighting. The current BRT projects in South Africa are listed in Appendix 4.

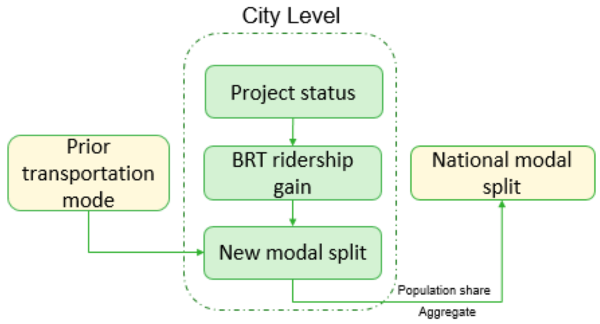


Figure 17. Schematic diagram of assessing BRT related policy impacts on national modal split

Table 34. Assumed prior transportation mode of BRT passengers, adjusted from [101]

Vehicle type	Share
Cars	13%
Buses	10%
Minibus-taxis	77%

3.4.3 New policy scenario

In the new policy scenario, the implementation of several more policies will be assumed to explore the potential in South Africa to further reduce emissions:

CARBON TAX

As a promising policy measure to reduce emissions, the carbon tax has been put on the agenda of South Africa's government, as introduced in *section 3.3.1*, but huge uncertainty exists regarding its implementation. Thus, the implementation of a carbon tax is included in the new policy scenario instead of the current policy scenario. In this scenario, carbon tax is assumed to be implemented from 2018.

The carbon tax influences emissions in a very complex way. Differences in factors such as the amount of carbon tax and the revenue recycling scheme can lead to significantly different effects on emission reduction. Thus, the assumptions made here are based on studies specifically for the carbon tax in South Africa. In general, a carbon tax can influence emissions mainly through the following aspects:

1) Decrease the speed of GDP growth. According to [105], the average annual growth rate of GDP in South Africa will be 0.05%-0.15% lower than BAU case if carbon tax is implemented. Thus, a 0.1% lower average annual growth rate of GDP is assumed in this research.

2) Incentivize the upgrade of fuel mix in electricity generation, i.e., accelerate the development of renewable energy. A carbon tax scenario has been discussed in South Africa's IRP 2010 [77], in which electricity generation capacity for each year has been planned until 2030. This plan is adopted in this study to estimate future fuel mix for electricity generation assuming implementation of a carbon tax in 2018. To estimate the fuel mix from the capacity plan in the IRP 2010, future capacity factors for each electricity generation technology are adopted from the WEO 2016 report [31].

3) Reduce productions or activities. According to [105], productions or activities will decrease by more than 15% in the following sectors because of a carbon tax: steel, transport, oil & gas, and other industry. Thus, it is assumed in this research that productions or activities in those sectors will be 15% lower compared with BAU scenario in those sectors since the implementation of the carbon tax, which is assumed to be 2018 in this study, until 2030.

ENERGY EFFICIENCY IMPROVEMENT

In fact, a carbon tax could also boost the improvement of energy efficiency, but the existing studies about impacts of carbon tax in South Africa have not taken this aspect into consideration. Thus, carbon tax-induced energy efficiency improvement is also not assessed in the above content. Nevertheless, the IEA has published an energy efficiency outlook for South Africa [34], in which the possible energy efficiencies in different sectors are analysed in the period to 2030, assuming that policies and their implementation are adequate to achieve the potential of all known energy efficiency measures which are economically viable. In this research, the same annual rate of energy efficiency improvement in different sectors that are given in [34] are assumed in the new policy scenario to analyse the possible emission reduction from energy efficiency improvement.

OTHER POLICIES

Apart from carbon tax and energy efficiency improvement, there are several more policies in the transport sector included in the new policy scenario:

1) BRT development: as analysed in the current policy scenario.
2) Mandatory Blending of Biofuels: it is assumed that the concentration of biofuel will be 5% in diesel and 2% for gasoline from 2018. With biofuel blending, the emission intensity will be 5% lower for diesel and 2% lower for gasoline than in the BAU scenario from 2018, since the biofuels can be considered as zero-emission.
3) Road freight strategy: it is assumed that the share of rail in the modal split of freight transport will increase by 2% per year over a period to 2019.

Chapter 4: Results

In this section, the main results of this research will be presented, including the PROSPECTS tool and policy scenarios for South Africa.

4.1 PROSPECTS tool validation

Historical data for South Africa has been collected and input into the PROSPECTS tool (which resulted in the emissions trend already shown in Figure 8). As a test case, this study has also done the same exercise for the European Union, to compare the situation for a region with excellent data availability (EU) with that of a region where data availability is deemed somewhat less good. This is an important indicator for the potential applicability of PROSPECTS to a wide range of regions. Data sources for this historical data can be found in Appendix 3.

Figure 18 and Figure 19 show the results for the EU and South Africa, respectively, compared to a number of other sources that report country- or region-wide emissions. In both figures, the orange lines with the legend “PROSPECTS” represent the results obtained from the PROSPECTS tool developed in this study. Other sources include CTI [106], UNFCCC[62], EDGAR [64], and ZAFNIR (South Africa’s 2013 National Inventory Report) [33]. The CTI data is only available for EU-28 for 1990, 2005, and 2010-2015. The ZAFNIR 2013 data is only available for South Africa for 2000-2010. The UNFCCC and EDGAR data is available for both EU-28 and South Africa.

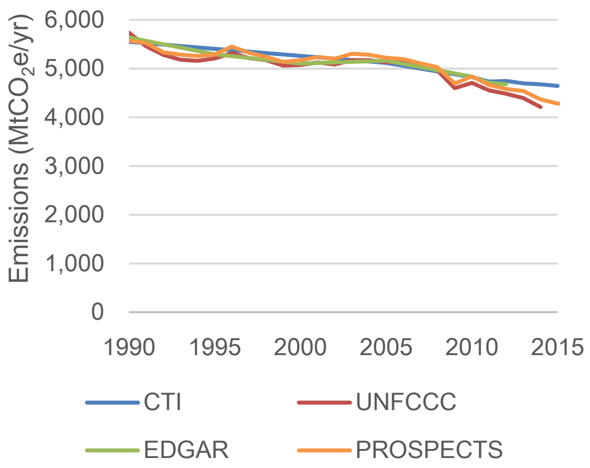


Figure 18. Overall emissions in EU-28 (excl. LULUCF) form different sources

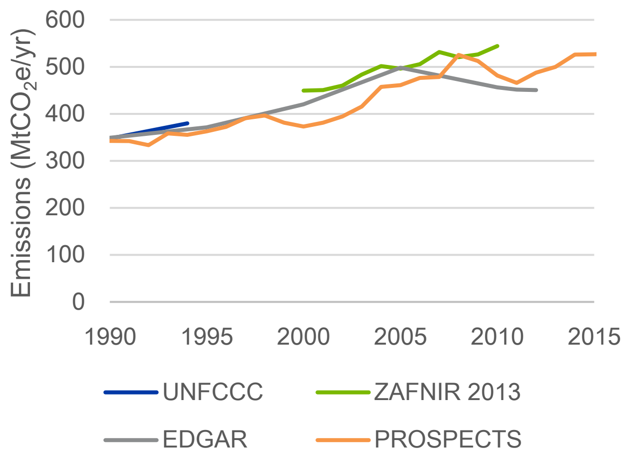


Figure 19. Overall emissions in South Africa (excl. LULUCF) from different sources

For EU-28, the data availability was found to be rather good. Detailed and often continuous data was collected from authoritative sources. When comparing the results for EU-28 with three external sources, the differences are within 3% for most data points and the maximum difference is less than 8%. Especially when compared with results from UNFCCC and EDGAR databases, the differences are within 4% for all data points.

For South Africa, the data availability was not as good as for the European Union. More assumptions were made when data for certain indicators was unavailable; simple data processing methods such as linear interpolation and extrapolation were used when data for certain years was missing. Comparing results from the PROSPECTS tool with results on South Africa’s emissions from external sources, differences are within 10% for most data points and the maximum difference is around 20%. Although the differences for South Africa are somewhat larger than for EU-28, the results are still considered very good considering the data availability.

The results for sectoral emissions in EU-28 and South Africa obtained by PROSPECTS are also compared to data in a number of other sources. A sectoral validation of emissions is necessary to demonstrate that an agreement of overall emissions with other data sources is not caused by deviations on sector-level cancelling each other out. Apart from the four sources mentioned above, sectoral emissions data in the following sources is used: IEA 2016: [107]; EEA, 2015: [108]; Ecofys et al., 2009: [108]; EUROFER, 2013: [109]; Pryce et al., 2001: [110]; European commission, n.d: [108]. In the following, electricity-related emissions in demand-side sectors are allocated to the electricity sector.

In the electricity sector, emissions for EU-28 from the PROSPECTS tool and CTI fit well, but the difference starts to increase from 2012 (Figure 20). The most significant difference between the two sources, around 13%, occurs in 2015, which is still deemed acceptable. For South Africa, emissions from the PROSPECTS tool and ZAFNIR 2013 also fit well (Figure 21). The differences are within 20%.

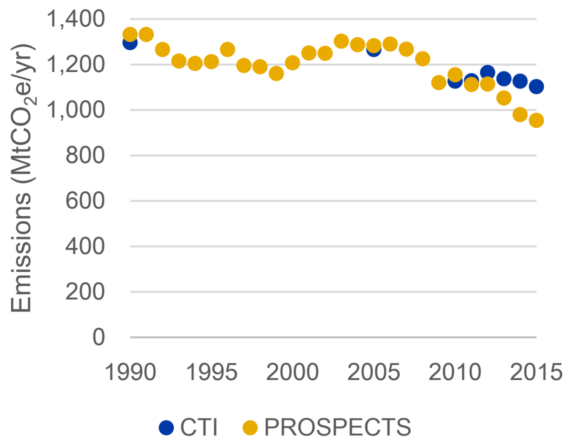


Figure 20. Electricity emissions in EU-28 from different sources

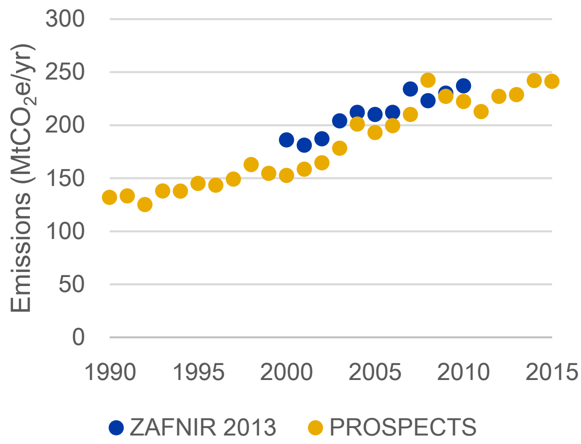


Figure 21. Electricity emissions in South Africa from different sources

In the transport sector, PROSPECTS results are compared with data in three other sources for EU-28 (Figure 22). Transport emissions in EU-28 given in PROSPECTS tool, UNFCCC, and IEA 2016 are very close, having differences within 13%. However, emissions according to the CTI tool are 15%-56% larger than PROSPECTS results. For South Africa, emissions given in ZAFNIR 2013 are very close to that in IEA 2016, but PROSPECTS results are around 26% larger than those of IEA 2016 (Figure 23). The larger differences for South Africa may come from the insufficient quality of the historical input data, as indicated in Appendix 4. For example, transport activity from different modes are obtained from [113] for only 2006 and 2010, so the activity for other years are scaled with GDP growth rate as assumptions, which increased the uncertainty of the emissions results. However, the overall trend matches reasonably well with the other sources.

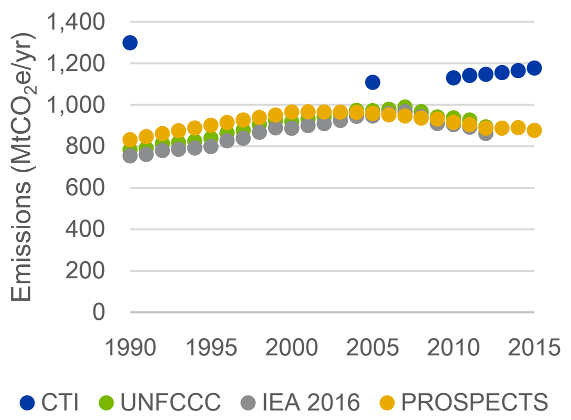


Figure 22. Transport emissions in EU-28 from different sources

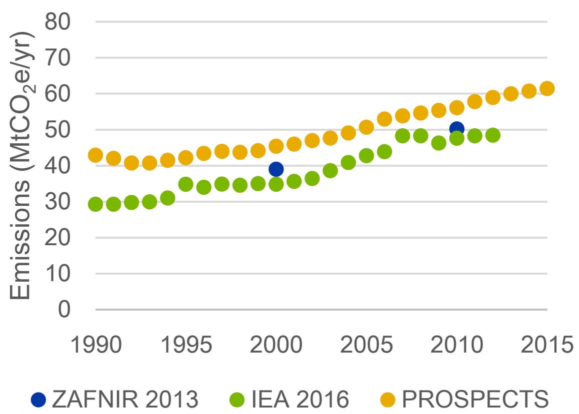


Figure 23. Transport emissions in South Africa from different sources

In the buildings sector, the PROSPECTS tool tends to give higher emissions for both EU-28 and South Africa compared with other sources. For EU-28, PROSPECTS results are around 50% higher than that in CTI and IEA 2016 (Figure 24). For South Africa, PROSPECTS results are around 50% higher than that in IEA 2016 (Figure 25). In terms of methodology, both sources include residential buildings and commercial buildings, and both sources consider emissions in buildings from energy use for space heating, space cooling, water heating, cooking, lighting and appliances. However, a number of assumptions are made for the energy demand related historical data in PROSPECTS, which increased the uncertainty of the results.

