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INN WATER

Promoting social innovation to renew
multi-level and cross sector water governance

D4.2: Modelling cross-sectoral interactions with water at river basin level

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Related deliverables

This study describes the development of the REWEFE-CGE model (the Reunion Island Water-Energy-Food-Environment (WEFE) nexus Computable General Equilibrium (CGE) model), which is itself part of the deliverable D4.2 and which will be represented on the "InnWater water governance platform" (D4.4, D4.5). As a macroeconomic simulation model, the REWEFE-CGE model will be linked to the microsimulation model developed in the task "Domestic water tariff dashboard" (Task 4.3) and deliverable "Methodology for analysing the socio-economic performance of household water demand management policies" (D4.3).

Furthermore, it can feed into the task "Pilot sites operation" (Task 5.2: Subtask 5.2.1) and thus be linked to the deliverable “Pilot sites implementation report“ (D5.2) by being presented to the local stakeholders. This study also presents options for replicating a WEFE-CGE model in other regions. Thus, D4.2 is also linked to the task “Replication assessment throughout Europe” (Task 6.3 in WP6), and the deliverable “Replication methodology and implementation progress” (D6.4).

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EXECUTIVE SUMMARY

The deliverable entitled **"Modelling cross-sectoral interactions with water at river basin level" (D4.2)** is related to the task “Cross-sector hybrid dashboard and simulation combining economic and physical indicators” (Task 4.2) within the work package “Digital tools for water governance” (WP4). The objective of Task 4.2 is to develop , a prototype of a **Computable General Equilibrium (CGE) model** that simulates the interactions between water uses, energy production and economic activities, and considers addressing the issues related to the environmental impacts of these economic activities. The deliverable entitled “Modelling cross-sectoral interactions with water at river basin level” (D4.2) presents the development of the CGE model and its database, **the Social Accounting Matrix (SAM)**. Furthermore, the text presents **a simulation of academic scenarios, followed by an** analysis of the results thereof. CGE models are macroeconomic analysis tools which allow for the simulation of scenarios. The basis of these models is statistical macroeconomic data and microeconomic theory. CGE models are used to analyse economic and policy scenarios when the **interaction between economic activities, markets and agents** needs to be considered. This deliverable presents the development of the **Reunion Island WEFE nexus CGE model** (REWEFE-CGE model), which considers the four WEFE nexus pillars: W(ater), E(nergy), F(ood) and E(cosystems).

The **Introduction** section provides a concise overview of the research question that forms the basis of this study. It also offers a contextual analysis of the WEFE nexus, water governance, economic activities, and the specific context of Reunion Island as the study region. **Section 01** introduces **the principles of CGE models.** It introduces the methodological framework of CGE modelling in the context of WEFE nexus research. A simplified description of the methodological framework provides a basic overview of the CGE model as a method, allowing for better comprehension of the context of later sections. A literature review shows that CGE models are frequently applied in **WEFE nexus research**. However, CGE studies that consider three or more WEFE nexus pillars are rare. The recently developed **REWEFE-CGE model** is among the first **CGE models to** represent the four WEFE nexus pillars. The literature review also shows that various studies apply the **PEP single-country standard models** to WEFE nexus-related research questions. Thus, the static single-country PEP standard model (**PEP-1-1**) or its dynamic version (PEP-1-t) is a suitable model for developing the REWEFE-CGE model. The literature review analyses the **production function specification** representing water as a production factor.

Section 2 presents data research and processing to extend the SAM as a **database for the WEFE Nexus CGE model**, including economic data, data on water usage and withdrawals, energy consumption, and pollutant emissions. The section describes how to compute **data on the water and sanitary sector, water pollutants, and CO_2 emissions** for environmental satellite accounts oriented towards the System of Environmental-Economic Accounting for Water (SEEA-W).

Section 3 presents the rules for developing the **Social Accounting Matrix (SAM).** It introduces the **basic principles of a SAM** and various approaches to extending a SAM with new items. The section presents a step-by-step procedure for how the WEFE nexus pillars can be included in the SAM and how the **physical emission and water accounts** are linked. Furthermore, it suggests guidelines for how to derive relevant data to construct **a river basin SAM.**

Section 4 presents the **Reunion Island WEFE nexus SAM** (REWEFE-SAM) and the **Reunion Island WEFE nexus CGE model** (REWEFE-CGE). It analyses the SAM using structure tables. **Structure tables** provide information on the shares of values of activities, commodities, agents, and factors

related to the economy and different sectors of the SAM (e.g., the contribution of factors to production). Furthermore, Section 4 presents the **specification of the REWEFE-CGE model** and the **linkage to the SEEA-W accounts**. It also explains the **principles behind the calibration** of the CGE model.

Section 5 presents **five academic scenarios**, their underlying scenario assumptions, and the technical implementation in the model. The academic scenarios are based on **narratives of potential interest for Reunion Island and defined by ad-hoc assumptions of shocks**. The academic scenarios are a **starting point** for the development of **empirically grounded scenarios** to be developed and tested in collaboration with experts, policymakers, and stakeholders (**co-modelling approach**). **Section 6** analyses the scenario results. The results inform about the **model performance** and **demonstrate plausible model reactions**. Thus, the analysis of the academic scenarios contributes, on the one hand, to the validation of the REWEFE-CGE model and, on the other, to the identification of the need to further refine the model prototype. Interpreting the model results illustrates different model reactions and contributes to understanding the CGE model mechanism. The results of the academic scenarios can also feed into **the discussion between researchers, policymakers, and other stakeholders**, e.g., to identify future demand for research.

Section 7 presents how the REWEFE-CGE model can be implemented and presented on the digital platform. The aggregated (macroeconomic) REWEFE-CGE model is linked to a **microeconomic simulation model (MSM)** to analyse the impacts of scenarios at the individual household level. The MSM simulates household responses to economic scenarios in terms of water consumption. The section also proposes how the REWEFE-CGE model results can be described and **visualised by graphs and tables**.

The **conclusion section** reviews the potential usage of the REWEFE-CGE model in research, policy-making, and other stakeholder-related work. It presents current **caveats and outlines solutions** to further develop the model in future work. The presentation of the REWEFE-CGE model contributes to the economic, environmental, and interdisciplinary research. The REWEFE-CGE model can serve as an instrument to **assess WEFE nexus-related research questions** for Reunion Island in a European context. It can feed into **European water governance** policy discussions regarding **the WEFE nexus aspects**. Furthermore, the information provided in the present study can serve researchers **as a guide to develop WEFE nexus CGE models** for other study regions. Thus, the REWEFE-CGE model as a stand-alone model and the study at hand represent a foundation for **future research and policy decision support**.

Within the **project InnWater,** the REWEFE-CGE model fulfils multiple functions. It contributes with model results to the digital platform as **a water government support tool** in the **"InnWater water governance platform" (Task 4.4)**. By interpreting results, the user can understand the **mechanisms between macroeconomic reactions and the WEFE resource nexus**. Linked to the **microsimulation model (MSM)**, the CGE-MSM integration enables complementary analysis at both macro and micro scales. The REWEFE-CGE model considers the whole economy and the **intersectoral linkages as a macroeconomic framework.** The MSM, as a microeconomic analysis framework, simulates and analyses the **behaviour of households, supporting the task "Domestic water tariff dashboard" (Task 4.3)**, and thus, represents socioeconomic aspects. Thus, the linkage between REWEFE-CGE and MSM complements the existing literature, by bringing **a socioeconomic aspect to the WEFE nexus** analysis. The combination of macroeconomic analysis and socioeconomic research focus is, to date, still under-represented in WEFE nexus literature.

Integrated into the digital platform, the linked REWEFE-CGE and MSM support users' **training in analysing water governance scenarios in the task "Pilot sites operation" (Task 5.2: Subtask 5.2.1)**. The extensive pool of information (theoretical base and practical know-how) in this study also supports the task **"Replication assessment throughout Europe" (Task 6.3 in WP 6)** by illustrating how to construct a WEFE nexus CGE model.

