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Assessment of Development Scenarios to Reach Net-Zero by Mid-Century: A System Dynamics Modelling Approach for South Africa

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Executive Summary

This report presents the findings of a system dynamics modelling assessment of development scenarios to support South Africa's transition to net-zero carbon dioxide emissions by mid-century. Developed to inform the country's evolving Long-Term Low-Emission Development Strategy (LT-LEDS) and associated Sectoral Emission Targets (SETs), the analysis applies the Millennium Institute's iSD model, customised for the South African context, to explore interactions across key systems including energy, transport, food, water, land use, production and consumption, and human development. The assessment is designed not only to examine emissions reduction pathways, but also to evaluate how these pathways interact with South Africa's broader development priorities, including the triple challenge of poverty, inequality and unemployment, together with the imperative of a just transition.

The report compares a baseline scenario with a holistic scenario that combines interventions across multiple sectors and systems. The results show that integrated action can produce important cross-sector gains. Relative to the baseline, the holistic scenario performs better across a range of economic, social and environmental indicators. GDP growth remains stronger over the long term, while poverty and unemployment decline modestly and the Human Development Index improves gradually. At the same time, the model indicates lower CO_2 emissions, reduced particulate air pollution, improved access to electricity, water and sanitation, lower undernourishment, and gains in selected land, mobility and service delivery indicators. Taken together, these findings suggest that climate-aligned development can also advance wider development goals when pursued through an integrated systems approach.

A central contribution of the report is its identification of synergies and trade-offs across systems. The analysis shows that electricity is the single most important enabling system, underpinning progress across economic performance, service delivery, access, and environmental outcomes. Food systems also emerge as highly influential, particularly for poverty, nutrition, health and resilience. Water, sanitation, transport, and production systems similarly shape the degree to which broader development gains can be realised. The implication is that isolated sectoral interventions are unlikely to be sufficient. Policy coherence, coordinated planning, and integrated investment will be essential if South Africa is to move toward Net-Zero while also improving social and development outcomes.

At the same time, the results show that the holistic scenario does not yet amount to a fully just transition. Inequality remains persistently high, with only limited improvement in the Gini coefficient, while long-term decoupling between economic growth and material consumption remains incomplete. This points to the need for stronger distributive measures, greater attention to circular economy transitions, and more explicit focus on institutional capability and structural transformation. Overall, the report concludes that South Africa's net-zero pathway is most plausible and most beneficial when framed not as a narrow technical decarbonisation exercise, but as an integrated developmental transition.

The model interface can be accessed here:
https://exchange.iseesystems.com/public/millenniuminstitute/isd-zaf-test/index.html#page1

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1. Background and introduction

As a signatory to the 2015 Paris Agreement and a Party to the United Nations Framework Convention on Climate Change (UNFCCC), South Africa has committed to a long-term, low-carbon development pathway. In its most recent Nationally Determined Contribution (NDC) submitted to the UNFCCC in October 2025 (RSA, 2025), the country affirms its intention to reach net-zero carbon dioxide emissions by mid-century (2050). These commitments form part of South Africa’s broader effort to align climate action with sustainable development and a just transition.

To advance the implementation of its climate commitments, the South African government is developing Sectoral Emission Targets (SETs) as a key instrument to steer climate policy and planning to guide sectoral mitigation efforts. In support of this, there is a need to analyse the operational trends and interlinkages across key economic sectors - including energy, transport, agriculture, forestry and other land use (AFOLU), water, and food systems - within the broader socio-economic context. Understanding the dynamics and interconnections across sectors is essential to designing development pathways that align sectoral growth with sustainable development and acknowledge national priorities, such as the just transition, the triple challenge, and the vision of a “Good Life by 2050.”

This project contributes to shaping South Africa’s development pathways by applying system dynamics modelling (SDM) to evaluate the technical feasibility and socio-economic implications. SDM provides a comprehensive, integrated approach to assess drivers and interconnections across sectors. SD modelling can hence identify potential synergies that could accelerate transformation, expose trade-offs and uncover key areas for policy intervention (see Figure 1). The resulting insights are intended to inform the design of effective SETs and support development of South Africa’s latest Long-Term Low-Emission Development Strategy (LT-LEDS), due to be submitted in 2026.

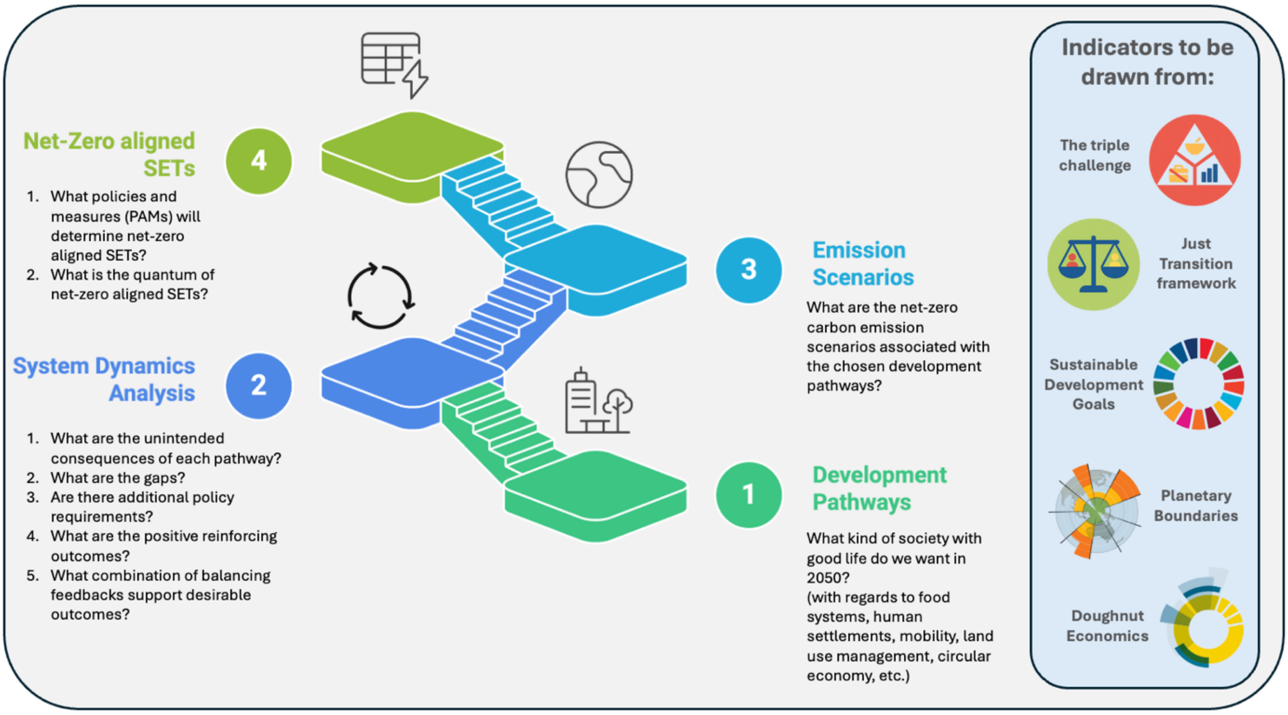

Figure 1: Situational placement of SDM analysis in relation to the broader LT-LEDs development process. Source: adapted from DFFE, 2025.

1.1 Situating the LT-LEDS in relation to broader policy and planning

South Africa's climate commitments are outlined and implemented through various national policy and legislative frameworks. The overarching objective is to achieve net-zero carbon dioxide emissions by 2050, in line with the global goal of limiting temperature increases to well below 2°C above pre-industrial levels, while pursuing efforts to limit warming to 1.5°C (UNFCCC, 2023). As the 20th largest global emitter and a fossil-fuel dependent economy (DFFE, 2020), South Africa holds a responsibility to reduce emissions while safeguarding national development priorities – needing to balance international obligations with supporting broader national development goals, including the triple challenge of poverty, inequality and unemployment, as identified in the National Development Plan (NDP) (NPC, 2017).

According to Article 2 of the Paris Agreement, South Africa is required to submit Nationally Determined Contributions (NDCs) every five years. The country's first intended NDC was drafted in 2015, ahead of COP 21, and subsequently refined into the first official NDC submitted in 2021 (RSA, 2021). More recently, the second NDC framework was published (RSA, 2025). These NDCs encompass national priorities across mitigation, adaptation, and loss and damage. On mitigation, the NDC defines economy-wide emission reduction targets aligned with South Africa's national circumstances. These mitigation targets are further informed by the national greenhouse gas (GHG) inventory, which applies an inventory-based approach for key sectors closely in line with the IPCC reporting standards (DFFE, 2024). In the NDC, GHG emissions are defined as "the total net GHG emissions in CO_2-eq across all sectors, including LULUCF but excluding emissions from natural disturbances in the land sector" (DFFE, 2025). Building on the previous NDC (2021), the second NDC communicates the mitigation target maintained for the period of 2026-2030 and communicate a new target range for the 2031-2035 (DFFE, 2025).

Beyond the NDCs, South Africa has voluntarily committed to developing its Long-Term Low-Emission Development Strategy (LT-LEDs). SA's LT-LEDs envisions "South Africa to follow a low-carbon growth trajectory while making a fair contribution to the global effort to limit average temperature increases, while ensuring a just transition and building resilience to climate change" (DFFE, 2020). While complementary to the NDC, the LT-LEDs provides longer-term pathways to achieve established targets in the NDC and, as part of a broader systematic planning process, considers the long-term delays associated with sectoral transformation (e.g. lifetime of infrastructure assets). First developed in 2020, the LT-LEDs is a living document, updated every five years to remain responsive to shifts in domestic policy, technological innovation, and the declining costs of emissions-reduction options.

The LT-LEDs further draws its foundations from the NDP, the National Climate Change Response Policy, and the Climate Change Act (2024). It is closely aligned with broader development priorities, including tackling unemployment, poverty, and inequality, while advancing the Sustainable Development Goals (SDGs). To benchmark the performance of the LT-LEDs strategy and the progress of the country's long term development trajectory, the strategy currently aligns the emission targets with those in the NDC framework between 2026-2035 (Republic of South Africa, 2024), until the longer-term trajectory is established by the LT-LEDs. Moreover, to guide mitigation efforts at a sectoral level, the government is in the process of developing sectoral emission targets (SETs), informed by specific policies and measures (PAMs) and a SET's investment plan (Lewis *et al.*, 2024). As it stands, SET's have only been developed for the 2026-2030 commitment period to support the implementation of the 2030 NDC mitigation targets. The aim of the latest LT-LEDs is to produce indicative SETs for the period 2031-2050 and the underlying development pathways. To support the implementation of the 2035 NDC, DFFE will develop SETs for the next commitment period covering the years 2031-2035. This process will likely start in 2029.

The development of SETs and the LT-LEDs has been informed by a range of modelling studies, including those undertaken by Cambridge Econometrics and The Green House (Hartvig *et al.*, 2024), as well as technical assessments of SA's net-zero emission pathways (e.g. PCC, 2024). These have provided the foundation for establishing the short-term SETs to 2030. In parallel, qualitative assessments have been conducted through stakeholder engagement and sectoral working groups to define development narratives towards achieving a "Good Life for All" by 2050 (Carbon Trust, unpublished). While these assignments have been valuable in framing long-term visions, further quantitative analysis is required to test the feasibility of different development pathways, explore synergies and trade-offs across sectors, and assess how they interact with broader societal goals and global dynamics (in line with the four-stage process outlined in Figure 1).

This project builds on existing work by applying system dynamics modelling (SDM) to evaluate the evolution and socio-economic viability of the proposed development pathways, and to assess the interconnections across sectors and identify policy levers that can accelerate the transition. It situates itself within the wider body of research commissioned by DFFE (as outlined in Figure 1), while focusing specifically on the assessments most relevant to the update of the upcoming LT-LEDs (Table 1). By integrating previous knowledge with new modelling insights, the project seeks to strengthen South Africa's ability to design effective SETs, inform its LT-LEDs strategy, and advance long-term development planning. Table 1 further outlines the key literature and sectoral policies that have been identified to inform the SDM analysis.

Table 1: Relevant literature, PAMs and stakeholders identified to inform the current analysis.

Sector	Literature	Stakeholder(s)
Cross-cutting	SA NDC, 2021 & 2025 (draft)	DFFE
	SA LT-LEDs 2020	DFFE
	9th National GHG Inventory Report	DFFE
	National Development Plan 2030	NPC
	Development Narratives	Carbon Trust
	Climate Change Act, 2024	DFFE
	Just Transition Framework, 2022	PCC
	Carbon Tax Act, 2019	DFFE
	Short-term Sectoral Emission Targets (2030)	The Greenhouse & Cambridge Econometrics
	Transformational Change Methodology (2020)	WRI
	Sustainable Development Methodology (2020)	WRI
	Journeys into our future: South Africa 2024 to 2035	Indlulamithi group
Energy	Integrated Energy Plan	DMRE
	Integrated Resource Plan	
	The National Energy Efficiency Strategy	
	National Building Regulations and Standards ACT, 1977	DTIC
	Renewable Energy Methodology: Assessing the greenhouse gas impacts of renewable energy policies (2020)	ICAT
	Buildings Efficiency Guidance (2018)	ICAT
Transport	2018 Green Transport strategy	DoT

Sector	Literature	Stakeholder(s)
	Transport Pricing Methodology: Assessing the greenhouse gas impacts of transport pricing policies (2020)	ICAT
AFOLU	Climate Change Adaptation and Mitigation Plan for SA Agriculture and Forestry sectors	DFFE
	Agriculture Methodology: Assessing the Greenhouse Gas Impacts of Agricultural Policies (2023)	ICAT
	Forest Methodology: Assessing the Greenhouse Gas Impacts of Forest Policies (2020)	ICAT
Industry	Industrial Policy Action Plan (IPAP)	DTIC
Waste	National Environmental Management ACT: Waste Act (National Waste Management Strategy).	DFFE
Financing	SET Investment Plan	The Greenhouse & Cambridge Econometrics
	South African Climate Finance Landscape (2023)	PCC
	JET investment Plan	PCC

*PAMs – Policies and Measures; DFFE – Department of Forestry, Fisheries and the Environment; NPC- National Planning Commission; DMRE – Department of Mineral and Energy Resources; DTIC – Department of Trade, Industry and Competition; DoT – Department of Transport; PCC – Presidential Climate Commission; WRI – World Resources Institute; ICAT – Initiative for Climate Action Transparency; AFOLU - Agriculture, Forestry and Other Land-Use.

1.2 Report overview

This report forms **Deliverables 3 and 4** of the project (Table 2) and, as such, focuses on presenting the model results and policy recommendations to inform the development pathways in South Africa. It has been updated following the stakeholder presentation (**Deliverable 5**) and thus now counts as the final report for the project.

Table 2: Project deliverables.

Deliverable number	Deliverable name
1	Inception Report (including work plan and methodology)
2	Systems Dynamics Models for Each Key Sector
3	Assessment Report on Draft Development Pathways
4	Policy Recommendations & Action Framework Addressing Identified Gaps and Opportunities
5	Stakeholder Presentation of Model Findings and Revised Narratives

The report is structured as follows:

- **Section 2** introduces the overall methodology, including SDM more broadly, and the iSD model in particular;
- **Section 3** describes the customisation of the iSD model for SA;
- **Section 4** summarises the model validation processes and protocols, including the calibration results;
- **Section 5** outlines the scenario design and associated assumptions;
- **Section 6** presents the results of the scenario analysis;
- **Section 7** presents the synergy and trade-off analysis; and finally,

- **Section 8** concludes the report by framing the key insights and messages, as well as the policy recommendations, emanating from this study.

The main report is supported by a number of annexures:

- **Annex 1** describes the indicator framework,
- **Annex 2** details the numerical results of the synergy analysis (as presented in **Section 7**),
- **Annex 3** documents the main questions and answers received during the final stakeholder engagement workshop**.**
- **Annex 4** presents the sector-level causal loop diagrams (CLDs) that were developed in the earlier, qualitative stage of the modelling process (providing further detail to the holistic CLD presented in **Section 3.3**).

2. Methodology

2.1 System Dynamics Modelling

System Dynamics Modelling (SDM) shares the principles of systems thinking, a holistic approach that focuses on how the elements within a system interact and influence one another (Forrester, 1994). Systems thinking is particularly valuable for improving understanding of underlying dynamics, projecting behaviour over time, and exploring how modifications to a system can produce desired outcomes and reduce undesired outcomes (Meadows, 2009).

SDM translates these concepts into a structured analytical modelling framework. It enables the simulation of drivers, interconnections, feedback and dynamic behaviour for complex development challenges (Ford, 2009). Unlike discrete event modelling, SDM employs continuous mathematical simulation, formulated by algebraic differential and integral equations that are primarily represented by stock-and-flow structures (Sterman, 2010). This enables SD models to simulate temporal change, making it particularly useful for long-term development planning and strategic decision-making in cross-sectoral settings.

SDM has a strong legacy in development planning (Pedercini, Arquitt and Chan, 2020). It was pioneered at MIT in the 1960s and gained international prominence through the Club of Rome's seminal *Limits to Growth* report, which drew on the WORLD3 system dynamics model (Forrester, 1997). Since then, the method has evolved into a robust analytical approach for examining interconnections, feedbacks, trade-offs, and synergies across multiple sectors and scales. In the context of climate transition, SDM has been broadly applied to support the climate movement and carbon transition, with wide recognition of Climate Interactive's En-ROADS and C-ROADS policy simulators[1], for example. Moreover, SDM has been previously within South Africa to support green economy and related studies in South Africa (e.g. Musango, Brent and Bassi, 2014). The strength and applicability of SDM lies in allowing decision-makers to explore how interventions may play out dynamically to better inform strategies in the face of uncertainty and complexity.

2.2 The iSD Model

The foundation of the methodology used in this project is the Integrated Sustainable Development (iSD) model (previously known as the Threshold-21 model), which has been implemented in more than 40 countries[2] and regions to support integrated policy design to achieve national development objectives, including addressing climate change, low-carbon development (LT-LEDs), and green economy objectives. The iSD model is based on the System Dynamics (SD) methodology and includes 24 interacting sectors integrated holistically across economic, social and environmental domains (Table 3).

Table 3: iSD Model Sectors.

Social	Economic	Environmental
1. Population	9. Agriculture	17. Land
2. Health	10. Firms	18. Soil
3. Education	11. GDP	19. Climate

[1] https://www.climateinteractive.org/en-roads/

[2] Visit https://www.millennium-institute.org/our-work for an overview of MI's modelling assessments.

Social	Economic	Environmental
4. Nutrition	12. Investment	20. Water
5. Buildings	13. Finance	21. Energy
6. Transport	14. Government	22. Materials
7. Employment	15. Households	23. Emissions
8. Access to basic services	16. Balance of Payments	24. Oceans

The project team has used the latest iSD model structure as a starting point and then calibrated and adapted the sub-models with the most recently sourced country data. Figure 2 shows a holistic representation of the iSD model structure consisting of a network of feedback loops across sectors and highlights the key sectors (energy, transport, agriculture, land, water, emissions and climate) relevant for the analysis.

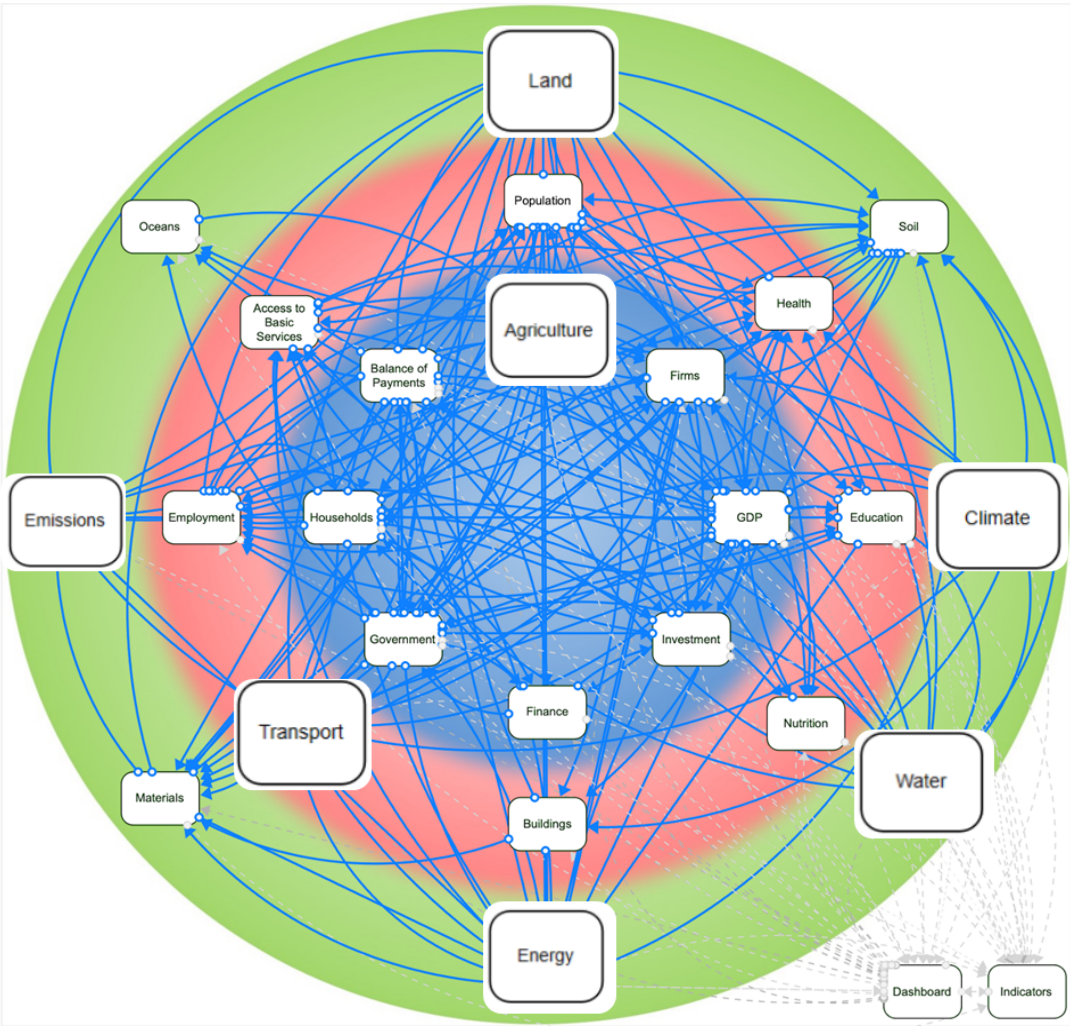

Figure 2: iSD modelling framework highlighting the key sectors relevant for the South African analysis. The modules broadly cover the economic and government (blue), social (red) and environmental (green) domains. Source: Millennium Institute.

The iSD model for SA is implemented in STELLA® Architect software. The iSD model is a well-vetted tool with the ability to deliver policy-relevant results within the short timeframe of this assessment. The model also has built in functionality to assess synergies and trade-offs between development indicators, and a web-based visual user interface (VUI) offering an accessible way for stakeholders to engage with the model - without needing access to model software. The iSD model is further structured to provide an overview of the causal relationships that exist within and across sectors of the national economy and simulate the development pathways at a national scale.

Drawing from the outcomes of the iSD model, the analyses can inform the sectoral development pathways and recommend a suite of policy interventions to achieve South Africa's LT-LEDs targets. While the current analysis is focused on net-zero emissions, the underlying modular structure of the model can be adapted to other thematic or specific development challenges, making the model a valuable tool for national developmental planning beyond the lifespan of this project.

2.3 Fundamental dynamics in the iSD Model

The following high-level description of the iSD model is drawn from the latest version of the *iSD model documentation* (Pedercini & Zaharia-Kézdi, 2025).

Multiple feedback loops drive - or hinder - development in the iSD model. These mechanisms include relationships that connect variables across the economic-social and environmental sectors, creating powerful reinforcing or balancing mechanisms. While it would be impractical to describe all those feedback loops, in this section we show some of the loops that, under normal circumstances, are central to the model behaviour.

2.3.1. The major feedback loops that drive development

While economic growth is not considered an absolute proxy for a country's development, economic activity is central to a country's transformation, in that it provides the means and resources to successfully undertake such a process. Figure 3 shows how various interconnected feedback loops link productivity drivers, production, government finance and investment in the iSD model. At the centre, productivity is influenced by key drivers such as energy, health, education, infrastructure and other societal factors. These drivers enhance productivity, which creates economic value through production. The total value added then contributes both to government and household revenue. Government revenue supports public expenditure and investment (via the *Public investment loop*), while households' revenue contributes to private investment (the *Investment loop*). Both public and private investments boost capital, which further increases the amount of value added. Simultaneously, increased households' revenue reinforces the *Access to Services loop*; while government expenditure (through the provision of social services and infrastructure) provides productivity gains that support the *Productivity loop*. Government investment can also lead to compressing the space for private investment (the *Crowding loop*) by absorbing private saving or exhausting viable opportunities for private investment. External financing further contributes to government revenue, providing an additional source of government revenue.

In summary, these feedback dynamics drive the growth in the productivity of society, which contributes to value creation through economic activities, and in turn reinforce government expenditure and investment (public and private) into the economy. These dynamics broadly reflect the macro-economic theory underlying neoclassical growth and endogenous economic growth, and the fundamental hypothesis on production (further described in **Section 2.3.3** and Figure 5).

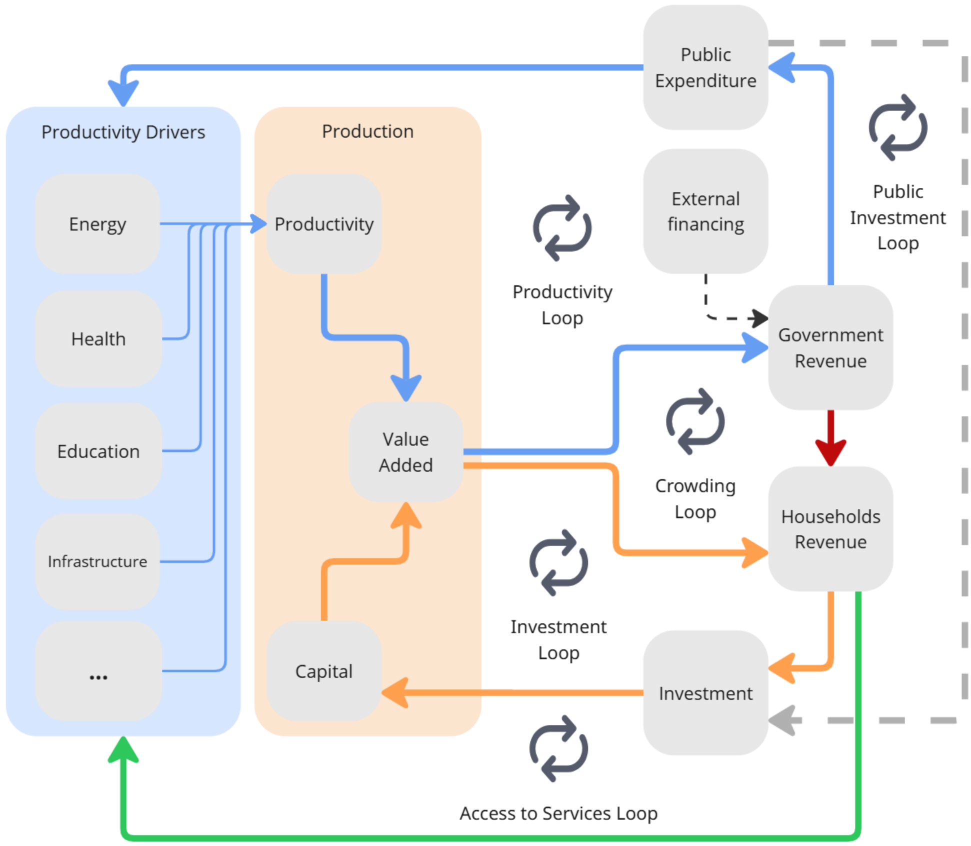

Figure 3: Fundamental dynamics 1: major feedback loops driving development. Source: reproduced from Pedercini & Zaharia-Kézdi (2025: 16).

2.3.2. Major feedback loops hindering development

While the feedback loops discussed in Figure 3 drive development in the iSD model, other key feedback loops slow development, by weakening or counteracting the reinforcing feedback loops. These main limiting (or balancing) feedback loops stabilise interactions between population growth, economic development and environmental sustainability, and are summarised in Figure 4 and explained below:

- Firstly, the *Population Control loop* shows how increases in added economic value - driven by economic activity and production - can lead to improvements in wealth and education, and in turn reduce fertility rates and population growth.
- The *Diminishing returns* loop captures the effects of ongoing investment into capital and productivity which progressively result in smaller gains, moderating economic growth.
- The *Production Cost loop* highlights the effects of environmental constraints, as a result of increased resource consumption from population and income growth. This in turn results in a decline in domestic resource availability, driving up resource and production costs hence limiting value addition.
- Lastly, *Human health* captures the role of environmental quality in sustaining the population and economy. As resource consumption degrades the environment, population health deteriorates, which in turn decreases labor productivity, income generation and constrains population growth.