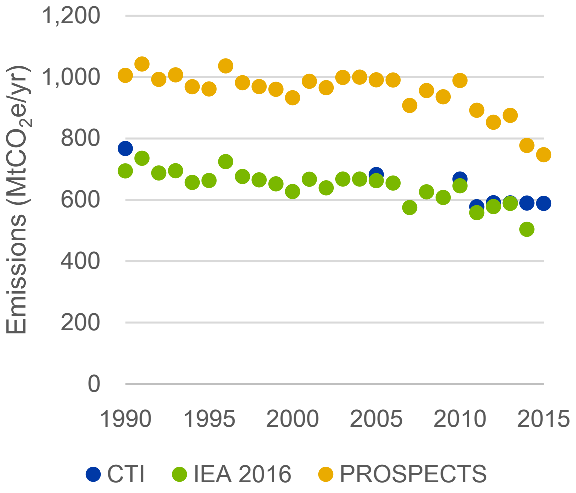


Figure 24. Buildings emissions in EU-28 from different sources

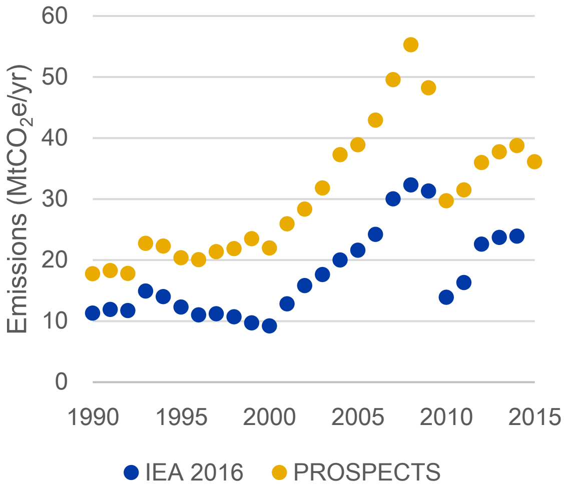


Figure 25. Buildings emissions in South Africa from different sources

In the steel sector, several sources are available with emission data for EU-28 (Figure 26). The data in CTI and EEA, 2015 fit relatively well (differences within 20%). Data in EUROFER, 2013 and Ecofys et al., 2009 is close to that in PROSPECTS (differences within 20%). For South Africa, emission data for 1995 is found in Pryce et al., 2001, which is only 10% larger than PROSPECTS results (Figure 27).

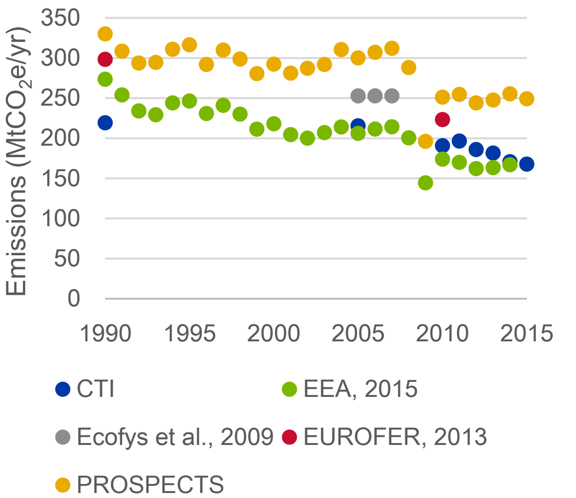


Figure 26. Steel emissions in EU-28 from different sources

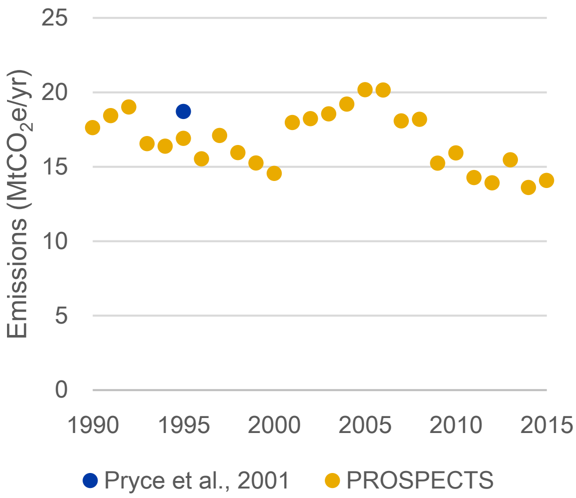


Figure 27. Steel emissions in South Africa from different sources

In the cement sector, two other sources are found for EU-28 (Figure 28), while no other data sources are found for South Africa in this study (Figure 29). For EU-28, the emission data in CTI is around 44% higher than that in PROSPECTS. However, the emission data in the European Commission study is very close to that in PROSPECTS (differences within 7%).

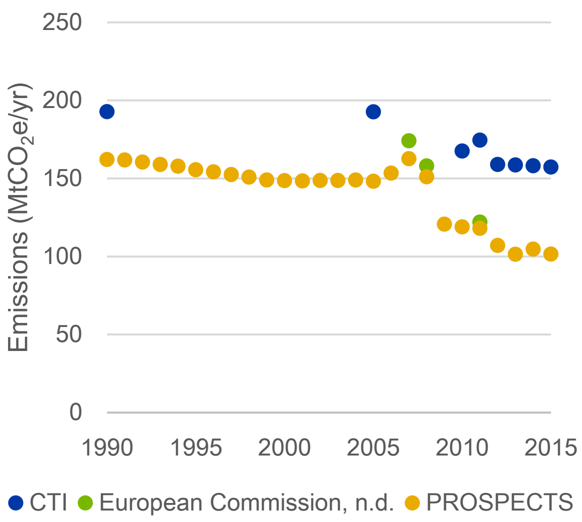


Figure 28. Cement emissions in EU-28 from different sources

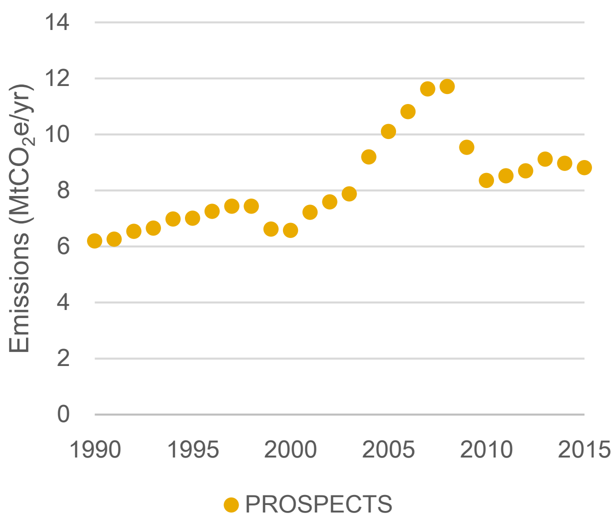


Figure 29. Cement emissions in South Africa from PROSPECTS

Figure 30 shows the emissions in the "other" industry in EU-28 from different sources. The CTI data is around 30% lower than that in PROSPECTS, while the data in EEA, 2015 is very close to PROSPECTS results (difference within 8%). The emission data in the "other" industry sector was difficult to collect for South Africa, so all industry emission data (aggregate of steel, cement, and "other" industry sectors in PROSPECTS) was collected and compared (Figure 31). In the period 1994-2003, emission data in IEA 2016, ZAFNIR and PROSPECTS fits very well (differences within 5%). Before 1995, the largest difference between data in IEA 2016 and PROSPECTS is 33%. After 2003, the data in PROSPECTS fits better with data in IEA 2016 (differences within 14%) than that in ZAFNIR 2013.

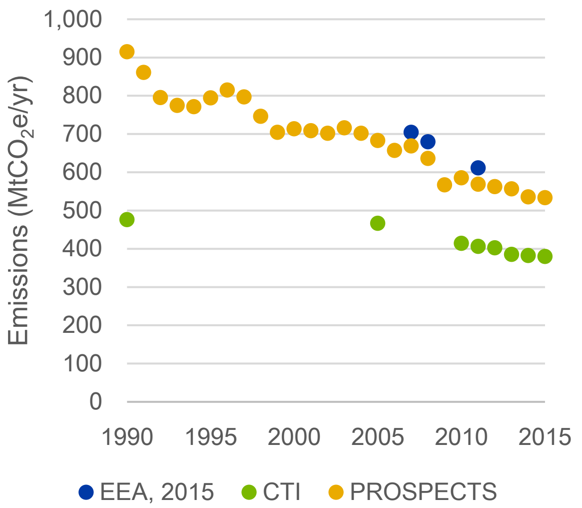


Figure 30. "Other" industry emissions in EU-28 form different sources

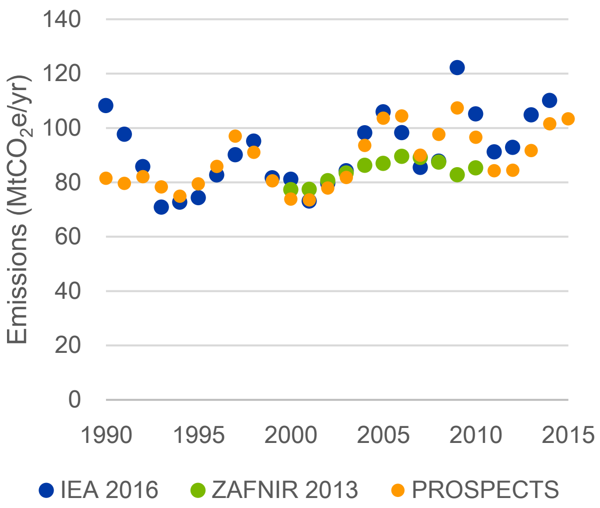


Figure 31. All industry emissions in South Africa from different sources

In the oil & gas sector, emission data for EU-28 is found in UNFCCC database (Figure 32), while no other source for South Africa is found in this study (Figure 33). For EU-28, the emission data from PROSPECTS is around 55% larger than that from UNFCCC. As explained in Appendix 3, the historical input data regarding to fugitive emissions and amount of gas flared in PROSPECTS is of very rough quality with a number of assumptions, which may be part of the reasons of the large difference. It can also be noticed from Figure 32 that the emissions given by PROSPECTS has a rapid increase in 1996. However, this may be reasonable because the oil and gas production, which drives the emissions in this sector, also has a rapid increase in that year according to [43].

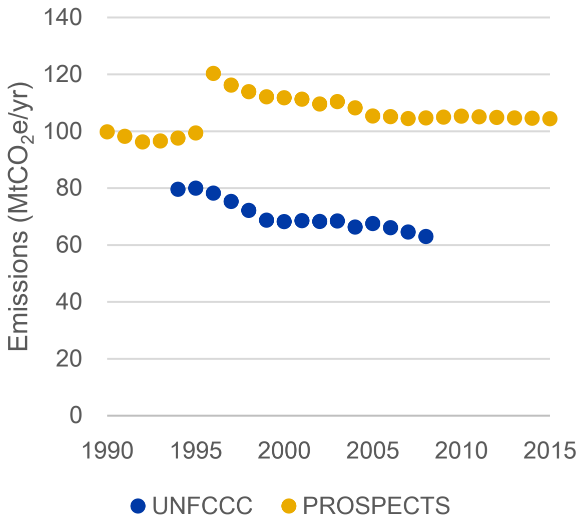


Figure 32. Oil & gas emissions in EU-28 from different sources

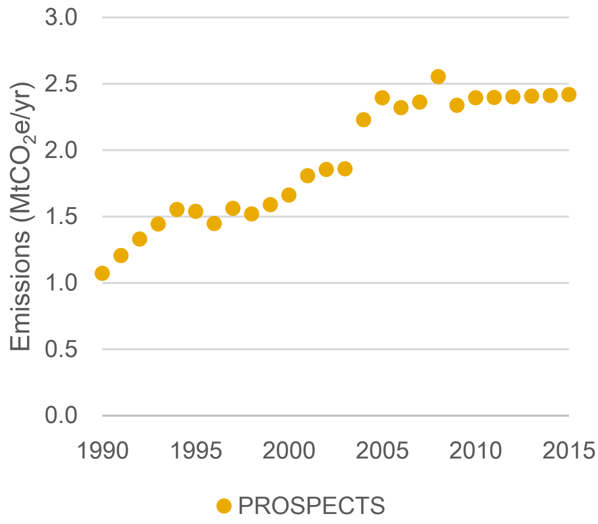


Figure 33. Oil & gas emissions in South Africa from PROSPECTS

In the waste sector, CTI and UNFCCC give similar emission values for EU-28, but emissions given by PROSPECTS are around 50% higher than that in UNFCCC (Figure 34). For South Africa, the situation is similar: emissions given by PROSPECTS are around 40% higher than that in UNFCCC (Figure 35). The methodologies used for calculating emissions from waste sector are almost the same in PROSPECTS and CTI, but the historical data is from different sources. The large difference may come from the assumptions made in the historical data, as explained in Appendix 3.

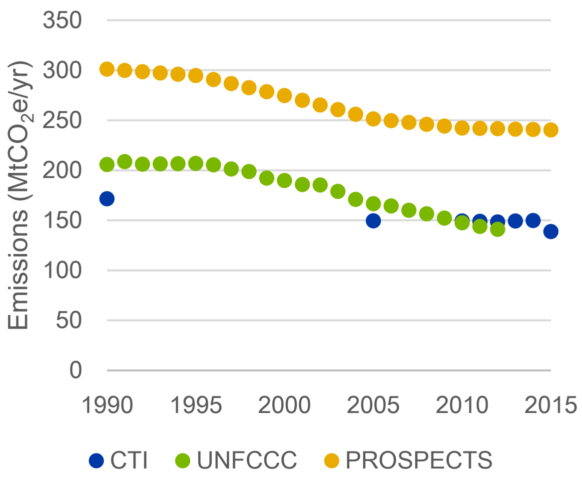


Figure 34. Waste emissions in EU-28 form different sources

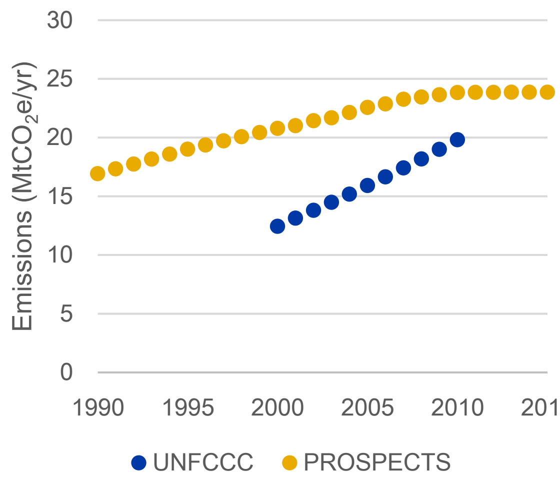


Figure 35. Waste emissions in South Africa form different sources

In the agriculture sector, other sources are available for both EU-28 and South Africa. For EU-28, data in CTI and PROSPECTS fits well (difference within 12%) (Figure 36). For South Africa, although emission data in ZAFNIR 2013 is only available for 2000 and 2010, its difference with PROSPECTS is within 4% (Figure 37). To some extent, this is due to the fact that some data from ZAFNIR 2013 itself was used in the data collection for PROSPECTS, though not exclusively.