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ACRONYMS

%p	percentage points
€ kWh^{-1}	Euros per kilowatt hour
CGE	Computable General Equilibrium
CGE-MSM	Macro-micro model linkage between CGE and microsimulation model
GAMS	General Algebraic Modeling System
GDP	gross domestic product
kWh	kilowatt hours
km	kilometres
M €	million Euros
M m^3	million cubic metres
m^3	cubic metres
MSM	micro simulation model
MWh	megawatt hours
RE	Reunion Island (i.e., the ISO 3166 Alpha 2 code) used in the model name
REU	Reunion Island (i.e., the ISO 3166 Alpha 3 code) used as acronym in the text to refer to Reunion Island as the study region

REWEFE-CGE	Reunion Island WEFE nexus CGE (model) for Reunion Island (RE), also short: REWEFE model
SAM-Omega	Social Accounting Matrix (SAM) for Reunion Island build in the project OMEGA (Outre-mer: Modèles d'équilibre Général Appliqués)
WP	work package

INTRODUCTION

Water is a natural resource that is indispensable to ecosystems, economic activities, and human consumption. To date, the impacts of climate change on water quantity have even reached regions that traditionally have not experienced water scarcity problems (IPCC, 2023). On the one hand, extended periods of low precipitation, or irregular precipitation cause droughts and consequent reduction in the levels of ground and surface water bodies. On the other hand, the high frequency of floods causes the destruction of infrastructure, houses, and land, and water pollution (United Nations, 2024; Guy Carpenter 2024, Toreti et al., 2023). In addition to these natural disasters, intensive economic activities are also causing problems with the supply of clean water. Industries using withdrawn water in large quantities and emit pollutants (e.g., agriculture or chemical industry), while private households consume and pollute water by consumption (European Environment Agency, 2024). Increasing pressure from climate, environment, industry and households creates a competing situation for using clean water. Consequently, there is an increasing need for meticulous water management and governance to ensure a sufficient water supply in both quantity and quality, whilst considering the boundaries of ecological and economic systems (World Bank, 2023a).

Since 2011, researchers, politicians and stakeholders have considered management and governance in the context of the WEFE nexus approach (Hoff, 2011; Pueppke, 2021). The WEFE nexus embodies a holistic approach, taking into account the interrelation between its four pillars of the resource nexus: W(ater), E(energy), F(ood) and E(ecosystems). Sustainable water management and governance require considering both systems' complexity and interlinkages, the natural resource (WEFE nexus) and economic systems (Schlemm et al., 2024). Economic systems include economic activities (industries), commodities, agents (e.g., households) and markets. It is evident that activities and agents utilise natural resources and pollute them via the emissions of pollutants. Computable General Equilibrium (CGE) models are macroeconomic analysis tools which facilitate comprehension of economic systems and their reactions in changed conditions (in scenarios) (Böhringer and Löschel, 2006). CGE models have been developed and applied for more than three decades for economic research on water and, more recently, for economic analysis of WEFE nexus research (Bardazzi and Bosello, 2021). These models facilitate the simulation and evaluation of environmental and economic scenarios, economic policies and investments.

This study presents the development of a CGE model simulating the WEFE nexus pillars for the study region Reunion Island. We call the new model the “REWEFE-CGE model” or shorter: the “REWEFE model”. The REWEFE model considers the four pillars of the WEFE nexus, thus facilitating a holistic, integrated analysis of water management and governance scenarios.

Reunion Island (REU) is a French volcanic island located in the western Indian Ocean, proximate to Madagascar and situated at 2000 km from the mainland (Mozambique). Most of Reunion Island's residencies are located along the narrow coastal strip. A large proportion of economic activities are concentrated in the south-western part of the country, near the harbour and tourism infrastructure. In 2021, 36% of Reunion Island’s population lived below the metropolitan poverty threshold, a significantly higher rate than in mainland France (15%). Furthermore, 19% of the active population is unemployed, a level still far above the national French average (7.3% in 2023) (INSEE, 2024). Reunion Island faces significant challenges for water management and governance within the context of the WEFE nexus. Reunion Island benefits from periodic significant rainfall (November to April) in the tropical climate zone. With an annual rainfall of less than 2000 mm per year, along the west coast even less than 1000 mm, the annual rainfall is significantly lower on the western part than on the eastern part of the island (with more than 3000 to 4000 mm rain per year) (Leroux et al., 2023). In the dryer part, the sugar industry and sugar cane cropping (i.e., the F-pillar) demand a high quantity of irrigation water. Agricultural production and the sugar industry have been identified as significant contributors to the emissions of water pollutants into aquatic ecosystems.

Residencies and industries consume piped water, which is produced by the local water supplier. However, it is estimated that leakage from the distribution infrastructure accounts for approximately 40% of water losses during the process of piped water distribution to the supplier. Investment is required to fix the pipes and reduce the losses. Consumers tend to waste water. The current water pricing system does not incentivise households to save water (Marchal, 2024). Thus, the implementation of a reform in water tariffication in Reunion Island constitutes a water governance measure aimed at reducing waste of water, whilst also addressing the challenge of covering the water distribution costs, without creating undue stress for the island's economically disadvantage population. Besides wasting water, households contribute to the pollution of water bodies. More than 50% of the households are not connected to the collective wastewater treatment systems and use autonomous sewage disposal systems. Using autonomous sewage disposal systems, households emit nitrogen and phosphor into the water bodies and contribute to environmental damages, e.g., in the coastal water zone. Investments to reduce autonomous sewage disposal should reduce this environmental pressure.

Next to the challenges water governance faces concerning the agri-food sector, water distribution, sewage disposal, and tariffication, Reunion Island aims to increase the share of self-sufficiency for food and electricity (Nuwer, 2023). Thermic electricity production is based on imported fossil fuels, demands cooling water, and emits CO_2. Reunion Island's alternatives for electricity production are biomass, wind, solar, and hydroelectricity (Selosse et al., 2018), energy sources linked to the WEFE nexus. The environmental and political objectives, water management and governance challenges, and Reunion Island's aim of self-sufficiency make using a WEFE nexus CGE model a valuable tool for scenario analysis and policy assessment.

Besides needing a WEFE nexus CGE model, Reunion Island represents a suitable study region with favourable data conditions. As a French overseas department, Reunion Island covers the same statistics for an administrative and geographic unit (i.e., the river basin of Reunion Island, an isolated ecosystem). Data availability promises a fruitful development of a model prototype for Reunion Island, which can later serve as a model blueprint for other study regions. Last but not least, regional policymakers are already using the support of an instructional CGE model for Reunion Island. The existing model provides the starting point for the database (i.e., the Social Accounting Matrix) and lets us expect an openness for using the REWEFE-CGE model as a policy support tool.

In this study, we

- present one of the first CGE models in the literature, which represents the four WEFE nexus pillars;
- develop the model database and the CGE model;
- simulate academic scenarios and interpret their results;

- provide the reader with the information required to understand the methodological background to use the model;
- provide information which can serve as support (or guide) for modellers to develop WEFE nexus CGE models for other study regions;

Section 1 provides information on the methodological background to explain the CGE model and the modelling rationale based on literature reviews. Section 2 presents the data research and processing required to extend the model database. Section 3 describes the extension of the Social Accounting Matrix (SAM) as the database of the CGE model. Section 4 presents the developed model database and the CGE model. Section 5 describes the academic scenarios simulated to test the model, while Section 6 analyses and discusses these results. Section 7 presents how the CGE model can be linked to a microsimulation model and how CGE model results can be presented on a governance platform. The Conclusion section discusses the value added by the study, the challenges and caveats, and the potential direction of future research. Section 8 is the Annexe and presents a glossary explaining technical terms. The remaining sections of the Annex mirror the structure of the main text and present supplementary material, e.g., the complete algebraic presentation of the CGE model.