Together, these loops slow down development, emphasizing the interconnectedness of society and economy with the environment. While some of these dynamics are difficult to appreciate in the short term, they can become dominant in the longer-term, and thus it is important to recognize them when crafting long term development strategies.

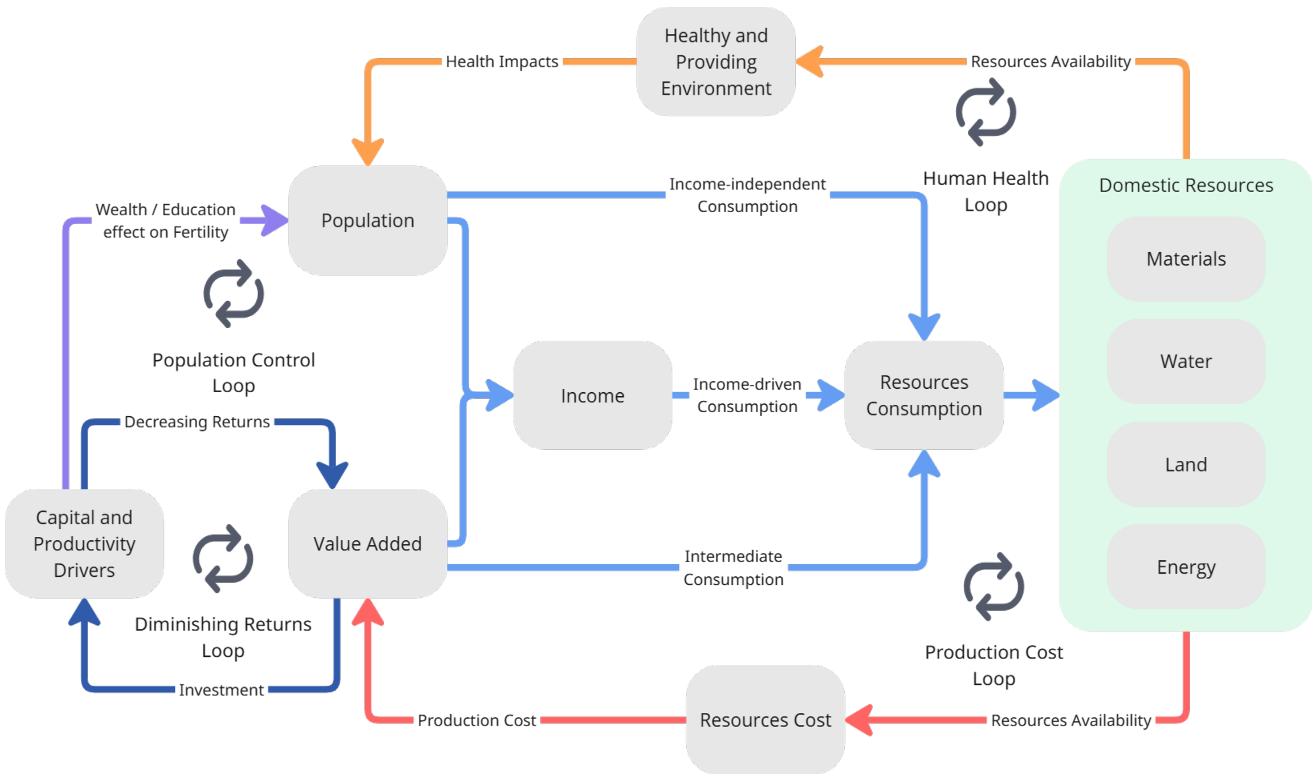

Figure 4: Fundamental dynamics 2: major feedback loops hindering development. Source: reproduced from Pedercini & Zaharia-Kézdi (2025: 17).

2.3.3. Fundamental hypotheses on production

The major feedback loops driving and limiting development further play a key role in formulating the *production hypothesis* in the iSD model (Figure 5). The Cobb-Douglas function captures the combined effects through which capital, labor and total factor productivity affect production capacity and eventually value added. Productivity is further dependent on a range of economic, social and biophysical drivers. The representation of the relationship between production capacity and value added can take on different forms, depending on the specific economic activity and the available data. The simplest, basic option, involves assuming a constant, direct proportionality between production capacity and value added, as illustrated by the green arrow in Figure 5 below. This is useful when data on physical output is not available, and thus capacity utilization cannot be computed. When such data is available, physical output is computed in the model, and a direct relationship is assumed between output and value added. Changes in consumption then affect the capacity utilization and hence the output and value added. In case Input-Output data is available, the relationship between output and value added can be further enriched, by considering the cost of input and determining value added by difference. This setup allows adapting swiftly to data availability and scope of the analysis.

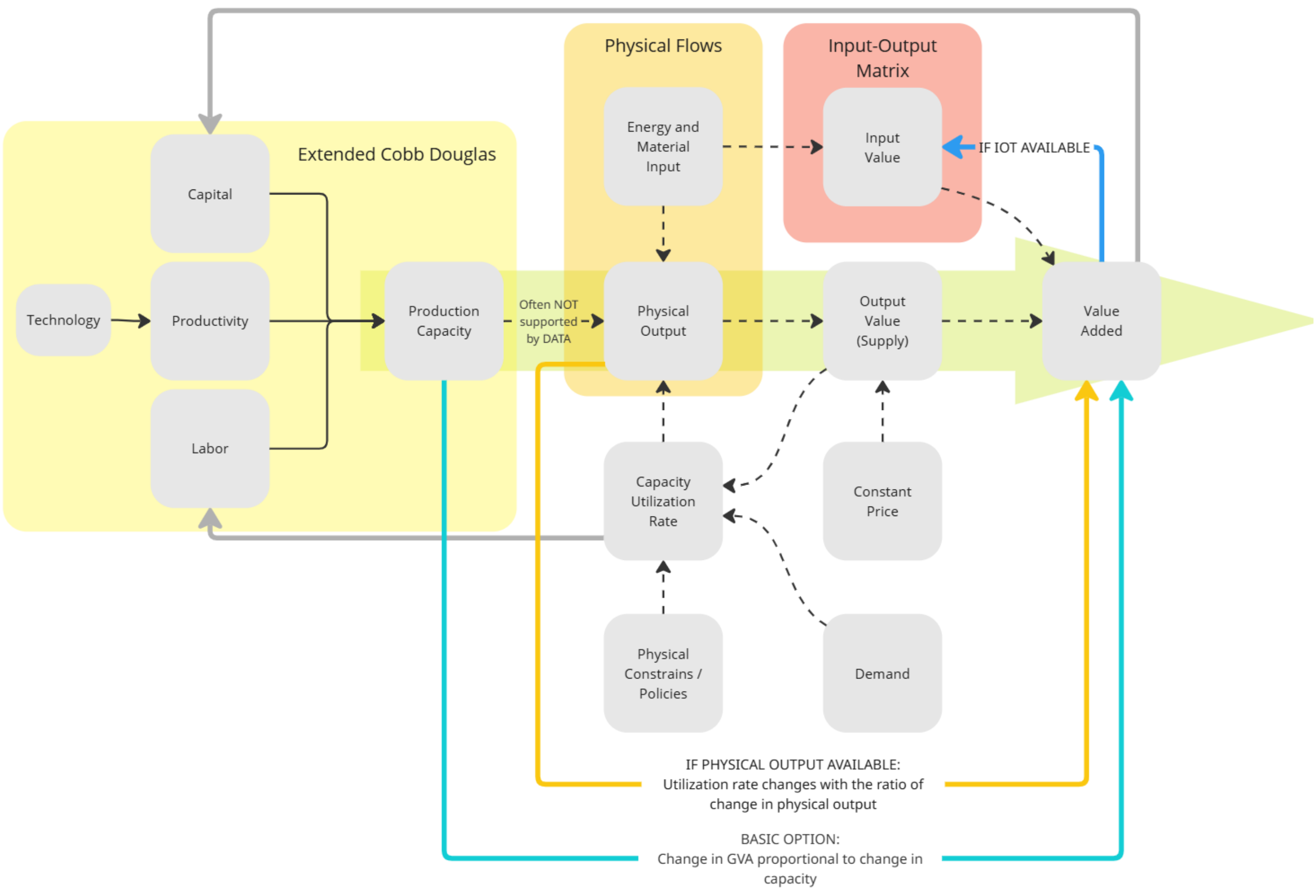

Figure 5: Fundamental hypotheses on production. Source: reproduced from Pedercini & Zaharia-Kézdi (2025: 18).

2.3.4. Climate impact pathways

Figure 6, below, illustrates the key climate pathways in the iSD model, which map the effects of climate change on development outcomes. The main climate variables (temperature change, disaster probability, drought conditions, precipitation etc.) are exogenous to the iSD model, meaning that the underlying climate conditions are ***not*** simulated within the model but are derived from external data, specifically the Climate Change Knowledge Portal (CCKP) of the World Bank (World Bank, 2024). The iSD model is not a climate model and therefore relies on external data from global climate model compilations derived from observations and climate ensembles. This ensures that the climate variables incorporated into the analysis are grounded in robust projections. Future climate conditions are further embedded in the scenarios from the Shared Socio-economic Pathways (SSP) framework to provide varying narratives for global development. The iSD model includes, by default, five SSPs that the user can rapidly select:

- SSP1 (1.9c increase in temperature by 2100);
- SSP1 (2.6c);
- SSP2 (4.5c);
- SSP3 (7.0c); and
- SSP5 (8.5c).

This broad range of external scenarios allows for exploring how domestic strategies can respond to a variety of possible future conditions.

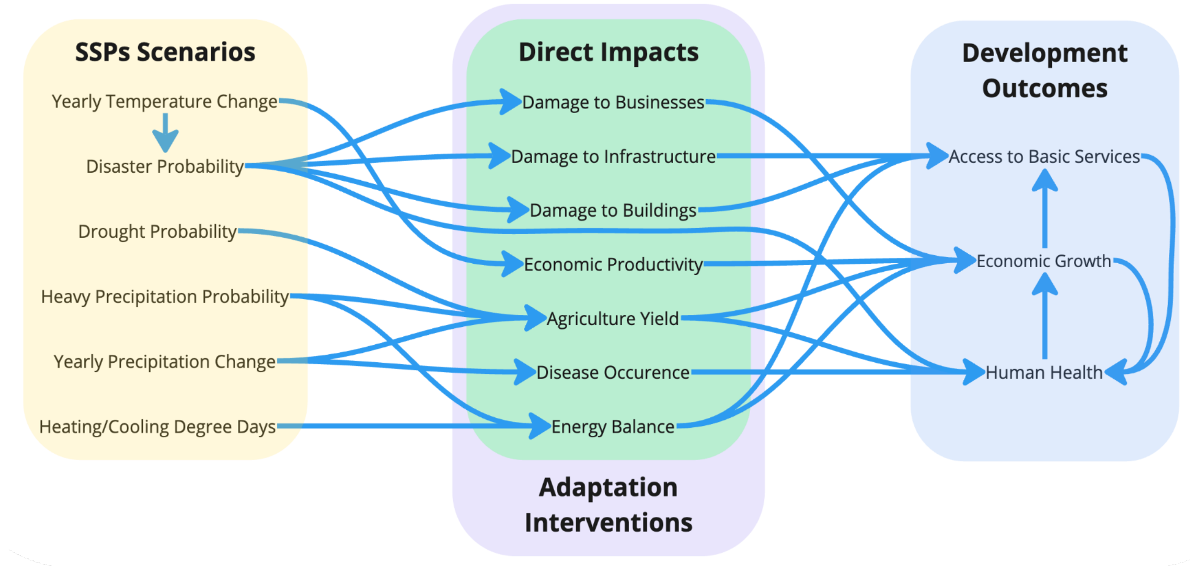

Figure 6: Climate impact pathways in the iSD model.

The key climate variables directly and indirectly affect multiple sectors in the model. Changes in temperature and precipitation directly affect agricultural yields, disease occurrence and disrupt the energy balance. Extreme climatic events cause direct damage to buildings, businesses, and infrastructure. All of these have longer-term effects on economic growth and human health, thus fundamentally affecting a nation's development trajectory. These climate pathways further present strategic opportunities for policy intervention. Targeted adaptation and mitigation measures, such as reforestation, investments in renewable energy, advanced irrigation technologies, and water-use efficiency improvements, amongst others, can mitigate the cascading climate impacts in the model.

3. Customising the iSD model for South Africa

This section summarises how the iSD model has been customised for the South African use case. The use of the seven narrative pathways (Figure 7) as the departure point is first described, along with a table relating the interventions in the iSD model to the pathways (Table 4). The additional model structure that was specifically added for the purpose of this analysis are subsequently described. Then, the causal loop diagram (CLD) representation of the holistic narrative/pathway are further unfolded between Figure 10 and Figure 17.

3.1 Developmental pathways departure point

The developmental pathways informing this project are based on the "Good Life for All by 2050" project (Carbon Trust, unpublished), which produced seven system narratives (Electricity, Food, Human Settlements, Land, Transport, Water, Production and Consumption - see Figure 7), with an eighth being a holistic 'Good-Life' system narrative (referred to here as 'the holistic' narrative, for short).

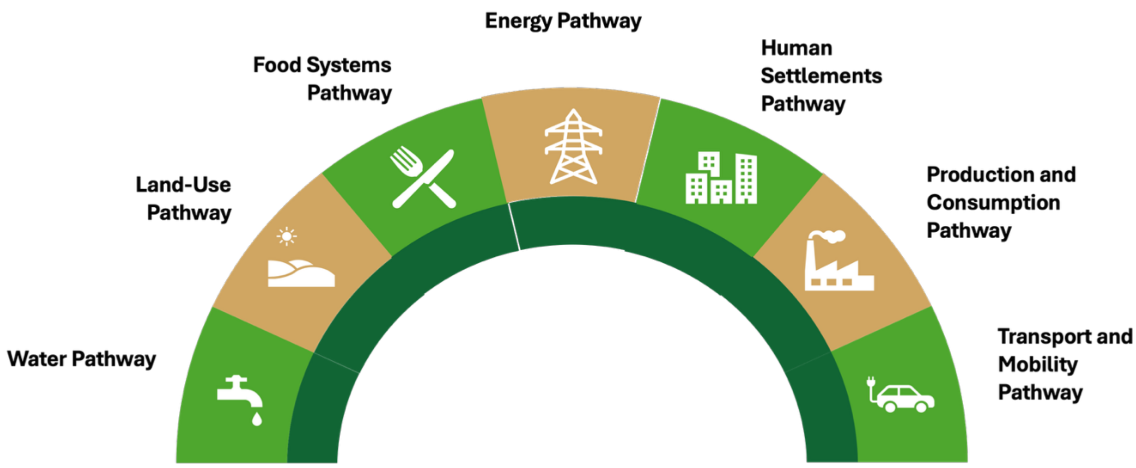

Figure 7: The seven pathways. Source: Carbon Trust (unpublished).

The seven system narratives were mapped in relation to the existing interventions built into the iSD model. Table 4, which follows, provides an alternate representation of the relationship between the system narratives and the iSD model, relating the narratives to the corresponding iSD sectors, indicators and interconnections.

Table 4: Overview of the key iSD model indicators and interconnections with corresponding system narrative and LT-LEDs sector.

System Narrative	LT-LEDs sector	iSD Sector	iSD indicators
Food	Agriculture, Forestry and Other Land Uses (AFOLU)	Agriculture	Crop production Yield Livestock production Fish capture Fish harvest
		Nutrition	Total pc daily calorie production Protein intake Undernourishment Stunting Wasting Overweight

System Narrative	LT-LEDs sector	iSD Sector	iSD indicators
Human Settlements		Land	Settlement land demand Population living in slums
Land			Agriculture land Forest Land Settlement land
Water	AFOLU, Energy, Industry	Water	Agriculture water withdrawal Industry water withdrawal Domestic and municipal water withdrawal
Electricity	Energy	Energy	Electricity generation by source Electricity general capacity
Transport		Transport	Vehicles by body and engine type Motor fuel consumption Transport infrastructure[road, rail]
Production & Consumption	Energy, Industry, Waste,	Materials	Fossil fuel production[coal, oil, gas] Construction & industry Metal ores Forest material extraction Food production Waste generation Urban waste collected and disposed
Cross-cutting	All	Emissions	Net CO_2 from land use change Fossil fuel CO_2 emissions Cement CO_2 emissions Agriculture CO_2 emissions Total GHG emissions in CO_2-eq
		GDP	GVA by sector GDP growth rate Investment GDP ratio
		Employment	Labor participation rate Unemployment rate Employment by sector
		Households	Population below national poverty line Gini coefficient Income shares by quintile
		Education	Access to education Average years of schooling Adult literacy rate by gender Enrollment rates
		Balance of Payments	Export & Imports Net current transfers Net primary income Current account balance
		Government	Government expenditure Taxes Revenue Debt Quality of Governance
		Indicators	SDGs[1-17] Human Development Index Other

** Note that this table is not inclusive of all iSD model indicators but only those identified to be directly relevant to the system boundary (i.e. the development narratives and LT-LEDs sectors).*

3.2 Model Extensions

As part of the initial mapping, the project team also assessed the extent to which the model structure was able to provide a broad representation of the seven narratives. The process identified three additional areas to be developed in the iSD model in relation to the narratives, namely:

- Tourism
- Social housing, and
- The informal economy.

Initial structures have been developed for tourism (focusing on biodiversity-driven tourism – as in Figure 8) and for social housing (Figure 9). Incorporation of the informal economy is, at this point, excluded due to limited information regarding the definition, boundary and concrete data to support the approximation in the model.

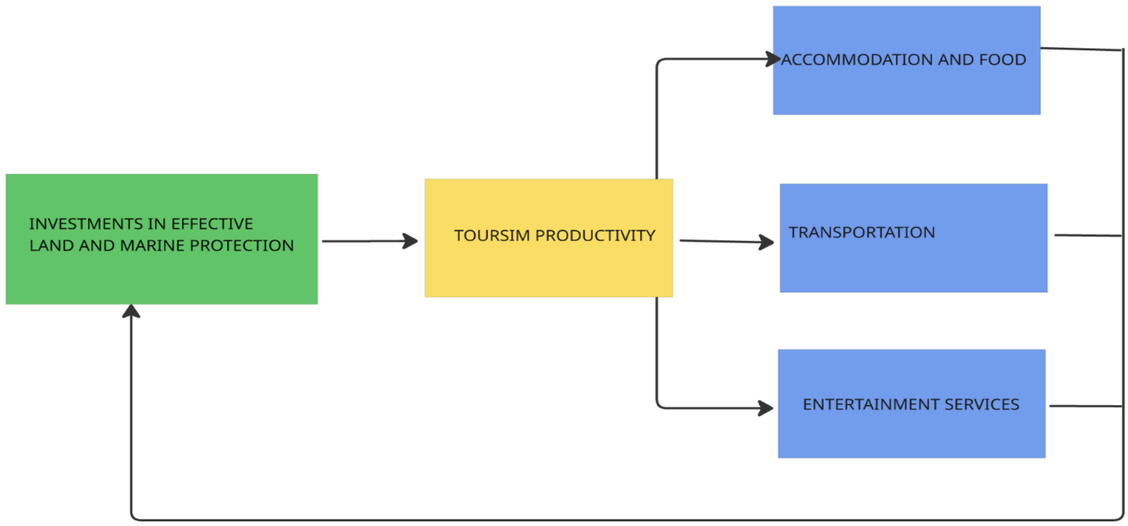

Figure 8: Basic structure for the biodiversity-driven tourism component.

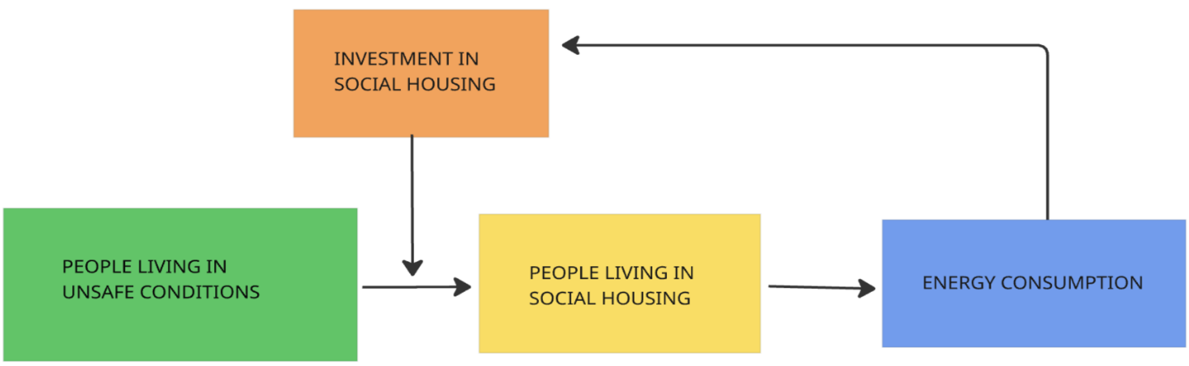

Figure 9: Basic structure for the social housing component.

3.3 Holistic CLD

The team's departure point was to map out the development pathways and system interconnections relevant to the sectors within the LT-LEDS framework (Energy, Industry, AFOLU and Waste), and the existing development narratives (Electricity, Food, Human Settlements, Land, Transport, Water and Production and Consumption) as captured in the iSD model. This was undertaken through the development of causal loop diagrams (CLDs), which:

- provide a qualitative representation of the model structure,
- visually represented by cause-and-effect relationships within and across sectors,
- showing how variables influence one another through reinforcing and balancing feedback relationships, and
- showing how key interdependencies and feedback loops drive the system behaviour.

The CLD offers a bridge between the more abstract system architecture of the iSD model (in Figure 3 to Figure 5) and the South Africa-specific development pathways that are assessed in this report. The holistic CLD is unfolded step by step in Figure 10 to Figure 17 in order to make the system easier to read and to progressively reveal the main feedbacks that drive behaviour in the broader system. The unfolding of the holistic CLD should be read alongside Sub-section 2.3. Figure 3 to Figure 5 introduced the major reinforcing loops that drive development, the major balancing loops that can slow or constrain development, and the production hypothesis that links productivity, capital, labour and value added in the iSD model. The figures below adapt and localise those same underlying dynamics for the South African context, while also positioning the seven development narratives within a single integrated system centred on emissions, including the broader net-zero transition, and the triple challenge of tackling unemployment, inequality, and poverty.

Figure 10 introduces the main sectors and variables that structure the holistic system narrative. At this first level, the diagram should be read primarily as an overview of the major interconnections between the economic, social and environmental sub-systems, rather than as a full account of feedback structure. The broad architecture already reflects the core logic of the iSD model as described in Figure 2 and Sub-section 2.3: namely, that economic activity, government, households, services, natural resources and environmental constraints are all linked in a single system, with productivity, value creation, public expenditure and resource use shaping one another over time.

At the centre of Figure 10 are the variables that connect the system to the climate transition challenge, especially emissions, namely the Net-Zero and the SETs. Around this centre sit the main domains that the South African model needs to represent: GDP, employment and the balance of payments on the economic side; education, health, population and access to basic services on the social side; and agriculture, land integrity, water, energy, materials and domestic resources on the environmental and biophysical side. In this sense, Figure 10 performs a similar role to the summarised and expanded CLDs described in Deliverable 2 (and summarised in **Annex 4**) which shows the CLD interpretations of the seven narratives: it establishes the main sub-systems, shows their first-order linkages, and locates the seven narratives in relation to the broader system and developmental context.

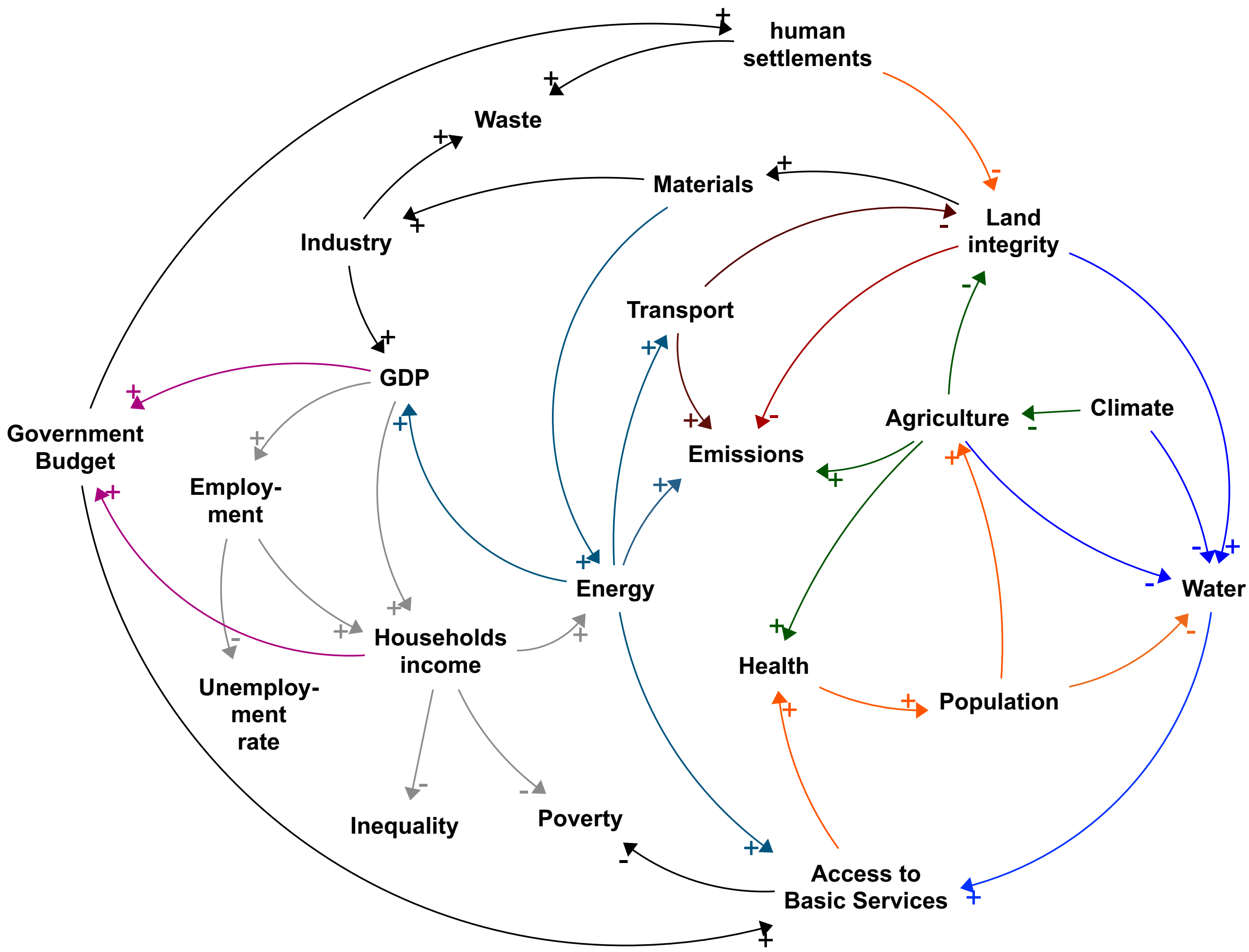

Figure 10: Overview (CLD Step 1).

In Step 2 of the unfolded CLD (Figure 11), the first set of **reinforcing feedback loops** are introduced (namely loops *R1* to *R4*). These loops are important because they represent the self-reinforcing development dynamics that, under favourable conditions, can improve well-being, strengthen productive capacity and support structural transformation, forming **virtuous cycles**. Under unfavourable conditions, these same loops can drive decreases in well-being, weaken productive capacity and fail to support structural transformation, forming a series of **vicious cycles**. This closely mirrors the role of the reinforcing loops discussed in Sub-section 2.3.1 and in Figure 3 of the report, where productivity, value added, government finance and investment reinforce one another over time.

The first loop, *R1*, is the *food security loop*. Here, stronger agricultural performance supports improved health and population well-being, which in turn supports the conditions for further agricultural productivity and food security. This reflects the broader iSD logic in which social and environmental drivers are not external to development, but form part of the productive system itself. The second loop, *R2*, is the *energy security loop*, in which greater energy availability supports production and GDP, which in turn enables further investment in the energy system. This is closely aligned with the productivity and investment dynamics shown in Figure 3 and the production logic later formalised in Figure 5.