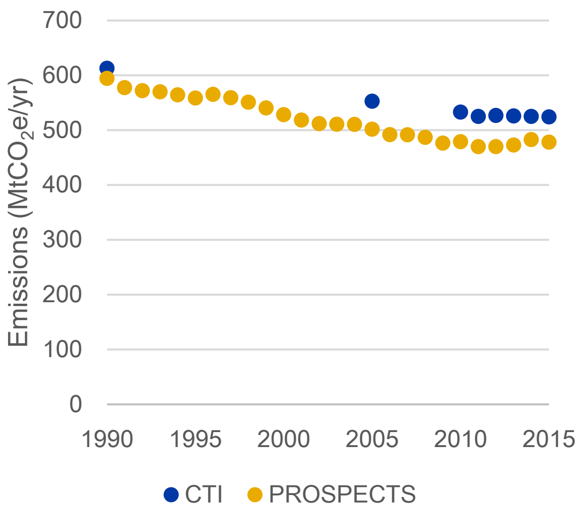


Figure 36. Agriculture emissions in EU-28 from different sources

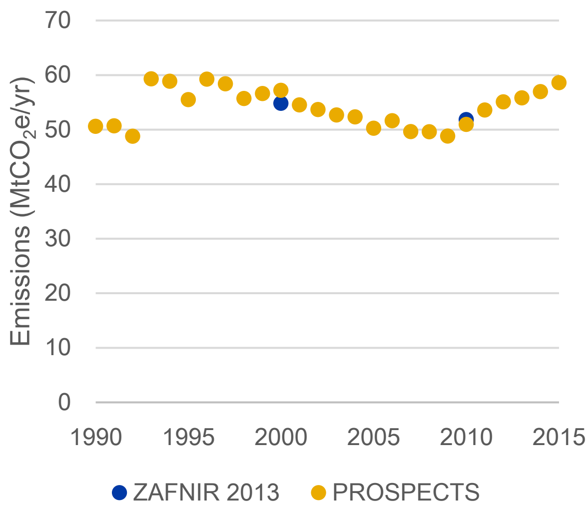


Figure 37. Agriculture emissions in South Africa form different sources

After comparing overall and sectoral emissions obtained by the PROSPECTS tool for EU-28 and South Africa with external data sources, it can be found that the overall emissions obtained by PROSPECTS tool fit well with other data sources, but in three sectors -- buildings, oil & gas, and waste -- the PROSPECTS tool tends to overestimate emissions compared with other sources. In other sectors, the PROSPECTS results fit relatively well with other sources. Future work should thus focus on improving the data quality in the buildings, oil & gas, and waste sectors.

4.2 Policy scenarios for South Africa

Three policy scenarios for South Africa are constructed as outcomes of the policy assessment in this research. By inputting the policy scenarios into the PROSPECTS tool, future emission trends for South Africa are projected. Emissions profiles under the three policy scenarios will be presented respectively in the following paragraphs.

4.2.1 Business-as-usual scenario

Figure 38 shows the projected total emissions in South Africa under the BAU scenario. Without mitigation measures, total emissions in South Africa will be around 730 Mt CO_2e per year in 2030, which is roughly a 38% increase compared to current level. As mentioned in *section 3.3.1*, South Africa’s NDC target is to keep emissions in a range between 398 and 614 Mt CO2e by 2025 and 2030. The upper range is shown in Figure 38 with the red line, while the lower range is shown with the yellow line. Under the BAU scenario, total emissions in South Africa will be 19% higher than the upper range of the NDC target in 2030.

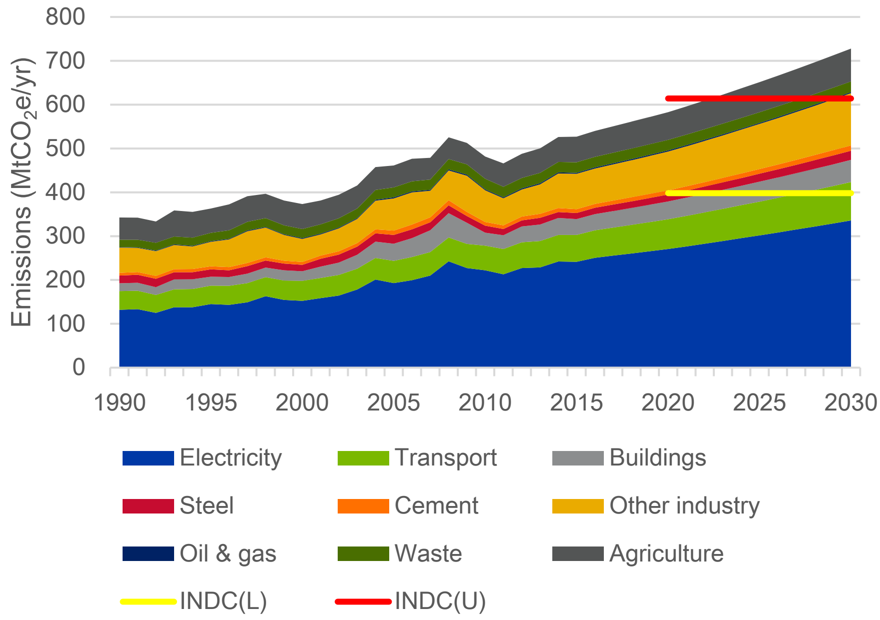


Figure 38. Projected total emissions in business-as-usual scenario (excl. LULUCF), South Africa

As a baseline scenario, the BAU scenario is very important because the other two scenarios are based on it. Thus, emissions under BAU scenario in this study are compared with emission projections under similar scenarios in other sources, as shown in Figure 39. The orange line represents emissions given by PROSPECTS, among which before 2015 are historical emissions, and after 2015 are projected emissions. The blue points come from the “growth without constraints” scenario in the Long Term Mitigation Scenarios (LTMS) [111], a study commissioned by the South African Cabinet to examine mitigation potential. The green points come from the “without measures” (WOM) scenario in the GIZ report [112].

Both the “growth without constraints” scenario and the WOM scenario are reference scenarios and assume no measures will be taken in the future to reduce emissions, which is same as the BAU scenario in this study. However, it can be noticed that emission projection in LTMS is around 40% higher than that in PROSPECTS in 2030, while the emission projection in the GIZ study is around 24% higher than that in PROSPECTS in 2030. It also can be noticed that, for emissions before 2015, which are calculated from historical data in PROSPECTS, values are also higher in LMTS and GIZ than in PROSPECTS.

The most important difference among the reference scenarios in the three studies is that they assume different GDP growth rates (Table 35). Thus, the assumptions of GDP growth rate in LMTS and GIZ are input into the BAU scenario in PROSPECTS, respectively, to assess their influence. The obtained emissions are then adjusted according to the differences in historical emissions to exclude the interference from the historical data in PROSPECTS. For example, the emissions before 2015 in LMTS is around 11% larger than that in PROPECTS, so the emissions obtained by inputting assumption of GDP growth rate in LMTS into the BAU scenario in PROSPECTS are multiplied by 1.11 to obtain the red line in Figure 40. The purple line in Figure 40 is obtained by the same method. It can be found that the red line and purple line fit very well with data points from LMTS and GIZ, which means that the lower emission projections given by the BAU scenario in PROSPECTS are mainly due to the lower value of assumed GDP growth rate.

Table 35. Assumptions on annual GDP growth rate in three different studies

Study	Assumption on annual GDP growth rate
PROSPECTS	2.3% over the period 2016-2020; 2.9% over the period 2021-2030. See *sector 3.4.1*
LMTS	Ranging between 3% and 6% over the period 2003 to 2050
GIZ	4.2% over the period 2015-2020; 4.3% over the period 2021-2050

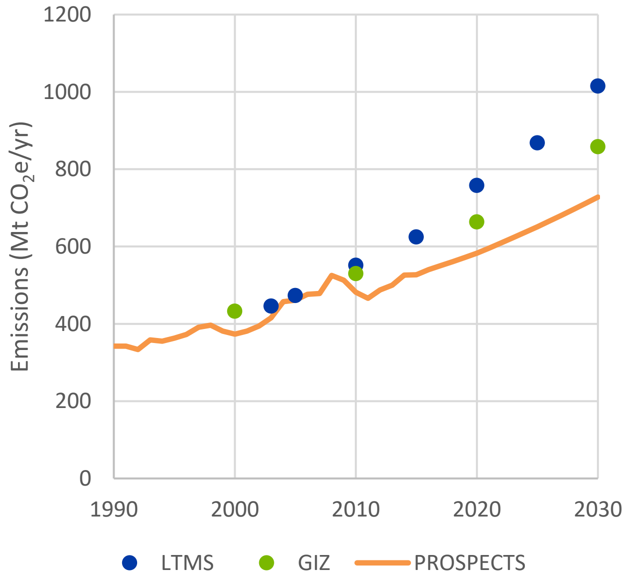


Figure 39. Emission projections for South Africa in different scenarios

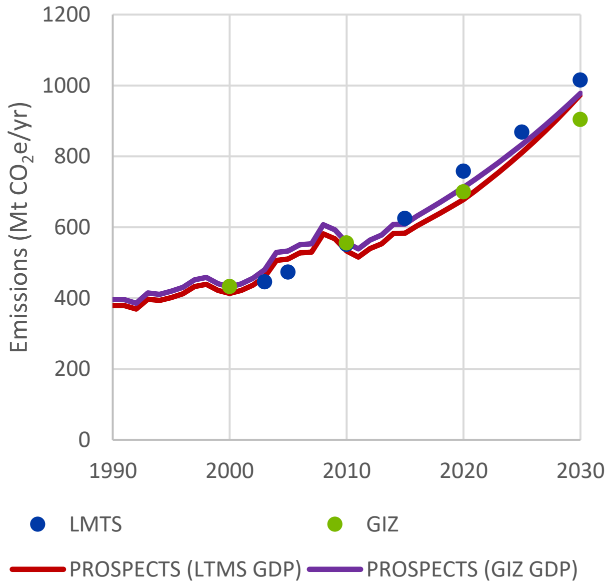


Figure 40. Emission projections with adjusted GDP growth rate in PROSPECTS

4.2.2 Current policy scenario

In the current policy scenario, the impacts of renewable energy support schemes in the electricity sector and impacts of BRT projects in the transport sector are considered.

With current policies, the share of wind and solar in the fuel mix of power generation is projected by this study to increase from around 1% in 2015 to around 4.5% in 2030 (Figure 41). This increase means a 4% deviation of emissions from the BAU scenario in the power sector and will bring around 13 $MtCO_2e$ emission reduction in 2030. The share of BRT in the modal split of passenger transport is projected to increase from less than 3% in 2015 to around 8.5% in 2030 (Figure 42). The developed BRT systems can lead to a 1.6% deviation of emissions from the BAU scenario in passenger transport and would then reduce emissions by 1.6 $MtCO_2e$ in 2030. In total, measures considered in current policy scenario can lead to an emission reduction of 15 $MtCO_2e$ in 2030, which is only a 2% deviation of the total emissions from the BAU scenario.

In Figure 43, the green area represents total emissions under the current policy scenario; the blue area represents emission reduction in the electricity sector due to the uptake of renewables; the purple area represents emission reductions in the transport sector due to the development of BRT systems (the purple area is almost invisible in the figure because the emission reduction related to BRT is small). Under the current policy scenario, the total emissions in South Africa will be around 713 $MtCO_2e$ in 2030, which is still 16% higher than the upper range of its NDC target (red line in Figure 43), although this value is considered as inadequate[7] for achieving the goals of Paris Agreement according to CAT [11].

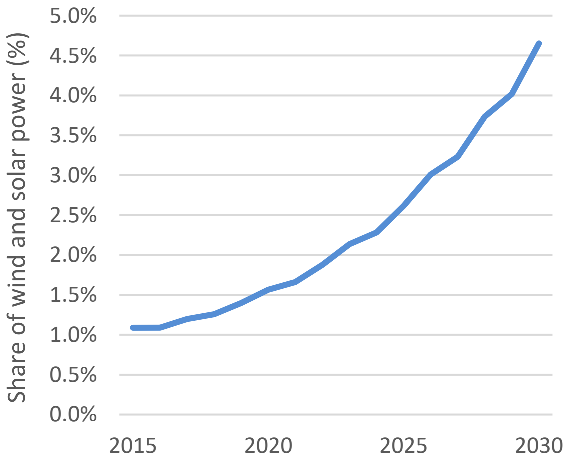


Figure 41. Projected share of wind and solar energy in the fuel mix of electricity generation, South Africa

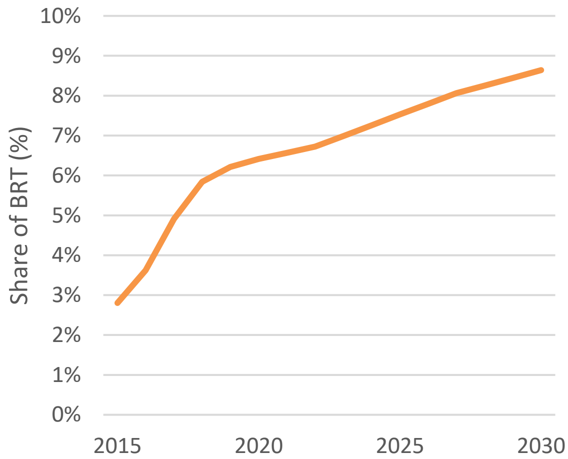


Figure 42. Projected share of BRT in the modal split of passenger transport, South Africa

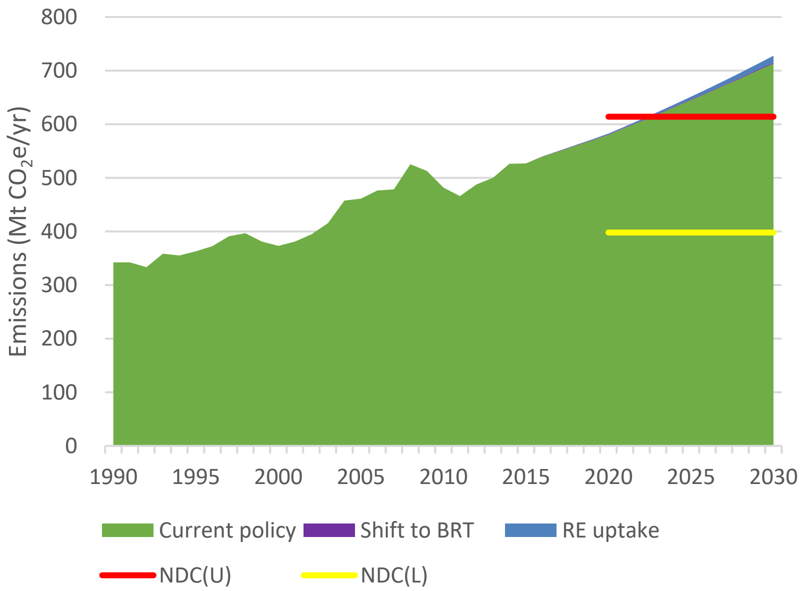


Figure 43. Projected total emissions in current policy scenario, South Africa

[7] "Inadequate" here means emissions targets in this area are less ambitious than the 2℃ range defined by the studies and if all governments adopted an inadequate position, warming would likely exceed 3-4℃ [140].