1. METHODOLOGY BACKGROUND

1.1 Introduction to CGE models

A computable general equilibrium (CGE) model is a **macroeconomic simulation and analysis tool**. The CGE model represents, through mathematical functions, the economic mechanisms of exchanging monetary values between economic activities, factors, agents and markets (including prices). Thus, the CGE model can simulate a whole economic system at a macroeconomic scale. CGE models are used to **analyse economic scenarios, such as economic shocks or policies** (e.g., water scarcity or pricing policies). CGE model simulation results are usually expressed in relative changes compared to the reference scenario. CGE model simulation can inform how the economic system responds to changes in settings compared to the situation if the economic settings stay unchanged. **Thus, CGE models are not forecasting instruments; they analyse how the economy changes if certain events occur.** With this, CGE models help researchers analyse the impacts of events and understand the direct and indirect economic mechanisms that may appear during such occurrences. CGE models are calibrated using data from **a Social Accounting Matrix (SAM), which represents a snapshot of the economy in a country or region in a given year.** CGE models can represent different temporal (static or dynamic) or regional resolutions (single-country or multi-country).

Computable General Equilibrium (CGE) models are macroeconomic models which represent the economic equilibrium between all economic activities, agents, and markets in a circular monetary flow. The "general" equilibrium contrasts the "partial" equilibrium in **Partial Equilibrium (PE) models.** The partial equilibrium represents only a part of the economic system (e.g., specific sectors or agents). "Computable" indicates that the model is based on algebraic functions and can be numerically solved. A CGE model is based on macroeconomic data and rigorous macro and microeconomic theory. A **macroeconomic analysis** considers the economy at an aggregated level. This means, instead of analysing individual households or producers, a macroeconomic analysis considers aggregated or representative actors, e.g., representative households and economic sectors. These representative and aggregated actors represent the totality of the economic actors in the study region, i.e., all households and all companies of an economic sector. In contrast, a **"microeconomic" analysis** considers the economic actors at an individual level with their economic behaviour and situation.

In a CGE model, **activities** (also called sectors or industries) represent the production of commodities and services. Activities require production factors and intermediate commodities (intermediate consumption) to produce. Factors in a CGE model refer to **production factors**, which are productive resources used to produce commodities and services. Production factors include labour (e.g., employees' working time), capital (e.g., machines, livestock), and natural resources (e.g., land and water). In a CGE model, the **agents (or institutions) are economic actors** in the form of representative agents. Typical agents in a CGE model are households, the government, and the rest of the world. Households own the production factors (e.g., labour) and sell them to the activities. Thus, households receive factor income and transfers (e.g., social aid from the government) and spend it to buy commodities, to pay transfers (e.g., taxes) or to do savings.

Commodities comprise both goods and services and are produced by activities. They come either from domestic or from international markets. They are bought by households for consumption, by activities as intermediate commodities (i.e., input for production), and by importing countries and used as investment goods. **Markets** link the activities' production with the agents' demand by computing a price for the commodities for which producers are willing to sell, and households are willing to buy, that is, the equilibrium price. In a CGE model, the markets interlink all activities, commodities, and agents by equilibrium prices. In simulations, the equilibrium prices change, and these changes spill over throughout the entire economic model.

A **Social Accounting Matrix (SAM)** is a macroeconomic framework that consistently represents the situation of an economy of a region (e.g., a country) for a specific year. This year is often used as the reference or base year to which the changes of a CGE model are compared. The SAM represents the exchange of monetary values between production activities, commodity markets, and economic agents. SAMs exist typically for national economies (at the national level). The cells that represent economic activities, commodities, and agents are called **accounts**. The results in a CGE model are macroeconomic **indicators** and their changes compared to the reference or base year. Typical results of a CGE model indicating the change in an economy are the change in the gross domestic product, the change in sector production, commodity prices, household (private) consumption, government income, and trade flows.

While CGE models represent the **economic system as a circular nexus**, where monetary values are exchanged and transformed, the WEFE nexus is a resource nexus of biophysical nature. Using a CGE model for WEFE nexus analysis requires linking the monetary economic nexus with the biophysical resource nexus. SAMs usually include some WEFE nexus pillars as accounts. Thus, CGE models based on such a SAM simulate the WEFE nexus pillar as activities, factors or commodities. Typical **WEFE nexus pillars in SAMs** are the agricultural and food processing activities and commodities (for the "food" pillar) and the energy activity and commodities (for the "energy" pillar). Within a CGE model, these activities are interlinked with other activities and commodities. Linking the CGE model with the WEFE nexus pillars outside the SAM framework requires that the biophysical information of the resource nexus be included in the SAM. Figure 1 presents the **CGE model as the economic nexus embedded in the WEFE resource nexus** (with a grey background). The information of the WEFE resource nexus is fed into the SAM and enters from there the CGE model. Within the CGE model, activities and agents exchange money through markets and transfers (blue arrows on white ground).

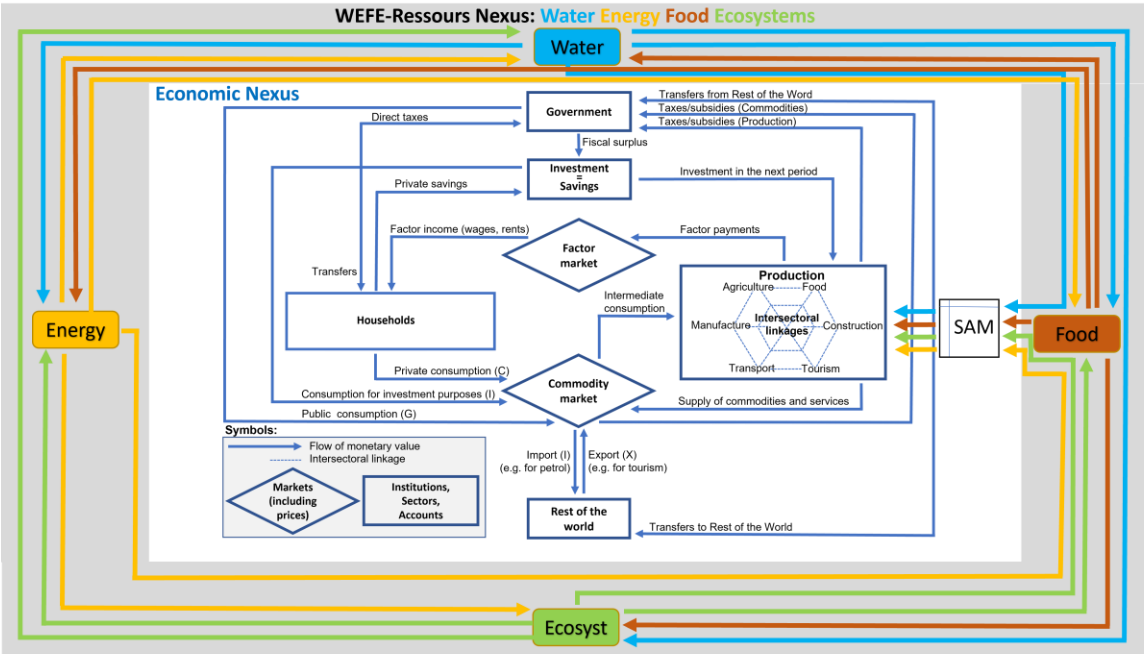

Figure 1: WEFE nexus and CGE model

Note: Graph adapted from Henseler et al. (2022)

Figure 1schematically presents the frameworks of WEFE nexus and CGE models. In the project InnWater, the WEFE **nexus pillar of primary interest is "water"** (the blue arrow on the grey background). For the CGE model, water enters the economic system as a production factor (e.g., groundwater or surface water). The **production factor water** enters production processes directly (e.g., as irrigation water in agriculture) or it is first processed as piped water by the water provider. Piped water is supplied to other industries and households. The intersectoral linkages between water and the other WEFE nexus pillars are defined by the water usage for consumption or production. **Industries using raw water** reduce natural water resources and emit pollutants into water as part of the ecosystem (the "ecosystem" pillar). Energy is used to produce water and food. However, energy consumption creates **emissions to the environment (CO_2 emissions),** which links energy to the ecosystem pillar. Energy production also requires water, e.g., cooling water. The production of food (i.e., the food pillar) requires water and, at the same time, contributes to the pollution of water as part of the ecosystem (e.g., through the **application of fertilisers and pesticides**). Finally, raw water is processed as piped water and consumed by households as drinking water. In InnWater, the REWEFE model was developed to analyse the **interactions between water use, energy and food production, ecosystems and economic activities in Reunion Island**.