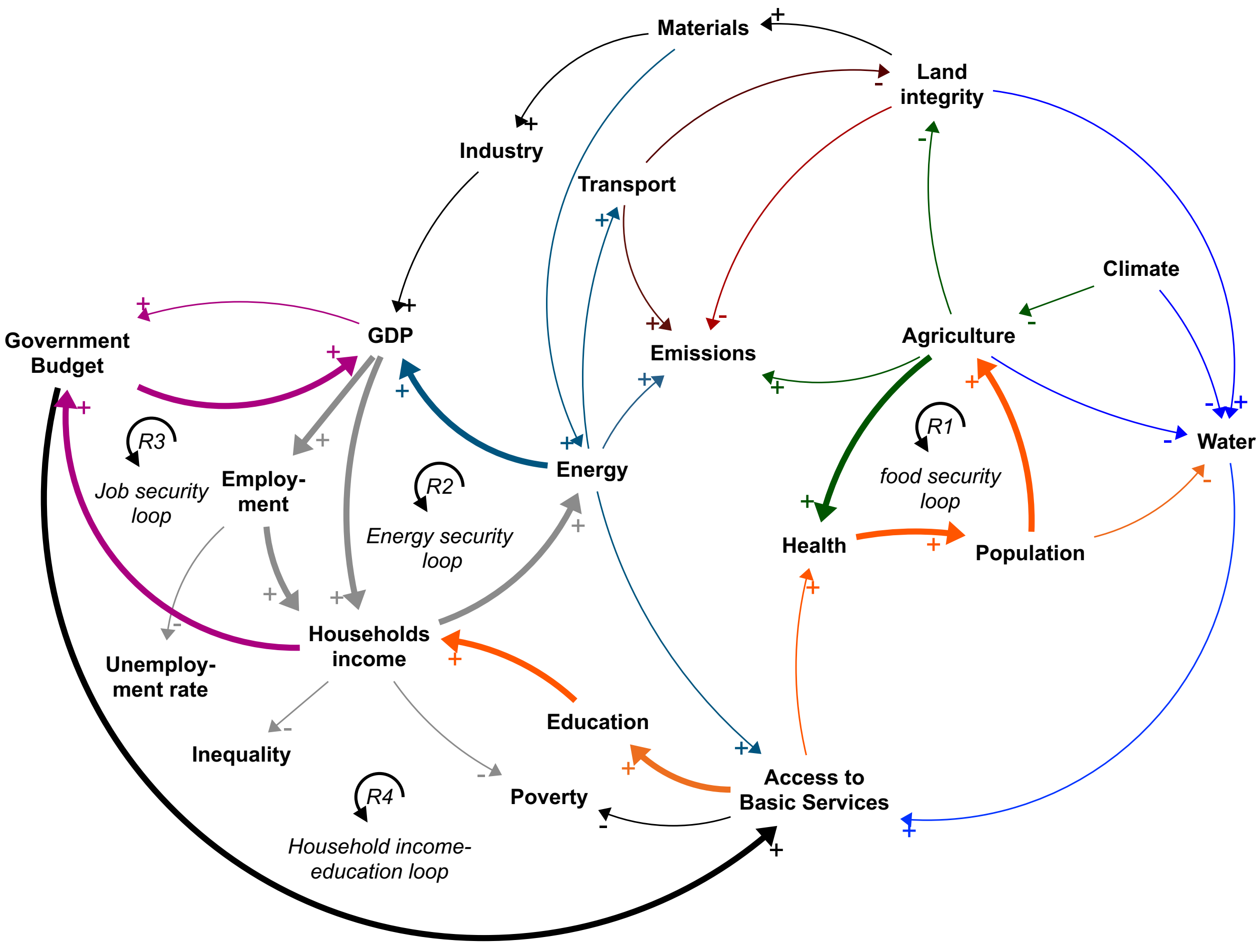

Figure 11: Reinforcing loops R1 – R4 (CLD Step 2).

The third loop, *R3*, is the *job security loop*, which captures the mutually reinforcing relationship between economic growth, employment and public revenue. As the national gross domestic product (GDP) rises, employment opportunities improve; stronger employment supports household income and wider economic demand; and the resulting growth in revenue supports further government expenditure and development. The fourth loop, *R4*, is the *household income–education loop*, which shows how rising household income can improve access to education, while better education strengthens human capabilities and, over time, supports further income growth. Together, these loops foreground the fact that development in the iSD model is **cumulative** and **path-dependent**: once gains begin to reinforce one another, they can support broader positive change across the system. This is precisely why Figure 3 in Sub-section 2.3 places such emphasis on the interaction between social drivers, productivity and value creation.

Step 3 introduces reinforcing loop *R5*, the *agricultural development loop*, as a reinforcing dynamic in its own right (Figure 12). This loop draws attention to the way in which agriculture is not only a food system variable, but also a productive sector within the broader economy. Higher agricultural production supports GDP and economic development; stronger economic performance can, in turn, support the capital, services, infrastructure and broader enabling conditions required for further agricultural expansion and intensification. In this way, agriculture links directly into the model's production logic and to the relationship between productivity, capital and value added described in Sub-section 2.3.3 and Figure 5.

This Step 3 is useful analytically because it begins to separate the different ways in which agriculture matters in the South African system. In the previous Figure 11 (CLD Step 2) agriculture is already present as part of a food security dynamic. In Figure 12 the emphasis shifts to agriculture as a driver of economic value, employment and linked development outcomes. This makes visible an important point that runs throughout the iSD architecture: the same sector can operate simultaneously as a source of human well-being, as an economic growth driver, and as a pressure on the biophysical resource base. Later steps in the unfolding diagram show why this dual role matters, as agricultural reinforcing loops are increasingly counterbalanced by land, water and environmental constraints.

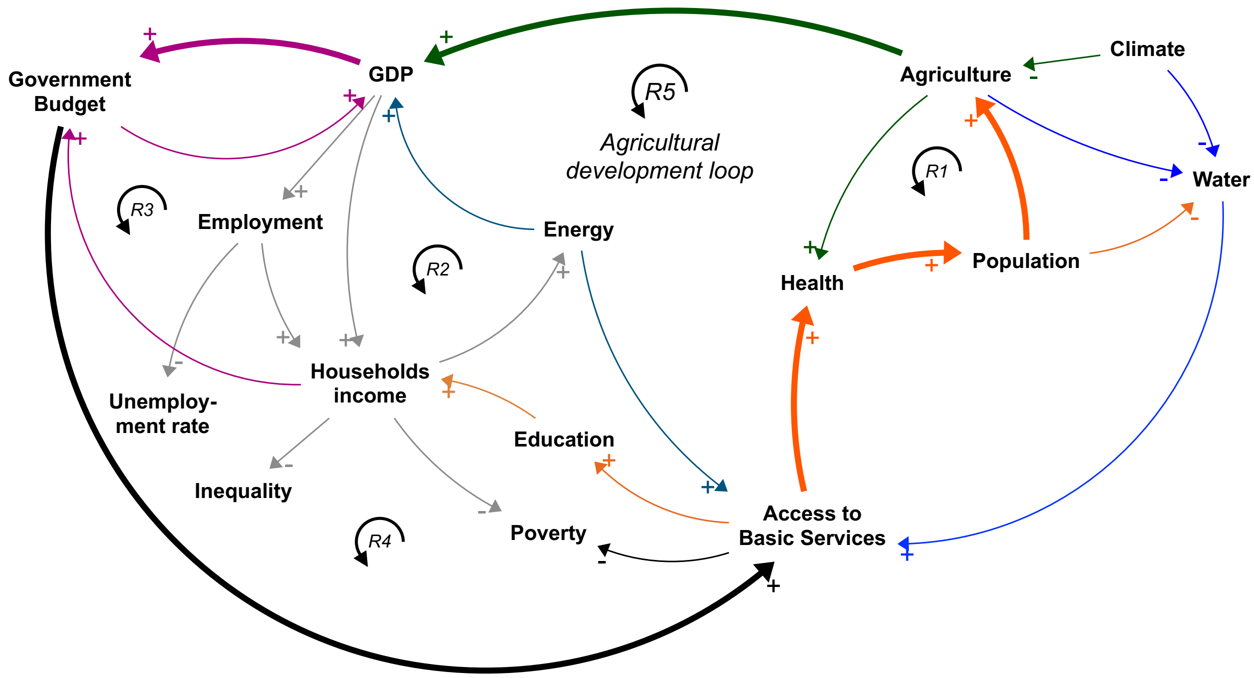

Figure 12: Reinforcing loop R5 (CLD Step 3). Note that for demonstration purposes, the majority of the other variables outside of the variables in Loop R5 are excluded from this diagram.

Step 4, shown in Figure 13, adds a further set of reinforcing loops centred more explicitly on the macro-economy, government finance and external economic relations. Figure 13 therefore deepens the link back to Sub-section 2.3.1, where Figure 3 showed that government revenue, public expenditure, private investment and external financing together help drive the reinforcing dynamics of development in the iSD model.

Loop R6 can be understood as the *fiscal growth loop*: higher GDP expands the fiscal base, which strengthens government budget, enabling greater public expenditure and investment, which in turn supports further growth. *Loop R7* is the *fiscal–external link loop*, which captures the way in which macroeconomic performance and external flows interact with the public sphere. *Loop R8* is the *external balance loop*, showing how GDP and the balance of payments (BOP) reinforce one another through trade, exports and wider macroeconomic performance. Taken together, Loops R6 – R8 make more explicit what Figure 3 had already suggested in a more stylised form: that development is reinforced not only through sector-specific gains, but also through the coupling of production, public finance and external economic performance.

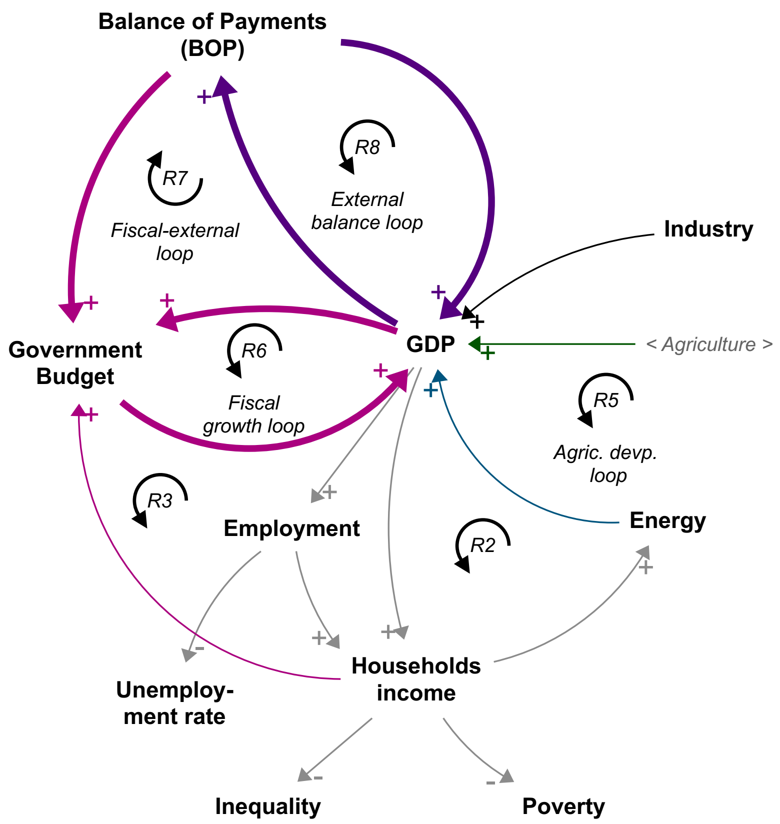

Figure 13: Detail of reinforcing loops R6 – R8 (note that R5 is named for ease of reference to the Figure 12). GDP = gross domestic product; BOP = Balance of Payments. (CLD Step 4).

CLD Step 4 (Figure 13) is also important because it clarifies the place of government within the holistic CLD. Government is not shown here as an external actor intervening into an otherwise self-contained economy. Rather, government budget, expenditure and revenue are themselves part of the system's endogenous feedback structure. This is consistent with the description in Sub-section 2.3.1 that government revenue supports public expenditure and investment, while government expenditure feeds back into productivity gains through services and infrastructure.

In Step 5 (shown in Figure 14) the first major **balancing loops** are introduced. These loops are conceptually important because they correspond closely to the "major feedback loops hindering development" described in Sub-section 2.3.2 and Figure 4 of the report. As explained there, these limiting loops stabilise interactions between population growth, economic development and environmental sustainability, and can become increasingly important over the longer term.

The first balancing loop, *B1*, is the *population control loop*. In the more stylised formulation in Figure 4, this loop captures how increases in added economic value can support wealth and education, which in turn reduce fertility rates and population growth. In the South Africa-specific CLD, this logic is unpacked through the mediating roles of access to basic services, education, fertility and population pressure.

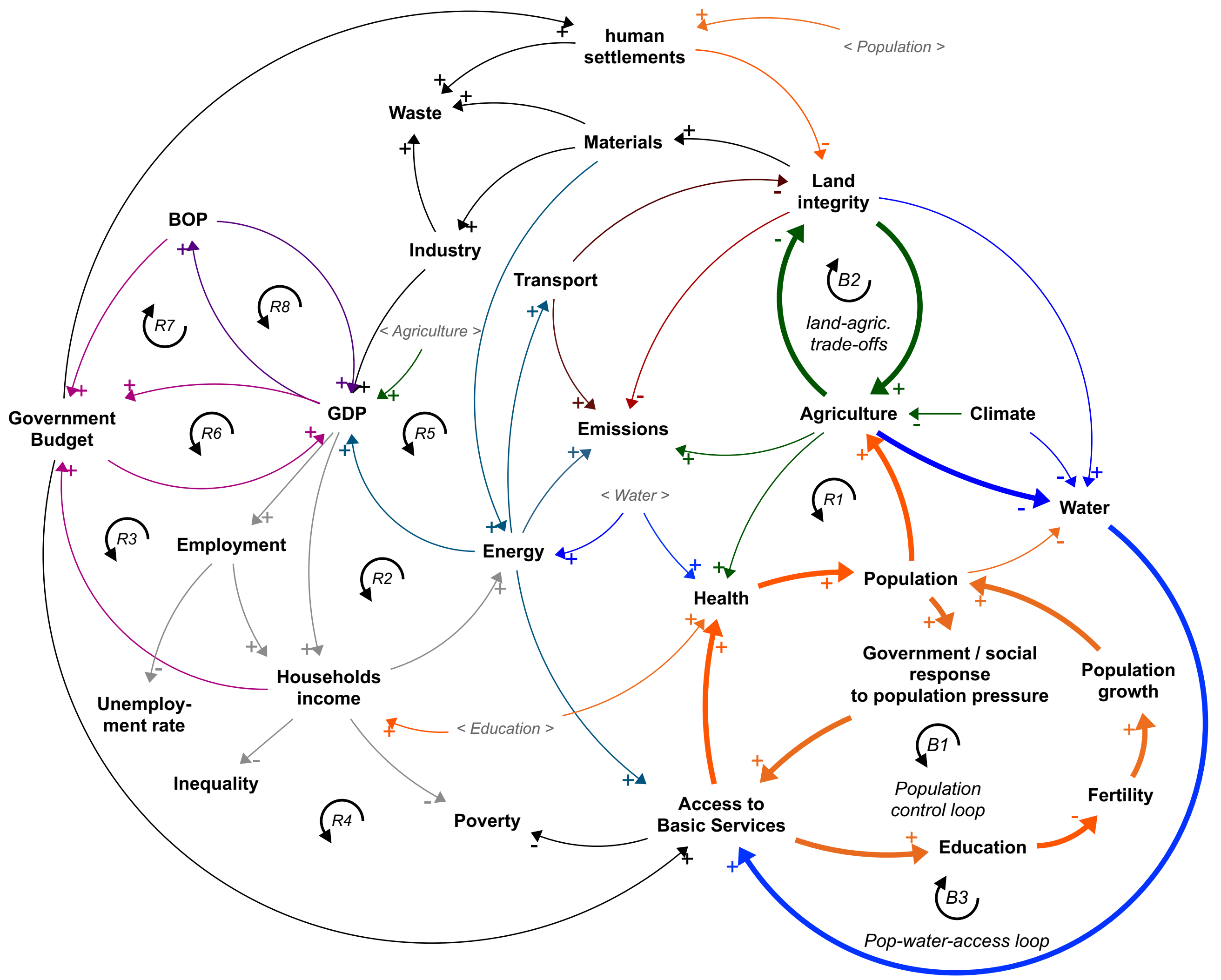

Figure 14: Balancing loops B1 to B3 (CLD Step 5). Note that the < italicised variables > are 'ghost' variables, meaning that they are copies of variables already in the model (which assists with reducing overlapping arrows and making the diagram easier to read).

The second balancing loop, *B2*, is the *land-agriculture trade-offs loop*, which shows how growth in agricultural production can, beyond a certain point, begin to undermine the very land integrity on which future productivity depends. *Loop B3* is the *population-water-access loop*, which shows how increases in population and water demand can begin to undermine the level of access to basic services, especially where water is a key enabling resource. This loop therefore complements *Loop B1*: while *B1* represents the demographic transition logic described in Sub-section 2.3.2, *Loop B3* draws out the material and service-delivery pressures that accompany population growth in a water-constrained development context (which is definitely true of water-scarce South Africa). Together, these three loops make visible how the developmental gains highlighted in earlier figures are checked by demographic, ecological and resource-based limits.

It is also in this step that the use of "ghost variables" becomes especially helpful (which are the < *italicised variables* > bracketed between less than (<) and greater than (>) characters, as shown with the < *Water* >, < *Population* >, < *Agriculture* > and < *Education* > variables in Figure 14). Ghost variables are duplicate representations of already-existing variables, inserted simply to reduce overlapping arrows and improve legibility in a complex diagram. Their use here allows the balancing structures to be shown more clearly without implying that new state variables (AKA 'stock variables) have been added to the underlying model.

Step 6 (Figure 15) introduces two further balancing loops that deepen the representation of environmental and spatial constraints. *Loop B4*, is the *agriculture–land–water trade-offs loop*, which extends this balancing logic further by showing how pressure on land integrity also feeds through to water availability and quality, creating constraints that can dampen future agricultural expansion.

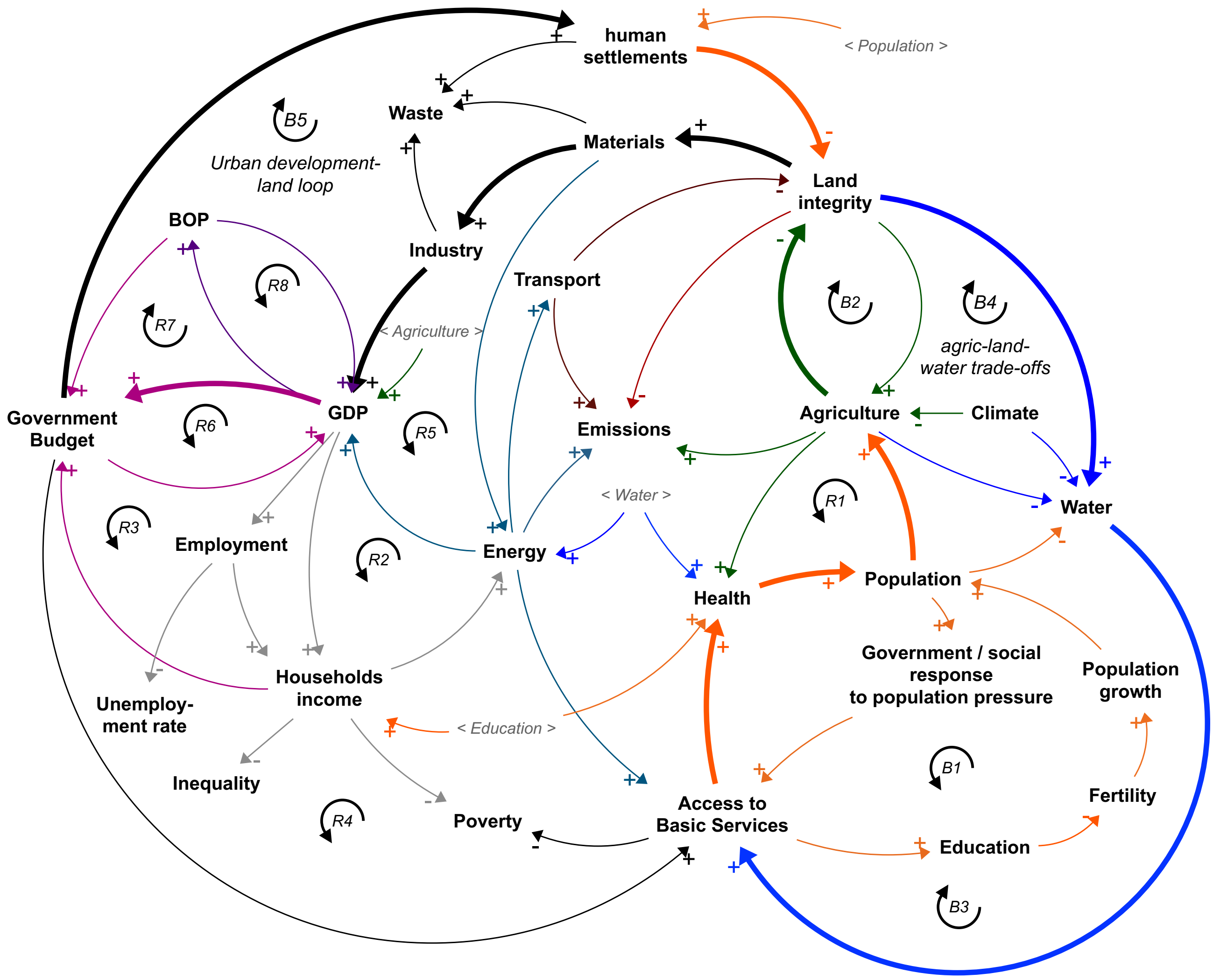

Figure 15: Detail of balancing loops B4 and B5 (CLD Step 6).

Balancing loop *B5* is the *urban development-land loop* (in the top left-hand corner of Figure 15), which captures the way in which expanding human settlements can weaken land integrity and thereby reduce the broader environmental base that supports domestic resources, production and ecosystem functioning. This balancing dynamic is especially important in the South African adaptation of the model because it links human settlements directly into the land and resource system, rather than treating settlements as a purely social or infrastructural domain. In this respect, Figure 15 extends the logic of the "Production Cost" loop described in Sub-section 2.3.3: as resource pressure and environmental degradation increase, production conditions become less favourable and developmental gains are moderated.

Step 7, in Figure 16, adds the final two balancing loops, namely loops B6 and B7. *Loop B6* is the *waste-human-health-population loop*, which shows how increasing human settlements, driven by a growing and increasingly urbanising population, generate larger quantities of solid waste and wastewater. Where waste management systems and waste-water treatment works (WWTWs) do not keep pace with this growth, the result is worsening environmental health conditions, both through the direct effects of physical garbage and refuse and through poorly managed effluent entering rivers, dams and other water bodies on which communities depend. These deteriorating conditions undermine human health and well-being, which in turn acts as a balancing constraint on wider social and demographic development. In this way, *Loop B6* highlights that waste is not simply a downstream by-product of development: if not properly managed, it feeds back into the system through human health impacts, placing limits on the sustainability of further settlement expansion and population-related development gains.

The final loop, *B7 – the resources-human-health loop* – links resource pressure, environmental quality and human health. This loop corresponds most directly to the **Human Health Loop** described in Sub-section 2.3.2 and Figure 4, where deteriorating environmental conditions reduce population health and, through this, weaken labour productivity, income generation and wider development prospects. In the South Africa-specific CLD, this logic is expressed through the interrelationships between domestic resources (consisting of land, water, energy, and materials) and human health and well-being.

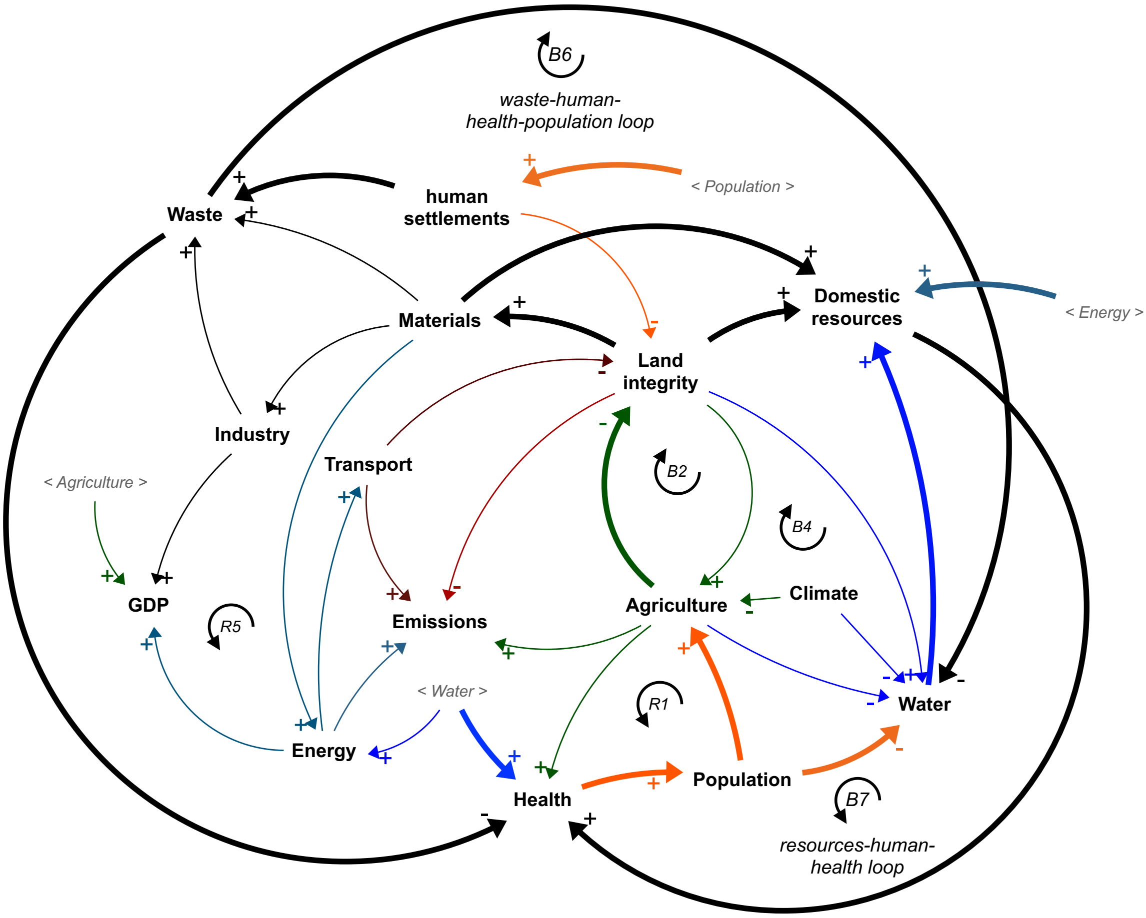

Figure 16: Detail of balancing loops B6 and B7. (CLD Step 7).

The importance of these final two balancing loops is they close the circle between the social and environmental sides of the system. Earlier reinforcing loops showed how development can improve income, services and productivity. The balancing loops added in Figure 14 to Figure 16 show that if resource use, waste, land conversion and environmental decline are not managed, they feed back negatively into health, labour capacity and the broader productivity base of the economy. This is why the *iSD model documentation* emphasises that some limiting dynamics are difficult to appreciate in the short term but can become dominant over longer time horizons (Pedercini & Zaharia-Kézdi, 2025). Figure 16 therefore helps explain why the Net-Zero transition cannot be treated as an emissions-only challenge: environmental quality and human well-being are integral parts of long-term developmental performance and of meeting the 'triple challenge' articulated in SA's NDP.

Figure 17 presents the full integrated CLD. At this stage, the value of the unfolding sequence (hopefully) becomes clear: what began in Figure 10 as a broad overview of the main sectors and linkages is now visible as an interconnected system in which economic growth, government finance, household well-being, education, services, land integrity, agriculture, water, energy, materials, human settlements and health all **co-evolve**. This final integrated figure thus localises, within the South African context, the broader iSD proposition that development is shaped by the interaction of reinforcing and balancing feedbacks across the economic, social and environmental domains.