4.2.3 New policy scenario

Under the new policy scenario, the total emissions in South Africa will significantly decrease in the period 2015-2030. By implementing a carbon tax, around 185 MtCO_2e of emission reduction can be achieved by 2030, a 25% deviation of total emissions from the BAU value. By improving energy efficiency, around 136 MtCO_2e of emission reduction can be achieved by 2030, a 19% deviation from the BAU value. Mitigation measures in transport can provide a further 7 MtCO_2e emission reduction by 2030. With all the measures in the new policy scenario, a substantial amount of emissions will be mitigated. The total emissions in 2030 will be around 400 MtCO_2e, a 55% reduction compared to total emissions under BAU scenario. In this case, the total emissions in 2030 will be consistent with the lower range of South Africa's NDC target (yellow line in Figure 44).

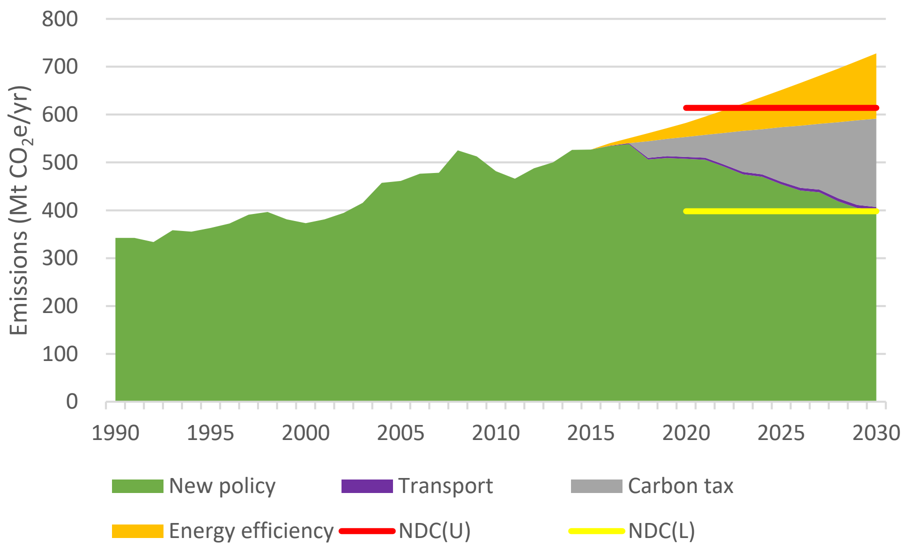


Figure 44. Projected total emissions in new policy scenario, South Africa

Chapter 5: Discussion

When validating the PROSPECTS tool by inputting historical data of EU-28 and South Africa, the emission results for EU-28 show somewhat better consistency with emission data in external sources. This fact does not necessary mean that the PROSPECTS tool performs better when modelling emissions in the EU-28 than in South Africa. Because data availability in South Africa is not as optimal as for the EU (but this applies to a very large number of countries/regions), more assumptions had to be made and more “proxy” data are used, so the total emissions in South Africa given by different sources lie in a wider range. With the ability to give reasonable emissions modelling results for South Africa’s overall emissions, the PROSPECTS tool has demonstrated its potential to be applied to a wide range of countries/regions. In terms of sectoral emissions, the PROSPECTS tool tends to overestimate emissions in the buildings, oil & gas, and waste sectors compared with other sources. Substantial improvements can still be made at sector level to modify the calculation method and to improve the quality of historical input data.

In the current policy scenario, it can be noticed that the emission reduction potential of the development of BRT systems is rather limited. The main reasons are:

1) The current BRT systems in South Africa still mainly rely on diesel. The current BRT related emission reduction is due to the efficiency improvement, but using cleaner fuel can provide larger potential of emission reduction. MyCiTi BRT in Cape Town has initiated to add electric buses to its fleet and studies such as [103] have also analysed the possibility to use CNG or biogas for BRT systems in south Africa. Those can be future directions of BRT systems.
2) Personal vehicles still dominate (around 63%) the modal split and account for around 83% of the emissions in passenger transport. Substantial emission reduction in the transport sector is hard to achieve without measures on personal vehicles. According to the IEA [113], electric vehicles (EV) began to appear in South Africa in 2013 with a number of 30, and there were only 290 electric vehicles in South Africa by 2015. The Department of Trade and Industry (DTI) has proposed government procurement of 3000 - 5000 electric vehicles per year from 2015 [114]. If an annual increase of 5000 EVs is assumed, which is the upper limit of the DTI’s proposal, the share of EVs in South Africa will be still around 1% in the vehicle fleet. Moreover, if the electricity sector is not clean enough in 2030, an increased share of EVs will not have a significant influence in emissions.

Although the upper range of South Africa’s NDC target is inadequate for achieving the goals of Paris Agreement [11], it still cannot be achieved under the current policy scenario. In order to achieve the goals of Paris Agreement, South Africa needs to enhance its mitigation policies to further reduce emissions.

The carbon tax and energy efficiency improvements have shown a relatively large potential for decarbonization in the new policy scenario. However, the assumptions made for the energy efficiency improvement may be difficult to achieve: it requires adequate policies and measures to achieve the potential of all known energy efficiency measures which are economically viable. Compared with this, the implementation of carbon tax has a higher possibility, since it has been put on the agenda of South Africa’s government, as mentioned in *section 3.3.1*. Even if only the carbon tax was implemented, the total emissions in South Africa would be around 543 $MtCO_2e$ in 2030, which lies in the range of its NDC target.

Chapter 6: Conclusions

In this study, the PROSPECTS emissions modelling tool has been developed and three policy scenarios for South Africa have been constructed.

The PROSPECTS tool is developed with a bottom-up methodology and covers all economic sectors excluding LULUCF. It allows users to define different scenarios base on different policy drivers, and can output emission trends at sectoral level and national level. By feeding historical data for EU-28 and South Africa, and comparing results with data in external sources, it has been demonstrated that the PROSPECTS approach has the ability to give reasonable emissions modelling results for overall historical emissions in EU-28 and South Africa. Given the challenges of data availability in South Africa, the PROSPECTS approach also demonstrated its potential to be applied to a wide range of countries/regions where data availability is at a comparable level. On the other hand, large differences still exist when comparing sectoral emissions given by PROSPECTS with that in other sources in a few sectors. Thus, improvements can still be made by improving the calculation logic and quality of input data at sector level.

In the case study for South Africa, three policy scenarios were constructed: a BAU scenario, a current policy scenario and a new policy scenario. Under the BAU scenario, total emissions in South Africa will be around 730 $MtCO_2e$ per year in 2030, a 38% increase compared to current levels and 19% higher than the upper range of its NDC target. Compared with emission projections in reference scenarios in other sources, emission projections given by the BAU scenario in this study is somewhat lower. The difference mainly come from the different assumptions of GDP growth rate. However, considering the recent recession in South Africa, it is considered reasonable to assume lower GDP growth rates in this study.

Under the current policy scenario, the renewable energy support schemes and the development of BRT systems in the transport sector have limited impacts on emission reduction, and the total emissions in 2030 will be 16% higher than the upper range of its NDC target. To substantially reduce emissions in transport, BRT systems need to switch to cleaner fuels and mitigation measures about personal vehicles should be taken. In the new policy scenario, a carbon tax appears to be a promising policy measure towards deeper decarbonization in South Africa, which has a potential to achieve 185 $MtCO_2e$ of emission reduction in 2030. The energy efficiency improvement also have large potential in emission reduction, but its implementation is of lower possibility compared with the carbon tax.

It should be mentioned that the emission projections made in this study are the results of policy scenario analysis and are not necessarily an accurate reflection of what will happen in the future, considering the multitude of indicators which shape future emissions may change over time and impact each other in a complex way, let alone external aspects which cannot be controlled. However, analyses such as done in this study hopefully remain useful by providing possible emission reduction outcomes under different policy scenarios, which can assist policy-makers in selecting the most appropriate and effective policies for decarbonization.

Chapter 7: Limitations and recommendations

Content-wise, the LULUCF sector is not included in PROSPECTS. The reasons for this are: (1). the complexity of this sector, which contains both emission sources and emission sinks. (2). the data availability of the LULUCF sector is generally poor. It is proposed that the LULUCF sector can be added into the PROSPECTS tool in the future as a separate free calculation area for completeness. Based on the available historical data and their aim of study, users can make their own assumptions and design the feasible calculations.

Structurally, policy assessment is conducted outside the PROSPECTS tool to construct policy scenarios in this research. In the future, the policy assessment can be integrated with the PROSPECTS tool to form a more comprehensive emissions modelling tool.

In this study, the PROSPECTS tool is only applied to EU-28 and South Africa. The PROSPECTS approach can be expanded to more countries/regions in the future to further test its applicability in a wider range of geographies. The data sources of the indicators suggested in *section 3.2.2* can be very helpful for the future test, since they contain data for a large number of countries.

The policy assessment in this research is only conducted for overarching policies and policies in key sectors, i.e., electricity generation sector and transport sector. For more comprehensive policy scenarios, policies in other sectors should also be analysed, especially for the buildings sector and industry sector[8], as they account for around 27% of the total emissions in South Africa (counting electricity-related emissions in the power sector).

Although the policy scenarios in this research are constructed for a specific country, i.e., South Africa, the logic and methods of policy assessment developed in this research can be transferred to the analysis of other countries/regions. Moreover, the S-curve approach is applied for estimating the uptake of renewable energy in electricity generation, but it could also be used for analysing the uptake of other carbon-saving technologies such as electric vehicles.

This research focused on the impacts of policies on emission reduction. In fact, those policies can also have co-benefits such as cleaner air, energy safety, and health and well-being. These benefits could be studied in the future researches.

The effective and accurate policy assessments and emissions projections may be an iterative process. This research is a start of this process. As new information and understanding develops through this study and other researches, methods proposed in this study can be improved and better projections can be made in the future.

[8] The industry sector refers to the sum of the cement sector, steel sector and "other" industry sector in the PROSPECTS tool.

Appendix 1 Emission categories included in PROSPECTS tool

Emissions included in every economic sector are identified with IPCC source/sink categories in the following table. The identification is based on revised 1996 IPCC guidelines for national greenhouse gas inventories [115].

The aim of specifying emissions in every sector with authoritative and widely accepted standards is: 1) to avoid omission or double counting in sectors and especially at the national level; 2) to increase the transparency of the results obtained from this research; and 3) to increase the validity of the results of this research and make the results better communicable and comparable.

Emission categories in PROSPECTS matched with categories in IPCC guidelines for national greenhouse gas inventories

Sector name	IPCC categories of emissions	IPCC category ID	Gases included (IPCC, 2006)	Emissions included in IPCC category [115]	Counted in which PROSPECTS category
Electricity & heat sector	Public electricity and heat generation	1A1a	CO_2, N_2O, CH_4	Total emissions of all greenhouse gases from all fuel combustion activities.	Emissions from own use and losses in power & heat sector
					Emissions from electricity production (can be allocated to demand sectors as well)
Transport sector	Domestic air transport	1A3a	CO_2, CH_4, N_2O	Emissions from combustion of fuels in domestic aviation (passenger/freight).	Direct energy-related emissions from transport (passenger as well as freight)
	Road transport	1A3b	CO_2, CH_4, N_2O	Emissions from combustion of fuels in road transport (passenger + freight).	
	Rail transport	1A3c	CO_2, CH_4, N_2O	Emissions from combustion of fuels in rail transport (passenger + freight).	
Buildings sector	Commercial and public services	1A4a	CO_2, CH_4, N_2O	Emissions from combustion of fuels in commercial and public services buildings	Direct energy-related emissions[9] from commercial buildings
	Residential	1A4b	CO_2, CH_4, N_2O	Emissions from combustion of fuels in residential buildings	Direct energy-related emissions from residential buildings (including combustion for auto-generation of electricity and heat)
Steel sector	Iron and steel	1A2a	CO_2, CH_4, N_2O	Emissions from combustion of fuels in iron and steel industry.	Direct energy-related emissions in iron and steel industry
	Iron and steel production	2C1	CO_2	Emissions from industrial processes in iron and steel industry.	Counted under above category
Cement sector	Other	1A2f	CO_2, CH_4, N_2O	Emissions from combustion of fuels in the cement industry is not specified in IPCC categories, so it is counted under "other" category 1A2f.	Direct energy-related emissions in cement industry
	Cement production	2A1	CO_2	Emissions from industrial processes in cement industry.	Process emissions from cement industry

[9] Throughout this table: direct energy-related emissions in PROSPECTS include combustion for auto-generation of electricity and heat.

