Macroeconomic Modeling

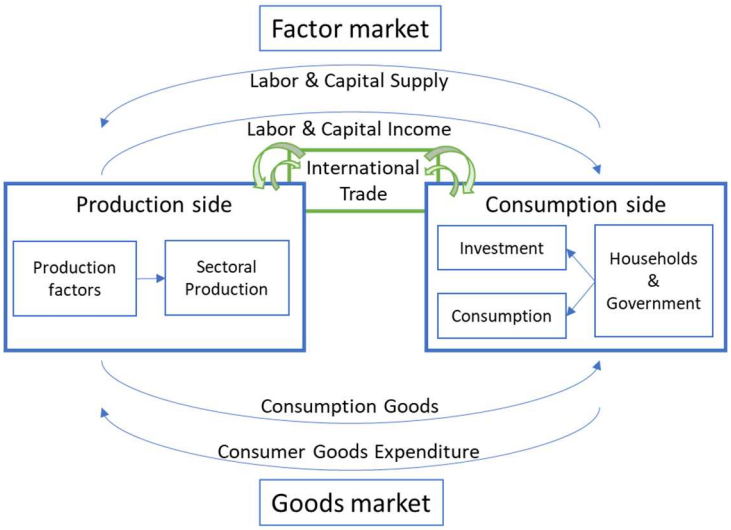
In order to analyze the macroeconomic effects of building up a hydrogen economy in Namibia, the Computable General Equilibrium (CGE) model NEWAGE-Namibia is applied. In the following, the CGE modeling approach, the NEWAGE-Namibia model and the scenarios defined for the modeling exercise are described.

CGE models

A **Computabel General Equilibrium (CGE)** [3] model is solved numerically (= computable), captures the whole economy (= general) and iterates for its solution until the macroeconomy is balanced (= equilibrium). CGE models are a powerful tool to analyze the potential impacts of policies or external shocks on an economy. Noteworthy, a CGE model allows to evaluate **net effects** due to the inclusion of indirect effects (e.g. feedback and rebound effects). They capture interdependencies between different sectors and regions and enable concrete welfare analysis for real policy making.

In CGE models[4] the economy is depicted as a **closed income cycle**:

On the **production side** companies use production factors such as capital, labor and raw materials for sectoral production. On the **consumption side** households and government can spend their income on either consumption or investment.

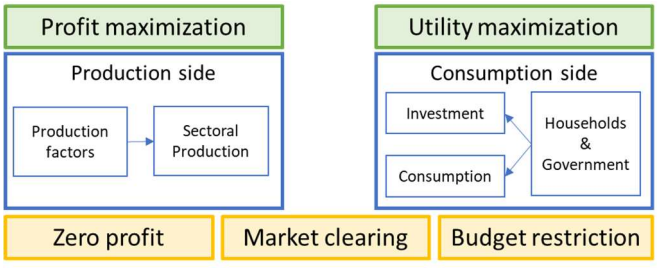


Production factors are traded in the **factor market**, where households offer their labor and capital supply and earn income in return. Similarly, the produced goods are traded in the **goods market**, where consumers spend their income and receive consumption goods in return.

In a multi-regional model **international trade** is taken into account as well. Consequently, foreign commodities can be imported to the domestic market for production or consumption, while domestic commodities can be exported to foreign markets.

For different economic agents, different **behavioral rules** apply (green boxes): While firms maximize their profits, consumers maximize their utility in form of consumption.

Additionally, for finding the equilibrium, a set of **equilibrium conditions** are defined and must be jointly satisfied (yellow boxes):



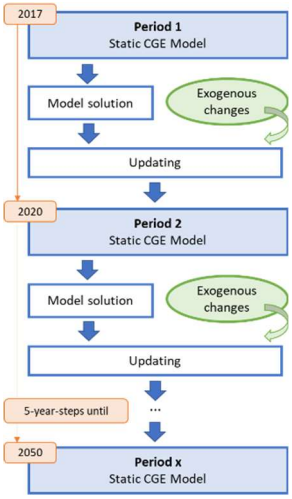
[3] This report only provides a rough overview of CGE modeling. For a more detailed introduction, see e.g. „Introduction to Computable General Equilibrium Models“ by Burfisher (2011).

[4] For more detailed information on CGE theory and modeling see e.g. Beestermöller (2017), Zürn (2010), Sue Wing (2001).