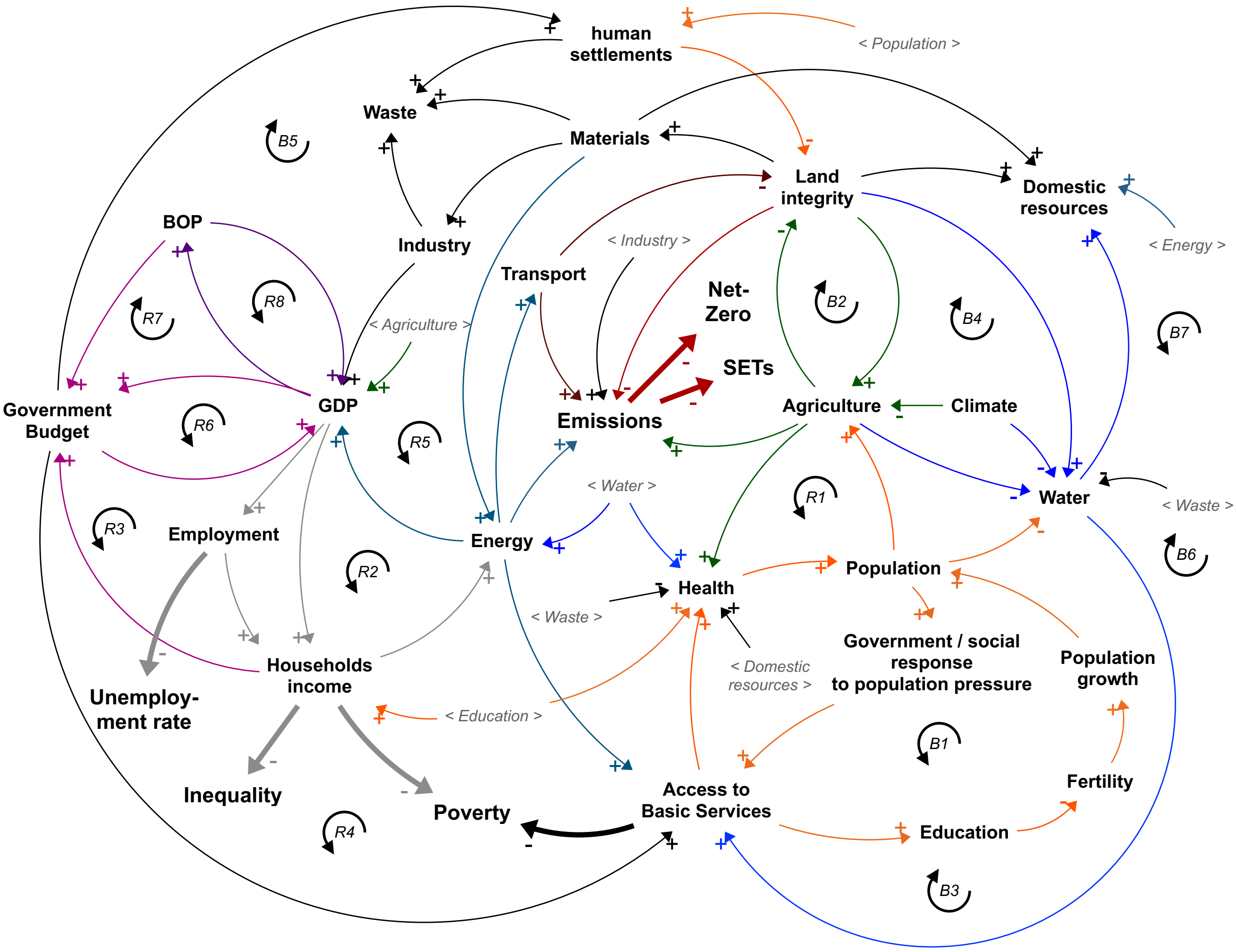

Figure 17: The full CLD, with key model indicators shown in bold, including unemployment rate, inequality, poverty, Net-Zero and the SETs (CLD Step 8). See Figure 11 to Figure 16, and the associated text, for the names and descriptions of the reinforcing (R) and balancing (B) feedback loops.

The complete CLD (Figure 17) also makes clearer why the South African transition challenge is fundamentally systemic. A number of **reinforcing loops** support desirable change, including:

- stronger energy security,
- rising educational attainment,
- agricultural development,
- improved job creation,
- stronger public finance and
- higher productive capacity

all of which can drive mutually reinforcing gains.

At the same time, those gains are moderated by **balancing loops** that are tied to

- population pressure,
- land degradation,
- water constraints,
- settlement expansion,
- resource depletion and
- human health impacts.

The full diagram (Figure 17) therefore shows that progress towards the SETs and Net-Zero is inseparable from how these wider developmental feedbacks are managed. In this sense, the final holistic CLD does not merely illustrate complexity for its own sake: rather, it identifies the structural interdependencies that any effective long-term development pathway for South Africa must account for.

4. Model Validation

The iSD model is structured to analyse medium to long-term development trends at the national scale to provide policy insights. Such estimates are not to be taken as forecasts, as no model can accurately forecast long-term development trends, but as potential outcomes based on a set of clear and well-grounded assumptions. The model's results inherently embed a high degree of uncertainty over the time horizon considered in the simulation.

To address the uncertainty, the iSD validation process focuses on strengthening the underlying assumptions based on currently available data and research. Validation is embedded in the broader model implementation, and includes structural and behavioural validation tests (Barlas, 1996). Structural validation tests involve direct verification of the assumptions made in the model structure and parameters. Behavioural validation tests involve the assessment of the model's ability to replicate the historical behaviour of the main indicators for the historical period of the simulation. Structural and behavioural validation techniques are discussed at a general level in the following section.

4.1 Structural and Behavioural Validation

The key purpose of validating the model structure is to determine how suitable the model is for evaluating the questions related to the analysis. This can be done by addressing the following questions:

1. Is the model structure consistent with qualitative knowledge?
2. Are the model equations dimensionally consistent?
3. Are concepts for addressing the questions represented in the model?
4. Are parameters consistent with descriptive and numerical knowledge?
5. Does the simulation result make sense when inputs take on extreme values?

These questions are addressed by MI during model development as well as throughout the implementation stages of the project. Throughout model development equations are evaluated to ensure model consistency. Further, during model calibration, parameter values are assessed both qualitatively and quantitatively to evaluate model fit. And, throughout calibration and BAU simulation, extreme conditions are tested to evaluate the robustness of the calibrated model. These considerations are necessary to verify that the model qualitatively and quantitatively represents the national context. The approach increases the rigor of the model application and ensures that the model will be useful for analysing the policy impacts.

Behaviour validation is a significant step during model development. In this context, behaviour describes the simulation results of the key variables in the model. Model calibration forms a key part of this process, to accurately reflect medium-term to long-term behaviour in historical data. Statistical summaries are used to validate the behaviour of the model against the respective reference data. The statistics used are standard econometric techniques for quantitatively assessing the degree to which the model replicates the trends and patterns in historical data.

4.2 Data and Calibration

The modelling process began with data collection, which was used to update the existing South Africa model database. The model particularly relies on a large set of data from international data sources in order to be calibrated to the national context. These sources are largely from international organisations and research institutions (as summarised in Table 5), however, in many instances, the international data sources draw data from the respective country's ministries on an annual basis. The modelling team has sought to fill data gaps where-ever identified, with input from the project partners (chiefly DFFE and The Green House (TGH)).

Table 5: iSD Data Sources.

Concept	Source
Population, Fertility, Mortality	UNPOP WPP, WB WDI, WHO
Education and Health	Barro Lee; WDI
Infrastructure	WB WDI, EMDAT
Vehicles	IEA, OICA, UNPOP WPP
Employment	ILO
Income and Poverty	UNDP, WB WDI, STATSSA
Poverty	UNDP; WDI
Production	FAO, WB WDI, IMF WEO, UNSD
Public Private Accounts	WB WDI, IMF WEO
Governance	WDI, WGI
Balance of Payments	IMF, WDI
Land and Soil	FAO, WDI, WRI
Water Supply Demand	FAO Aquastat, WB WDI, WHO, UNICEF
Energy Supply Demand	IEA, EIA, WDI
Material Consumption	EIA, GMF
Emissions and Waste	EIA, GCP, WB WDI, FAO, WB WAW
Biodiversity	WDI, REDD+, UNSTATS GSDGD, SAU

With the updated data, the model was then calibrated based on historical data for the period from 2000-2023(24), pending the latest available data year. The calibration process specifically aimed to reduce simulation error and measure the model's ability to replicate the behaviour of historical data and capture the key national trends in the country. To measure the calibration performance and robustness of the model structure, a range of summary statistics were calculated and assessed, including:

- the coefficient of determination (R2),
- the Root Mean Square Percent Error (RMSPE), and
- the use of Theil for error decomposition.

The calibration results are summarised in Table 6 below, which shows that the calibration process reduced the simulation error to approximately 10%, in line with MI's standard target for calibrating the iSD model to a particular country or context. The results of the Theil Bias (TBIAS) component are shown to describe the average difference between the simulation and historical data. If the error is large and a majority of error lies in TBIAS, it can indicate a systematic error to the model.

Table 6: Calibration results.

Variable	RMSPE	TBIAS
population by gender[FEMALE]	0.00282702	0.375554288
population by gender[MALE]	0.00545307	0.074867879
total fertility rate	0.043709	0.377616932
life expectancy[FEMALE]	0.03133929	0.075963222
life expectancy[MALE]	0.01721227	0.145090641
average years of schooling[FEMALE]	0.04796406	0.00975299
average years of schooling[MALE]	0.03348327	0.012895877
infrastructure[roads a]	0.16447256	0.142737752
infrastructure[roads b]	0.13474236	0.170756579
infrastructure[rail]	0.00387983	0.190337977
total vehicle by body[passenger cars]	0.15553217	0.066504281
total vehicle by body[freight and bus]	0.15948816	0.227947665
employment by sector[A01]	0.09150637	0.041335164
employment by sector[A02]	0.17432522	0.000134935
employment by sector[A03]	0.26026485	0.122263766
employment by sector[B]	0.23789	0.072267253
employment by sector[C]	0.06771476	0.33038236
employment by sector[D]	0.1891869	0.006798071
employment by sector[F]	0.09574696	1.37934E-06
employment by sector[G]	0.05221885	0.33211063
employment by sector[H]	0.07790866	0.36543279
employment by sector[I]	0.06027125	0.003709783
employment by sector[J]	0.06804541	0.447789688
employment by sector[K]	0.0623769	0.27503368
employment by sector[O]	0.09599263	0.101332641
employment by sector[P]	0.05736169	0.298557889
employment by sector[Q]	0.08427595	0.242501421
employment by sector[S]	0.06962607	0.018989735
gini coefficient	0.02316365	0.041009001
income share[qnt 1]	0.6786132	0.982743112
income share[qnt 2]	0.24973877	0.007056105
income share[qnt 3]	0.25960673	0.043005328
income share[qnt 4]	0.09224508	0.689700846
income share[qnt 5]	0.10425651	0.567036738
proportion of population below national poverty line	0.11400823	0.160018866
real GVA by sector[A01]	0.06781686	0.186911053
real GVA by sector[A02]	0.17599068	0.523528568
real GVA by sector[A03]	0.17416849	0.003024072
real GVA by sector[B]	0.04685138	0.108275403
real GVA by sector[C]	0.02410762	0.000460944
real GVA by sector[D]	0.07114811	0.016221774

Variable	RMSPE	TBIAS
real GVA by sector[F]	0.24204744	0.259244007
real GVA by sector[G]	0.05297698	0.449930254
real GVA by sector[H]	0.12382458	0.423446086
real GVA by sector[I]	0.11426175	8.68538E-08
real GVA by sector[J]	0.09503327	0.551085287
real GVA by sector[K]	0.05986392	0.285598195
real GVA by sector[O]	0.10522879	0.181396655
real GVA by sector[P]	0.06510663	0.298215327
real GVA by sector[Q]	0.10015147	0.666817476
real GVA by sector[S]	0.13584103	0.335229561
access to safely managed water source[rural]	0.09376516	0.569713765
access to safely managed water source[urban]	0.21129586	0.026958097
access to safely managed sanitation facility[rural]	0.0861059	0.195198115
access to safely managed sanitation facility[urban]	0.15907244	0.871061341
CO2 emissions	0.06039426	0.140366421
final energy consumption[OIL]	0.17591996	0.705992257
final energy consumption[GAS]	0.34957097	0.296412838
final energy consumption[COAL]	0.14164837	0.034667949
final energy consumption[BIO]	0.10902889	0.645219827
final energy consumption[ELE]	0.10819342	0.437092852
final energy consumption[HEAT]	0.29447283	0.450705673
total final energy consumption by sector[agr]	0.0934476	1.77766E-05
total final energy consumption by sector[ind]	0.0585921	0.02283734
total final energy consumption by sector[ser]	0.11370616	0.081110114
total final energy consumption by sector[res]	0.11260538	0.160389522
total final energy consumption by sector[tra]	0.11916882	0.658095393
total final energy consumption by sector[oth]	0.13164282	0.00170664
AVERAGE	**0.10149614**	

5. Scenario Design and Assumptions

5.1. Baseline Scenario

Following calibration of the model, scenarios were developed to assess the outcomes of the development pathways on the key development indicators. This consisted of two scenarios, one to measure the baseline (also known as a Business-as-Usual (BaU) scenario) results, and a second to capture a 'Holistic' development scenario, consisting of a combination of sectoral policy interventions as reflected in the '*Development Pathway'* narratives.

The baseline scenario serves as a reference run and hence assumes no changes to the current policy context and that the nominal expenditure (expressed as a % of GDP) remains the same from the projected departure point (2024) until 2050. This approach enables a comparison of development pathway scenarios to the baseline and to isolate potential impacts of changes in future policy. The modelling team has subsequently run the iSD model to produce the baseline results, which are underpinned by a series of assumptions, as detailed in Table 7.

Table 7: Future baseline assumptions for exogenous data variables.

Variable (units)	**BaU assumption**
World GDP growth rate (%/yr)	Based on SSP scenarios, specifically SSP2. Data: IIASA Energy program
US average years of schooling (years)	2030: 14.2 2050: 15.2
Official exchange rate	IMF projection to 2050
Operations and maintenance costs by source of energy (USD10/MWh)	2050 assumptions: Oil; Gas; Coal; Hydro; Nuclear; Bio - IEA Projected Costs of Generating Electricity 2020; World Energy Outlook 2021 Solar & Wind: IRENA; IEA World Energy Outlook 2021
Reference electricity capacity cost by source (USD10/kw)	2030 & 2050 assumptions: IRENA; IEA World Energy Outlook 2021
Reference fuel price per mtbu (USD10/MBTU)	2030 & 2050 assumptions: EIA; IEA World Energy Outlook 2021
VALCOE adjustment factor (dmnl)	2030 & 2050: IEA World Energy Outlook 2021
Electricity generation efficiency by source	2035: IEA assumptions
Global average energy intensity (Kg Oil eq./$1000 GDP 2011 PPP)	2025 & 2030 assumptions: IEA
Relative average global water efficiency (dmnl)	2050: WDI
Cement production non energy emission per ton (dmnl)	WDI and IPCC 2006
Heating degree days	Assumptions based on SSP2 data from the World Bank Climate Change knowledge portal
Cooling degree days	
Expected SPEI drought index in 2050	
Expected temperature change by 2050	
Expected days of heavy precipitation in 2050	

Variable (units)	BaU assumption
Expected yearly precipitation in 2050	

The baseline results are presented here against the agreed-upon reporting indicators (as per [Annex 1](#)) and are summarised in Table 17 (for the Tier 1 indicators) and in Table 18 (for the Tier 2 indicators).

5.2 Holistic Scenario

To design the Holistic development scenario, a number of investment plans and reports were drawn from, including the SET investment plan (Lewis *et al. 2024*) and the report on South Africa's Energy Sector Investment Requirements to achieve energy security and net zero goals by 2050 (DBSA et al., 2025). These resources were used to inform the expenditure budget across policy interventions (Table 8). Additional future assumptions on the country's energy transition, particularly the decommissioning of existing coal-capacity, was informed by the Integrated Resource Plan (IRP), 2023.

The total budget for policy expenditure was implemented as an additional expenditure to the baseline expenditure, to measure the relative impact over the implementation period of 25 years (i.e. 2025-2050). This budget has then been distributed evenly across the list of interventions identified among the *Development Pathways'* narratives. A total additional budget of **6.4 % of GDP**, equivalent to approximately **266 billion** (2019 ZAR) has been used, where GDP is calculated relative to total nominal GDP at basic prices. This is derived by adding to the budget set in the SET investment plan of 3.2% of 2019 GDP the same amount (i.e. 3.2% of GDP) to simulate an effort in tackling the socio-economic issues at least equal to the one needed for the energy transition. Distributed across the interventions (Table 8) this amounts to 0.28% GDP (or 11,5 billion ZAR), per intervention, in addition to the BAU expenditure, where expenditure is distributed across the implementation period (2025-2050). Financing assumptions in the Holistic scenario assume that the additional funding constitutes 86% from the private sector, primarily through Foreign Direct Investment (FDI), and 14% public deficit financing.

Table 8: Model interventions included in the scenario analysis.

Intervention	
general education	small photovoltaic
general health	large photovoltaic
general agriculture	large hydropower
fertilizer subsidies	vehicles efficiency
water access	industry energy
sanitation access	households' energy
roads a	water efficiency
railways	general transfers
waste management	climate adaptation
land protection	agriculture training
marine protection	social housing
reforestation	
Total: 266,4 billion (2019 ZAR)	

6. Scenario Results

This section describes the results obtained from simulating the baseline and holistic scenario as described above. The results of the absolute values are presented as a set of **Tier 1** and another of **Tier 2** indicators (see **Annex 1)** and their values for **2030, 2035** and **2050**. To assess the performance of change, Figure 18 and Figure 20 show the percentage change between the BAU and holistic scenario, with additional insights provided by the behaviour over time plots for key variables of interest (see Figure 19 and Figure 21 through to Figure 28). Historical data are additionally shown in the behaviour over time plots where data was available and used in the model.

6.1 Tier 1 indicators

Figure 18 shows the percentage change in the key tier 1 indicators under the Holistic scenario across 2030, 2035, and 2050. The results indicate improvements in economic performance, with GDP growth increasing by 18% in 2030, peaking at 29% in 2035, and remaining elevated with 25% change by 2050. In absolute terms, this shows GDP growth rate (at market price) achieving 3.5% p.a. by 2050 (Figure 19). Human development shows gradual improvement, with HDI increasing modestly from 1% in 2030 to 3% by 2050. In contrast, social indicators demonstrate more significant improvements over time, with reductions in poverty (measured in proportion of population below the lower bound poverty line) from 0.31 to 0.28 (approximately -10%) and unemployment from 0.40 to 0.39 (approximately -4%) by 2050. However, inequality remains broadly unchanged in the short to medium term but shows a slight reduction of 1% by 2050, with a Gini coefficient of 63% in 2050. These results suggest that the Holistic scenario delivers higher economic performance alongside gradual but positive improvements in social outcomes, particularly in the long term, but does not substantially affect income distribution.

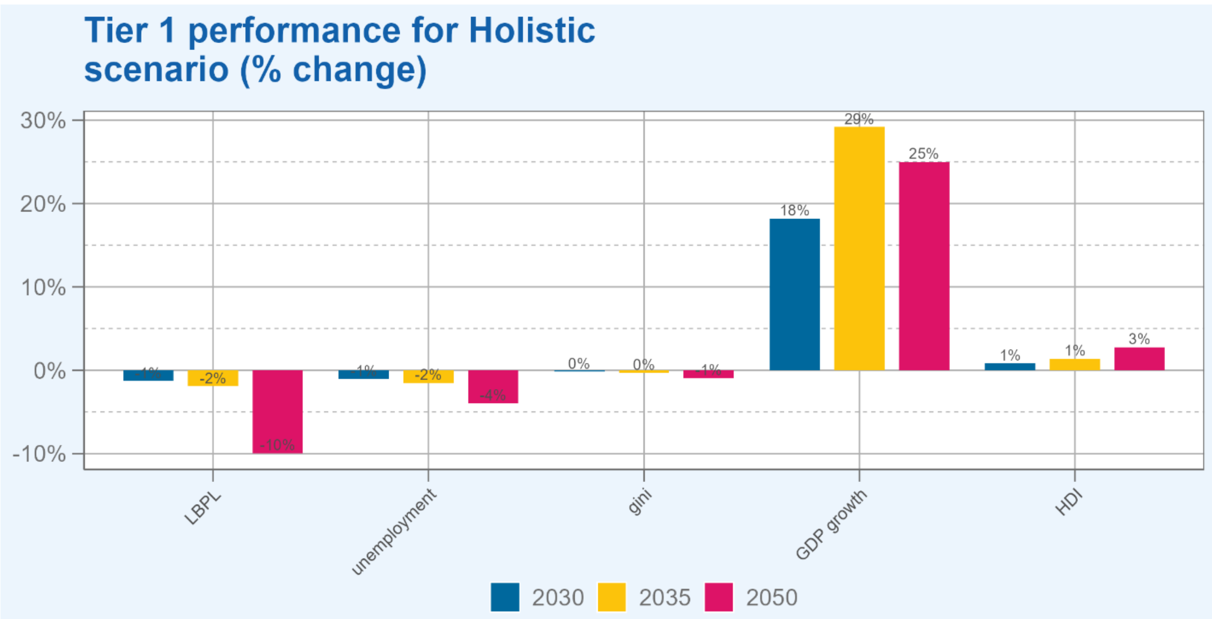

Figure 18: Holistic scenario results for the Tier 1 indicators. Results show the percentage change of the Holistic relative to the base scenario for the years 2030, 2035 and 2050.

These outcomes are driven by the reinforcing dynamics across economic, social, and environmental sectors in the iSD model. Investments in productive sectors, particularly agriculture (including training, fertiliser subsidies, and water efficiency), energy (solar, hydropower, and efficiency measures), and infrastructure (roads and rail), increase economic output, supporting sustained GDP growth. This in turn stimulates job creation and raises household incomes, contributing to reductions in poverty and unemployment. At the same time, investments in human capital, including education, health, and social transfers, improve labour productivity, reinforcing growth while driving improvements in the HDI. Expanded access to basic services such as water and sanitation further improves health outcomes and living standards. Lastly, environmental and climate interventions, including reforestation, land protection, and climate adaptation, increase resilience in natural resources reducing exposure to climate shocks and supporting long term productivity.

These results show that while some indicators are in line with national development targets, the holistic scenario, as currently configured, does not achieve all development targets related to the triple challenge and does not result in a just transition, with inequality remaining a challenge in the long-term. By 2030, according to the 10-year review of the National Development Plan (NPC, 2017), inequality is aimed to reach approximately 60%, unemployment levels 6%, poverty (below the LBPL) 0% and GDP growth 5.4%. Results from the holistic scenario show change in a positive direction by 2030, with inequality at 62%, poverty at 31%, unemployment 38% and GDP growth 2.6%, more in line with current observations as recorded in the latest poverty report by (Statistics South Africa, 2025). Under this trajectory the holistic scenario shows improvement to the triple challenge indicators in the long-term (see 2030, 2035, and 2050 results in Table 9).

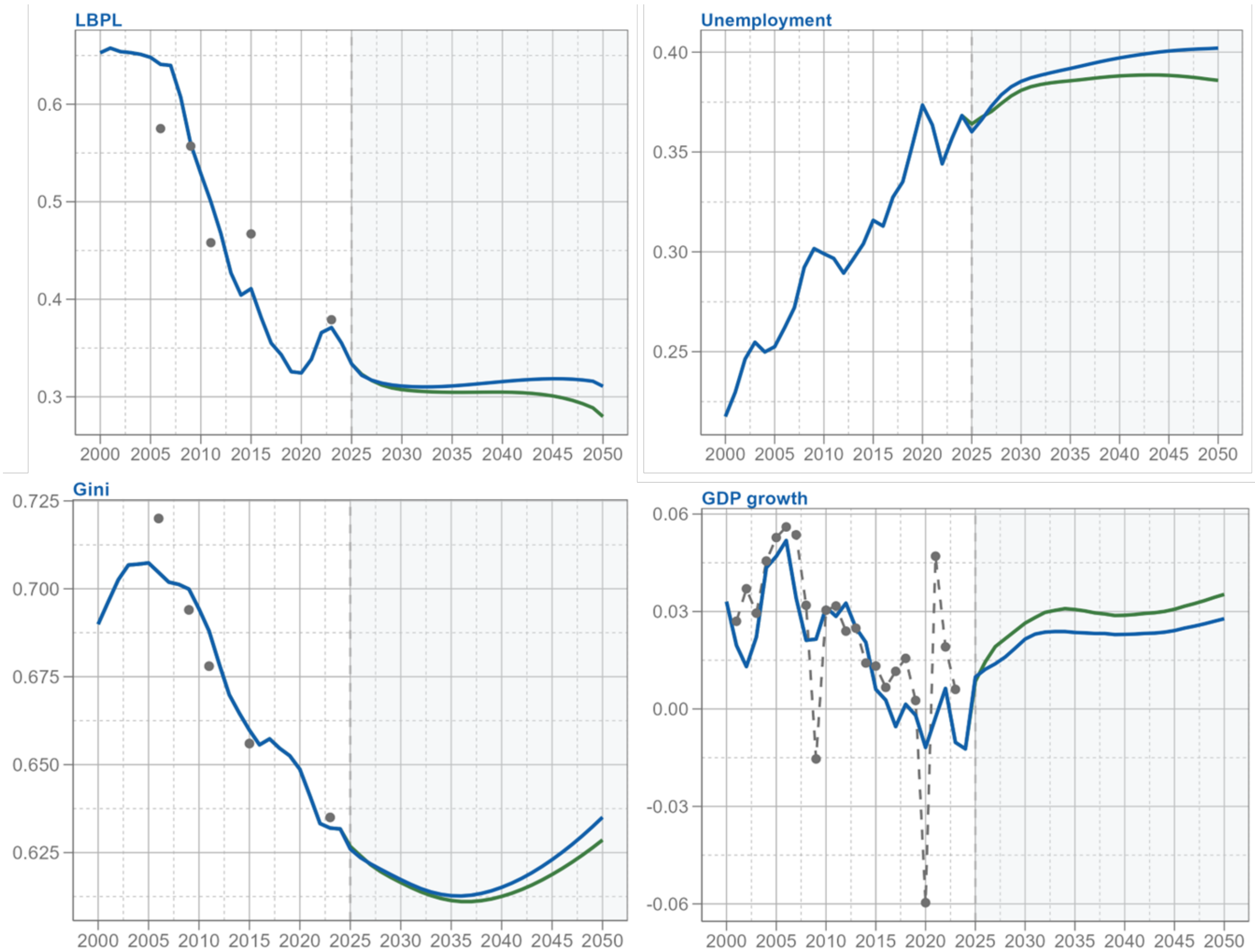

Figure 19: Behaviour Over Time (BOT) graphs of key Tier 1 indicators. Top-left: Proportion of the population below the lower bound poverty line (units = proportion). Top-right: Unemployment (units = proportion). Bottom-left: Gini coefficient (units = proportion). Bottom-right: GDP growth at market price (units = % per annum). Dots represent discrete values from historical data against baseline simulation (blue) and holistic scenario (green).

Table 9: Comparison between BaU and Holistic (Hol.) scenario results for the Tier 1 indicators (for 2030, 2035 and 2050), with the percentage (%) change shown in red font (if the change is in a undesirable direction) and green font (if the change is in a desirable direction).

Indicator (unit)	2030			2035			2050		
	BaU	Hol.	% change	BaU	Hol.	% change	BaU	Hol.	% change
Proportion of population below national poverty line (LBPL) (dmnl)	0.311	0.308	**-1.04**	0.311	0.305	**-2.04**	0.311	0.279	**-10.1**
Unemployment rate (dmnl)	0.385	0.384	**-0.34**	0.391	0.388	**-0.86**	0.402	0.386	**-3.93**
Gini coefficient (dmnl)	0.617	0.617	**-0.02**	0.613	0.612	**-0.08**	0.635	0.629	**-0.87**
Real GDP mp growth rate (dmnl)	0.022	0.026	**21.92**	0.024	0.031	**30.93**	0.028	0.035	**27.34**
Human Development Index (HDI) (dmnl)	0.705	0.71	**0.76**	0.72	0.729	**1.35**	0.76	0.782	**2.8**
Premature non communicable disease mortality (dmnl)	0.175	0.168	**-3.78**	0.167	0.156	**-6.54**	0.137	0.118	**-14.06**
Employment to adult population ratio [FEMALE]	0.304	0.305	**0.29**	0.301	0.303	**0.68**	0.3	0.31	**3.36**
Employment to adult population ratio [MALE]	0.4	0.401	**0.29**	0.392	0.395	**0.7**	0.377	0.391	**3.55**

6.2 Tier 2 indicators

The Holistic scenario delivers substantial improvements across Tier 2 indicators. CO_2 emissions decline by around 8% in 2030, 26% in 2035, and remain 19% lower by 2050 relative to the baseline. Access to electricity increases by approximately 3% in 2030, 8% in 2035, and 6% by 2050. This is supported by a shift in the energy mix, with electricity from non-GHG emitting sources increasing accordingly (Figure 20 and 21). At the same time, air pollution (PM2.5) declines by 17% in 2035 and 14% by 2050, suggesting that increases in energy demand eventually offset these reductions in the long-term.

Agricultural interventions contribute to reductions in undernourishment, which declines by 6% in 2035 and 12% by 2050. In terms of transport, mobility and rail infrastructure show modest improvements, with mobility increasing by 2–4% and rail infrastructure by 1–7% over time, as for mobility vir public transport. Access to water and sanitation show improvements, though the magnitude of performance remains uncertain owing to insufficient data regarding large scale infrastructure investments implemented in the model. Sanitation access increases by 28% in 2030 and 42% in 2050, while water access increases by 3% and 5% by 2030 and 2050 respectively.