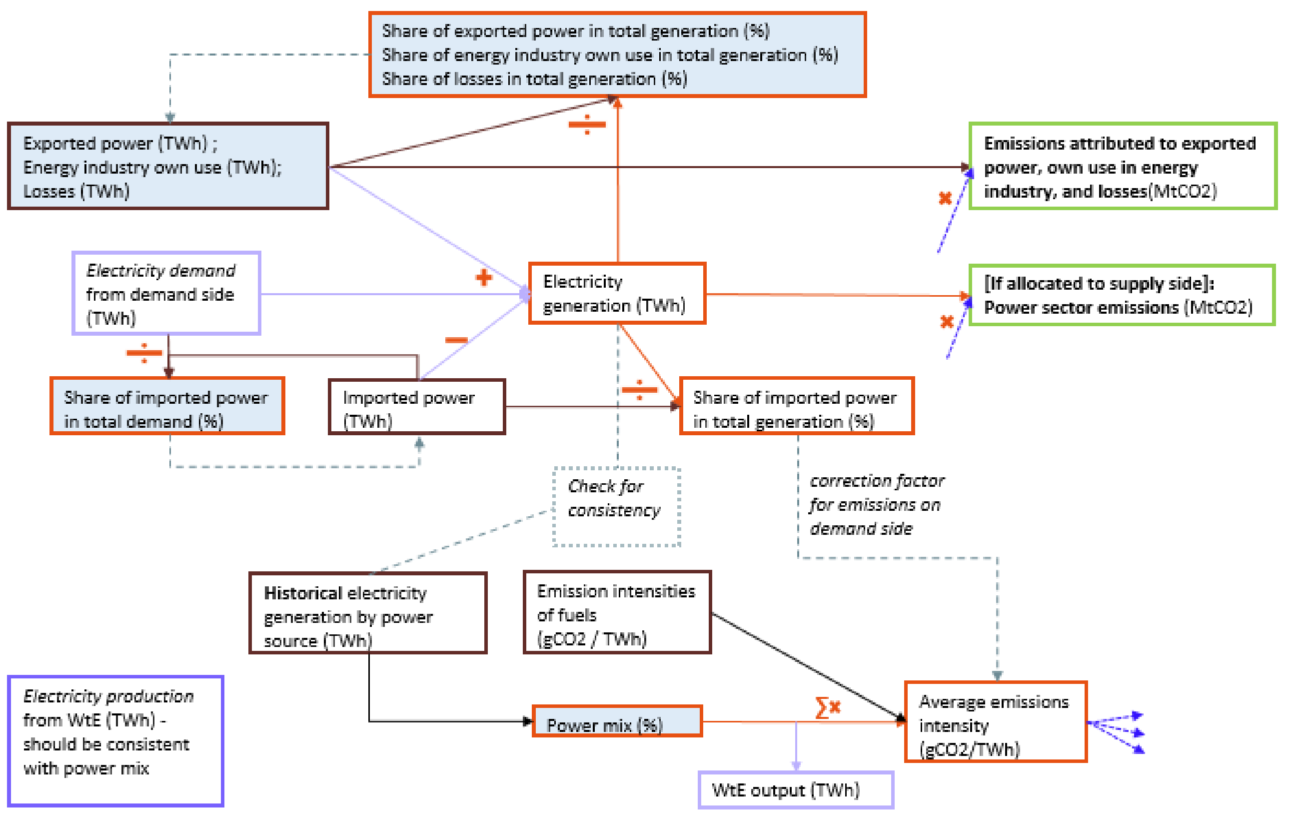
Other industry	Non-ferrous metals	1A2b	CO_2, CH_4, N_2O	Emissions from combustion of fuels in non-ferrous metals industry.	Direct energy-related emissions in "other" industry
	Chemicals	1A2c	CO_2, CH_4, N_2O	Emissions from combustion of fuels in chemicals industry.	
	Pulp and paper	1A2d	CO_2, CH_4, N_2O	Emissions from combustion of fuels in pulp and paper industry.	
	Food and tobacco	1A2e	CO_2, CH_4, N_2O	Emissions from combustion of fuels in food and tobacco industry.	
	Other industries	1A2f	CO_2, CH_4, N_2O	Emissions from combustion of fuels in industries not included above.	
	Mineral products	2A	CO_2	Emissions from industrial processes in mineral products industry.	Partly counted under process emissions from cement industry; the remainder (equivalent to category 2A – 2A1) under process emissions in "other" industry.
	Production of chemicals	2B	CO_2, CH_4, N_2O	Emissions from industrial processes in chemical industry.	Process emissions in "other" industry
	Metal production	2C	CO_2	Emissions from industrial processes in metal production industry.	Partly counted under process emissions from iron and steel industry; the remainder (equivalent to category 2C – 2C1) under process emissions in "other" industry.
	Other production	2D	CO_2	Emissions from industrial processes in pulp and paper industry and food and drink industry, and any other categories not included above.	Process emissions in "other" industry
	Production of halocarbons and SF_6	2E	HFCs, PFCs, other halogenated gases, SF_6	Emissions from production of halocarbons and SF_6 (by-product emissions and fugitive emissions).	
	Consumption of halocarbons and SF_6	2F	HFCs, PFCs, other halogenated gases, SF_6	Emissions from consumption of halocarbons and SF_6 (refrigeration and air-conditioning equipment, fire extinguishers, aerosols, solvents)	
Oil & gas sector	Oil and natural gas	1B2	CO_2, CH_4	Fugitive emissions and flaring emissions from oil and gas emissions.	Fugitive and flaring emissions in oil & gas industry
Waste sector	Solid waste disposal on land	6A	CH_4	Emissions from managed and unmanaged waste disposal.	Emissions from solid waste landfill
	Wastewater handling	6B	CH_4, N_2O	Emissions from industrial, domestic, and commercial wastewater.	Emissions from wastewater in waste sector
Agriculture sector	Agriculture	1A4c1	CO_2, CH_4, N_2O	Emissions from fuel combustion in agriculture.	Direct energy-related emissions in agriculture
	Enteric fermentation	4A	CH_4	Methane production from herbivores as a by-product of enteric fermentation.	Emissions from enteric fermentation in animal-related emissions
	Manure management	4B	CH_4, N_2O	Methane and nitrous oxide emissions from the decomposition of manure under low oxygen or anaerobic conditions.	Emissions from manure management in animal-related emissions
	Rice cultivation	4C	CH_4	Methane emissions from the anaerobic decomposition of organic material in flooded rice fields.	Rice-related emissions
	Agricultural soils	4D	CO_2, N_2O	Emissions and removals of CH_4 and N_2O from agricultural soil/land.	Other land-related emissions

Appendix 2 Logic trees for sectoral calculations in PROSPECTS tool

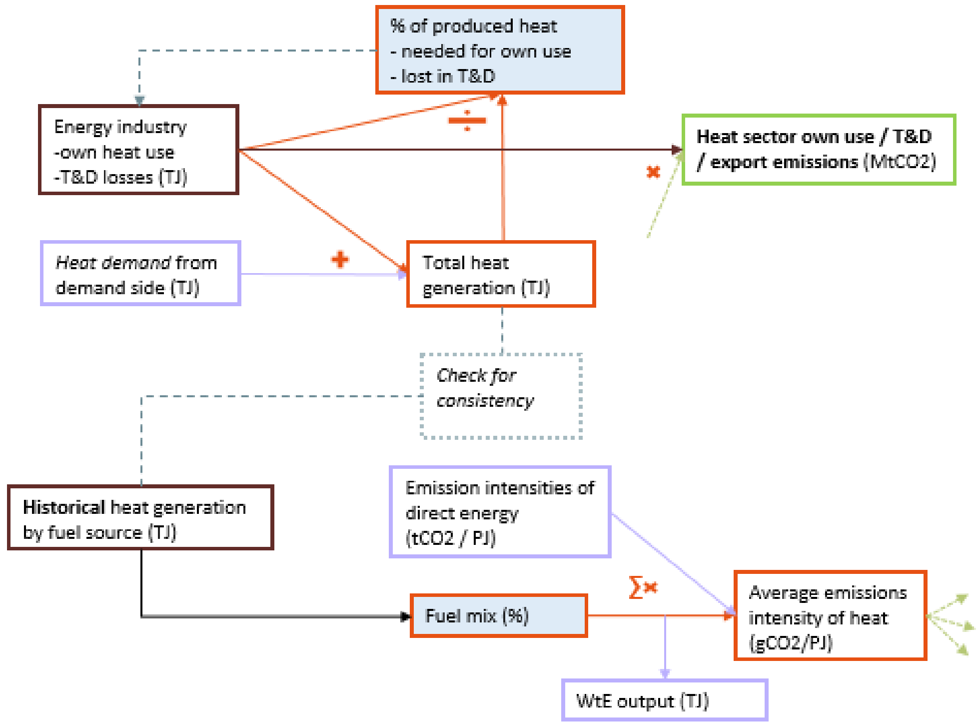
Legend

Input data	Input data needed on sectoral level
Cross-sectoral	Data used across different sectors
Calculated	Indicator to be calculated from input data
Emissions	Output emissions
Policy drivers	Drivers in policy scenarios
- - - →	Electricity emissions intensity from power sector
→	Electricity demand feeding into power sector
- - - →	Heat emission factor feeds into demand sectors
- - - →	Indicator calculated from input data feeding back into projection calculations
+	Addition
−	Subtraction
×	Multiplication
÷	Division
∑×	Sum-product
warning	Consistency check and warning