As with all research methodologies and techniques, CGE models have advantages and disadvantages exist, making CGE models a favourable tool for research questions for which the advantages outweigh the disadvantages.

Advantages: One advantage of CGE model is that they are **comprehensive frameworks** to capture the entire economy, including interactions between different sectors, markets, and agents (households, firms, government, and the rest of the world). They allow for **detailed sectoral analysis**, such as examining specific sectors or industries and their interlinkages, helping to assess the impact of economic changes on agents and markets. CGE models can be used as

effective tools for policy evaluation. The impact of various policies (changes in taxes, tariffs, subsidies, investments or trade agreements) can be assessed by using CGE models. CGE models can also be used for scenario impact analysis, investigating how certain economic or environmental changes impact the economy. CGE modelling provides great **flexibility** to incorporate different types of economic shocks (e.g., supply, demand, or policy changes) and assess their transmission across the economy. Given the required data, CGE models can be extended and specified to address a large set of different research questions. CGE models are calibrated using **statistical macroeconomic data**, providing a solid empirical base. The model behaviour and computation of functional parameters are based on **microeconomic foundation.** Based on microeconomic principles (e.g., utility maximisation, profit maximisation, and market clearing), CGE models are theoretically sound and conceptually rigorous.

Disadvantages: CGE models **require detailed data**, particularly in the form of a Social Accounting Matrix (SAM). If SAMs are not available, it can be costly and time-consuming to compile a new SAM. If, however, a SAM is available, a CGE model can be specified. CGE models are **calibrated to the historical data of a SAM**. Thus, the model behaviour is strongly data-dependent, and the behaviour of the model calibrated to historical data might not represent the behaviour of a model with current or future data. Thus, CGE model results need to be interpreted with reference to their historical database and must not be used for forecasting analysis. Because they are calibrated to historical years, CGE models have a **static character**. Dynamic CGE modelling allows to simulate economic changes over time. However, the model reactions are still mainly driven by the historical situation. Dynamic development is included via strong exogenous assumptions about how the future may unfold . Thus, even dynamic CGE models are not forecasting tools; they only simulate scenarios in different periods, which is useful if scenario shocks change over time (e.g., climatic change shocks).

Methodological challenges arise if CGE models are used for the simulation of extremely long periods, e.g., to analyse the impact of climate change. CGE models often rely on **simplifying assumptions** (e.g., perfect competition, constant returns to scale, or fixed elasticities of substitution), which may not always reflect real-world conditions. These simplifying assumptions can be problematic if the markets represented in the CGE model do not function accordingly. Due to their **complexity, CGE models can be difficult** for policymakers or researchers without specialised knowledge in economics and computational techniques to understand and use. Without sufficiently transparent documentation of the model, CGE models can be perceived as “black-box” tools. Their rich output, composed of multiple indicators, can create confusion and requires expert interpretation to extract useful information and avoid misinterpretation.

Comparing the advantages and disadvantages leads to the conclusion that, for the study’s objective of analysing water governance scenarios within the context of the WEFE nexus, CGE models appear to be suitable instruments. The disadvantages partially apply. They need to be considered regarding the scope of the simulation, the interpretation of results, and collaboration with stakeholders and experts. A transparent presentation and guiding documentation can counteract the risk of the “black-box” perception. Collaboration with stakeholders and experts (e.g., in a co-modelling process) can help validate the model’s assumptions and performance.

1.2 Literature review

To obtain an initial overview of the scope and challenges of CGE model development and application in WEFE nexus research we execute an umbrella review of existing literature reviews. Furthermore, we undertake a scoping review.[1] By using key word search[2] in literature database “ScienceDirect,” “Web of Science,” and “Google Scholar” we retrieve a variety of studies classified as academic journal articles or as grey literature. We also screen several repositories of international research institutions from which we expect to find working papers and model documentation on WEFE nexus CGE model. Such institutions include, for example, the Partnership for Economic Policy (PEP) and the International Food Policy Research Institute (IFPRI). With this approach of collecting literature, including grey literature, we aim to cover a broad scope of the field. By reviewing existing literature reviews and case studies we address the following questions: First, are CGE models suitable tools to be applied for WEFE research questions? What are the challenges and limitation of CGE model application in the WEFE research? What are the identified research gaps? Second, is the chosen standard model, PEP-1-1, suitable for building a WEFE nexus CGE model? Third, how is water represented in CGE models as the first pillar of the WEFE nexus?

1.2.1 CGE models in WEFE nexus research: an umbrella review

We analyse existing literature reviews on the development and application of CGE models to WEFE nexus research topics. The review provides an overview of the state –of –the art in model development, the challenges and research gaps. We focus our analysis on the studies presented in Table 1. Johannson (2005) presents CGE models applied for water research topics in the context of valuation of irrigation water. Johannson presents five CGE studies following the pioneering work by Berck et al. in 1990. Dudu and Chumi (2008) extend Johannson’s review by presenting CGE models as analytical tools for irrigation water management. Dinar (2014) expands the review by Dudu and Chumi (2008) and identifies 49 papers published between 2000 and 2011. Dinar (2014) presents CGE models in the context of water and policy intervention, =thereby broadening the scope beyond agricultural use to other activities and agents competing for water.

Calzadilla et al. (2016) analyse 30 studies between 1991 and 2016. They differentiate between models according to whether water is modelled as a production factor (implicitly or explicitly) and consider different degrees of substitution between water and primary production factors. Bardazzi and Boselo (2021) systematically review CGE studies with respect to water and the WEF nexus research questions. For the period between 2000 and 2021, they identify 46 studies with a water-food linkage, of which 25 represent water as an explicit production factor. Castelli et al. (2024) review 27 articles between 2000 and 2021 and finds 12 articles representing water: 5 in with W-F linkage, 3 with a W-E, 3 representing water without WEFE nexus linkage, 1 article considering the WEF linkageTable 1 provides an overview of the number of studies and the

[1] To provide more evidence and to confirm the findings of the scoping review we additionally undertake a systematic literature review of journal articles. The reviewed articles describe CGE models in which water is represented as a production factor or as a commodity. The results of this review are presented in a separate paper.

[2] We keep the keyword search broad by using the key words: “computable general equilibrium” & “water”, “CGE” & “water”. To screen for literature reviews, we add the keyword “literature review”.

WEFE nexus pillars covered. The table shows that the number of studies using CGE models to analyse research questions related to water and WEFE nexus has significantly increased over time.

The umbrella review allows us to identify the following **challenges and research gaps**: The increasing number of CGE models applied in water or WEFE nexus research indicates that **CGE models are a suitable** tool for WEFE-nexus research analysis. The increasing number of studies covering different WEFE nexus research questions indicates that linkages between the water and food pillars are sufficiently represented in the CGE models. The number of studies representing water-energy linkages is small, while **studies covering three or four pillars (i.e., WEF or WEFE) are underrepresented**. Castelli et al. (2024) identify only one study representing the WEF nexus and do not identify any CGE study representing the full WEFE nexus, with four pillars. In the macroeconomic modelling framework, **socioeconomic aspects are not considered** due to the aggregated nature of CGE model.

In the present study, we develop the **Reunion Island WEFE nexus CGE model** (REWEFE-CGE model) and address two major methodological **research gaps:** (i) we consider, in the modelling, the interlinkages between the WEFE nexus pillars (water, energy, food and ecosystem) making the REWEFE-CGE one of the first CGE models to consider all four pillars of the WEFE nexus; and (ii) we link the CGE model to a microsimulation model (MSM),thus capturing the socioeconomic dimension in the CGE-MSM compound model.