Material consumption increases in absolute terms, with per capita material consumption rising by 4% in 2035 and 17% by 2050, while market domestic material consumption, expressed relative to economic growth, increases to a lower degree by 1% by 2050. This is because, efficiency improves, with per capita material footprint declining by 8% in 2035 and 3% by 2050, and market material footprint decreasing by 13% in 2035 and 16% by 2050. In terms of waste, waste generation remains broadly stable, with marginal increases of around 1% by 2050.

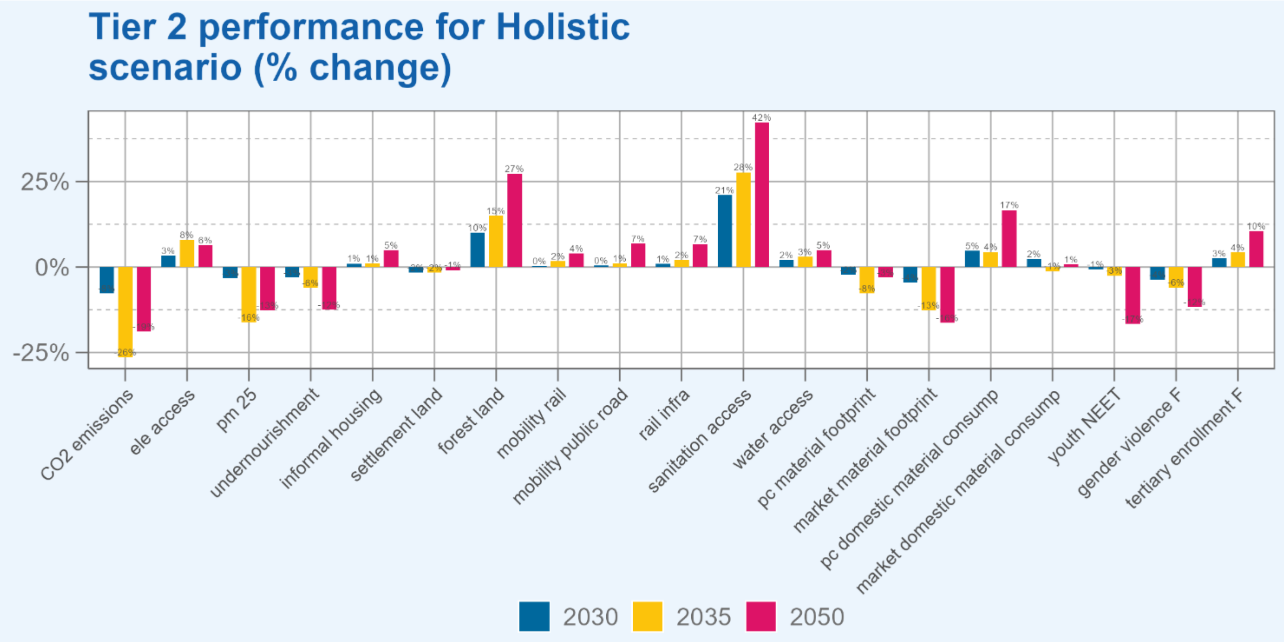

Figure 20. Holistic scenario results for the Tier 2 indicators. Results show the percentage change of the Holistic relative to the base scenario for the years 2030, 2035 and 2050

Additional indicators particularly focussed on the youth and the female gender show positive improvements. These include youth NEET (not in employment or education), which declines by 3% in 2035 and 17% by 2050, and gender-based violence (defined by the annual number of female victims to violence) decreases by 6% in 2035 and 12% by 2050. Female education outcomes, specifically in terms of tertiary enrolment increases steadily by 3% in 2030, 4% in 2035, and 10% by 2050. Overall, the results highlight gains in infrastructure, and economic activity, alongside gradual improvements in environmental and social outcomes, with relative trade-offs emerging from increased consumption and growth. Additional insights into the underlying causal dynamics and feedback loops are discussed alongside the behaviour over time (BOT) plots below. The results for 2030, 2035, and 2050 are summarised in Table 10, which follows on from the BOT plots.

6.2.1. Electricity system

The electricity system results show a clear transition towards a cleaner and more accessible energy system under the Holistic scenario (Figure 21). CO_2 emissions stabilise at around 400 Mt under the baseline, but decline under the Holistic pathway after 2025, reaching approximately 365 Mt by 2030, 294 Mt by 2035 and 335 Mt by 2050. This reflects reduced reliance on carbon intensive generation alongside increased deployment of renewables. These results fall within reach of South Africa's NDC targets which aim to decrease GHG emissions to the range of 350 - 420 Mt CO_2-eq in 2030, and between 320 – 380 Mt CO_2-eq in 2035 (DFFE, 2025).

Further, electricity access rises from around 0.81 in 2025 to approximately 0.91 by 2050 under the baseline, while the Holistic scenario accelerates progress, reaching about 0.97 by 2050. This is supported by a rapid increase in non-GHG electricity generating sources, which grows from roughly 30% in 2025 to over 80% by 2035. Air pollution (PM2.5) also declines more strongly under the Holistic scenario, falling from around 225 μg/m³ in 2025 to approximately 164 μg/m³ by 2050, compared to more gradual reductions under the baseline.

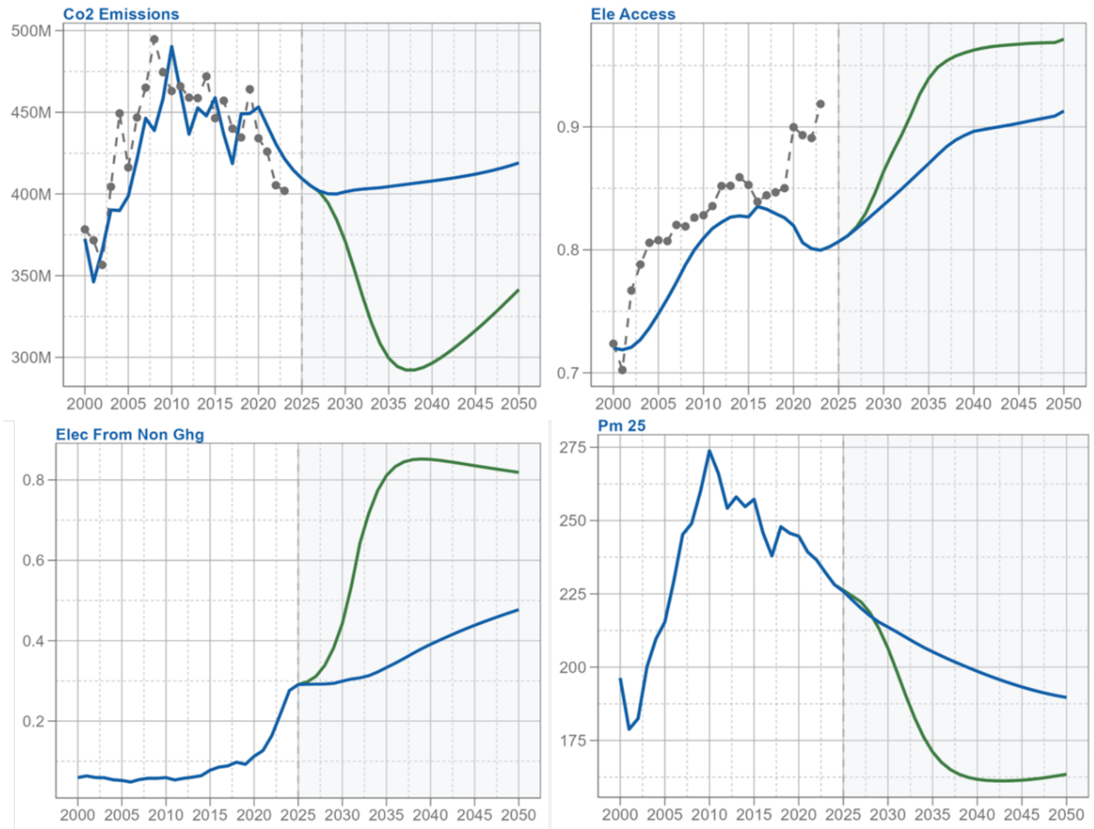

Figure 21. Behaviour over time graphs of key indicators in the electricity system. Top-left: CO2 emissions (tons/year). Top-right: Proportion of population with access to electricity (proportion). Bottom-left: Proportion of electricity from non-ghg emitting sources (proportion) and bottom-right: Air pollution measured as particulate matter 25 (µg/m^3).

These temporal changes are driven by reinforcing feedback between energy investment, improved efficiency, and demand. Increased investment in renewable energy capacity, particularly in solar, shifts the electricity mix towards low emission sources, reducing emissions and air pollution. At the same time, improved electricity access supports economic activity increasing demand for electricity. Efficiency improvements in industry, transport, and households further moderate energy intensity, allowing emissions to decline even as the economy grows. While these results indicate progress and place emissions within reach of national targets, the pace of the transition remains constrained by the speed of infrastructure deployment and dependence on existing carbon intensive assets. This highlights the importance of sustained investment to accelerate the energy transition to align with long term climate objectives. The electricity system indicators further show that sustained investments are required to maintain the electricity capacity from renewable sources to maintain CO2 targets in the long term.

6.2.2. Food system

The food system results show a divergence between the baseline and Holistic scenario after 2025, driven by investments in agriculture training, fertiliser subsidies and agriculture capital. The results are driven by feedback between agricultural productivity, food production, and nutrition outcomes. Increased adoption of sustainable practices supports higher yields, which improves food availability and reduces undernourishment over time. At the same time, improved resilience to climate variability helps stabilise production, limiting future shocks to food systems.

Undernourishment increases steadily under the baseline, while the Holistic scenario moderates this trend, peaking earlier and declining to 8% by 2050 (Figure 22). This indicates improved food security outcomes over the long term, although underlying demand from population growth remains. These improvements are linked to the rapid expansion of sustainable agricultural land under the Holistic scenario, which increases from near zero to full adoption by around 2050. This result implies that the budget allocation in the model far exceeds to agricultural training need, resulting in exaggerated growth in sustainable agriculture land, that could alternatively be directed to an alternative government intervention.

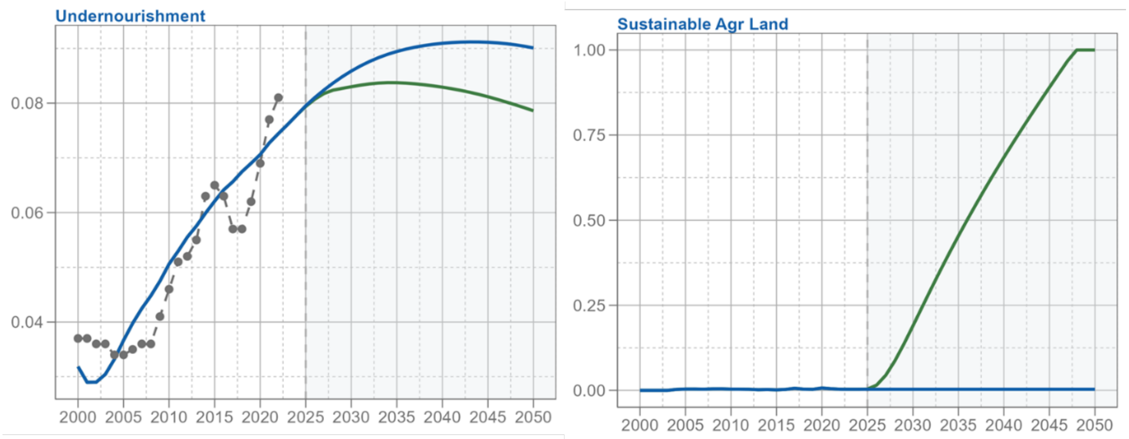

Figure 22. Left: Prevalence of undernourishment (proportion) and Right: Proportion of harvested area sustainability managed.

6.2.3. Transport system

Rail infrastructure declines steadily under both scenarios after 2025, reflecting ongoing depreciation and limited expansion, though the Holistic scenario moderates this decline maintaining infrastructure at around 18K km by 2050, indicating a slower rate of deterioration (Figure 23). By 2050, infrastructure levels remain notably higher under the Holistic pathway, suggesting partial mitigation of long-term degradation. This trend is consistent with the improvements observed in rail and public transport mobility, which increase modestly in the short to medium term (around 2–4%) (see (Figure 20). Together, these results indicate that while infrastructure constraints persist, targeted investments under the Holistic scenario help sustain rail and public transport usage and efficiency, supporting broader transport connectivity over time.

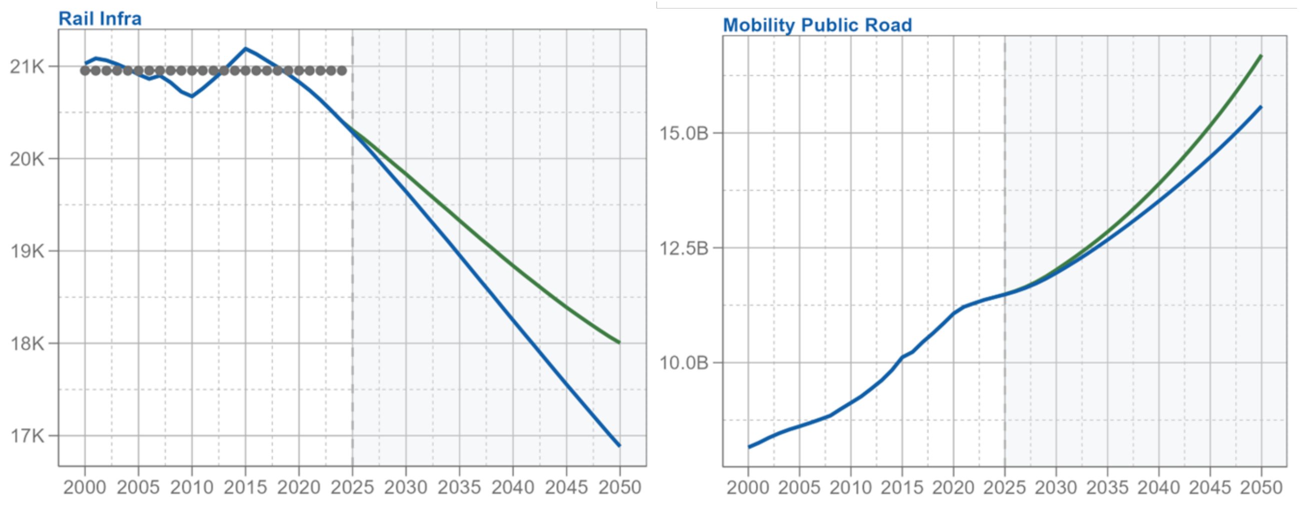

*Figure 23. Functioning rail infrastructure (km) (left) and Public road mobility (person*km/year) (right).*

6.2.4. Production & Consumption

Under the Holistic scenario, production and consumption reflect changes in both demand and resource use efficiency. Higher economic activity and consumption cause domestic material consumption to increase after 2025, reaching around 755 million tonnes by 2050. However, in terms of resource use, the trend in per capita material footprint declines to approximately 7.0 tonnes by 2030, with a gradual increase to around 7.5 tonnes by 2050, below the baseline levels indicating improvements in resource efficiency.

In the model, these trends are specifically driven by feedback between economic growth, consumption, and efficiency. Increased economic activity raises demand for materials, leading to higher total consumption, while investments in technology and efficiency reduce the material intensity of production. As a result, the Holistic scenario captures a relative decoupling, where material use per capita declines even as total consumption increases, highlighting a trade-off between rising consumption and resource efficiency.

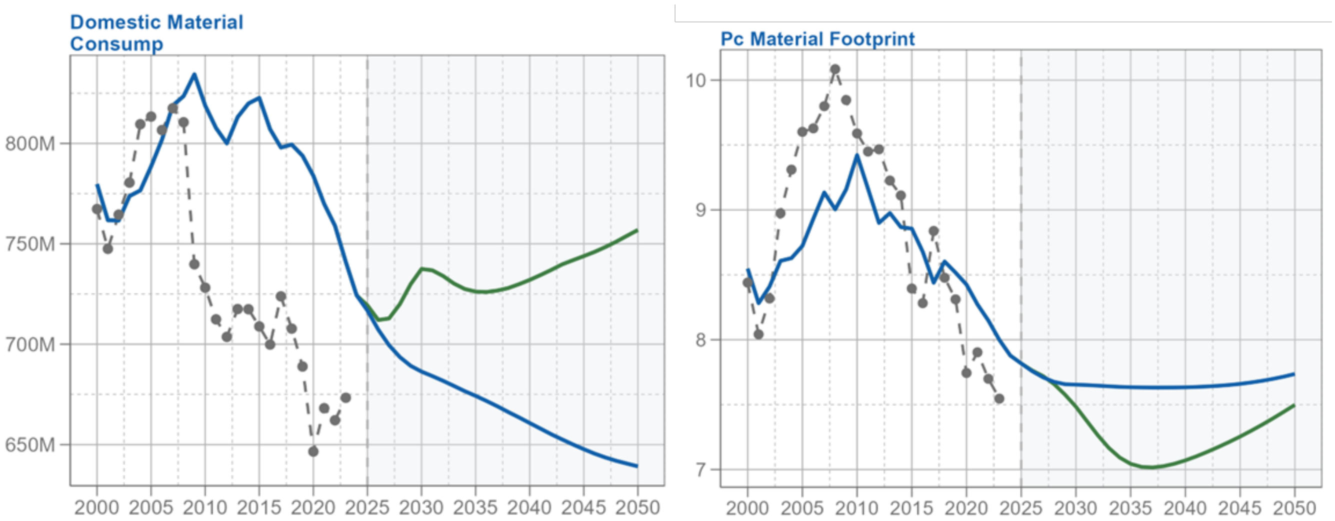

Figure 24. Domestic material consumption (tonne/year) (left) and per capita (PC) material footprint (tonne/person/year).

6.2.5. Land & Human Settlements

For the Land and Human settlements system, the results show a divergence between conservation and urban growth. Natural forest land declines under the baseline, while the Holistic scenario reverses this trend after 2025, peaking at just over 18 million hectares in the early 2030s and stabilising at around 16.5 million hectares by 2050. This reflects the impact of reforestation and land protection efforts. Settlement land increases in both scenarios, rising from about 300,000 hectares to around 750,000 hectares by 2050 under the baseline. The Holistic scenario follows a similar trend but stabilises slightly lower at around 740,000 hectares, indicating modest containment of urban expansion.

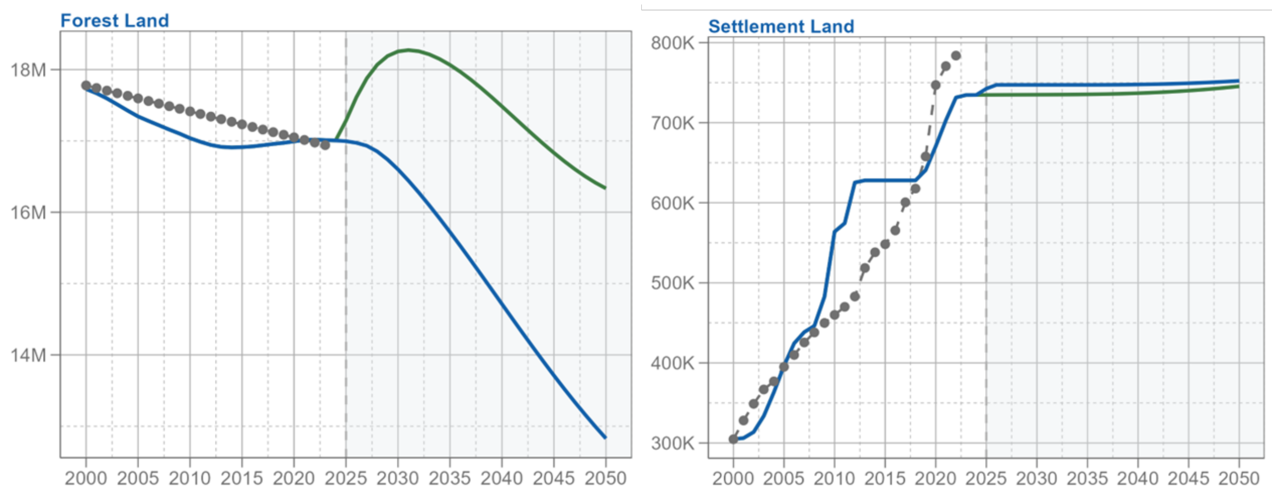

Figure 25. Natural Forest land (Ha) (left) settlement land (Ha) (right).

6.2.6. Water system

Access to water and sanitation improves under both scenarios, but more so under the Holistic scenario after 2025. Water access increases from around 87% in 2025 to approximately 0.98 by 2050 under the Holistic scenario, while sanitation access rises from 70% in 2025 to 100% access by 2050. While the scenario shows positive change, the rate of change for sanitation access is exaggerated owed to overinvestment relative to need or public sanitation infrastructure costs in the model. In terms of the underlying dynamics, improved access is driven by reinforcing dynamics between infrastructure investment and public health. Increased investment in water and sanitation systems expands access, which improves health outcomes and supports productivity. At the same time, higher income levels and urbanisation increase demand for services, which is met through sustained infrastructure expansion under the Holistic scenario.

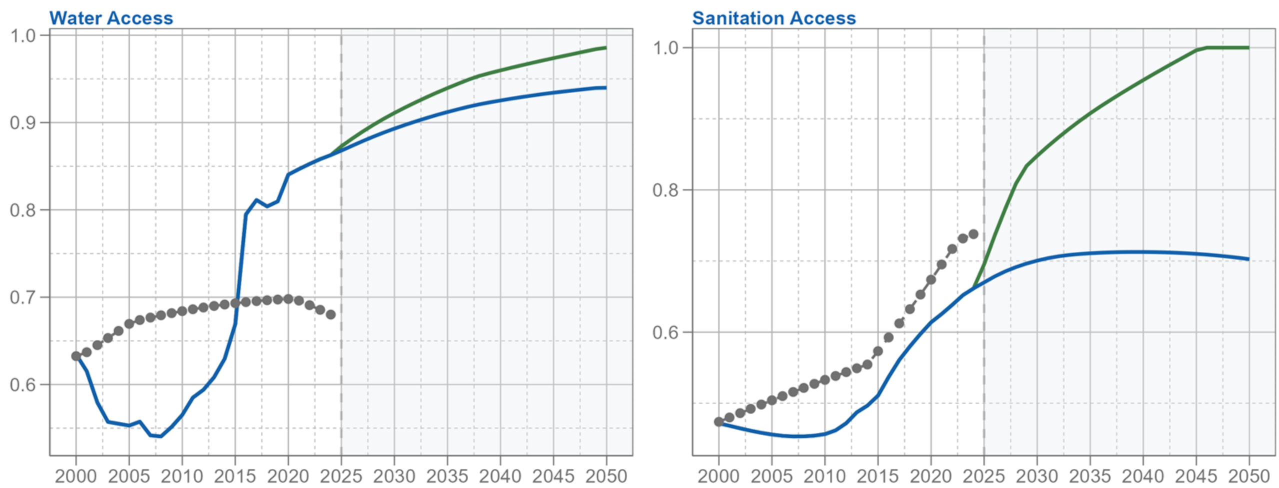

Figure 26. Proportion of population with access to water (left), and access to sanitation infrastructure (right).

6.2.7. Youth & Gender

In terms of youth and gender, the following graphs specifically report on youth unemployment, gender violence against woman and woman education. Under the holistic scenario, youth NEET (not in education or employment) decreases after 2025, improving to approximately 19% by 2050. This is because investments in education and social support contribute to higher participation in employment and training over time, highlighting the need for continued focus on youth labour market inclusion.

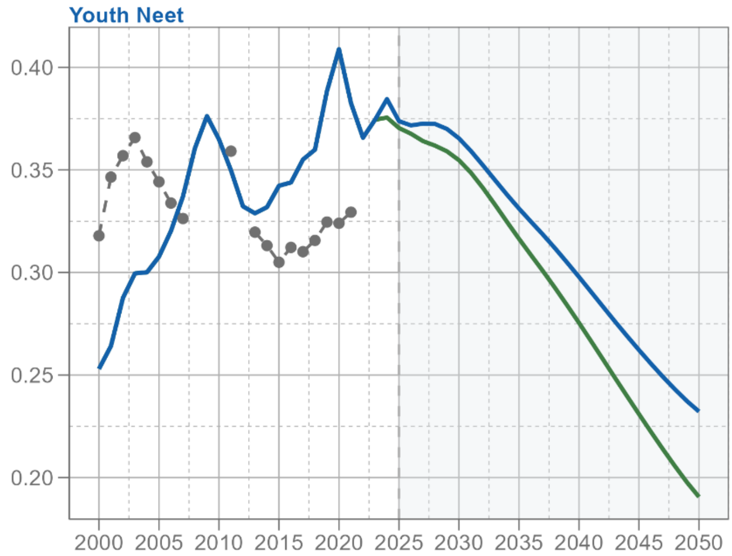

Figure 27. Share of youth not in education, employment or training (NEET) (proportion of population aged 15 to 24).

In terms of female inclusion, tertiary enrolment increases steadily in both scenarios, but more rapidly under the Holistic pathway. Enrolment rises from around 24% in 2025 to approximately 33% by 2050 under the Holistic scenario, compared to about 30% under the baseline. This reflects that sustained improvements in access to education and investment in human capital can support long-term outcomes for women. In contrast, gender-based violence against woman increases under the baseline, though this is moderated under the Holistic scenario declining to around 5,500 victims (persons/year) by 2050. This suggests that while underlying social pressures persist, targeted interventions and broader socio-economic improvements can contribute to reducing the prevalence of violence over time.

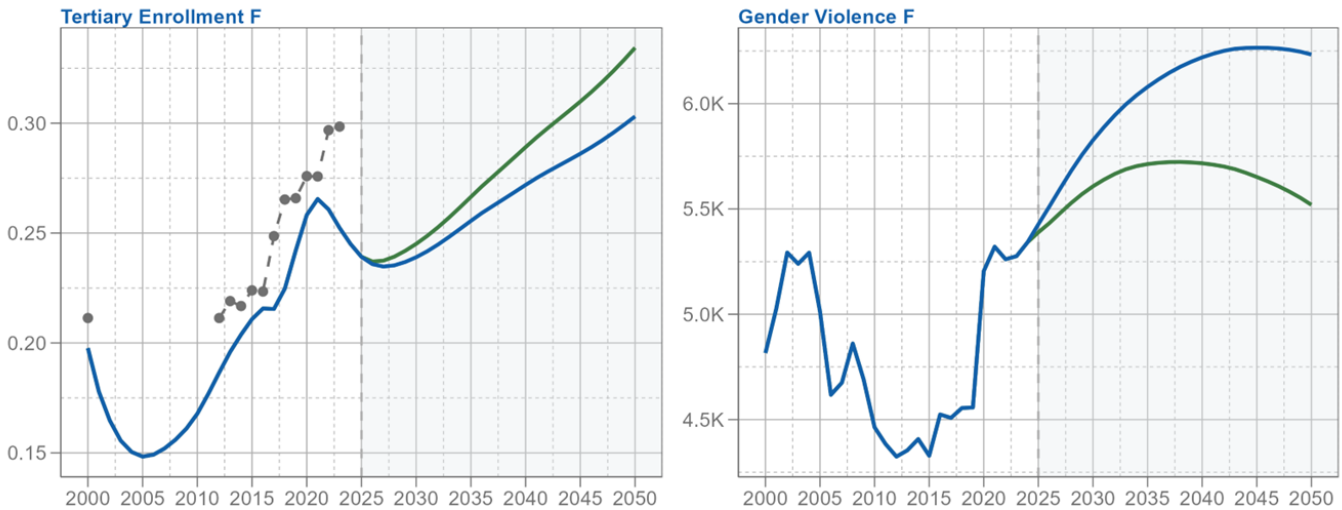

Figure 28. Gross tertiary enrolment rate (proportion) (left) and victims of violence (person/yr) (right) for the female population.

Table 10: Comparison between BaU and Holistic (Hol.) scenario results for the Tier 2 indicators (for 2030, 2035 and 2050), with the percentage (%) change shown in red font (if the change is in a undesirable direction) and green font (if the change is in a desirable direction).