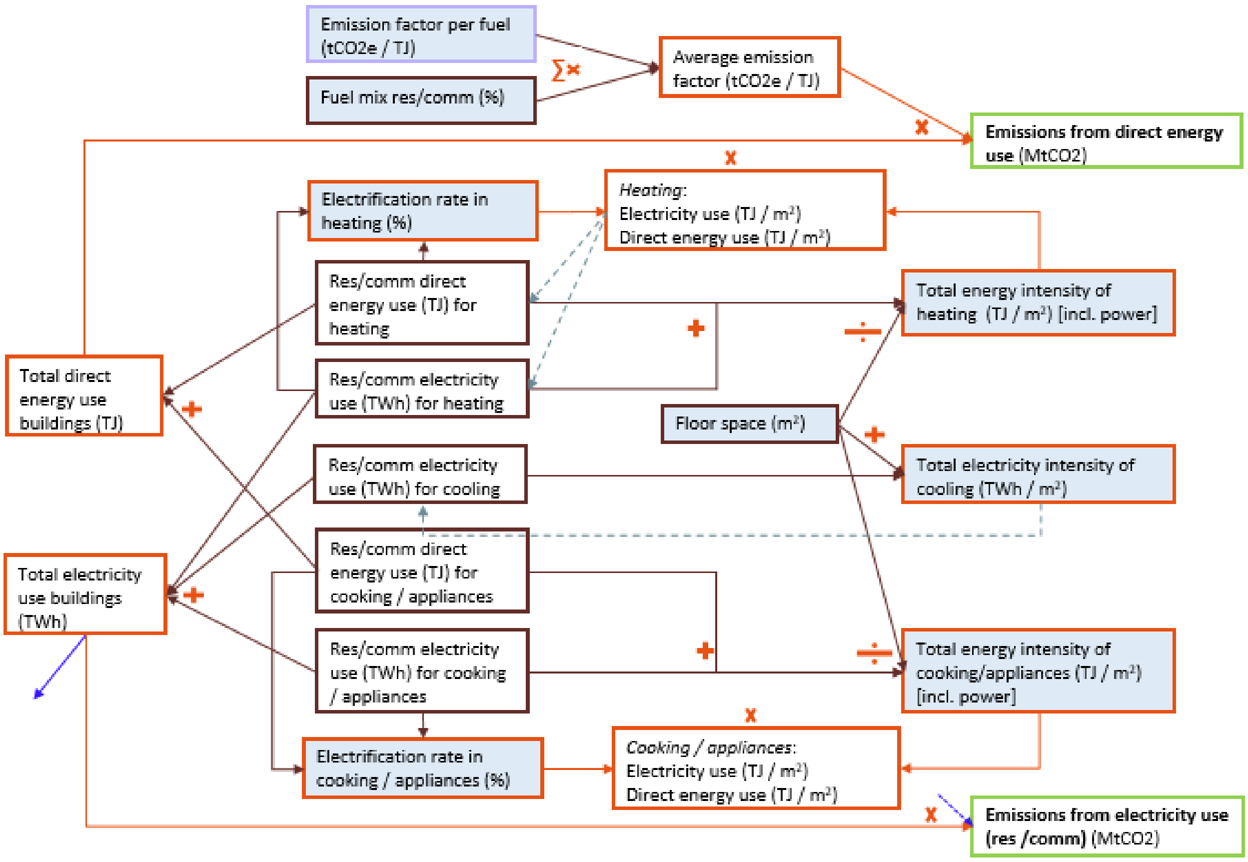
Electricity supply

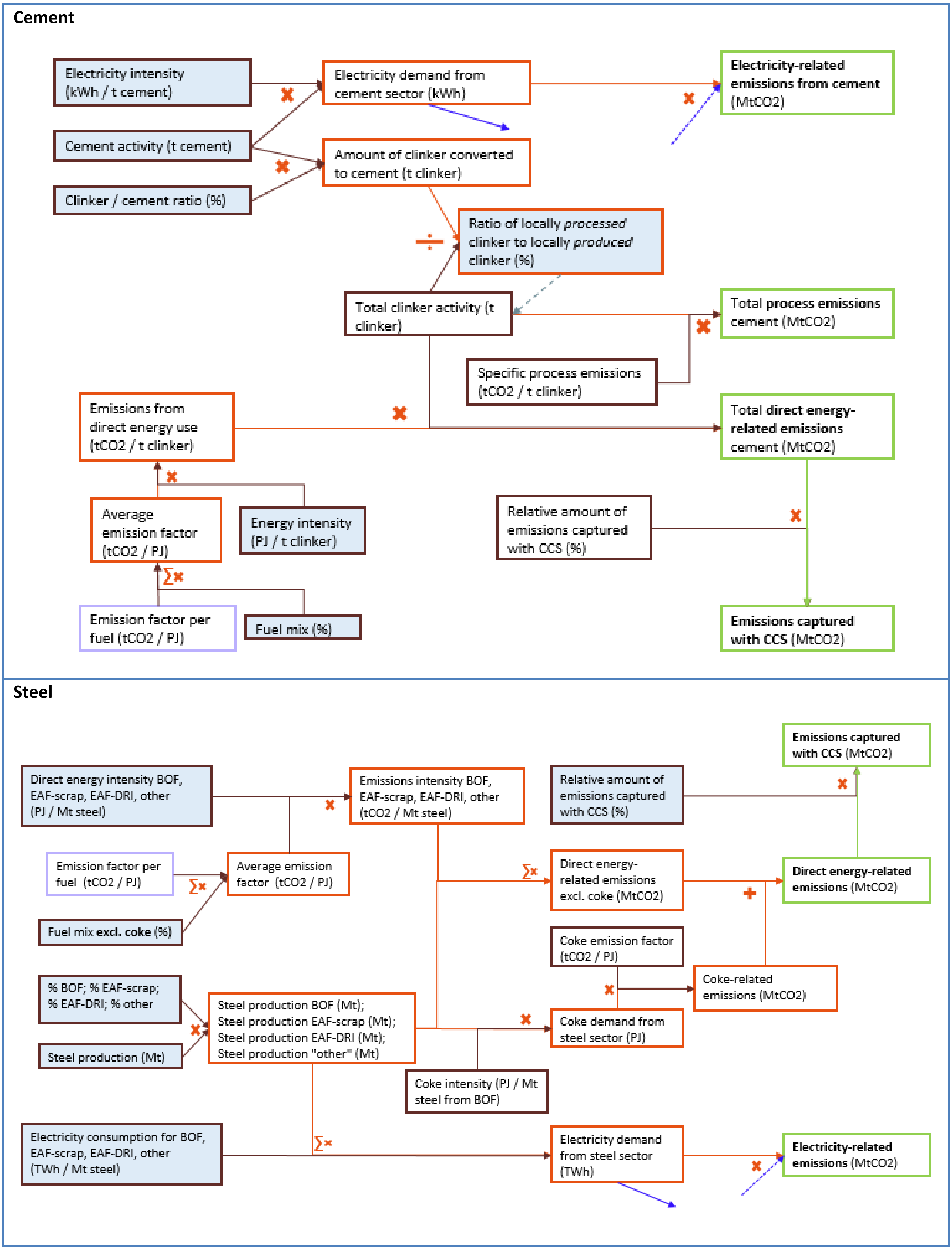


Heat supply

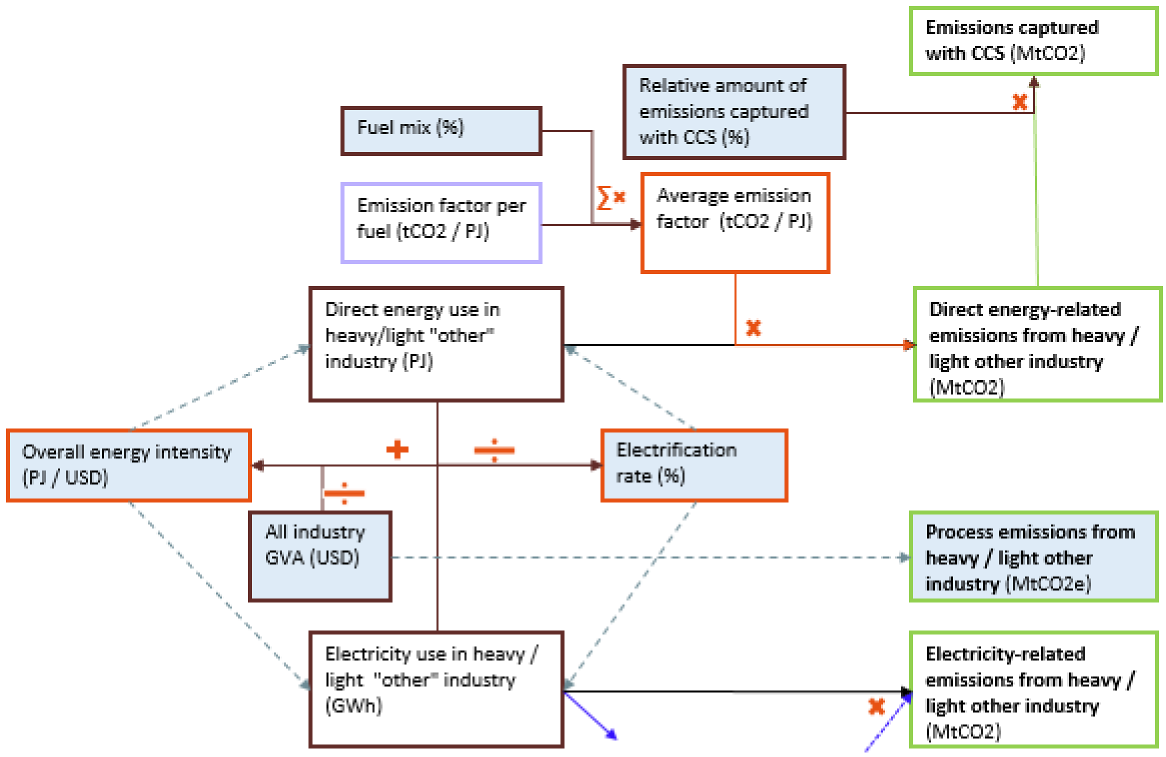


Buildings

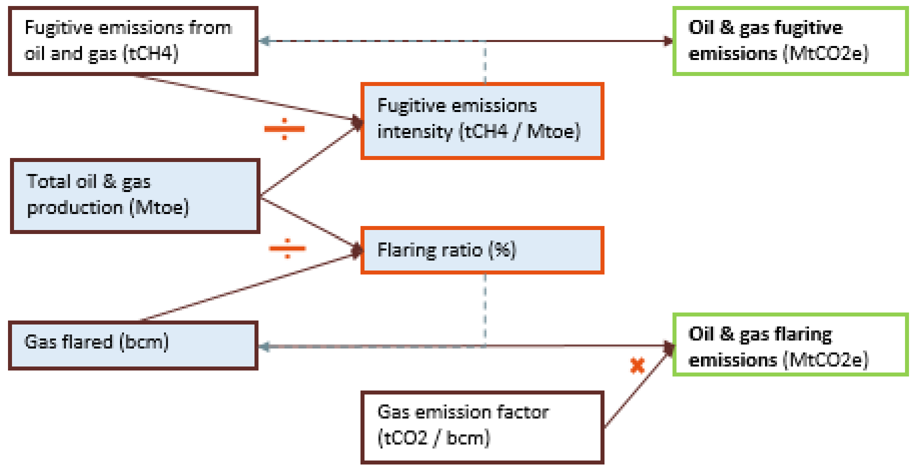


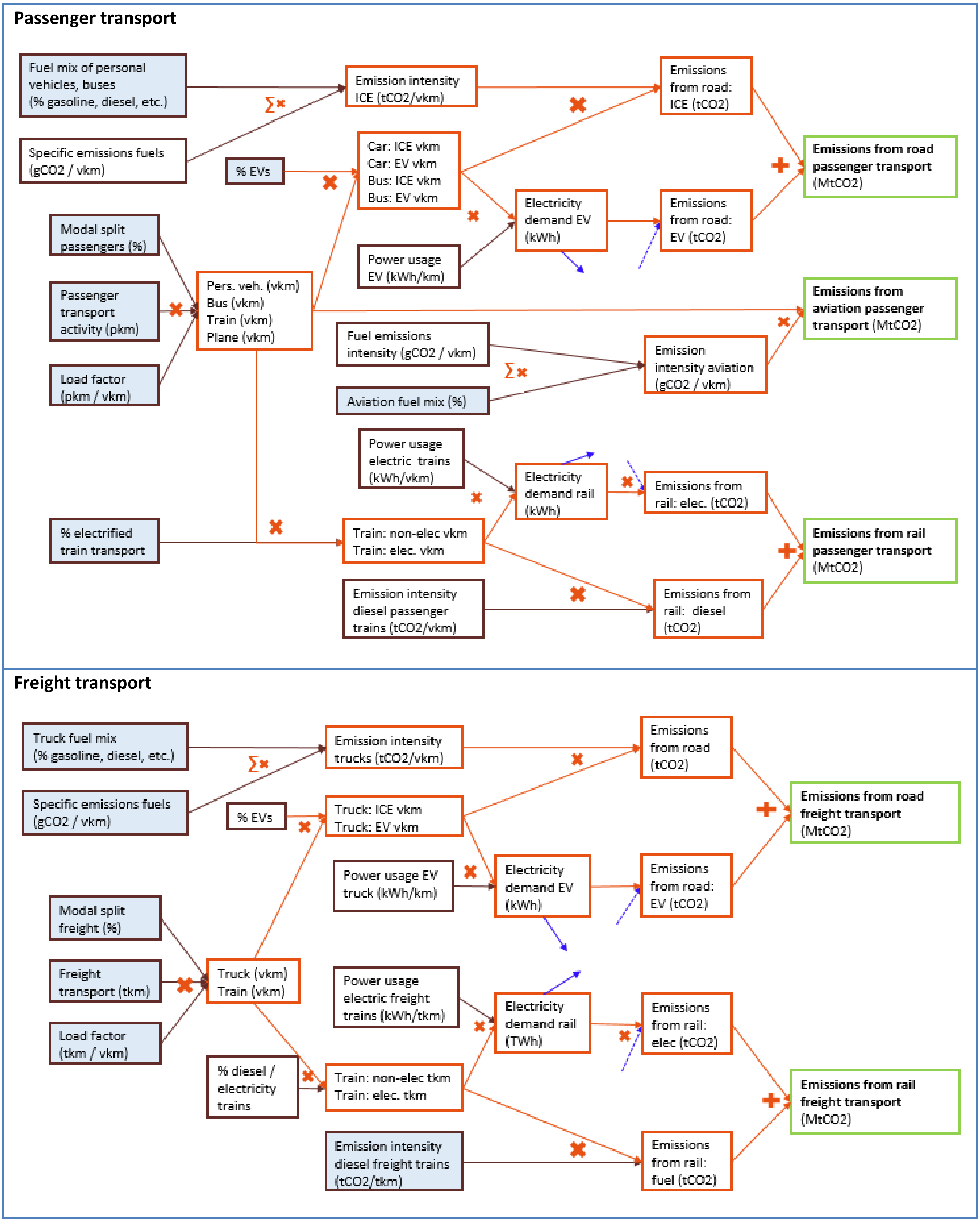

Cement
Electricity intensity (kWh / t cement)
Cement activity (t cement)
Clinker / cement ratio (%)
Electricity demand from cement sector (kWh)
Amount of clinker converted to cement (t clinker)
Electricity-related emissions from cement (MtCO2)
Ratio of locally processed clinker to locally produced clinker (%)
Total clinker activity (t clinker)
Total process emissions cement (MtCO2)
Specific process emissions (tCO2 / t clinker)
Emissions from direct energy use (tCO2 / t clinker)
Total direct energy-related emissions cement (MtCO2)
Average emission factor (tCO2 / PJ)
Energy intensity (PJ / t clinker)
Relative amount of emissions captured with CCS (%)
Emission factor per fuel (tCO2 / PJ)
Fuel mix (%)
Emissions captured with CCS (MtCO2)
Steel
Emissions captured with CCS (MtCO2)
Direct energy intensity BOF, EAF-scrap, EAF-DRI, other (PJ / Mt steel)
Emissions intensity BOF, EAF-scrap, EAF-DRI, other (tCO2 / Mt steel)
Relative amount of emissions captured with CCS (%)
Emission factor per fuel (tCO2 / PJ)
Average emission factor (tCO2 / PJ)
Direct energy-related emissions excl. coke (MtCO2)
Direct energy-related emissions (MtCO2)
Fuel mix excl. coke (%)
Coke emission factor (tCO2 / PJ)
% BOF; % EAF-scrap; % EAF-DRI; % other
Steel production BOF (Mt); Steel production EAF-scrap (Mt); Steel production EAF-DRI (Mt); Steel production "other" (Mt)
Coke-related emissions (MtCO2)
Coke demand from steel sector (PJ)
Steel production (Mt)
Coke intensity (PJ / Mt steel from BOF)
Electricity consumption for BOF, EAF-scrap, EAF-DRI, other (TWh / Mt steel)
Electricity demand from steel sector (TWh)
Electricity-related emissions (MtCO2)