Table 1: Studies presenting literature reviews on CGE model and WEFE nexus research

Study	Period	WEFE Nexus Pillar	Number of studies
Johannson (2005)	1991-2002	W	5
Dudu and Chumi (2008)	2000-2007	W	7
Dinar (2014)	2000-2011	W	49
Calzadilla et al. (2016)	1991-2016	W	30
Bardazzi and Boselo (2021)	2000-2021	WE, WF	67
Castelli et al. (2024)	2000-2021	W, WE, WF, WEF	12

1.2.2 The PEP-1-1 model in WEFE nexus related research

As a starting point, we use the **PEP single country static standard model** (PEP-1-1), as described in Decaluwé et al. (2013), as a template CGE model. The PEP-1-1 model has been applied in various research projects covering a broad range of topics. The strength of this standard model is its flexibility, which allows the trained user to customise the standard model in many ways and to address the research question of interest. The majority of the projects focus on the evaluation of economic policies and distributional impacts, but a considerable number of studies shows the frequent application of the standard models in WEFE nexus-related research questions (e.g., agriculture, food, climate change, energy, natural resources, fuels, mining).

Table 2 presents selected studies that apply the PEP-1-1 model (or its dynamic version PEP-1-t) for the evaluation of WEFE nexus topics, including environmental or natural resource issues. The wide application of the PEP-1-1 (or PEP-1-t) model between 2006 and 2024, suggests good suitability for addressing WEFE nexus research questions. The application to different research questions in different countries illustrates the flexibility of the PEP models for various case studies. While most studies using PEP models address the topics agriculture, food and energy, only few studies represent the WEFE pillars water and ecosystems.

Table 2: Studies using the PEP-1-1 or PEP-1-t models to address WEFE nexus pillar topic

Study	WEFE Nexus Pillar	Pub. Type	Reference
Sawadogo & Maisonnave (2024)	Climate change/food in Burkina Faso	JA	Sawadogo and Maisonnave (2024)
Sikube Takamagno et al. (2023)	Water/food/agriculture/ climate change in Cameroon	WP	Sikube Takamagno et al. (2023)
Koinda et al. (2023)	Water/food/agriculture in Burkina Faso	WP	Koinda et al. (2023).
Escalante & Maisonnave (2023)	Climate change/food in Boliva	JA	Escalante and Maisonnave (2023)
Escalante & Maisonnave (2022)	Food/agriculture/climate change in Bolivia	JA	Escalante & Maisonnave (2022)
Chitiga-Mabugu et al (2022)	Ecosystem/environment in South Africa	JA	Chitiga-Mabugu et al (2022)
Mbanda & Ncube (2021)	Food/agriculture in South Africa	WP	Mbanda & Ncube (2021)
Baroki et al (2021)	Food/agriculture in DR of Congo	WP	Baroki et al (2021)
Ikhide et al. (2021)	Food in NIgeria	WP	Ikhide et al. (2021)
Sawadogo & Fofana (2021)	Ecosystem/climate change/water in Burkina Faso	WP	Sawadogo and Fofana (2021)
Sawadogo & Maisonnave (2021)	Food/agriculture in Burkina Faso	JA	Sawadogo and Maisonnave (2021)
Ide et al. (2019)	Water/agriculture in Niger	WP	Ide et al. (2019)
Vargas et al (2018)	Water/food/agriculture/ climate change in Guatemala	JA	Vargas et al (2018)
Galindev & Maisonnave (2018)	Energy/mining in Mongolia	JA	Galindev and Maisonnave (2018)
Sangare & Maisonnave (2018)	Energy/mining in Niger	JA	Sangare and Maisonnave (2018)
Henseler & Maisonnave (2018)	Energy in South Africa	JA	Henseler and Maisonnave (2018)
Beyene & Engida (2013)	Water/food/agriculture in Ethiopia	WP	Beyene and Engida (2013)
Corong & Cororaton (2006)	Food/agriculture in the Philippines	WP	Corong and Cororaton (2006)
Note: Pub.Type = Publication Type; WP = Working Paper; JA = Journal Article			

1.2.3 Water in CGE production functions

Besides the challenge of estimating the value of water, as it is represented in a CGE model, the mathematical definition of water as a variable is of high importance. The mathematical definition determines how water is linked within the economic system to other elements of the economy (e.g., factors, markets). In a scoping review, we analyse and compare the ways water is represented in CGE models as a factor in production functions. We consider journal articles from referenced academic journals and grey literature. Grey literature (e.g., research reports and working papers) often provide more detailed descriptions of technical characteristics of CGE models than journal articles.

We retrieve 57 studies, of which we consider 51 relevant for deriving information on production functions. Based on the results, we derive four types of production trees representing water as a production factor. A production tree is a common graphical illustration of the production function in a CGE model. It indicates the interconnection, hierarchy and substitutability of all production factors. Figure 2 to Figure 6 present different types of production trees identified in the reviewed studies as the most representative.

Table 3 describes the five types of production function including water as a production factor. In the 51 reviewed studies, we find many other hybrid forms and extensions of the production trees by electricity and land. The Appendix Section 8.1.2 presents 27 production trees, in a harmonised, comparable format.

Figure 2 presents the generic production tree describing that the output of an activity (XS) is composed of intermediate inputs (CI), different commodities, and services (e.g., energy, fertilizer, construction materials) and the primary production factors: labour (L) and capital (K). The primary production factors are combined in a bundle which represents the value added (VA). In this presentation we name the value-added composite by combining the names of the production factors; here it is LK (composite of labour and capital). The intermediate inputs (CI) and the value added of labour capital value (LK) combine in a linear way to produce the output (XS). This linear combination is symbolised by a rectangular connection, showing that one unit of value added of labour capital value (LK) combines with a fixed defined unit of intermediate inputs (CI), whereas the proportion between CI and LK does not change. This linear function between the intermediate commodities (CI) and the primary production factors (L and K) is called a Leontief function.

Labour and capital combine to the value-added (LK) in a substitutable way. This means, that labour (L) can substitute for capital (K) and vice versa. This is not the case for the intermediate inputs and the value added, for which the proportions of the inputs are fixed. The degree of substitution is defined by the elasticity of substitution. If the value of the elasticity of substitution is small, the flexibility of the production function to substitute the production factors by each other is small. If the elasticity is high, substitution between the factors is flexible. The function which allows the substitution between the factors is called Constant Elasticity of Substitution (CES) function. The CES type of function is symbolised as an acute angle with an arc. In CGE models without specification of water, water can be implicitly included in capital as a natural resource. In this general production function, the value of water is not explicitly indicated but is aggregated with other forms of capital. Similar applies for the production factor land. If land is not explicitly specified in the production function, land is included within the aggregate of capital. For example, the agricultural sector demands production capital, including machines, buildings, livestock and land. In Figure 2 we indicate the implicit consideration of water in capital by indicating water in brackets as “(W)”.

Figure 3 presents the implementation of water as an intermediate commodity, as a linearly considered production factor. This representation is suitable if the CGE model represents water as a commodity produced by activities (or imported) (e.g., piped water produced by the water industry). Figure 4 considers water as a primary factor in different types in a bundle together with non-water capital. In this specification water can be substituted by non-water capital (e.g., land, machines, livestock), and vice versa. To represent this in the REWEFE model, we separate within the SAM, the monetary value of water from the aggregate capital. Then, we specify a variable in the production function for this disaggregated production factor, water.

Figure 5 considers water as a bundle in the same level as the primary factors labour (L) and capital (K). Labour, non-water capital (K) and water can substitute for other, and water types can substitute for each other. Figure 6 presents a production tree with water as one bundle and the primary production factors as another bundle. In this specification, the bundle of labour and capital can substitute the bundle of water and vice versa, while within the bundles the factors can substitute for each other: labour can substitute capital and vice versa, and the water types can substitute for each other. The function can be specified with a low elasticity of substitution, so that substitution between the labour-capital bundle and the water bundle is minimised. This means water can only minimally substitute for capital or labour, and labour can only minimally substitute for water. Water is also considered as an intermediate commodity.

The production trees in Figure 2 to Figure 6 illustrate the types of production trees we find in the reviewed studies, with water as a production factor. However, the number of potential production functions is much larger (see Section 8.1.2 in the Appendix). The big variation of production trees indicates the large flexibility of CGE models. CGE models allow for different specifications of the functions. In the logic of CGE modelling, the CGE model is specified according to the research question and the assumptions the modeller makes concerning the economy. The specification starts already with the aggregation of the SAM. The accounts of the SAM can be aggregated for the items that are not subject to the research question. A simple and less complex specification is usually preferred to a highly disaggregated and more complex one. In other words: the degree of complexity of the CGE is usually increased only as much as is required to address the research question.