First, perfect competition among firms is assumed and, hence, the **zero profit** condition holds. Second, consumers cannot violate the **budget restriction**, meaning only available income can be spent on consumption. Third, in equilibrium all markets have to clear (**market clearing**), there can neither be excess supply, nor excess demand. However, it is possible to model exceptions to these standard assumptions, for example, unemployment which violates the assumption of labor market clearing.

The mathematical framework applied to represent the equilibrium conditions and behavioral rules and find the model solution is called **Mixed Complementarity Problem** (MCP). A MCP is a system of equalities and inequalities that need to hold simultaneously.

As stated above, the model iterates until all equilibrium conditions are fulfilled and the economy is balanced. So far, a static equilibrium, considering only one specific point in time (the model base year, e.g. 2017), was defined. To capture inter-temporal effects, the model needs to have a dynamic component, as well. This is achieved through **recursive-dynamics**. In a recursive-dynamic model a series of static equilibria is solved. Each subsequent equilibriums base data is built from the preceding model solution. This creates a chain of interrelated equilibrium solutions over time and enables the modeler to account for feedback effects and intertemporal dynamics. Investment in period 1, for example, directly adds up to capital endowment in period 2. Additionally, exogenous changes of certain parameters over time are considered. The exogenously defined parameters include assumptions on population growth or increases in factor productivity or energy efficiency, among others.

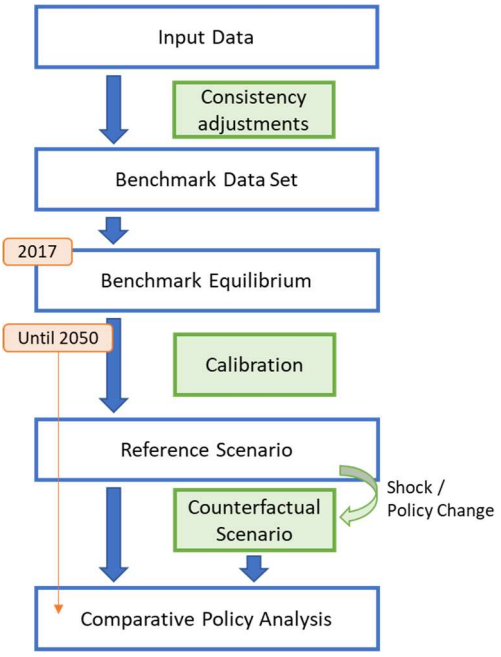


The aim of CGE modeling frequently is to support policy makers in assessing the potential macroeconomic impacts of their political decisions. In order to compare different policy frameworks it is necessary to conduct a scenario analysis. The **scenario modeling process**[5] is shown in the following flow chart:

First, a consistent benchmark data set is constructed from the input data. This includes input-output tables, trade data, labor force dynamics, tax data and elasticities of substitution, among others. From the benchmark data set the base year **benchmark equilibrium** is defined.

Second, the benchmark equilibrium is calibrated to a chosen reference scenario. The **reference scenario** includes assumptions on the regulatory framework until 2050. The calibration process ensures that an equilibrium consistent with the reference scenario is reached.

Third, an **exogenous shock or policy change** is implemented and the model solves for an alternative equilibrium. Subsequently, the reference scenario can be compared with one or several counterfactual scenarios in order to draw conclusions on the expected effects of the shock or policy change.



[5] Adapted from „Applying General Equilibrium“ by Shoven and Whalley (1998), p. 103 – 106.

In principle, a wide range of **policy instruments** can be represented in CGE models:

Policy instrument	Examples
Trade policies	Tariffs, quotas
Tax policies	Tax on income / consumption
Transfer payments	Subsidies
Environmental policies	Carbon tax, cap-and-trade system
Investment policies	Changes in investment incentives

By following these steps, CGE modeling can provide a basis to support political decision-making and can help to develop a better understanding of macroeconomic relations and interactions. The CGE modeling results enable the quantitative **comparison of different policy frameworks** and enable the modeler to identify an optimal desing of policy instruments.

Results typically include the development of different **indicators across the specified scenarios and over the modeled time horizon**. Specifically, the following indicators provide useful insights into the wider economic impact of policies and are therefore frequently reported:

Indicators across regions to quantify effects on international trade and competitiveness.

Indicators across sectors to examine sector-specific impacts and help identify winners and losers within the economy.

Indicators at the macro-economic level to evaluate social and economic welfare.

Depending on the specific model features further variables can be included in the analysis. For example, if the model comprises of some technological components like disaggregated electricity production, the structure of the energy system can be studied.