Other industry

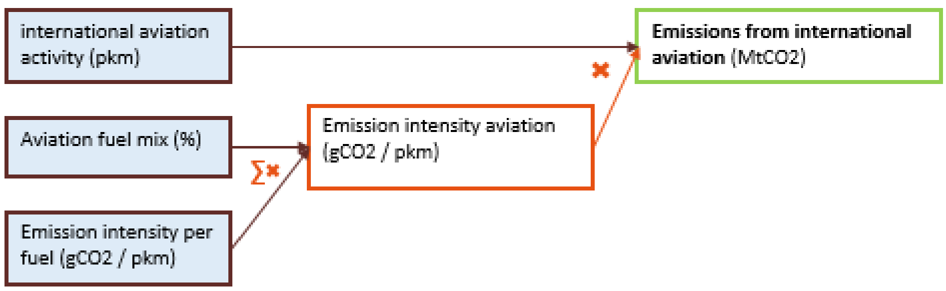


Oil & gas

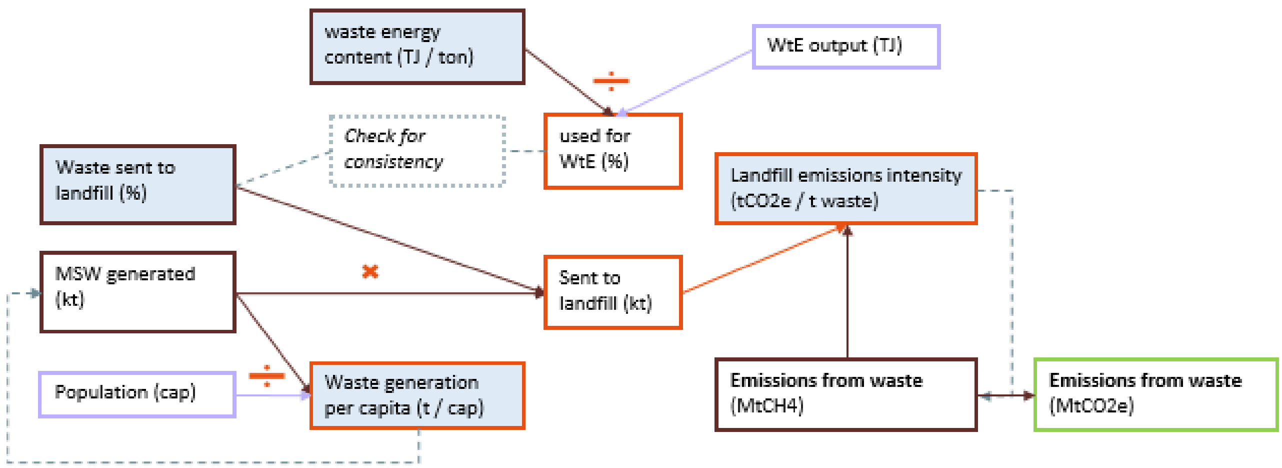



Passenger transport
Fuel mix of personal vehicles, buses (% gasoline, diesel, etc.)
Specific emissions fuels (gCO2 / vkm)
Emission intensity ICE (tCO2/vkm)
Emissions from road: ICE (tCO2)
% EVs
Car: ICE vkm
Car: EV vkm
Bus: ICE vkm
Bus: EV vkm
Electricity demand EV (kWh)
Emissions from road: EV (tCO2)
Emissions from road passenger transport (MtCO2)
Power usage EV (kWh/km)
Modal split passengers (%)
Passenger transport activity (pkm)
Load factor (pkm / vkm)
Pers. veh. (vkm)
Bus (vkm)
Train (vkm)
Plane (vkm)
Emissions from aviation passenger transport (MtCO2)
Fuel emissions intensity (gCO2 / vkm)
Aviation fuel mix (%)
Emission intensity aviation (gCO2 / vkm)
Power usage electric trains (kWh/vkm)
Electricity demand rail (kWh)
Emissions from rail: elec. (tCO2)
% electrified train transport
Train: non-elec vkm
Train: elec. vkm
Emissions from rail passenger transport (MtCO2)
Emission intensity diesel passenger trains (tCO2/vkm)
Emissions from rail: diesel (tCO2)
Freight transport
Truck fuel mix (% gasoline, diesel, etc.)
Specific emissions fuels (gCO2 / vkm)
Emission intensity trucks (tCO2/vkm)
Emissions from road (tCO2)
% EVs
Truck: ICE vkm
Truck: EV vkm
Emissions from road freight transport (MtCO2)
Power usage EV truck (kWh/km)
Electricity demand EV (kWh)
Emissions from road: EV (tCO2)
Modal split freight (%)
Freight transport (tkm)
Load factor (tkm / vkm)
Truck (vkm)
Train (vkm)
Power usage electric freight trains (kWh/tkm)
Electricity demand rail (TWh)
Emissions from rail: elec (tCO2)
% diesel / electricity trains
Train: non-elec tkm
Train: elec. tkm
Emissions from rail freight transport (MtCO2)
Emission intensity diesel freight trains (tCO2/tkm)
Emissions from rail: fuel (tCO2)

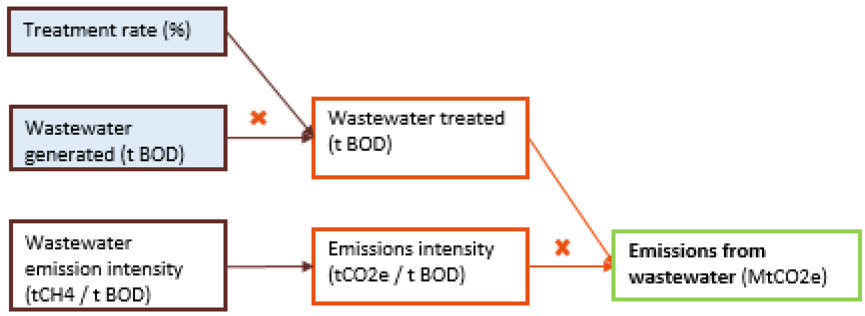
International aviation



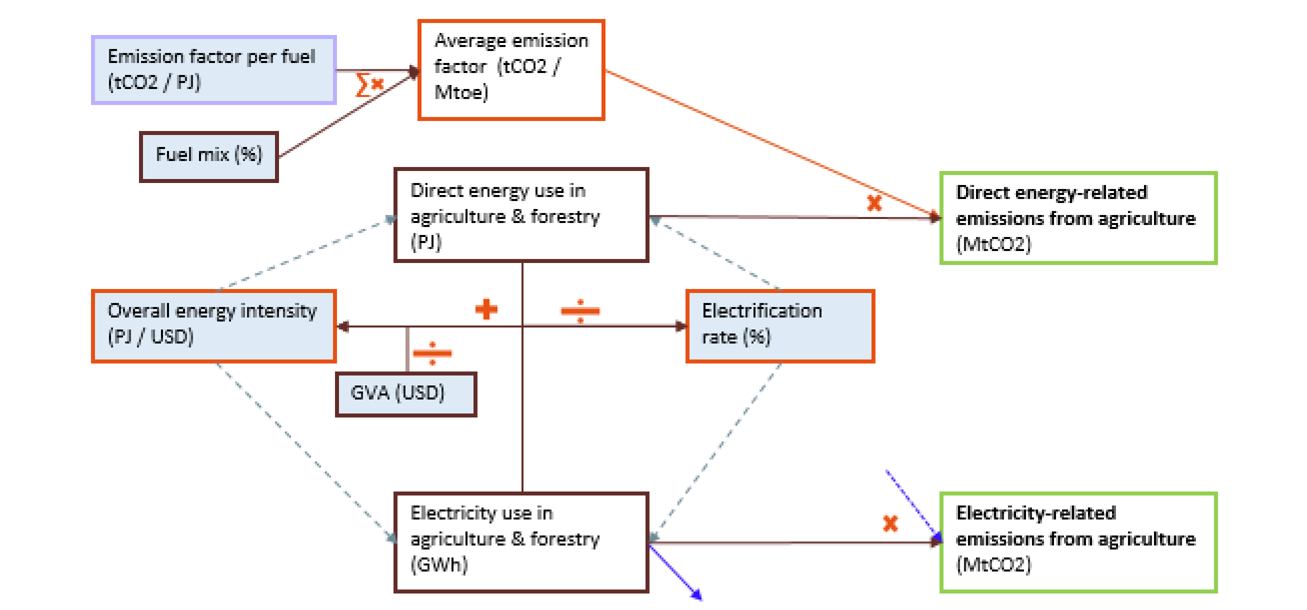
Solid waste



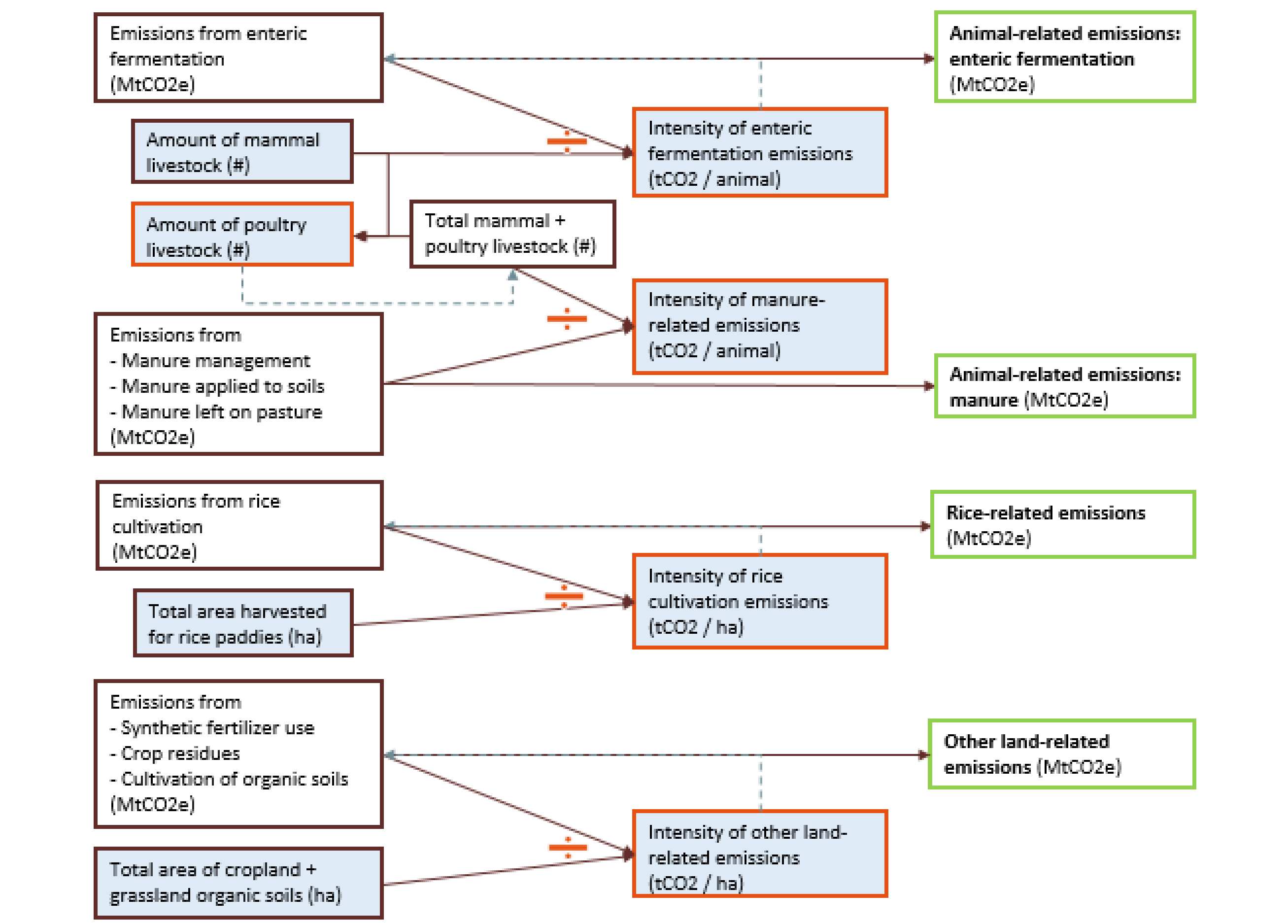
Waste water



Agriculture energy use related emissions



Agriculture other emissions



Appendix 3 Data sources used for PROSPECTS-EU and PROSPECTS-South Africa

This Appendix lists specific data sources and estimations that were used in constructing the historical time series of emissions in the EU-28 and South Africa.

The data collection was not a main focus of this thesis work, but had to be provided in parallel to make the analysis possible. It was mainly done by Lindee Wong and Tom Berg (Ecofys), Fabio Sferra (Climate Analytics) and Sebastian Sterl (NewClimate Institute), with the author of this thesis contributing to the data collection of EU-28 in electricity generation, steel industry, and cement industry sectors. For transparency reasons, it is documented here. Note that the approaches on selecting a data source in cases more than one was available, and the approaches on intra- and extrapolation, were made by the analysts involved in this work based on their expert judgement.

Indicators	Units	Data sources (EU)	Data sources (South Africa)
Electricity generation			
Emissions intensity by fuel type	$MtCO_2e$ / TWh	[43]; full time series from 1990-2014, 2015 value obtained by extrapolation of 2010-2014 trend.	
Electricity generation by fuel type	TWh		
Electricity needed for energy industry own use			
Losses (T&D)			
Imports			
Exports			
Heat generation			
Heat generation by fuel type	TJ	[43]; note that heat generation numbers reported to the IEA for South Africa were zero throughout, so the heat generation sector plays no role in PROSPECTS-South Africa.	
Heat needed for energy industries own use			
Losses (T&D)			
Transport - passenger			
Passenger transport activity	pkm	[116]; Sum of activity from different modes. 1990-1994 numbers estimated using 1995-2000 trend; 2015 number estimated using 2010-2014 trend.	Sum of activity from different modes obtained from [117] for 2006 and 2010. Activity for other years scaled with GDP growth rate with 2006 or 2010 as base year. 2010 value for air transport not available, but estimated using growth rates of total passenger volume carried, from [118]. Modal split inferred from same data, assuming constant values before 2006 and post-2010 values following 2006-2010 trend.
Modal split	% of pkm with personal vehicle, bus, train, airplane		
Load factor for each mode (for personal vehicles, buses, trains, airplanes, other)	pkm / vkm	[45]. Assumed constant before 2000.	For personal vehicles: [119]; for other vehicles: [117]. Values assumed constant over time.
Share of electrified passenger transport activity (for personal vehicles, buses, trains, other)	%	For cars: [47]. For buses: [47]. 2013 value assumed same for 2014-2015. Scaled backwards proportionally with EVs% in car fleet. For trains: [43]. Estimated from proportion of energy demand for trains met with electricity.	For cars and buses: assumed zero. For trains: [43]. Estimated from proportion of energy demand for trains met with electricity.

Electricity intensity of electrified transport (for personal vehicles, buses, trains, other)	kWh / vkm	For cars: [120] For buses: [121] For trains: [45]. Values for “Africa” taken as proxy for South Africa.	
Fuel mix for non-electrified transport (for personal vehicles, buses, trains, airplanes, other)	% of each fuel source	For personal vehicles: - Gasoline and diesel: [45]; with 1990-1999 numbers estimated from 2000-2005 trend, and 2011-2015 numbers from 2005-2010 trend. - LPG: [122]. Numbers available from 2008 onwards; assumed zero pre-2000 and linear development 2001-2007. - Biofuels: [43]. Estimated from proportion of energy demand for trains met with biofuels. For buses: from [45]; with 1990-1999 numbers estimated from 2000-2005 trend, and assuming that LPG and biofuel shares are zero. For trains: biofuel share estimated from [43] (from proportion of energy demand for trains met with biofuels); assumed that the rest (close to 100%) is diesel. For airplanes: assumed 100% jet fuel (no biofuels).	For personal vehicles and minibus-taxis: - Gasoline and diesel: 2010 value from [117] (different value for personal vehicles than for minibus-taxis); 2000-2009 values estimated using growth rates of gasoline and diesel in *overall transport* fuel mix from South Africa’s GHG emissions inventory [123]. Values pre-2000 assumed constant, values post-2010 extrapolated from trend 2000-2010. - LPG and biofuels: assumed zero share. For buses: Assumed 100% diesel, based on [117]. For trains: Assumed 100% diesel. For airplanes: assumed 100% jet fuel (no biofuels).
Energy intensity by fuel type (for personal vehicles, buses, trains, airplanes, other)	MJ/ vkm or MJ / pkm for each fuel source	[45]. 1990-1999 numbers estimated from 2000-2005 trend, except for airplanes, where 1990-1999 values are taken equal to 2000 value. Values for “Africa” taken as proxy for South Africa. Values for minibus-taxis in South Africa taken from [117] for 2010; back-casting done with the same growth rate as for personal vehicles from [45], with further adjustment by timing a ratio between 2010 values in [119] and 2010 values from [45].	
Emission intensity by fuel type (for personal vehicles, buses, trains, airplanes)	tCO_2e / MJ	Standard values taken from [45].	For gasoline, diesel, CNG/LPG: [119]; for other fuels: Standard values taken from [45]
Transport - freight			
Freight transport activity	tkm	[116]. Sum of activity from different modes. 1990-1994 numbers estimated using 1995-2000 trend (for trucks); 2015 number estimated using 2010-2014 trend.	Same as for passenger transport for South Africa, but with a price elasticity to GDP of 0.8 based on [117].
Modal split	% truck, train		
Load factor for each mode (for trucks, trains)	tkm / vkm	[45]. Assumed constant.	[117]. Values assumed constant over time.
Share of electrified transport activity (for trucks, trains)	%	Trucks: assumed zero. Trains: assumed same as for passenger transport.	
Electricity intensity of electrified transport (for trucks, trains)	kWh / vkm	Trucks: [124]. Trains: [45]. Assumed constant before 2000. Values for “Africa” taken as proxy for South Africa.	
Fuel mix for non-electrified transport (for trucks, trains)	%	Trucks: taken as 100% gasoline, based on [45]. Trains: assumed same as for passenger transport.	Trucks: Same approach as for personal vehicles and minibus-taxis. Trains: assumed same as for passenger transport.
Energy intensity by fuel type (for trucks, trains)	MJ / vkm or MJ / tkm for each fuel source	[45]. 1990-1999 numbers estimated from 2000-2005 trend. Values for “Africa” taken as proxy for South Africa.	
Emission intensity by fuel type (for personal vehicles, buses, trains, airplanes)	tCO_2e / MJ	Standard values taken from [45].	