We consider the type presented in Figure 6 as the most suitable for specifying the factor water in the production function of the REWEFE model. This type allows the representation of piped water as an intermediate commodity and the representation of two raw water types (e.g., ground- and surface water). Both raw water types are combined in the raw water composite bundle (WC). The raw water composite (WC) combines with the labour-capital bundle (LK) to form a value added composed of labour, capital and water (LKW). By defining a small value for the elasticity of substitution between the bundles of labour-capital (KL) and raw water (WC), the substitution between the factor bundles can be minimised. This means that raw water can only minimally substitute for labour and capital, and vice versa. We assume that such a representation with minimal substitutability best represents the technical reality in Reunion Island.

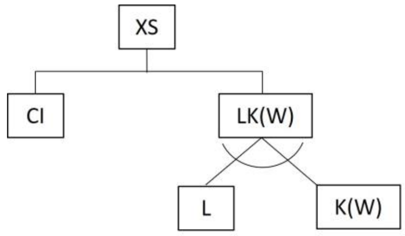

Figure 2: Production tree with water implicitly modelled as a bundle with capital

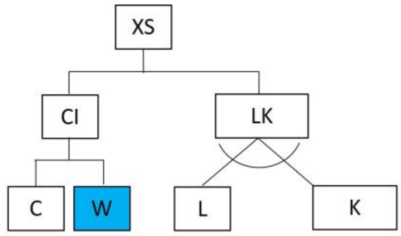

Figure 3: Production tree with water modelled as an intermediate commodity

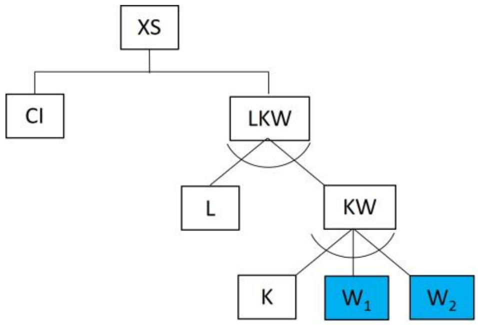

Figure 4: Production tree with water in capital bundle (i.e., in the PEP-1-1 standard model)

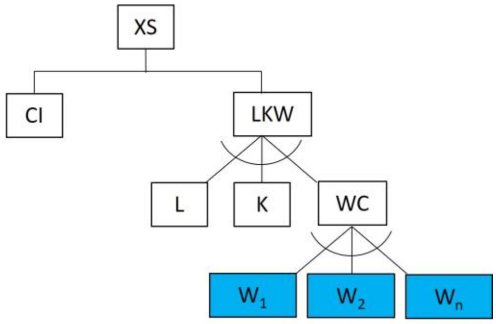

Figure 5: Production tree with water bundle, same level to labour and capital

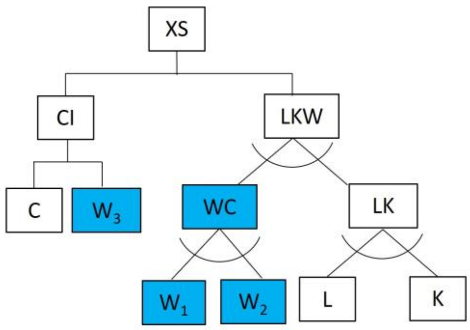

Figure 6: Production tree with water bundle and labour - capital at same level, water as intermediate commodity

Note:
C = other intermediate commodities as input;
CI = intermediate consumption;
K = capital (K) as single production factor or as composite of different capital types;
K(W) = as primary production factor including implicitly water (W) as natural capital production factor;
L = labour (L) as primary production factor or as composite of different labour types;
LK = value added resulting from labour (L) and capital (K);
LK(W) = value added resulting from labour (L) and capital (K) with water (W) included implicitly as a natural capital;
LKW = value added resulting from labour (L) and capital (K) and water (W);
W = water as an intermediate production factor;
W_1 = raw water type 1 as a production factor (e.g., groundwater);
W_2 = raw water type 2 as a production factor (e.g., surface water);
W_3 = water as intermediate commodity (e.g., piped water);
WC = raw water composite as a production factor;
W_n = undefined raw water types (e.g., sea water, brackish water);
XS = output of production;

Table 3: Types of production trees with water as a production factor researched in the literature

Type	Figure	Study
Water implicitly aggregated with capital	Figure 2	Many studies in which water is considered implicitly as a bundle aggregated with capital (e.g., as irrigated land)
Production tree with water modelled as an intermediate commodity	Figure 3	Gao et al. (2022), Ma et al. (2022), Peng et al (2022)
Production tree with water in capital bundle (i.e., direct implementation in the PEP-1-1 standard model)	Figure 4	Idé et al. (2019), Koopmann et al. (2017), Zang et al. (2022), Cazcarro et al. (2020)
Production tree with water bundle, same level to labour and capital	Figure 5	Briand et al. (2023), Luckmann et al. (2014a), Peng et al. (2020), Tian et al. (2020), Liu et al. (2017), Luckmann et al. (2016b), Luckmann et al. (2016a)
Production tree with water bundle and labour - capital at same level, water as intermediate commodity	Figure 6	Shahpari et al. (2022), Xin et al. (2022)

2. DATA

This section presents the data sources researched and the processing we executed to obtain the information to extend the REWEFE-SAM and to integrate the WEFE nexus pillars into the REWEFE model. We build the REWEFE-SAM based on the SAM-Omega, which is a regional SAM for Reunion Island (Croissant et al., 2023). For representing new items in a CGE model (i.e., new activities, commodities or agents), we require the information of monetary values, which represent the corresponding item in the economy. In the CGE model framework, these are the values in the SAM accounts. For example, for a commodity, the values in the SAM express how much of a commodity is consumed, produced, or demanded as an intermediate commodity for production. With this monetary value information, the items can be defined in the SAM and integrated consistently into the CGE model. To model the WEFE nexus pillars in the REWEFE model, we need information about water and sanitary services, energy (electricity), food (agriculture), and ecosystems (pollution and CO_2 emissions). In this study, we apply three approaches to obtain data for extending the SAM: (i) retrieving value data from reports or statistical databases, (ii) computing values based on quantity and price data and (iii) applying data from a macroeconomic consistent framework, such as a SAM or input/output tables.

2.1 Water and sanitary services

To represent **water as the W-pillar of WEFE nexus** in the REWEFE model, we research and compile information on water usage and costs, sewage discharge, water treatment costs and water extraction quantities and extraction costs. This information allows us to model water extraction, piped water distribution and wastewater services as activities, commodities, and production factors. . Table 4 presents an overview of the different aspects considered in the data and in the REWEFE model. For the data research and processing, we differentiate between three activities: agriculture (as the primary sector), industry (i.e., industrial production) as the secondary sector, and services as the tertiary sector of the economy. Furthermore, we consider households as consumer of water and wastewater services. We assume that collective water usage is attributed to households as user of these public services. We do not model water usage by the government to which we attribute only the use of electricity. We research the information to model water in the REWEFE model using three special reports: IREEDD (2019), Office de l'Eau (2019a) and (2022).

Table 4: Water production, usage and wastewater discharge considered in the model

Water type	Production & services	Activities and agents				
		Agriculture	Industry	Services	Households	Government
Fresh water	Production and distribution of piped water	Usage of piped water	Usage of piped water		Usage of piped water	
	Extraction by industries	Extraction for irrigation water	Industrial water (food, granulate, cooling)	Extraction GW and SW for piped water production		
	Treatment by industries		Industrial water			
Waste-water	Collective wastewater treatment	Public discharge	Public discharge		Public discharge	
	Non-collective wastewater discharge				Autonomous discharge	
	Industrial treatment	Considered in public discharge	Considered in public discharge			
Note: GW = groundwater; SW = surface water						

2.1.1 Water usage

For the study region, Reunion Island, special reports provide information on water quantities. The quantities indicate the raw water extracted by the industries, the piped water produced and distributed, and the piped water consumed by households and industries. Based on these values, we derive a water balance for the years 2016 and 2020. For modelling water in the REWEFE model, we use data from the year 2016. The year 2020 serves as supplementary information on changes in water data between 2016 and 2020.Table 4 shows how water is represented in the REWEFE model for different water usages by activities and economic agents.Table 5 present the physical water accounts, quantities of water extraction and usage in Reunion Island, for the years 2016 and 2020. The value for industrial water extraction in 2016 is estimated based on the proportion in 2020.