Indicator (unit)	2030			2035			2050		
	BaU	Hol.	% change	BaU	Hol.	% change	BaU	Hol.	% change
CO2 emissions (tonne/yr)	395,805,927.3	365,343,765.8	-7.7	398,959,494.7	293,894,459.2	-26.33	412,531,855.9	334,730,186.6	-18.86
Average proportion of population with access to electricity (dmnl)	0.837	0.864	3.27	0.87	0.939	7.95	0.913	0.971	6.4
Total pm 25 emissions (kt/year)	213.193	206.356	-3.21	204.372	171.418	-16.12	187.973	164.257	-12.62
Proportion of electricity from non GHG emitting sources (dmnl)	0.299	0.443	48.04	0.333	0.811	143.5	0.477	0.819	71.62
Prevalence of undernourishment (dmnl)	0.086	0.084	-3.07	0.09	0.084	-6.05	0.091	0.079	-12.48
Proportion of population living in informal housing (dmnl)	0.25	0.252	1	0.259	0.261	1.13	0.309	0.324	4.94
Settlement Land (Ha)	747,244.528	734,976.752	-1.64	747,248.307	735,405.875	-1.58	752,301.748	745,433.463	-0.91
Forest Land (Ha)	16,600,491.95	18,255,051.15	9.97	15,722,064.58	18065866.15	14.91	12,828,173.99	16,333,689.66	27.33
People mobility by transportation mode[Rail] (person*km)/year)	12,634,633,722	12,673,700,941	0.31	13,220,816,415	13,447,285,209	1.71	14,827,674,989	15,421,025,447	4
People mobility by transportation mode[Public rubber] (person*km)/year)	11,908,988,231	11,954,550,972	0.38	12,620,653,776	12,760,599,282	1.11	15,505,871,576	16,559,151,826	6.79
People mobility by transportation mode[Private rubber] (person*km)/year)	5,024,151,631	5,039,885,917	0.31	5,336,368,911	5,369,196,232	0.62	6,292,591,399	6,486,809,464	3.09
Transportation infrastructure[rail] (Km)	19,642.146	19,831.742	0.97	18,953.034	19,328.664	1.98	16,882.328	18,002.92	6.64
Material footprint (Tonne/Year)	532,641,391.4	521,156,926.6	-2.16	559,193,656.7	517,261,537.3	-7.5	643,759,297.7	630,699,701.7	-2.03
per capita material footprint (Tonne/(Year*person))	7.627	7.455	-2.25	7.608	7.018	-7.75	7.708	7.474	-3.03

Indicator (unit)	2030			2035			2050		
	BaU	Hol.	% change	BaU	Hol.	% change	BaU	Hol.	% change
Material footprint per unit of value added (kg/usd 2017)	0.646	0.617	-4.5	0.602	0.526	-12.69	0.482	0.403	-16.29
Domestic material consumption (Tonne/Year)	688,377,150.1	722,140,826	4.9	676,707,234.1	708,166,595.2	4.65	640,229,303.7	754,547,331.8	17.86
per capita domestic material consumption (Tonne/(Year*person))	9.856	10.33	4.8	9.207	9.608	4.36	7.666	8.942	16.65
Domestic material consumption per unit of value added (kg/usd 2017)	0.835	0.854	2.39	0.729	0.72	-1.23	0.479	0.482	0.7
Average per capita waste generation (kg/(person*day))	1.016	1.017	0.1	1.033	1.036	0.24	1.08	1.088	0.66
Share of youth not in education employment or training (dmnl)	0.364	0.362	-0.71	0.331	0.323	-2.51	0.233	0.195	-16.58
Total death by cause [FEMALE] (person/year)	5,823.237	5,605.143	-3.75	6,077.121	5,710.731	-6.03	6,235.03	5,509.311	-11.64
Total death by cause [MALE] (person/year)	17,626.158	16,929.231	-3.95	18,153.614	16,977.85	-6.48	17,835.044	15,494.421	-13.12
Tertiary gross enrollment rate [FEMALE] (dmnl)	0.239	0.245	2.51	0.256	0.266	4.24	0.303	0.335	10.44
Tertiary gross enrollment rate [MALE] (dmnl)	0.27	0.277	2.52	0.289	0.301	4.25	0.342	0.378	10.47
Sanitation access (dmnl)	0.701	0.848	21.04	0.711	0.908	27.68	0.703	1	42.34
Water access (dmnl)	0.893	0.911	2.01	0.912	0.939	3.01	0.94	0.986	4.89

6.3. Model Interface

The iSD model has built-in functionality to explore scenarios and outcomes of various development indicators via a web-based visual user interface (VUI). This provides an accessible way for stakeholders to engage with the model - without needing access to model software. Access to the model is provided via the following instructions:

1. Click on the link below and follow ‘help’ and (i) buttons to navigate the interface
2. To test additional scenarios, click on the *Simulation tab* – *Start New* – set intervention policies – press *Run*.
3. Further explore the model dynamics under *View - Model* and click around on different sub-models.

https://exchange.iseesystems.com/public/millenniuminstitute/isd-zaf-test/index.html#page1.

7. Synergy and Trade-off Analysis

In order to isolate the effects from the interventions, the interventions were grouped per development pathway. By assessing the effects of interventions per development pathway against a scenario including every intervention, it is possible to isolate and analyse the individual contribution of the interventions to the synergistic effects between interventions. This enables the identification of how interventions add to one another (i.e. synergies) or detract from one another (i.e. trade-offs) for key development indicators.

7.1. Analytical Process

For this analysis, eight scenarios were simulated (one for the holistic narrative and seven representing each of the *Development Pathways'* narrative). To simulate the scenarios, the model interventions were mapped to the respective system pathway (Table 11). Finally, the synergy analysis was assessed relative to the performance outcomes of the Tier 1 and Tier 2 indicators.

Table 11: Matrix relating the interventions in the iSD model to the seven pathways, as used in the SDG framework.

iSD intervention	Holistic	Elect-ricity (Ele)	Food (Fds)	Human settle-ments (HuS)	Land Use (Lnd)	Trans-port (Trt)	Water (Was)	Production & Consump-tion (PrC)
general education	X							X
general health	X		X					
general agriculture	X		X					
water access	X						X	
sanitation access	X						X	
roads a	X					X		
railways	X					X		
waste management	X							X
land protection	X				X			
marine protection	X		X					
reforestation	X				X			
small photovoltaic	X	X						
large photovoltaic	X	X						
large hydropower	X	X						
vehicles efficiency	X					X		
industry energy	X							X
households energy	X							X
water efficiency	X		X					

iSD intervention	Holistic	Elect-ricity (Ele)	Food (Fds)	Human settle-ments (HuS)	Land Use (Lnd)	Trans-port (Trt)	Water (Was)	Production & Consump-tion (PrC)
general transfers	X			X				
climate adaptation	X							X
agriculture training	X		X					
social housing	X			X				

***large wind power:** this was not explicitly mentioned in the narratives and so we have not included it at this point, however, given that a significant portion of SA's clean energy is expected to be wind-generated by 2050, this is a limitation that needs acknowledging.*

7.2 Synergy Results

The following section details the results of the analysis, with the objectives being two-fold: firstly, it is to report the performance of indicators across the development pathway scenarios to identify the key drivers of change, and secondly to identify the synergies and trade-offs across the development systems. Each scenario is analysed to determine its policy impact on the attainment of the Tier 1 and 2 indicators. The combined performance of interventions reported in the Holistic scenario provides a comprehensive picture of the combined impact of policy scenarios. However, isolating the impact of interventions through the *Development pathway scenarios* enables analysing the contribution of the intervention groups and how these intervention groups interact across systems. Determining the characteristics of the interaction between interventions is critical to understanding the indicator performance.

Detailed values for the attainment and contribution of each intervention group are reported in **Annex 2: Synergy Tables**. Figure 29 and Figure 31 displays the stacked contributions of intervention groups and the synergy impact across the interventions when simulated relative to the *Holistic scenario*. It is important to note, that the sum of the change across the intervention scenarios will not exactly equal the results of the change of the Holistic scenario, due to the interconnection effects across systems as measured by the synergy analysis (Figure 30 and Figure 32). This is due to the dynamic effects of the model sectors' interaction that differ as the policy inputs of the simulation scenarios change.

7.2.1. Tier 1

The scenario contribution analysis (Figure 29) shows that improvements across Tier 1 indicators are driven by a combination of intervention groups, with electricity emerging as the dominant contributor, particularly for GDP growth, poverty reduction (LBPL), and HDI. Contributions to GDP growth are strongly positive and primarily led by electricity, with additional support from food and transport systems, while a small negative synergy effect indicates minor trade-offs when interventions are combined. Poverty reduction and unemployment reflect more distributed contributions across electricity, food, and other systems, with small synergy effects suggesting largely additive outcomes with limited interaction. In contrast, inequality (Gini) shows minimal change and limited contributions across all intervention groups, indicating weak system change. Improvements in HDI are driven by combined gains across sectors, though to a lesser magnitude than GDP growth. Overall, the results reinforce that Tier 1 outcomes are largely shaped by energy-led economic transformation, supported by food and productive systems, while interaction effects remain relatively small, highlighting the importance of coordinated but complementary policy implementation.

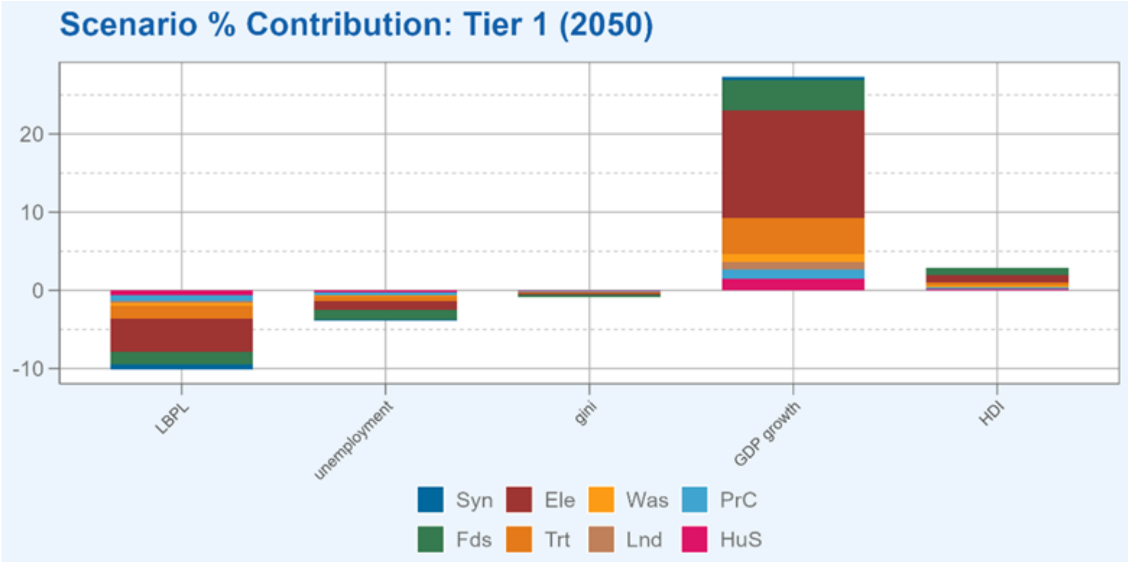

Figure 29: Scenario contribution (%) across development scenarios for Tier 1 indicators in 2050. Syn represents the synergy that exists between the Holistic scenario and the sum of intervention groups. The synergy effect is dependent on the sign of the indicator, where a negative synergy for LBPL, unemployment and Gini implies a positive, reinforcing effect.

The synergy results (Figure 30) further illustrate that the holistic scenario consistently outperforms the sum of individual interventions across all Tier 1 indicators due to positive interaction effects between sectors of the economy. It is important to note that the interpretation of synergy depends on the direction of the indicator: for indicators such as poverty (LBPL), unemployment, and inequality (Gini), where reductions represent improvement, negative synergy values indicate reinforcing effects. In this context, the negative synergies observed for LBPL and unemployment reflect stronger-than-expected improvements under the integrated scenario. Similarly, the near-zero but slightly negative effects for HDI and Gini suggest largely additive but still reinforcing interactions. In contrast, GDP growth shows a positive synergy, indicating that combined interventions generate greater economic gains than the sum of individual effects. Overall, the results demonstrate that system interactions strengthen outcomes across all indicators.

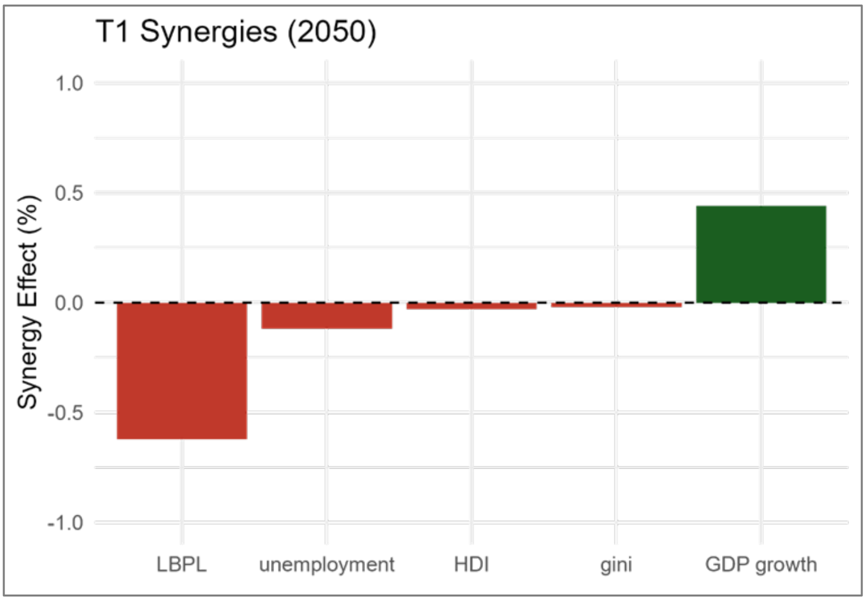

Figure 30: Tier 1 synergy results between the sum of scenarios groups and the holistic scenario in 2050.

7.2.2 Tier 2

The scenario analysis for Tier 2 indicators (Figure 31) shows that outcomes are driven by a combined effect from the interventions, with electricity, water, food, and transport systems playing prominent roles. Improvements in access to basic services, particularly sanitation and water, are strongly driven by water system interventions, highlighting the importance of service delivery infrastructure. Electricity interventions contribute significantly to improvements in energy access and environmental outcomes, including reductions in CO_2 emissions and PM2.5. Food systems play a key role in social indicators such as undernourishment and domestic material consumption, while transport interventions dominate mobility and rail infrastructure outcomes. Material use and waste-related indicators are shaped by production and consumption systems, reflecting their influence on resource efficiency and economic activity. Overall, the results demonstrate that Tier 2 outcomes are shaped by multiple interventions, with electricity and food playing a central role, underscoring the need for coordinated, cross-sectoral policy implementation.

The synergy results for Tier 2 indicators (Figure 32) show that combining interventions leads to better outcomes than implementing them individually, although the effects vary across indicators. For indicators where a decrease is an improvement (such as CO_2 emissions, air pollution, informal housing, and material use), negative values indicate reinforcing effects. In this case, negative synergies for CO_2 emissions and PM2.5 indicate that integrated policies deliver larger-than-expected improvements. Some indicators also show diminishing effects, where the combined impact is smaller than the sum of individual interventions. This occurs when multiple interventions target the same drivers, for example, both energy and production systems reduce emissions, leading to overlapping rather than additive impacts, or where improvements approach practical limits. For indicators where an increase is desirable, such as water access, rail infrastructure, and education, positive synergy values reflect additional gains from combined interventions. Overall, the results show that integrated policies can improve outcomes across indicators, further highlighting the importance of policy coordination to manage overlaps and maximise development outcomes.

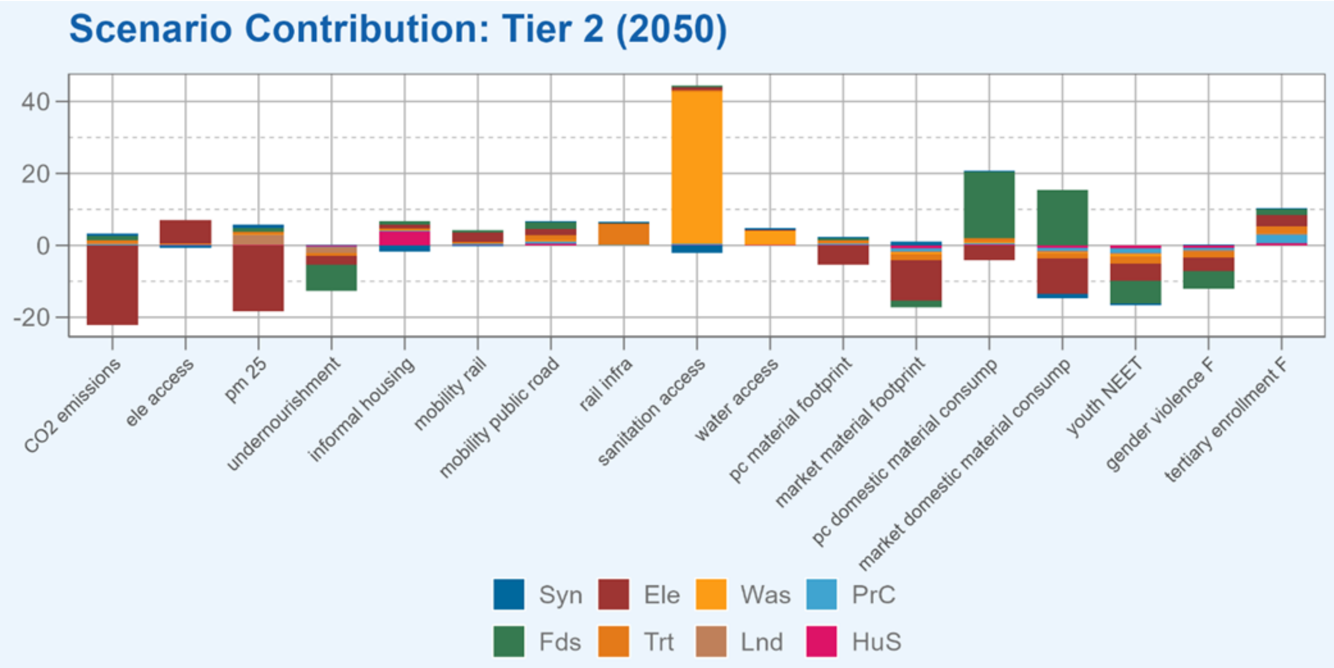

Figure 31: Scenario contribution (%) across development scenarios for Tier 2 indicators in 2050. Syn represents the synergy that exists between the Holistic scenario and the sum of intervention groups. A negative synergy represents a diminishing effect, whereas a positive synergy represents a reinforcing effect.

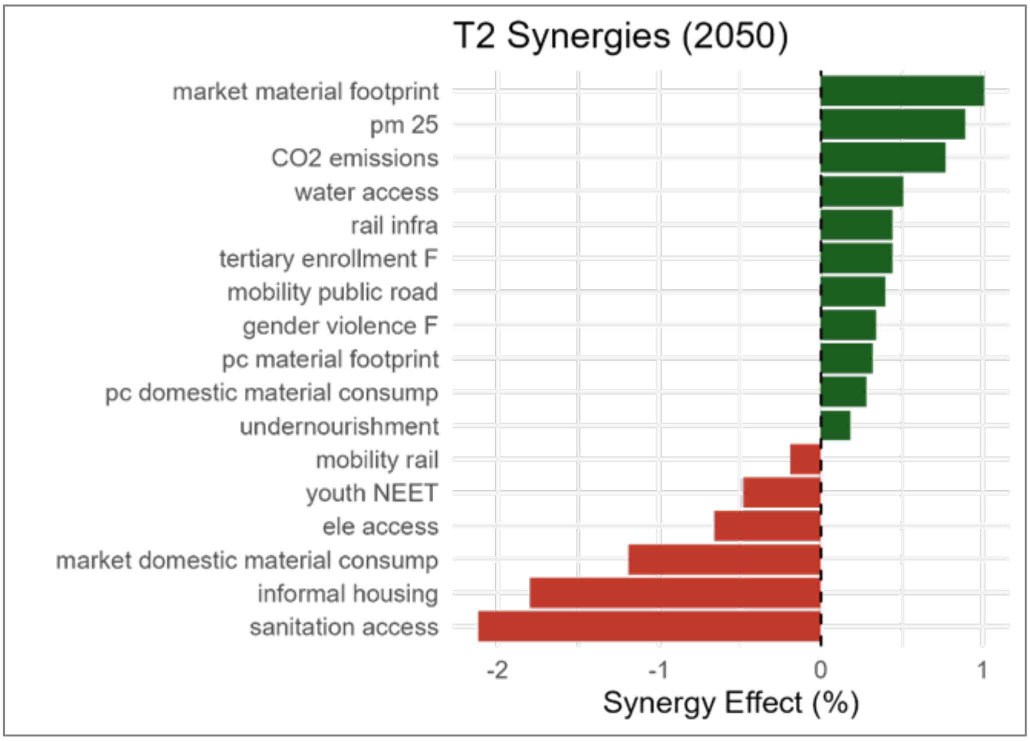

Figure 32: Tier 2 synergy results between the sum of scenarios groups and the holistic scenario in 2050.

8. Policy Recommendations

8.1 Key Insights

The results of this assessment suggest that South Africa's pathway to net-zero by mid-century should not be approached narrowly as a technical decarbonisation challenge. Rather, it should be understood as part of a broader development transition that responds directly to the country's persistent triple challenge of poverty, inequality and unemployment. In this regard, the holistic scenario demonstrates that climate-aligned investment can support positive outcomes across a range of economic, social and environmental indicators. Relative to the baseline, the scenario performs better on economic output, poverty reduction, employment, access to services, undernourishment, and several sustainability indicators. This supports the view that climate action and development need not be treated as competing agendas but can be mutually reinforcing when pursued through an integrated systems approach.

At the same time, the analysis also shows that these improvements are not sufficient, on their own, to deliver a fully just transition. Most notably, **inequality remains stubbornly high** over the simulation period, with only limited improvement in the Gini coefficient by 2050. This is an important finding and is the first key insight of the assessment, suggesting that while the holistic scenario improves many socio-economic outcomes, the benefits of growth and transition are insufficiently redistributed. In practical terms, this means that a pathway can be greener and more productive without yet being meaningfully more equal. This points to the need to increase and broaden economic participation to benefit from developmental gains.

A second key insight is that the model does not yet demonstrate strong **long-term decoupling between economic growth and material consumption**. Although the holistic scenario improves emissions intensity and resource efficiency, domestic material consumption remains under pressure as the economy expands. The results therefore suggest that relative efficiency gains alone may be insufficient to sustain environmental improvements over the long term. Future policy design will likely need to place greater emphasis on

- circular economy transitions,
- material demand management, and
- deeper forms of structural transformation.

A third insight concerns **the importance of enabling systems**. The analysis indicates that some interventions have broader systemic effects than others. In particular, electricity, food systems, basic service infrastructure, and transport repeatedly emerge as high-leverage areas because they shape outcomes across multiple sectors simultaneously. Electricity, for example, is central not only to emissions reduction, but also to service delivery, economic activity and household well-being. Food systems, similarly, influence undernourishment, poverty, health and resilience. This reinforces the value of integrated planning and suggests that the most effective policy packages will be those that focus on enabling systems with strong cross-sector spillovers.

Finally, the analysis highlights **the importance of institutional capability and policy coherence**. The holistic scenario results assume that investments translate into implementation, coordination and sustained public benefit. In practice, however, South Africa's development context remains shaped by uneven state capability, infrastructure delivery challenges, and fragmented planning. The implication is that achieving the gains modelled here will depend not only on choosing the right interventions, but also on improving institutional alignment, implementation capacity, and the quality of long-term planning across the state.

Table 12 and Table 13 further summarise the key findings and system drivers effecting the Tier 1 and 2 indicators, highlighting the dominant systems influencing each indicator and the corresponding policy levers for accelerating development outcomes. The results illustrate that achieving national development outcomes requires coordinated, cross-sector policy design, with particular emphasis on high-impact systems.

Table 12. Summary of system contributions to key Tier 1 development indicators based on the scenario and synergy analysis.

Indicator	Key Findings	System Drivers	Policy Levers
Inequality (Gini)	Minor improvements across interventions (-1% by 2050). Outcomes largely reflect additive sector effects with limited system interaction.	**Food**, Electricity	Food affordability through households' support; expand electricity access. Broaden economic participation.
Poverty (LBPL)	Poverty declines under the holistic scenario (-10% by 2050). Electricity provides the largest individual contribution, supported by food and circular economy interventions.	**Electricity**, Food, Production & Consumption	Expand affordable electricity access; strengthen agricultural productivity; promote circular economy, material and resource efficiency.
Unemployment	Unemployment declines most strongly under the holistic scenario (-4% by 2050), reflecting broad economic restructuring across the industry, service and agriculture sectors.	**Electricity**, Food, Transport	Promote energy-driven economic growth; support agricultural employment; improve transport and logistics connectivity, with a focus on rail infrastructure.
GDP growth	Economic growth is strongly driven by electricity interventions, with additional contributions from transport and production systems (+27% by 2050).	**Electricity**, Transport, Food, Production & Consumption	Accelerate energy system transformation; invest in transport infrastructure; promote resource-efficient industrial production.
Human Development Index (HDI)	Modest improvements in HDI (+3% by 2050) improve through combined gains in health, income, and education	**Electricity**, Food	Expand energy access, strengthen food systems, transport accessibility to support mobility.

Table 13. Summary of system contributions to key Tier 2 development indicators based on the scenario and synergy analysis. Reported percentage change for 2050 values.

Indicator	Key Findings	System Drivers	Policy Levers
CO_2 emissions	Significant reductions across systems (-19%)	Electricity, Production	Promote solar uptake to decarbonize energy and industry
PM2.5	Air quality improves through board economic interconnections (-13%)	Electricity, Land	Reduce emissions through uptake of non-GHG emitting electricity sources and improve land management
Electricity access	Strong increase driven almost entirely by electricity interventions (+6%)	**Electricity**	Expand grid access, invest in clean energy infrastructure

Indicator	Key Findings	System Drivers	Policy Levers
Sanitation access	Major improvements dominated by water systems (+40%)	**Water**	Invest in sanitation infrastructure and service provision
Water access	Large contribution from electricity and water systems (+5%)	**Electricity**, Water	Improve water infrastructure and energy access for service delivery
Education (tertiary)	Cross-sectoral benefits across multiple systems (+10%)	**Electricity**, Transport	Expand access to education through mobility infrastructure and economic development
Youth NEET	Significant reductions driven by electricity, food and transport systems (-17%)	**Electricity**, Food, Transport	Promote job creation, skills development and access
Land protection	Moderate improvements driven by electricity and land systems (+27%)	Land, Electricity	Strengthen land governance and sustainable land use practices
Material footprint per unit of value added	Reductions achieved through synergy interactions across sectors (-16%)	Production & Consumption, Electricity	Promote resource efficiency and circular economy policies
Domestic material consumption per unit of value added	Increases linked to economic expansion (+0.7%)	**Food**, Production	Manage material demand alongside economic growth
Undernourishment	Strong reductions driven by food systems (-12%)	**Food**	Improve food access, nutrition awareness, and agricultural productivity
Gender-based violence	Reductions supported by multiple systems (-12%)	Food, Electricity	Strengthen social protection and economic inclusion policies
Transport & mobility [Rail]	Improvements driven by transport and electricity systems (+4-6%)	**Transport**, Electricity	Invest in public transport and infrastructure

8.2 Policy Levers

The analysis identified a set of priority policy levers that can deliver broad and mutually reinforcing socio-economic and environmental benefits. These should be understood as interdependent components of a wider development transition, rather than as isolated sectoral interventions. As tested in the model, they point toward a policy package that is both climate-aligned and development-oriented. These priority interventions (or policy levers) that can deliver broad socio-economic benefits are shown in Table 12, for the Tier 1 indicators, and Table 13, for the Tier 2 indicators, and are summarised in Figure 33 below.

A first priority is to **scale up clean and reliable electricity systems**. Continued investment in renewable energy generation, grid expansion, and broader energy access remains foundational to the transition. Beyond its direct mitigation role, electricity acts as an enabling system for economic growth, service delivery, mobility and social well-being. Electricity reform should therefore be linked not only to decarbonisation, but also to affordability, industrial development, and developmental inclusion.