Transport – international aviation			
International aviation activity	pkm	Taken as the difference between overall aviation activity from [45] and domestic aviation activity from [116]. 1990-1999 numbers from [45] estimated by backcasting the per-capita demand for aviation activity (in pkm) using the 2000-2010 trend.	Taken from [125] for 2012-2014. Scaled with GDP/capita for the years before and after.
Fuel mix (jet fuel vs. biofuel)	%	Same as for domestic aviation.	
Emission intensity by fuel type	tCO_2e / pkm		
Buildings			
Total floor space	million m^2	Residential buildings: [126]. Latest data runs to 2011. Scaled with GDP/capita for years post-2011. Commercial buildings: [51]. Only data points for 2005 and 2010 available, hence is assumed that for the pre-2005 years the m^2/GDP/capita is constant. Floor data is scaled accordingly.	[51]. Only data points for 2005 and 2010 available, hence is assumed that for the pre-2005 years the m^2/GDP/capita is constant. Floor data is scaled accordingly.
Direct energy demand for heating	PJ	From [127], [128] and [50]. For 2012 and 2013, data on shares of electricity and direct energy by end-use were not available and thus a constant share was assumed based on 2011 data. This gives three data points (2011, 2012, 2013). Other years scaled to energy consumption in the relevant sector [43], pre-2011 values have base year 2011 and post-2013 values have base year 2013. Hence, we assume that the ratio of energy consumption in services for heating and total energy consumption in residential sector is constant over time. Latest data point interpolated based on 5 years before. For cooling in the residential sector: only the 2013 value from ETP is used, other values are scaled according to total residential energy consumption from the IEA energy statistics and balances. NB: For South Africa, 2013 data differed strongly in a number of cases from 2011-2012 data, and was omitted in those cases (and instead estimated using the same approach as for the other years).	
Direct energy demand for cooking/appliances	PJ		
Electricity demand for water / space heating	TWh		
Electricity demand for cooling	TWh		
Electricity demand for cooking / lighting / appliances	TWh		
Fuel mix direct energy use	%	[43]; full time series from 1990-2014, 2015 value obtained by extrapolation of 2010-2014 trend.	
Steel industry			
Steel production	Mt steel	[52] (and previous editions of the same)	
Share of production methods (BF-BOF, EAF-scrap, EAF-DRI, “other”)	%		
Electricity intensity of steel production (BF-BOF, EAF-scrap, EAF-DRI, “other”)	TWh / Mt steel	EU-specific final energy intensity of the EAF route (7.33 GJ/ton; [129] converted to TWh/Mt and multiplied by the share of electricity and direct energy use in the EAF process (54.1% and 45.9; [130]) EU-specific final energy intensity of the BF-BOF route (20 GJ/ton; [131]) converted to TWh/Mt and multiplied by the share of electricity and direct energy use in the BF-BOF process (4.1% and 95.9%; [130]) The same approach was chosen for South Africa, but using final energy intensities of the BF-BOF route for China as a proxy [132].	
Direct energy intensity of steel production (BF-BOF, EAF-scrap, EAF-DRI, “other”)	PJ / Mt steel		
Coke intensity of steel production (BF-BOF)	PJ / Mt steel	Estimated from [131] (data given in MJ / tonne hot metal, converted to MJ / tonne final steel)	Derived assuming an equal share of coke in direct energy intensity as implied by the EU data.
Direct energy fuel mix	%	[43]; full time series from 1990-2014, 2015 value obtained by extrapolation of 2010-2014 trend.	
Direct energy emissions intensity of coke	$MtCO_2e$ / PJ	[43]; estimated from emission and energy stats in the steel sector related to coke oven coke, coke oven gas and blast furnace gas.	
Emissions captured with CCS	% of direct energy-related emissions (incl. from coke)	Assumed zero	

Cement industry			
Cement production	Mt cement	[133]. 2015 values estimated by extrapolating 2010-2014 trend	[60]. Earliest available data point is 1998 so interpolated backwards for missing values from period 1998-2014. Interpolated for 2015 based on latest 5 years.
Clinker / cement ratio	%		Assumed global values from [133].
Total clinker production	Mt clinker		SA specific data not found. Estimated by multiplying cement production by clinker/cement ratio.
Electricity intensity of cement production	TWh / Mt cement		Assumed global values from [133]. Assumed constant intensity (based on earliest 2012 data point for pre-2012 values and latest data point in 2014 for 2015 value).
Direct energy intensity of clinker production	PJ / Mt clinker		Assumed global values from [133].
Direct energy fuel mix	% share	[43] (category "non-metallic minerals")	
Process emission intensity	$MtCO_2e$ / Mt clinker	Global value of 0.507 tCO_2 / t clinker from the IPCC guidelines [57]	
Emissions captured with CCS	% of process and direct energy emissions	Assumed zero	
Other industry			
Value added in other industry	million USD 2012	Difference between total value added and value added in steel and cement industry. Total value added in industry from [63] (1990 value extrapolated from next 5 years); value added at factor cost in steel and cement industry from [134]. The latter scaled with steel production in years where it was not available.	Difference between total value added and value added in steel and cement industry. Total value added in industry from [63]; value added in cement and steel estimated by assuming the same value added per tonne steel as in the EU.
Direct energy demand in other industry (heavy / light industry)	PJ	[43] (category "industry" minus "iron and steel" and "non-metallic minerals")	
Electricity demand in other industry (heavy / light industry)	TWh		
Direct energy fuel mix (heavy / light industry)	%		
Process emissions	$MtCO_2e$	[62]. Difference between categories 2 (total industry) and [2.A.1 (cement) + 2.C.1 (iron and steel)].	[62] (category 2), cement (2.A.1), and steel (2.C.1), respectively.
Emissions captured with CCS (heavy / light industry)	% of process and direct energy emissions	Assumed zero	
Oil and gas			
Fugitive emissions	tCH_4	[64]. Assumed constant post-2010.	[64]. Post-2010 trend follows 2005-2010 trend.
Amount of gas flared	Gm^3	[66]. Extrapolated to period 1990-1994 and 2011-2015 with exponentially decreasing function.	
Total production of oil & gas	Mtoe	[43] (categories: Oil shale and oil sands, Crude, NGL and feedstocks, Oil products, Natural gas). 2015 value assumed equal to 2014.	
Waste and wastewater			
Amount of MSW generated	kt	Based on MSW generation per capita from [135]; values for 1990-1996 taken equal to average level 1997-2005.	2013 value from [136]; extrapolated to other years based on population growth

Share of MSW sent to landfill	%	From [135]; values for 1990-2005 estimated with exponentially decreasing function as based on 2006-2015 trend.	rate. Share sent to landfill assumed constant.
Emissions from landfills	tCH_4	[137]	
Amount of wastewater generated	t BOD	Value for Europe from [138] (60 g BOD / person / day) taken as proxy for EU-28, and for Africa (37 g BOD / person / day) taken as proxy for South Africa.	
Wastewater treatment rate	%	"Guesstimate" of 80%, based on [135].	Data for 2001-2011 from [139]; extrapolated with exponential function for periods before and after.
Wastewater emissions intensity	tCH_4 / t BOD	Default value of 0.6 tCH_4 / t BOD from [138]	
Agriculture			
Energy-related			
Direct energy use in agriculture	PJ	[43]; full time series from 1990-2014, 2015 value obtained by extrapolation of 2010-2014 trend.	
Electricity use in agriculture	GWh		
Direct energy fuel mix	%		
Total GVA of agriculture	USD 2012	[72]. 1990 value estimated from 1991-2000 trend.	
Animal-related			
Emissions from enteric fermentation	$MtCO_2e$	[73]. 2015 values estimated from 2010-2014 trends.	
Stock of animals responsible for enteric fermentation (= total mammal livestock)	#		
Stock of animals (= total mammal livestock + total poultry livestock)	#		
Emissions from manure management / manure applied to soils / manure left on pasture	$MtCO_2e$		
Rice-related			
Emissions from rice cultivation	$MtCO_2e$	[73]. 2015 values estimated from 2010-2014 trends.	
Area harvested for rice paddy	ha		
Other land-related			
Emissions from synthetic fertilizer, crop residues and cultivation of organic soils	$MtCO_2e$	[73]. 2015 values estimated from 2010-2014 trends.	2000-2010 values from [123]; extrapolated to periods before and after using growth rates of land-related emissions in [73].
Total area of grassland and cropland organic soils	ha		

Appendix 4 Fuel categories in PROSPECTS tool corresponding to fuel categories in IEA database

This appendix shows how the fuel categories in PROSPRCTS tool correspond to the fuel categories in IEA database. It should be noticed that when calculating the emission intensity of direct energy use in the steel sector in PROSPECTS tool using IEA database, emissions from coke related products, including coke oven coke, coke oven gas, and blast furnace gas, are excluded from the emissions of the category “coal” in PROSPECTS, as mentioned in *section 3.2.2.*

PROSPECTS Category	IEA Category
Coal	Hard coal, Brown coal, Anthracite, Coking coal, Other bituminous coal, Sub-bituminous coal, Lignite, Patent fuel, Coke oven coke, Gas coke, Coal tar, BKB, Gas works gas, Coke oven gas, Blast furnace gas, Other recovered gases, Peat, Peat products, Oil shale
Gas	Natural gas
Oil	Crude/NGL/feedstocks, Crude oil, , Natural gas liquids, Refinery feedstocks, Additives/blending components, Orimulsion, Other hydrocarbons, Refinery gas, Ethane, Liquefied petroleum gases (LPG), Motor gasoline excl. biofuels, Aviation gasoline, Gasoline type jet fuel, Kerosene type jet fuel excl. biofuels, Other kerosene, Gas/diesel oil excl. biofuels, Fuel oil, Naphtha, White spirit & SBP, Lubricants, Bitumen, Paraffin waxes, Petroleum coke, Non-specified oil products
Waste	Industrial waste, Municipal waste
Biomass	Primary solid biofuels, Biogases, Biogasoline, Biodiesels, Other liquid biofuels, Non-specified primary biofuels/waste, Charcoal, Elec/heat output from non-specified manufactured gases, Heat output from non-specified combustible fuels
Nuclear	Nuclear
Hydro	Hydro
Solar	Solar photovoltaics, Solar thermal
Wind	Offshore wind, Onshore wind
Geothermal	Geothermal
Marine	Tide, wave and ocean

Appendix 5 BRT systems in South Africa

BRT system	City	Status	Link
Rea Vaya BRT	Johannesburg	Phase 1B finished in 2014; Phase 1C is planned to finish in 2018	https://www.reavaya.org.za/
MyCiTi BRT	Cape Town	Phase 1 and partial Phase 2 (N2 Express) have been in operation in 2015; Phase 2 is planned to be in operation in 2020.	https://myciti.org.za/en/about/media-marketing/myciti-news/myciti-phase-2-a-link-to-metro-south-east/
Go George BRT	George	Phase 2 started in 2015; all routes have been in operation in 2016.	http://www.gogeorge.org.za/faq/
Libhongolethu BRT	Nelson Mandela Bay	Pilot phase has been in operation since 2013	http://www.nelsonmandelabay.gov.za/datarepository/documents/1Y66K_DRAFT%20Annual%20Report%202012-13.pdf
A Re Yeng BRT	Tshwane	Phase 1A has been in operation 2015; Phase 1B and Phase 1C are expected to be completed in 2016; Phase 1D is expected to be completed in 2017; Full Phase 1 is expected to be completed in 2019	http://www.engineeringnews.co.za/print-version/a-re-yeng-tshwane-rapid-transit-system-south-africa-2016-01-08
The Yarona BRT	Rustenburg	Project launched in 2016, including four phases and Phase 1 is divided into Phase 1A, 1B and 1C; Testing of Phase 1 is expected to be completed in 2017	http://www.engineeringnews.co.za/print-version/rustenburg-rapid-transport-project-south-africa-2014-10-17
Harambee BRT	Ekurhuleni	Phase 1 launched in 2016, including Phase 1A, 1B, 1C and 1D; Phase 1A has been in operation in 2016. Entire project is planned to be in operation in 2017	http://www.gov.za/about-government/government-programmes/bus-rapid-transit-system-brt
Go Durban! BRT	eThekwini	Phase 1 is planned to be in operation in 2018	http://www.news24.com/archives/witness/phase-1-of-go-durban-expected-to-go-live-in-2018-20150430
East London	Buffalo City	Planned to launch in 2020	http://www.transport.gov.za/Portals/0/Annual%20Reports/2015/DoT%20SP%202015-2020.pdf
Bloemfontein	Mangaung		
Nelspruit	Mbombela		
Pietermaritzburg	Msunduzi		
Polokwane	Polokwane		

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