Figure 7 presents the water quantity data as Sankey chart for the year 2020. About one third of the extracted raw water is groundwater. More than two thirds of the extracted water are used for piped water production, with comparable shares covered by groundwater and surface water. Nearly half of the produced piped water is lost through leakages. The remaining half is consumed by households and through public distribution. Industrial water usage represents a minor share, most of which is used as cooling water for electricity production and in sugar production. Other industries consume only marginal quantities of piped water and extracted raw water. Agriculture uses nearly a quarter of the extracted raw water for irrigation, mainly supplied by surface water. Agriculture demands only small quantities of piped water, e.g., for livestock feeding.

Table 5: Water extraction and usage in 2020 and 2016

	2020	2016	2020	2016
	M m³		Share of total	
Extraction for piped water production	**152.74**	**142.43**		
Surface water extracted for piped water production	84.00	75.49	55%	53%
Groundwater extracted for piped water production	68.73	66.94	45%	47%
Distribution piped water	146.60	136.71	96%	96%
Stockage piped water	0.42	0.39	0%	0%
Losses Piped water	65.16	69.32	43%	49%
Usage piped water	**88.00**	**82.06**		
Domestic usage (households)	74.80	69.75	85%	85%
Collective usage	9.68	9.03	11%	11%
Agriculture	1.76	1.64	2%	2%
Industries	1.76	1.64	2%	2%
Extraction for irrigation	**52.85**	**49.01**		
Surface water extracted for irrigation	49.15	44.60	93%	91%
Groundwater extracted for irrigation	3.70	4.41	7%	9%
Extraction by industries	**10.59**	**10.18**		
Surface water extracted by industries	8.26	6.92	78%	68%
Groundwater extracted by industries	2.33	3.26	22%	32%
Electricity production (thermic)	5.61	5.39[a]	53%	53%
Sugar production	3.18	3.05[a]	30%[a]	
Beverages (milk, soda, rum)	1.16	1.12[a]	11%[a]	
Granulate production	0.42	0.41[a]	4%[a]	
Bottled water production	0.11	0.10[a]	1%[a]	
Other industries	0.11	0.10[a]	1%[a]	
Recharge of rivers	**3.56**	**0.00**	**NA**	**NA**
[a] Derived for 2016 based on the shares of 2020. Source: Office de l'eau (2019a), Office de l'eau (2022)				

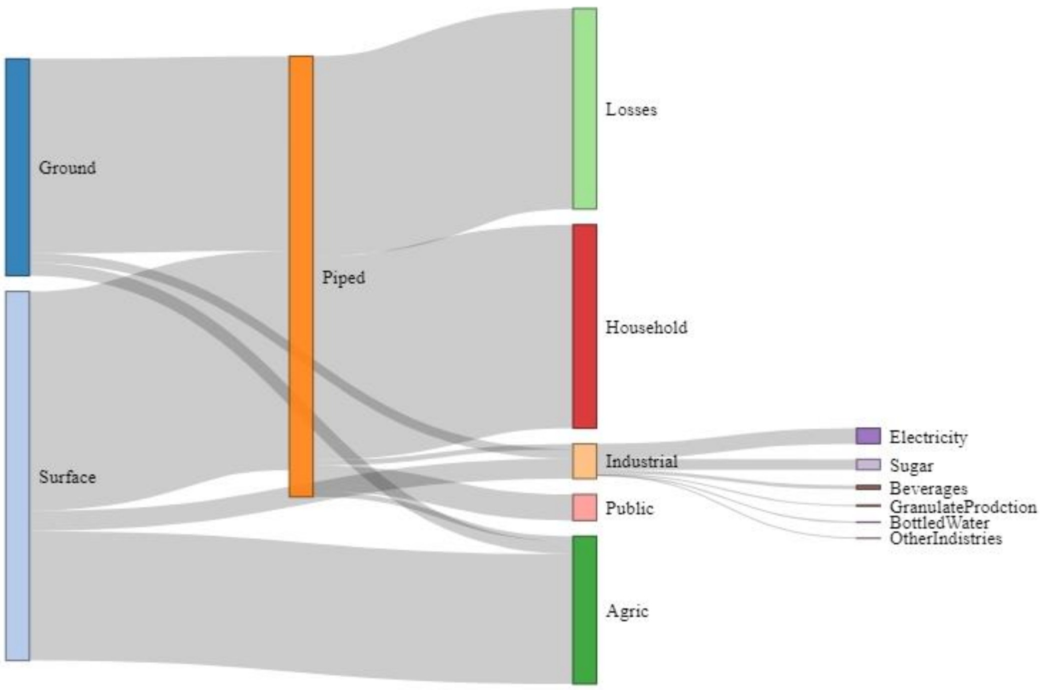

Figure 7: Water extraction and usage as Sankey chart

Note: Surface = surface water; Ground = ground water; Piped = Piped water; Losses = water lossses by leakages; Household = water used by housholds; Industrial = industrial water usage; Public = collective water usage; Agric = agricultural water usage; Electricity = water usage in electricity production; Sugar = water usage in sugar production; Beverages = water usage in beverages production (e.g., rum); GranulateProduction = water usage in granulate production; BottledWater = water usage for bottled water; OtherIndustries = water usage in other industries; Source: Data based on Office de l'Eau (2019a), Office de l'Eau (2022)

Table 6 presents the costs for piped water usage and fees for agriculture, industry and services, and household as final consumer. Households pay the highest amount, approximately €150M, followed by industries, which pay the majority share for water treatment. We assume that the costs of €126M in purification costs incurred by industries Table 7) are allocated equally between freshwater and wastewater. Agriculture accounts for a small share, with €7M. We do not attribute piped water consumption to the service sectors or to the government agent.

Table 6: Costs for usage of piped water

	Unit	Activities and agents				
		Agriculture	Industry	Services	Housholds	Government
Piped water usage	M m^3	1.56	4.02	NA	76.59	NA
Pipe water price	€ m^{-3}	1.87	1.87	NA	1.87	NA
Cost for piped water usage	M €	**2.92**	**7.52**	NA	**143.22**	NA
Piped water fees	M €	4.12	0.41	NA	3.79	NA
Piped water demand for animal feeding	M €	0.26	0.00	NA	0.00	NA
Raw water treatment costs[a]	M €	0.00	63.30	NA	0.00	NA
Total piped water costs	M €	**7.30**	**71.22**	NA	**147.01**	NA
[a] Derived as 50% from the purification costs, assuming these costs are half attributed to the usage and half to the discharge. Source: IRREED (2019)						

2.1.2 Sanitary services

Table 7 presents the wastewater treatment and discharge costs for the activities and agents. Households pay the highest costs for collective wastewater treatment at nearly €78M, including various environmental fees. More than 60% of households do not use the collective system. They pay €74M for non-collective sewage discharge. Industries pay €68M for autonomous purification and associated fees. IRREED (2019) reports twice this value, but we assume that only half of these costs are attributed to water, and the other half is counted as general production costs. For agriculture, treatment costs are small, at €12M, consisting of water fees and treatment costs for manure.