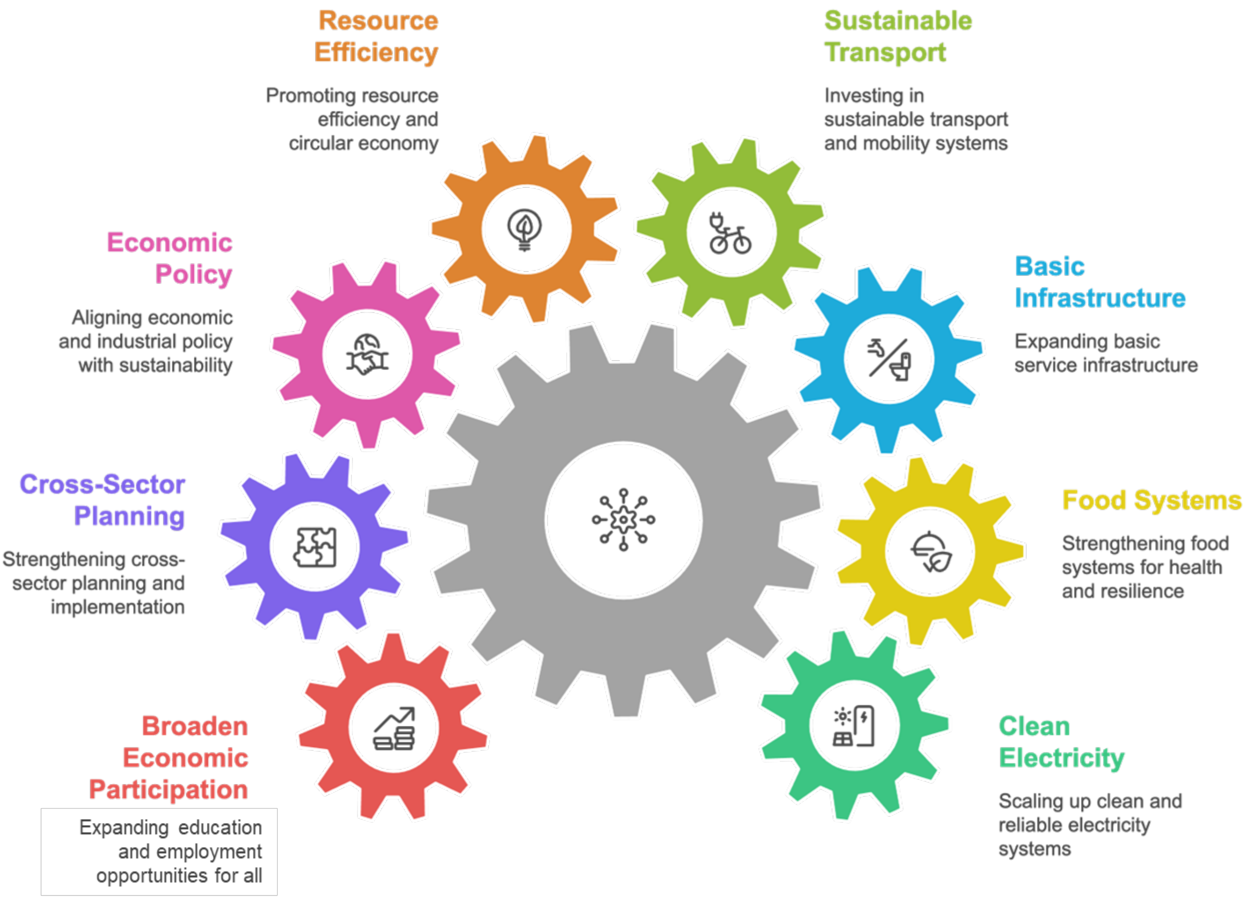

Figure 33: Summary of policy priorities.

A second priority is to **strengthen food systems for health and resilience**. Investments in agricultural productivity, food access and nutrition can generate benefits well beyond the agricultural sector itself. In the model, food-related interventions make an important contribution to reducing undernourishment and poverty, while also supporting broader human development outcomes. Food system policy should therefore be treated as central to both social justice and climate resilience.

A third priority is to **expand basic service infrastructure**, especially in relation to water, sanitation and waste systems. These interventions improve living conditions directly, while also supporting health, dignity, environmental quality and resilience in underserved areas. In the South African context, improvements in basic services remain indispensable to any meaningful effort to reduce structural exclusion and inequality. This further suggests that the just transition must include sustained investment in socially necessary infrastructure, even where such investment is not immediately commercially attractive.

A fourth priority is to **invest in sustainable transport and mobility systems**. Expanded public transport, rail infrastructure, and improved connectivity can enhance access to employment, education and services, while also reducing dependence on more carbon-intensive and spatially unequal transport systems. Mobility should therefore be treated not only as a transport issue, but as part of a broader agenda of inclusion, labour absorption and spatial justice.

A fifth priority is to **promote resource efficiency, circular economy transitions, and material demand management**. The results suggest that cleaner production alone may not be sufficient to secure long-term decoupling between growth and material throughput. Policy should therefore support more circular systems of use, recovery, repair and reduced material intensity across the economy. This becomes increasingly important in a long-term net-zero pathway where rising material demand could otherwise erode environmental gains.

A sixth priority is to **align economic and industrial policy more explicitly with sustainability goals**. South Africa's development challenge is not simply to grow, but to grow in ways that are lower-carbon, more resource-efficient, more employment-intensive and more inclusive. Industrial policy, infrastructure policy and climate policy cannot continue to operate in parallel. A more integrated approach is needed to ensure that current investment decisions support long-term structural transformation rather than future lock-in.

A seventh priority is to **strengthen cross-sector planning and implementation capability**. Because the systems under analysis are tightly interconnected, poorly coordinated policy can easily weaken wider gains. Integrated planning mechanisms, improved sequencing of investments, clearer institutional mandates, and stronger state capability are therefore essential preconditions for success.

An eighth and critical cross-cutting lever is to **broaden economic participation**. The limited movement in inequality suggests that future policy packages must go further in broadening who benefits from the transition. This includes formalising more sectors of the economy, increasing employment opportunities, youth opportunity pathways, and targeted, place-based support for vulnerable households. In this sense, the just transition should not be treated as an adjunct to climate policy, but as one of the conditions for its legitimacy and long-term success.

8.3 Financial implications and limitations

The financial implications of the holistic scenario highlight that the net-zero transition is not only a question of total investment volume, but also of investment structure, sequencing, and financing composition. In the model, total additional policy expenditure is set at 6.4% of GDP, equivalent to approximately ZAR 266 billion in 2019 prices, distributed over the period from 2025 to 2050. This is based on adding an amount comparable to the SET investment effort in order to simulate a similar scale of socio-economic investment alongside the low-emission transition. As currently configured, the expenditure is distributed evenly across the selected interventions. This even distribution is useful for comparative modelling and synergy analysis, but it should not be interpreted as a realistic implementation pathway. In practice, different sectors and interventions would require different levels and timing of finance:

- Some interventions – such as grid expansion, public transport infrastructure, and major service investments – are likely to require larger and earlier capital outlays;
- Other interventions may need to scale more gradually, or rely on different mixes of public and private funding.

The holistic scenario should therefore be read as indicative of broad investment needs and strategic priorities, rather than as a detailed expenditure plan.

The model further assumes that the additional investment is financed through a mix of 86% private-sector financing, primarily through foreign direct investment (FDI), and 14% public deficit financing. This assumption highlights an important policy trade-off:

- On the one hand, greater reliance on private and foreign capital can reduce pressure on the public fiscus and support faster infrastructure build-out, particularly in relatively bankable sectors such as energy and selected industrial activities.
- On the other hand, private capital does not automatically flow to areas of greatest social need. Investments in sanitation, rural services, social protection, community resilience, and local economic diversification may remain underfunded if transition finance is shaped too strongly by commercial bankability.

Public finance therefore remains indispensable, not only as a direct funding source, but also as a tool for de-risking investment, crowding in private capital, and ensuring that socially necessary interventions are not neglected.

From a just transition perspective, the financing challenge extends well beyond decarbonisation infrastructure. It also includes support for workers and communities affected by structural change, reskilling and skills development, social protection, economic diversification, and strengthened institutional capability. These categories are often less visible in headline transition finance discussions, yet they are essential if the pathway is to be socially legitimate and politically durable. South Africa's just transition policy architecture has already stressed that capital mobilisation must include both public and private sources, domestic and international, and that climate finance should support justice outcomes rather than infrastructure alone (PCC, 2022).

A further limitation relates to uncertainty around infrastructure costs and future expenditure needs. The holistic scenario necessarily relies on broad assumptions and indicative cost parameters, while real-world costs will be shaped by a range of factors that are not accounted for in the model, including:

- exchange-rate movements,
- technology shifts,
- infrastructure bottlenecks, and
- evolving sectoral assumptions.

The model's financing outputs should therefore be interpreted as directional rather than fixed. Their main value lies in showing order-of-magnitude needs, strategic trade-offs, and the importance of blended and adaptive financing arrangements. Over time, these estimates would need to be refined through closer alignment with sector-specific investment plans, infrastructure costing studies, and updated fiscal assumptions.

Overall, the financial implication is clear: South Africa's transition will require a blended financing approach, involving a combination of

- Public finance,
- concessional and catalytic finance,
- domestic private capital, and
- international investment,

all of which have important roles to play. The central challenge is not just mobilising capital at scale, but rather of ensuring that financing arrangements are aligned with the country's developmental priorities, institutional realities, and just transition commitments.

8.4 Conclusion

This assessment suggests that South Africa can make meaningful progress toward a net-zero, low-emission future while also improving a range of development outcomes. The holistic scenario demonstrates that integrated investment across energy, food systems, transport, services, natural resources, and human development can generate positive cross-sector effects, supporting stronger economic performance, lower poverty and unemployment, improved service access, and reduced emissions intensity. These findings reinforce the value of systems-based planning and show that climate ambition can, in principle, be aligned with broader social and developmental objectives. However, the results also make clear that positive movement does not automatically amount to transformational change. The pathway, as currently configured, does not fully resolve South Africa's triple challenge, nor does it yet amount to a fully just transition. Inequality remains persistently high, and some longer-term environmental pressures, particularly around material demand, remain insufficiently addressed. This is an important conclusion of the study. It suggests that while the holistic scenario is directionally promising, the next phase of policy design must go further in integrating redistribution, inclusion, and structural transformation into the core of transition planning.

The broader implication is that South Africa's net-zero pathway should not be framed simply as a climate pathway, nor only as an energy transition pathway. It should rather be framed as an integrated developmental transition that explicitly responds to poverty, unemployment and inequality while also advancing resilience, sustainability, and long-term emissions reduction. This is consistent with the broader thrust of national policy in SA (including the National Development Plan), which emphasises that sustainable development, social justice, and institutional capability are mutually dependent rather than separable goals.

In practical terms, the assessment points toward a strategic agenda centered on:

- high-leverage enabling systems,
- stronger policy coherence,
- more deliberate distributive measures, and
- a financing architecture that supports both climate mitigation and adaptation and along with justice.

Future work should refine expenditure pathways, strengthen long-term decoupling strategies, and further examine the conditions under which the benefits of transition can be more widely shared. The central message is therefore that South Africa's net-zero future is most plausible, and most desirable, when pursued not as a narrow technical end-state, but as part of a broader and explicitly just transformation of the country's development pathway.

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Annex 1 – Indicator framework

Table 14: Reporting indicator framework for Tier 1 (which primarily addresses the triple challenge and economic growth).

Tier	Develop-ment Narrative	Outcome indicator(s)		
		Proposed indicator	DFFE comments / suggestions	Team response
Tier 1	Holistic	Poverty	Poverty definition should be based on STATSA definition: Source: Living Condition Survey: https://www.statssa.gov.za/?p=12075	We propose to use "PROPORTION OF POPULATION BELOW NATIONAL POVERTY LINE" as defined by the world bank. However, we have additionally added a poverty indicator as defined by StatsSA to measure poverty relative to the Lower Bound Poverty (LBPL).
		Unemploy-ment		We have added 'employment to adult population ratio' to capture change in employment by gender to the Tier 2 indicators table since it shows the most change between the BAU and holistic scenario out of those 3 variables
		Inequality (Gini coefficient)		We have proposed moving the Gini coefficient up to being a Tier 1 indicator, which then ensures that we have indicators for unemployment, poverty, and inequality (covering all 3 parts of the Triple Challenge - while the Gini is by no means perfect, it is a globally recognised measure of inequality).
		GDP growth rate		
		Human Development Index (HDI)*		
		-	Burden of Disease (non-communicable disease)	We don't have this indicator, but we can use "PREMATURE NON-COMMUNICABLE DISEASE MORTALITY" as a proxy
* The Human Development Index (HDI) is a composite metric defined by UNDP to measure countries' achievements in terms of health (life expectancy), education (schooling years), and standard of living (income per capita).				

Table 15: Reporting indicator framework for Tier 2, which reflects outcomes based on the development narratives and broader sustainable development goals.

Tier	Develop-ment Narrative	Outcome indicator(s)		
		Proposed indicator	**DFFE comments / suggestions**	**Team response**
Tier 2	Holistic + electricity	Total CO2 emissions		
	Electricity	Proportion of population with access to electricity		
		Air quality – pm2.5 emissions		
		Renewable energy share in the total final energy consumption	Reword to "Non-GHG emitting technology share in the total final energy consumption" (both renewables and nuclear have to be included)	We have created this indicator, as the components are included in the model.
	Food	Prevalence of undernourishment		
		Proportion of agricultural area under productive and sustainable agriculture		
	Human Settlements	Proportion of population in informal housing		
	Land Use	Terrestrial and Forest land effectively protected		
	Transport	Transportation infrastructure per thousand people Relative transportation use intensity	Replace with "PASSENGER KMS TRAVELLED BY RAIL, BUS, PRIVATE CAR"	Included
			Kms rail infrastructure	Included
			% of disposable income spent on transport	We do not have this data, so we cannot include this indicator at this point
			Accidents/deaths on transport	We propose to use "TOTAL ROAD FATALITIES" as a proxy

Tier	Develop-ment Narrative	Outcome indicator(s)		
		Proposed indicator	**DFFE comments / suggestions**	**Team response**
	Water and Sanitation	Proportion of population with access to safe water		
		Proportion of population with access to safe sanitation		
	Production & Consumption	Material footprint (MF) and MF per capita, per GDP		
			GDP from Green Industry	We don't have Green Industry in the default model, so we can't include this indicator at this point
		Domestic material consumption (DMC) and DMC per capita, per GDP		
		-	Waste per capita	Included
		-	% of waste recycled	we don't have this data, so we propose to use "% OF URBAN WASTE COLLECTED AND DISPOSED"

Table 16: Additional cross-cutting indicators suggested by DFFE to the project team, along with the team's associated responses.

Tier	Cross-cutting theme	Outcome indicator(s)		
		Proposed indicator	**DFFE comments / suggestions**	**Team response**
Tier 2	Safety and Security	-	Number of victims of intentional homicide per 100,000 population, by sex and age	We don't have this data as such, but we can use "VIOLENT DEATH BY GENDER AND AGE"
	Education	-	Percentage of population in a given age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex	We propose to use the "SHARE OF ADULT POPULATION HAVING COMPLETED AT LEAST PRIMARY SCHOOL" as a proxy
		-	Education participation rate	We propose to use 'EDUCATION ENROLLMENT BY EDUCATION LEVEL AND GENDER' as a proxy.
		-	% of students in STEM	We don't have this data and therefore cannot include this indicator at this point

Tier	Cross-cutting theme	Outcome indicator(s)		
		Proposed indicator	**DFFE comments / suggestions**	**Team response**
	Other		Youth Unemployment Rate (see https://www.statssa.gov.za/?p=18398)	Including this indicator requires some time-consuming modelling work, hence we propose to use instead "SHARE OF YOUTH NOT IN EDUCATION EMPLOYMENT OR TRAINING" as a proxy.
	Gender		Comment from WRI: Any other indicators that can be disaggregated by gender? This would be helpful since the narratives included significant economic progress for women and I'm concerned that won't be fully captured here with this set of indicators.	We have included the employment indicator as mentioned above, in addition to 'total deaths by violence[gender]' and 'tertiary gross enrollment rate by gender' since these showed more change relative to other gender related indicators. These are added to Tier 2 indicators

Annex 2 – Synergy Tables

Table 17 and Table 18 indicate the performance of the Tier indicators for each scenario relative to the BAU performance. In other words, each development scenario measures the change in indicator performance if that scenario was run in isolation (and not together as in the case of the holistic scenario). Note the synergy analysis was only conducted for 2050.

Table 17: Tier 1 indicator performance in % change between each scenario and the BAU for 2050. Fds = food system; Ele = electricity; Trt = transport; Was = water and sanitation; PrC = production and consumption; HuS = human settlements; and Lnd = Land use.

Variable	Holistic	Fds	Ele	Trt	Was	PrC	HuS	Lnd
LBPL	-9.97	-1.61	-5.14	-1.61	-0.32	-0.64	-0.64	-0.32
unemployment	-3.98	-1.24	-1.49	-0.5	0	-0.25	-0.25	-0.25
Gini	-0.94	-0.47	-0.16	-0.16	0	-0.16	0	-0.16
GDP growth	25	3.57	14.29	3.57	0	0	0	0
HDI	2.76	0.79	1.05	0.39	0.26	0.26	0.13	0.13
disease mortality	-13.87	-5.84	-5.11	-1.46	-0.73	-0.73	-0.73	-0.73
employment ratio F	3.68	1.34	1.34	0.67	0.33	0.33	0.33	0.33
employment ratio M	3.71	1.33	1.33	0.53	0	0.27	0.27	0.27

Table 18: Tier 2 indicator performance in % change between each scenario and the BAU for 2050.

Variable	Holistic	Fds	Ele	Trt	Was	PrC	HuS	Lnd
CO2 emissions	-18.5	1.08	0.69	0.66	0.22	0.23	0.04	0.27
ele access	6.35	0.11	6.46	0.11	0	0.22	0.11	0
pm 25	-13.81	0.63	-0.01	0.5	0.17	0.03	0.03	2.25
elec from non GHG	71.7	0.42	46.96	0.42	0.21	-7.97	-0.21	0.21
undernourishment	-21.59	-17.61	-2.33	-0.66	0	-0.33	-0.33	-0.33
sustainable agr land	33233.33	33233.33	0	0	0	0	0	0
informal housing %	-41.76	-0.59	-1.76	-0.59	-43.82	-0.29	-0.29	-0.29
land protection	2.46	-0.53	2.15	0.38	-0.04	0.27	0.27	0.14
mobility rail	4.02	0.6	2.73	0.44	0.12	0.31	0.05	0.02
mobility public road	6.73	1.73	2.26	1.37	0.32	0.46	0.44	0.27
mobility private road	3.08	1.09	0.58	0.83	0.2	0.16	0.21	0.13
rail infra	6.63	0.08	0.17	5.84	0.03	0.07	0.02	0.01
road fatalities	16.22	3.02	7.26	2.96	0.6	1.21	1	0.59
water access rural	76.37	3.35	7.23	2.65	57.67	1.41	1.06	0.71
water access urban	0	0	0	0	0	0	0	0
sanitation access rural	38.12	2.76	5.94	2.21	38.12	1.24	0.97	0.69
sanitation access urban	51.52	0.3	0.91	0.3	51.52	0.15	0.15	0.15
material footprint	-2.04	1.18	1.79	0.71	0.23	0.34	0.21	0.19
pc material footprint	-3.08	0.54	1.56	0.65	0.13	0.3	0.18	0.17
market material footprint	-16.15	-1.66	-5.59	-1.86	-0.21	-0.83	-0.62	-0.21
domestic material consump	18.42	18.89	3.43	1.24	0.32	0.46	0.25	0.52
pc domestic material consump	17.16	18.12	3.2	1.16	0.21	0.4	0.22	0.5

Variable	Holistic	Fds	Ele	Trt	Was	PrC	HuS	Lnd
market domestic material consump	1.25	15.24	-4.18	-1.46	-0.42	-0.84	-0.84	-0.21
pc waste generation	0.65	0.19	0.37	0.19	0.09	0.09	0.09	0.09
waste collection urban	998.9	2.2	6.59	2.2	0	998.9	0	0
youth NEET	-11.11	-3.7	-4.04	-1.35	-0.34	-0.67	-0.67	-0.34
gender violence F	-11.45	-4.67	-4.44	-1.58	0	-0.76	-0.63	-0.36
gender violence M	-12.96	-5.35	-4.92	-1.76	-0.18	-0.85	-0.7	-0.41
tertiary enrollment F	10.23	1.32	3.63	1.98	0.33	2.31	0.66	0.33
tertiary enrollment M	10.53	1.46	3.8	2.05	0.29	2.63	0.58	0.29

Table 19 and Table 20 indicate the synergy results for the Tier 1 and 2 indicators in 2050, respectively (i.e. the difference between the sum of the intervention scenarios relative to the holistic difference). This involved subtracting the performance across the system scenarios from the holistic performance. A positive synergy therefore means that the holistic scenario performs better than the sum of the performance across the individual system scenarios (i.e. reinforcing interactions), whereas a negative synergy means that the indicator performs worse under the holistic scenario compared to the sum of scenarios, commonly due to existing trade-offs or diminishing returns.

Table 19: Tier 1 synergy results for 2050.

Variable	Holistic Difference	Intervention Difference	Synergy
LBPL	-9.97	-10.28	0.31
unemployment	-3.98	-3.98	0
Gini	-0.94	-1.11	0.17
GDP growth	25	21.43	3.57
HDI	2.76	3.01	-0.25
disease mortality	-13.87	-15.33	1.46
employment ratio F	3.68	4.67	-0.99
employment ratio M	3.71	4	-0.29

Table 20: Tier 2 Synergy results for 2050.

Variable	Holistic Difference	Intervention Difference	Synergy
CO2 emissions	-18.5	3.19	-21.69
ele access	6.35	7.01	-0.66
pm 25	-13.81	3.6	-17.41
elec from non GHG	71.7	40.04	31.66
undernourishment	-21.59	-21.59	0
sustainable agr land	33233.33	33233.33	0
informal housing %	-41.76	-47.63	5.87
land protection	2.46	2.64	-0.18
mobility rail	4.02	4.27	-0.25
mobility public road	6.73	6.85	-0.12
mobility private road	3.08	3.2	-0.12

Variable	Holistic Difference	Intervention Difference	Synergy
rail infra	6.63	6.22	0.41
road fatalities	16.22	16.64	-0.42
water access rural	76.37	74.08	2.29
water access urban	0	0	0
sanitation access rural	38.12	51.93	-13.81
sanitation access urban	51.52	53.48	-1.96
material footprint	-2.04	4.65	-6.69
pc material footprint	-3.08	3.53	-6.61
market material footprint	-16.15	-10.98	-5.17
domestic material consump	18.42	25.11	-6.69
pc domestic material consump	17.16	23.81	-6.65
market domestic material consump	1.25	7.29	-6.04
pc waste generation	0.65	1.11	-0.46
waste collection urban	998.9	1009.89	-10.99
youth NEET	-11.11	-11.11	1.78E-15
gender violence F	-11.45	-12.44	0.99
gender violence M	-12.96	-14.17	1.21
tertiary enrollment F	10.23	10.56	-0.33
tertiary enrollment M	10.53	11.1	-0.57

Annex 3 – Final Stakeholder Engagement Q&A

A virtual stakeholder engagement session was held as follows:
Date: 29th April 2026
Time: 09h00 – 12h00
Platform: Microsoft Teams

More than 70 participants joined online, with 45 individuals signing the attendance register. Signed attendants included representatives from:

- other national government departments,
- provincial and local government departments and agencies,
- universities and research institutes,
- companies and sector associations and councils, and
- civil society organisations.

Q.1. The model excludes a lot of current dynamics relative to the global context. For e.g., we're seeing [an] energy crisis in terms of fossil fuel production. How is that accommodated in the model? A second one is international trade, where there is strong development in sustainable products. A third element is innovation. It's related, obviously, to education and higher education, but it extends so much further into development of SMMEs and startups and so on, [and] that does not seem to be accommodated.

Response: The iSD model is not configured to answer every current socioeconomic question. The questions that are answered and addressed were those relative to the study context and model boundary. Models continuously have to be updated to keep up with current dynamics and incorporate global shocks. Having said that, the first question was how is it dealing, for example, with the current fossil fuel crisis? No, it does not deal with this because this is a complete external shock. That is something that can't be projected going forward. So, in this case, no, it excludes this kind of assumption. If you wanted to include this kind of assumption in the future, you'd specifically have to insert this as a shock into your future assumptions to see the impacts it would have on the different indicators. And then secondly, yes, similarly in terms of international trade, in terms of innovation, yes, so it includes aspects of innovation, specifically in terms of efficiency, household efficiency, industry efficiency, vehicle efficiency in transport wise. But generally, of course, there's various innovative solutions that are not implemented, because innovative solutions can range from a small-scale solution relative to what's being implemented at a national scale. And our innovative interventions are what is budgeted and implemented on innovation at a national scale. SMEs and startup dynamics are excluded and that is generally an area that would be an area for improvement in the model.

Q.2. Does the model assume that social and ecological pressures increase? And governance and policy responses also adapt and stabilize the system. What I'm trying to understand is how does a model account for risk that essentially that these pressures actually overwhelm governance capacity and then in turn weakening responses and reinforcing instability rather than correcting it. So to kind of reinforce the previous question, how does the model remain as sort of like a complex adaptive system to sort of consider those feedback loops, particularly in terms of governance?

Response: How does the model consider the reinforcing impacts of the socioeconomic pressures on the government capacity? And that's a very good question. Because essentially, how the government simulates the government system is through its budgets. So, we have, for example, our expenditure budget, we have our sources of revenue relative to the expenses. And of course, then we have our deficits. So of course, we cannot continue to keep spending relative to what the government can afford because they'll just increase the debt and the deficits. And this is linked because there is an extent to which the government cannot implement more of these interventions. So, in this case now, we are assuming that this expenditure is additional to government expenditure and that, you know, the financing assumptions was that only 14% is coming from the public and 86% of private. So it's assuming and reliant on private investments in this case. Different assumptions can be tested in this case. However, the government's capacity to implement this is governed then in the model by the budget that it has available to implement these changes.

Q.3. Is the data publicly available?

Response: The data file itself is not publicly available. However, the model results and data can be visualized through the use of the model interface.

Q.4. You mentioned SDGs. Do you also mention national indicators?

Response: Yes, we do include various national indicators relevant to the National Development Plan and other government planning frameworks, including the triple challenge indicators.

Q.5: Which SSP scenario was used?

Response: SSP 2-4.5 – The 'middle of the road' scenario – the SSP data is exogenously fed into the model.

Q.6. Do you explicitly model finance as distinct from economic costs?

Response: Yes, the source of the additional budget financing is included. Financing assumptions in the Holistic scenario assume that the additional funding constitutes 86% from the private sector, primarily through Foreign Direct Investment (FDI), and 14% public deficit financing.

Financing plans, such as that of the Just Energy Transition, were considered and helped informed the assumptions in the model. Climate finance, is obviously a very big domain in all sorts of different directions, is one of the areas that is quite limited in the model, but we hope in the future could be improved and could then account for some of the different forms of finance that are required to further kind of decarbonize the economy, and particularly to kind of push it. pace of decarbonisation.

Q.7. Do emissions reflect the national CO2 emissions?

Response: Yes – not 100% mapped to the NDC greenhouse gas inventory though, there are slight discrepancies, but yes national scale emissions are captured in the model

Q.8. Was a basic income grant considered?

Response: Social transfers are included as an intervention, which does impact household income. The model does not experiment with a universal basic income policy; this is excluded at this point.

Q.9. Please elaborate on the results behind the NEET indicator? In reality, the government has extremely high expenditure on education, but we are not seeing this progress [in terms of results].

Response: NEET is shown to decrease in the model. The model does include a governance index which effects the effectiveness of policy expenditure and efficiency of expenditure, though it is limited to the extent that it may not capture national issues such as the misappropriation of funds.

Q.10. Does the model consider mining?
Response: Yes, the model does include aggregate mining dynamics, includes metals and material consumption. It doesn't specifically implement, pressures to decrease mining, but different GDP growth scenarios effect the drivers and have an impact on mining.

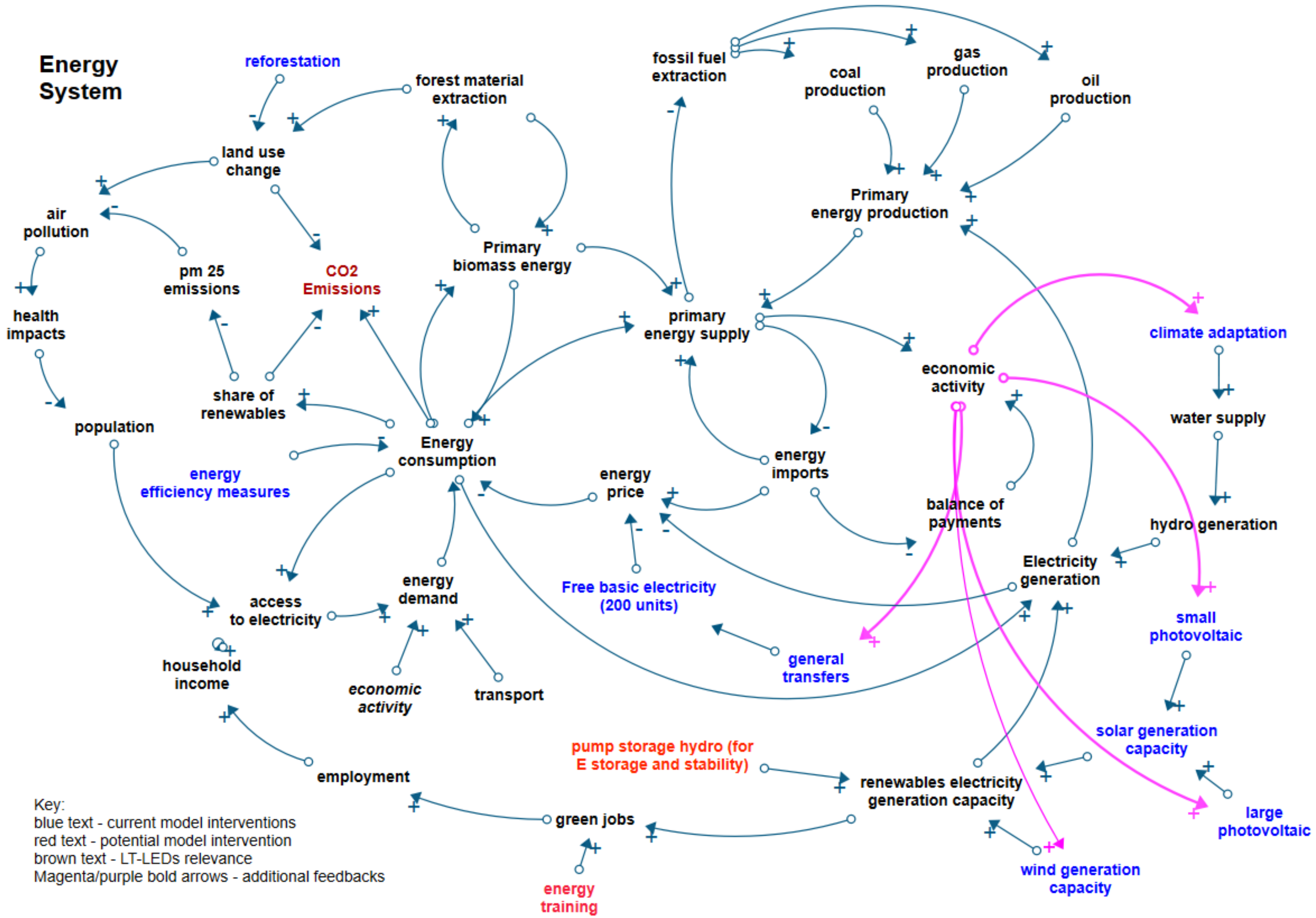
Q.11. Have we considered Johan Fourie's work on inequality?
Response: No, we are not familiar with this work, but we will take note of this for future possible inclusion.

Q.12. Does electricity access indicator factor in affordability?
Response: Yes. Access to electricity is affected by affordability, household affordability to electricity because electricity costs are formulated in the model.

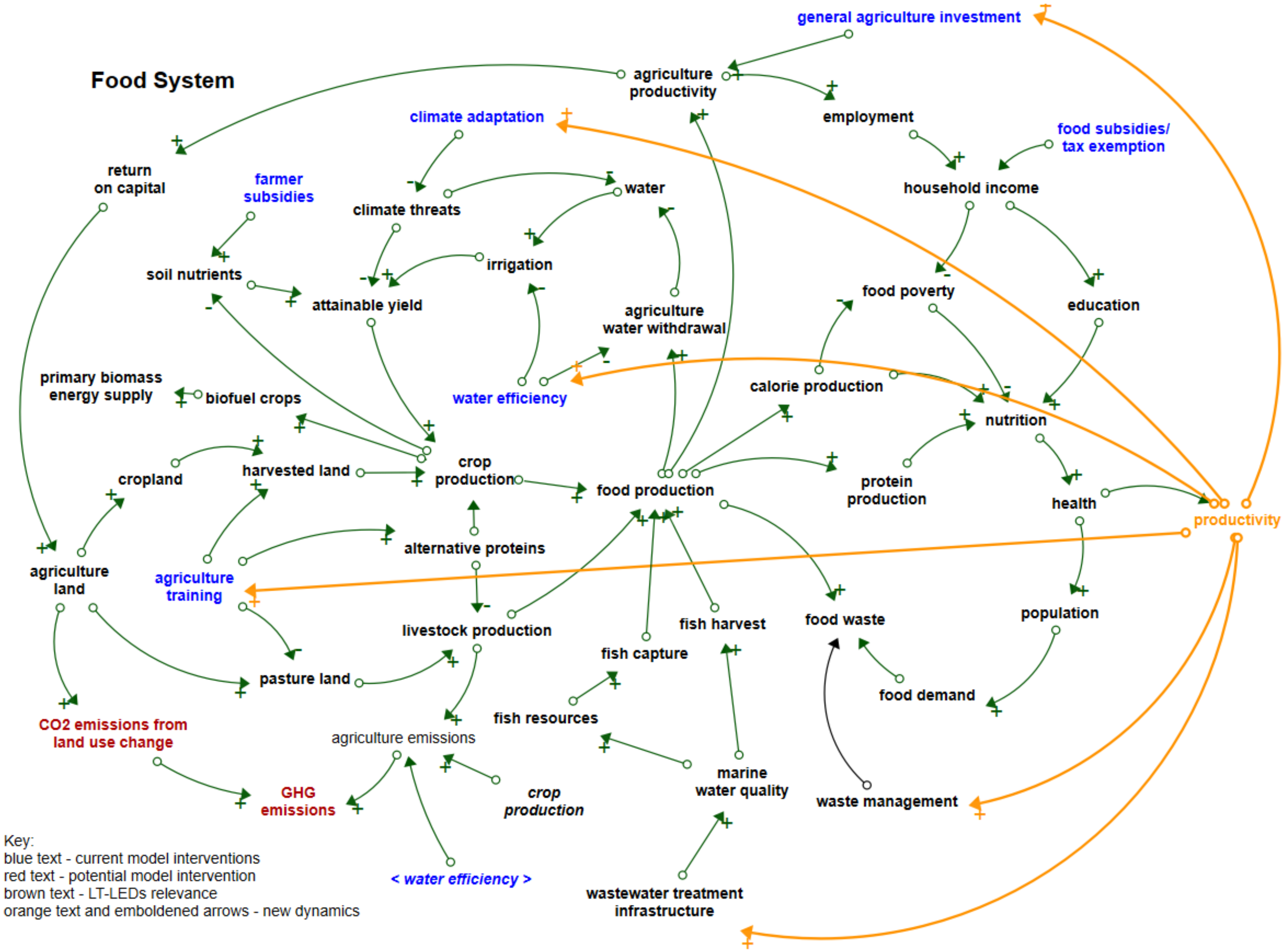
Q.13. What was the period of investment in the model?
Response: The additional expenditure implementation period if 2025-2050.

Q.14. Is this the full extent of this work or are they still going to be doing anything further with what they've produced to date?
Response: Our scope of work was to perform the system dynamics analysis. So, from system dynamics lens, looking at the causal relationships and effects between all the different sectors and indicators, and testing the outcomes with respect to the different development pathways. So, the work falls within this boundary, however, outcomes, assumptions and underlying data is also intended to inform the follow-up socioeconomic modelling. The studies should ultimately complement each other across to support the broader LT-LEDS process.

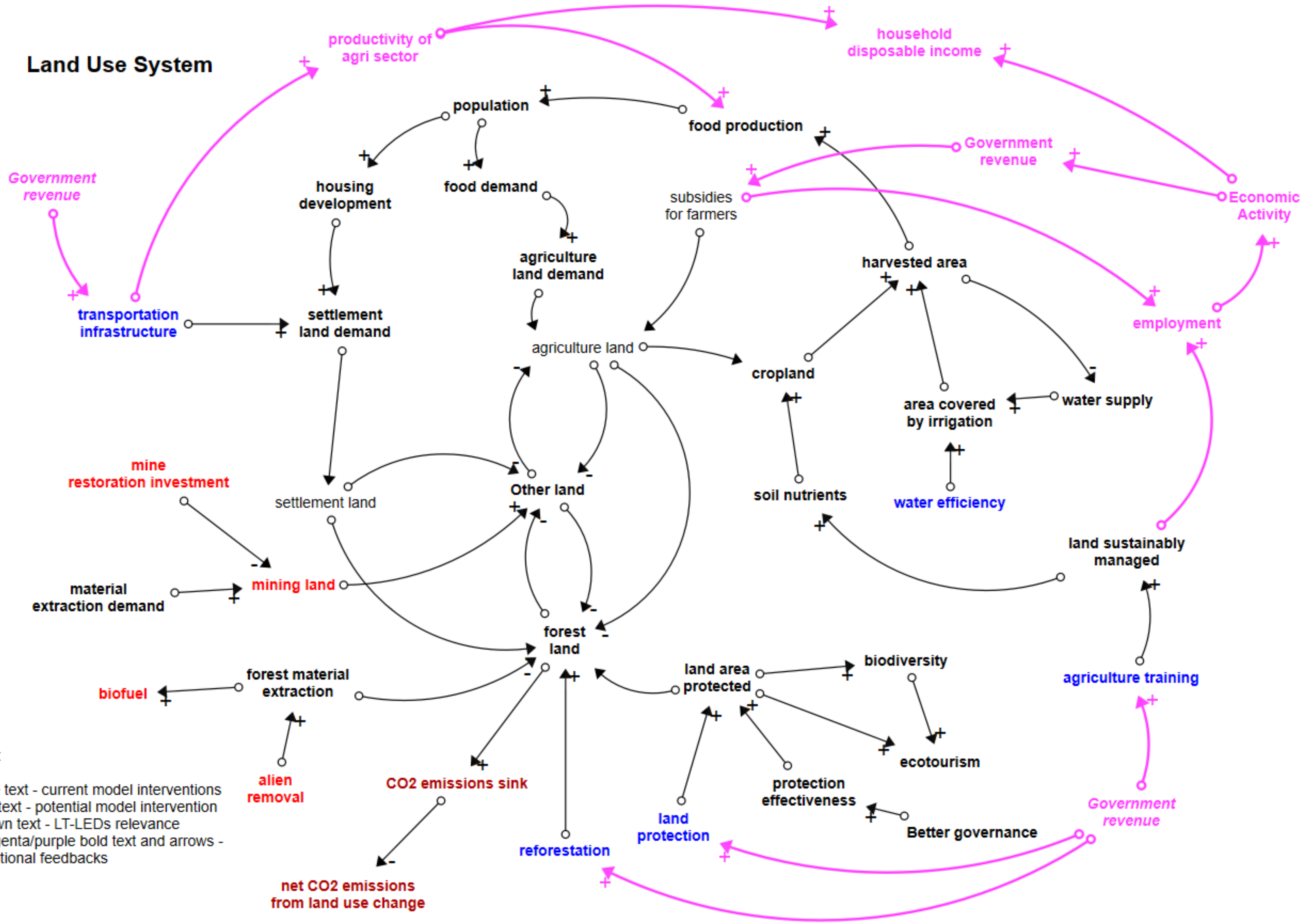
Annex 4 – Sector/pathway CLDs



Key:
blue text - current model interventions
red text - potential model intervention
brown text - LT-LEDs relevance
Magenta/purple bold arrows - additional feedbacks

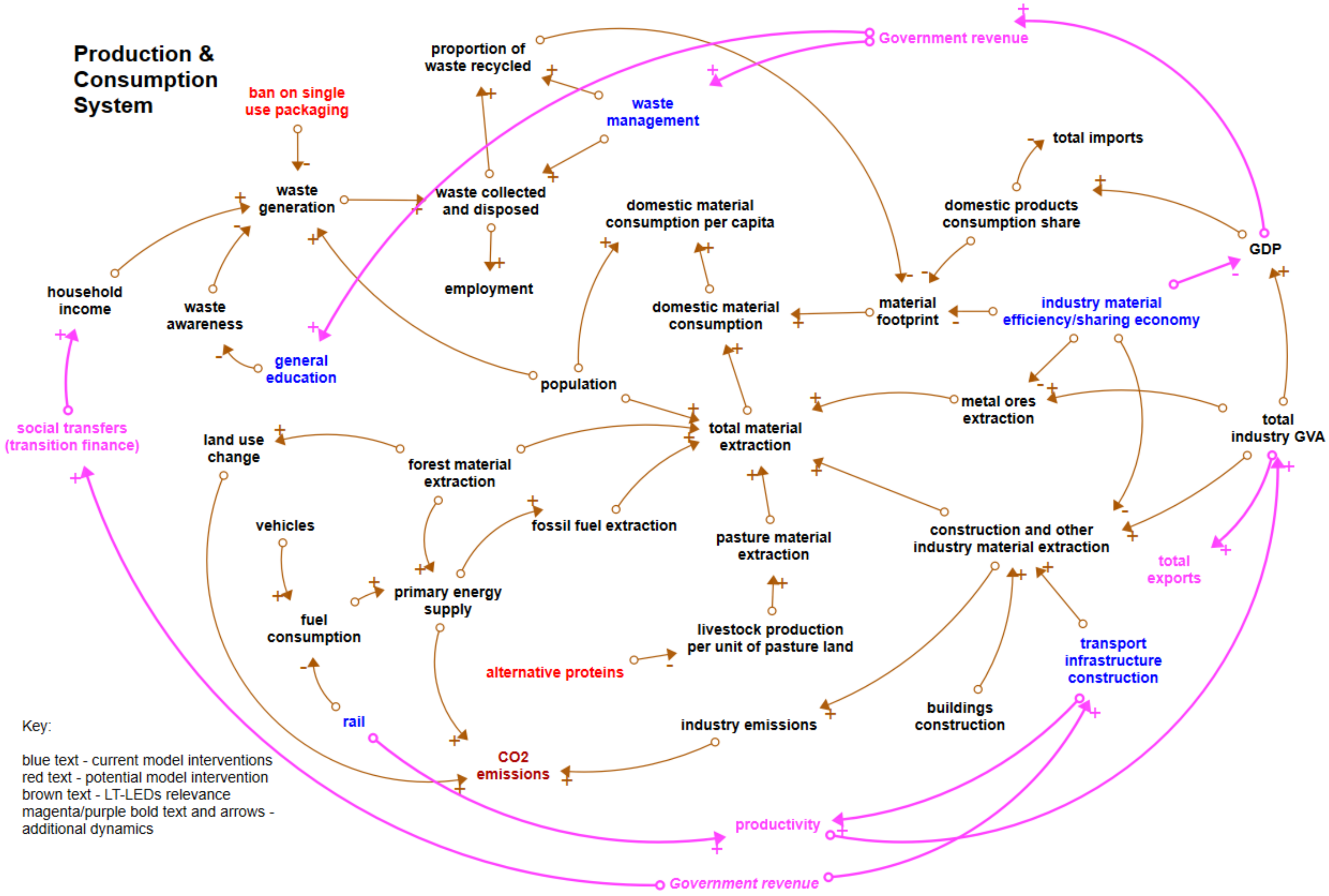


Food System
general agriculture investment
agriculture productivity
employment
climate adaptation
food subsidies/ tax exemption
household income
return on capital
farmer subsidies
climate threats
water
soil nutrients
irrigation
attainable yield
agriculture water withdrawal
food poverty
education
primary biomass energy supply
biofuel crops
water efficiency
calorie production
nutrition
cropland
harvested land
crop production
food production
protein production
health
productivity
alternative proteins
agriculture land
agriculture training
livestock production
fish harvest
food waste
population
fish capture
pasture land
food demand
fish resources
CO2 emissions from land use change
agriculture emissions
marine water quality
GHG emissions
crop production
waste management
< water efficiency >
wastewater treatment infrastructure
Key:
blue text - current model interventions
red text - potential model intervention
brown text - LT-LEDs relevance
orange text and emboldened arrows - new dynamics



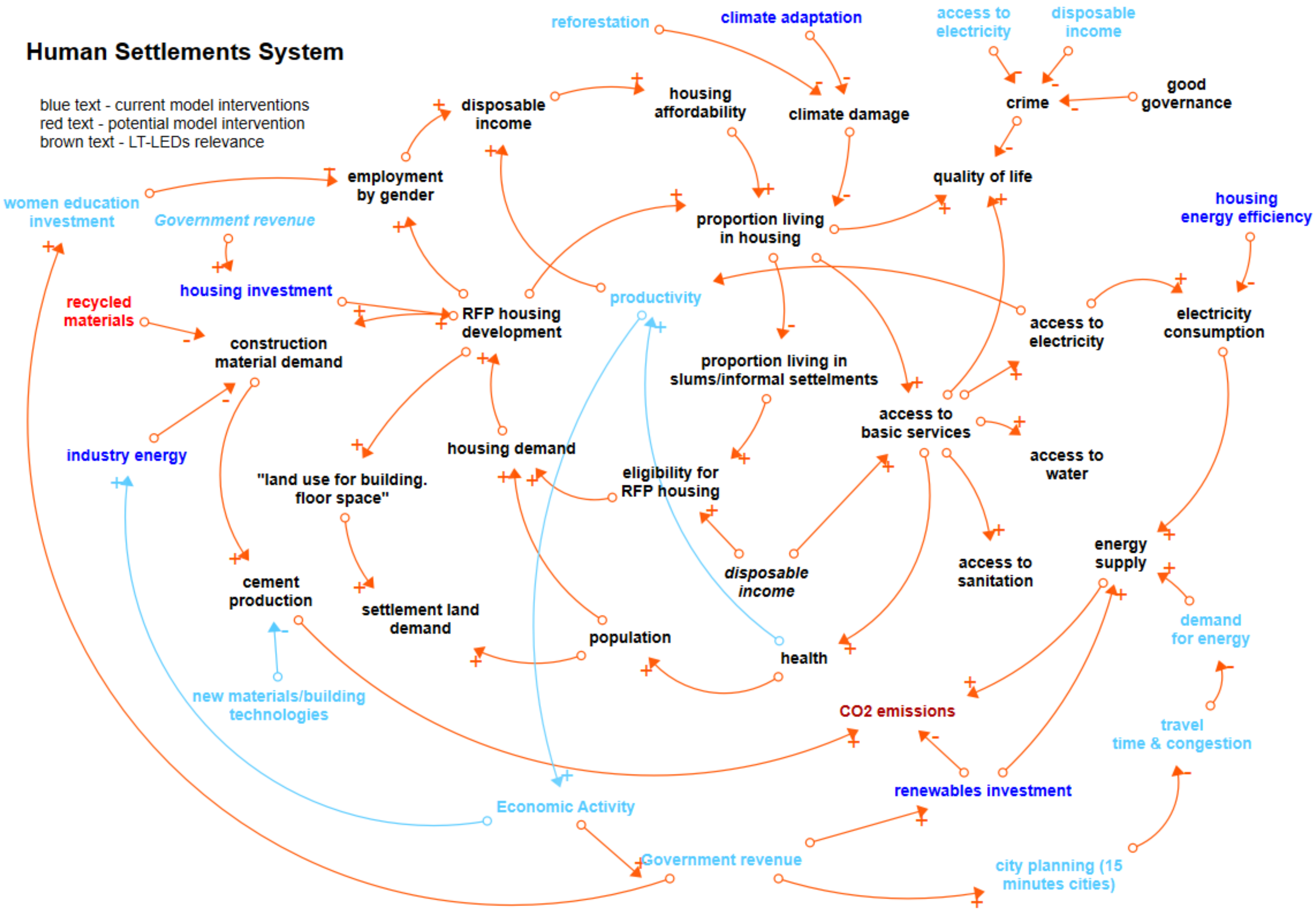
Key:

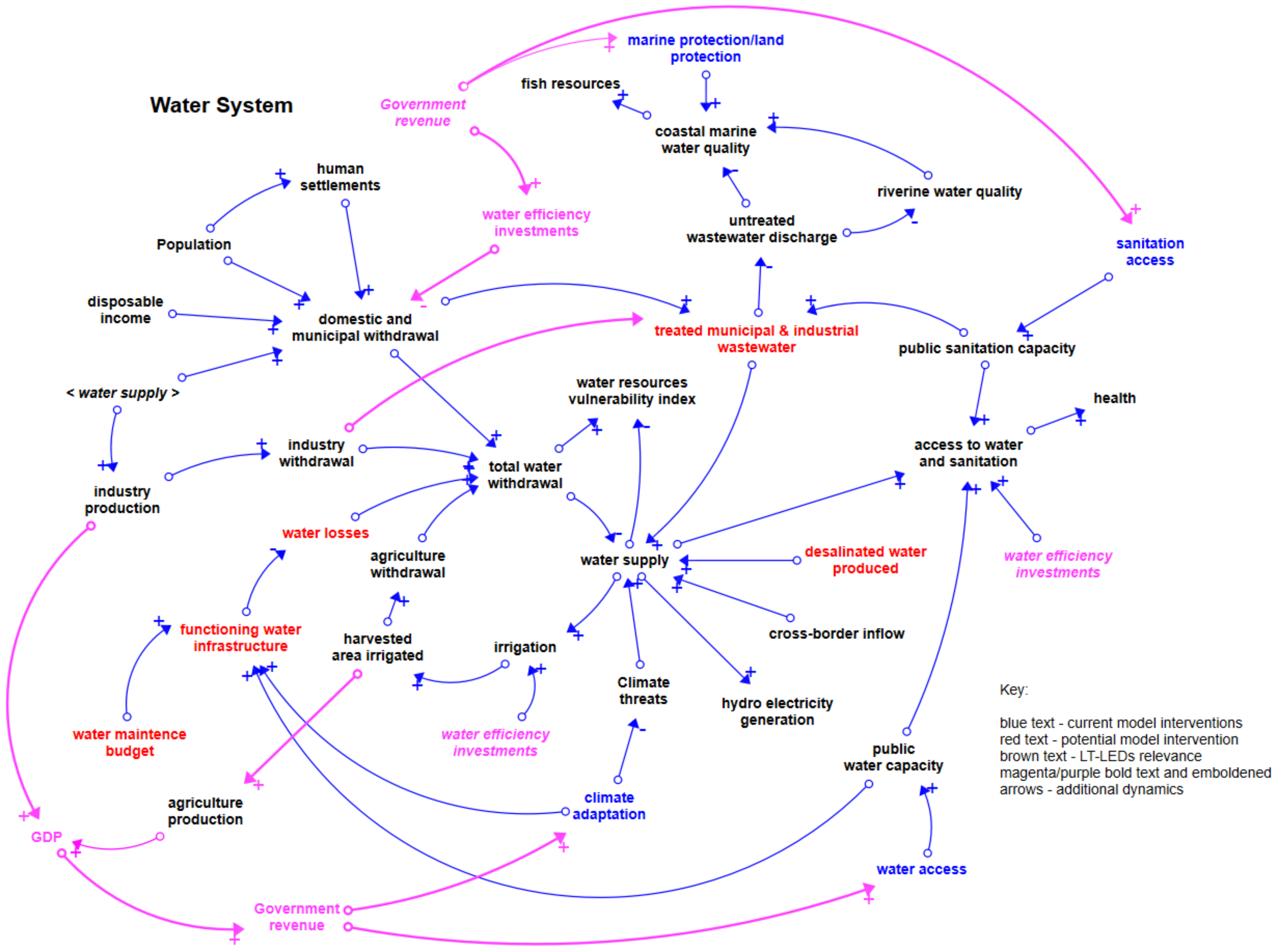
blue text - current model interventions
red text - potential model intervention
brown text - LT-LEDs relevance
magenta/purple bold text and arrows - additional feedbacks

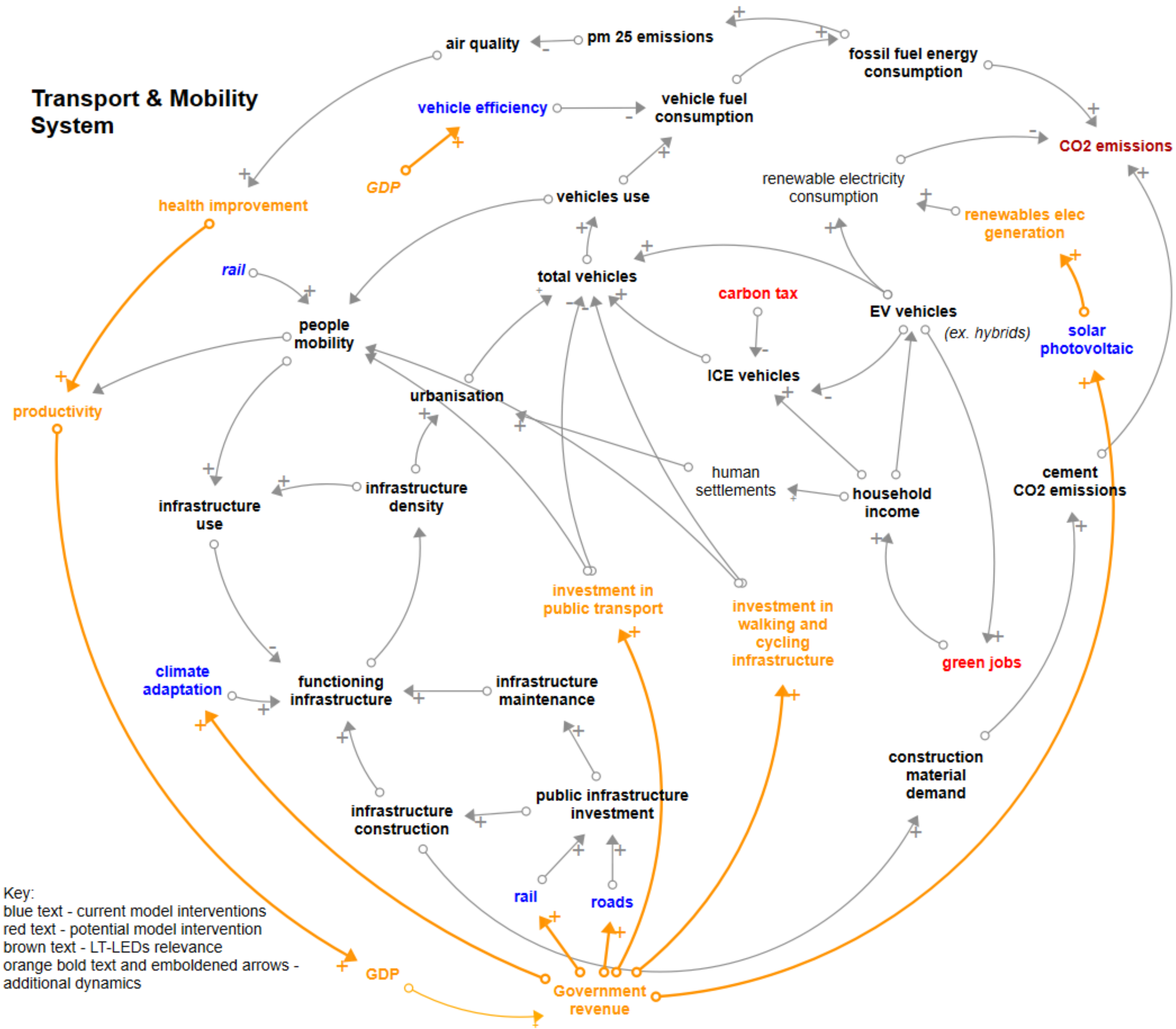


Key:

blue text - current model interventions
red text - potential model intervention
brown text - LT-LEDs relevance
magenta/purple bold text and arrows - additional dynamics


Human Settlements System
blue text - current model interventions
red text - potential model intervention
brown text - LT-LEDs relevance
reforestation
climate adaptation
access to electricity
disposable income
housing affordability
climate damage
crime
good governance
disposable income
employment by gender
quality of life
women education investment
Government revenue
proportion living in housing
housing energy efficiency
housing investment
recycled materials
RFP housing development
productivity
access to electricity
electricity consumption
construction material demand
proportion living in slums/informal settlements
access to basic services
industry energy
housing demand
access to water
"land use for building. floor space"
eligibility for RFP housing
energy supply
cement production
disposable income
access to sanitation
settlement land demand
demand for energy
population
health
new materials/building technologies
CO2 emissions
travel time & congestion
renewables investment
Economic Activity
Government revenue
city planning (15 minutes cities)


Water System
Government revenue
marine protection/land protection
fish resources
coastal marine water quality
riverine water quality
untreated wastewater discharge
sanitation access
human settlements
Population
water efficiency investments
disposable income
domestic and municipal withdrawal
treated municipal & industrial wastewater
public sanitation capacity
< water supply >
water resources vulnerability index
health
industry withdrawal
total water withdrawal
access to water and sanitation
industry production
water losses
agriculture withdrawal
water supply
desalinated water produced
water efficiency investments
functioning water infrastructure
harvested area irrigated
irrigation
cross-border inflow
water maintence budget
water efficiency investments
Climate threats
hydro electricity generation
public water capacity
agriculture production
climate adaptation
GDP
water access
Government revenue
Key:
blue text - current model interventions
red text - potential model intervention
brown text - LT-LEDs relevance
magenta/purple bold text and emboldened arrows - additional dynamics


Transport & Mobility System
air quality
pm 25 emissions
fossil fuel energy consumption
vehicle efficiency
vehicle fuel consumption
CO2 emissions
GDP
health improvement
vehicles use
renewable electricity consumption
renewables elec generation
rail
total vehicles
carbon tax
EV vehicles
(ex. hybrids)
solar photovoltaic
people mobility
ICE vehicles
productivity
urbanisation
human settlements
household income
cement CO2 emissions
infrastructure use
infrastructure density
investment in public transport
investment in walking and cycling infrastructure
green jobs
climate adaptation
functioning infrastructure
infrastructure maintenance
construction material demand
infrastructure construction
public infrastructure investment
rail
roads
GDP
Government revenue
Key:
blue text - current model interventions
red text - potential model intervention
brown text - LT-LEDs relevance
orange bold text and emboldened arrows - additional dynamics