Table 7: Costs of wastewater treatment and discharge for the activities and agents

	Unit	Activities and agents				
		Agriculture	Industry	Services	Households	Government
Waste water quantity	M m^3	1.56	4.02	NA	76.59	NA
Price for wastewater discharge	€ m^{-3}	0.95	0.95	NA	0.95	NA
Waste water discharge costs	**M €**	**1.48**	**3.82**	**NA**	**72.76**	**NA**
Water fees	M €	5.62	0.54	NA	5.07	NA
Environmental fees	M €	0.02	0.26	NA	0.01	NA
Industrial water treatment cost (epuration autonomous)	M €	0	63.30	NA	0	NA
Treatment for manure	M €	4.13	0	NA	0	NA
Phytosanitary costs	M €	0.37	0	NA	0.04	NA
Total treatment costs	**M €**	**11.62**	**67.91**	**NA**	**77.88**	**NA**
Non collective water discharge	**M €**	**0.00**	**0.00**	**NA**	**73.90**	**NA**
Source: IRREED (2019)						

Table 8 compiles the total costs for piped water usage, collective wastewater treatment, and non-collective wastewater discharge. The values represent the shares that activities and agents spend on water and wastewater services. We use these data as the base to derive the shares of commodities for final consumption (for households) and intermediate consumption (for activities) in the extended SAM.

Table 8: Summary of costs for water distribution and wastewater services

		Activities and agents				
item	Unit	Agriculture	Industry	Services	Households	Government
Total piped water costs	M €	7.30	71.22	NA	147.01	NA
Total treatment costs	M €	11.62	67.91	0.00	77.88	
Non collective water discharge	M €	0.00	0.00	0.00	73.90	

2.1.3 Water extraction

We derive the cost of water extraction per raw water type, i.e., for groundwater and surface water. Based on the raw water quantities extracted by activities and the per unit extraction costs we compute the extraction cost per raw water type and activity. For piped water production and agricultural irrigation, we distinguish between extraction from surface and groundwater. For the activities with small marginal extraction quantities, we simplify the attribution of extraction (see Figure 7). We assume that food production exclusively extracts groundwater, which is of higher quality and less exposed to emissions than surface water. We assume that thermal electricity production uses only surface water as cooling water. We also assume that other industries (e.g., granulate production) extract only surface water as a production factor. We simplify the representation of small quantities to avoid very small values that would result from further differentiation into groundwater and surface water. Avoiding the attribution of marginal water sources helps to prevent potential modelling issues.

Table 9 presents the computed water extraction costs for groundwater and surface water, per activity and commodity for which raw water is used as a production factor. The major extractors of raw water are piped water production and agricultural irrigation. The water supplier extracts groundwater and surface water in a comparable proportion of 67 and 75 M m^3, respectively. We assume the per-unit cost for raw water extraction itself to be very low, at €0.03 perm^{-3}. We also assume that all other costs to process piped water are covered by non-water capital (e.g., pumps and pipes) and intermediate commodities (e.g., energy). For agricultural irrigation, we derive the production costs directly from a value provided by IRREED (2019), totalling €13.49M. We derive the shares for surface water and groundwater using proportions we computed based on Office de l'Eau (2019a) and extraction costs by IRREED (2019). We calculate the cost proportions as 9% for groundwater and 91% for surface water. With €1M for groundwater and €12M for surface water, we find that agricultural water extraction costs are much higher than for the water supplier. We assume that agricultural water extraction costs for irrigation include all costs for extraction, transport, and irrigation technology.

Table 9: Water extraction costs for the activities

Activity		Commodity	Unit	Surface water	Ground-water
Extraction water supplier	Price	Per unit costs for extraction	€ m^{-3}	0.03	0.03
	Quantity	Piped water	M m^3	75.49	66.94
	Total cost	**Total extraction cost**	**M €**	**2.26**	**2.01**
Agriculture	Quantity	Irrigation	M m^3	44.6	4.41
	Total cost [a]	Irrigation	M €	12.27[a]	1.21[a]
Food industry	Price	Per unit costs for extraction	€ m^{-3}		1.21
	Quantity	Sugar	M m^3		3.05
		Beverages (rum, milk, soda)	M m^3		1.12
		Bottled water	M m^3		0.10
	Cost	Sugar	M €		3.69
		Beverages (rum, milk, soda)	M €		1.35
		Bottled water	M €		0.12
	Total cost		**M €**		**5.17**
Other industries	Price	Per unit costs for extraction	€ m^{-3}	0.58	
	Quantity	Granulate	M m^3	0.41	
		Other industries	M m^3	0.10	
	Cost	Granulate	M €	0.24	
		Other industries	M €	0.06	
	Total cost		**M €**	**0.30**	
Thermic electricity production	Price	Per unit costs for extraction	€ m^{-3}	0.05	
		Cooling water	M m^3	5.39	
	Total cost		**M €**	**0.24**	

[a] For irrigation water we research the value of total water costs in IRREED (2019) at 13.49 M €. Based on water quantities derived from Office de l'Eau (2019a) and extraction costs by IRREED (2019), we compute the proportions of costs of 9% for groundwater and 91% for surface water.

2.2 Energy and electricity

To represent **energy as the E-pillar of the WEFE nexus in** the REWEFE model, we collect and compile information on energy usage and cost. The SAM-Omega provides data on the supply and demand of petrol as a primary energy source, for activities (e.g., the transport sector) as intermediate consumption and for households as final consumption. As a secondary energy source, the production and use of electricity is highly relevant in Reunion Island. While the SAM-Omega provides data for the supply and demand of petrol, the base data for electricity needs to be derived. Modelling the usage and production of electricity allows us to represent electricity production as an activity, a commodity, and a production factor (intermediate commodity).

Table 10 provides an overview of the different aspects considered in the data and in the REWEFE model. For data research and processing, we differentiate three activities, agriculture, industry, and services, as economic activities, and households and the government as economic agents. In the REWEFE model, we consider three types of electricity production: fossil fuel-based (thermal) production, biomass-based production, and production from other renewable energies (e.g., hydroelectricity, wind, solar). To model electricity consumption, we use information from the regional database Région Réunion (2024) and the online article by LINFO.re (2024). For representing the **production of electricity (i.e., the energy activities),** we use data provided by Garabedian et al. (2020) and by energy economists from the University of Reunion Island, from the institute CEMOI (Centre d'Économie et de Management de l'Océan Indien).

Table 10: Production and usage of energy considered in the REWEFE model

Production & services	Activities and agents				
	Agriculture	Industry	Services	Households	Government
Supply of petrol			Imported petrol		
Usage of petrol	Usage of petrol as primary energy source for production			Usage of petrol as primary energy source for transport and heating	
Distribution of electricity	Usage of electricity for production	Usage of electricity for production	Usage of electricity for production	Usage of electricity	Usage of electricity
Production of electricity		Thermic fossil fuel-based production, biomass-based production and other renewable energy sources			

To compute the cost of electricity, we use consumption data from Région Réunion (2024) (Table 11). The data provides sectoral electricity consumption for the years 2017 to 2021. As a proxy for electricity consumption in 2016, we calculate the average for the year 2017 to 2019 and 2021. We exclude 2020 from the average as a non-representative year, due to the influence of the COVID-19 pandemic and related hygienic measures. Thus, we do not consider 2020 as a normal representative year, assuming that compared to other years, electricity consumption was higher in households and lower in industries. We compute the electricity cost by multiplying consumption by an electricity price of €0.2 per kWh. To represent the true value of consumption, we use the production price without any subsidies. We apply the same price for intermediate consumption by the activities and for final consumption by households. We do not compute separate data for government consumption, since the SAM provides data for electricity demand by the government. Households consume €246M of electricity, less than the €280 M consumed by production activities.

Table 11: Electricity consumption wastewater services

		Activities and agents					
Year	Unit	Agriculture	Industry	Services	Households	Government	Source
2017	MWh	18686	457261	839297	1189788	NA	Région Réunion (2024)
2018	MWh	21646	300507	1097609	1211464	NA	Région Réunion (2024)
2019	MWh	17184	292879	1128790	1229689	NA	Région Réunion (2024)
2020[a]	MWh	17970	276253	1088782	1272268	NA	Région Réunion (2024)
2021	MWh	19327	284991	1153368	1293107	NA	Région Réunion (2024)
Averageb	MWh	19211	333909	1054766	1231012	NA	
2016	€ kWh^{-1}	0.20 [c]	0.20 [c]	0.20 [c]	0.20 [c]	NA	LINFO.re (2024)
	M €	**3.84**	**66.78**	**210.95**	**246.20**	**NA**	

Notes:
[a] We exclude the year 2020 from the computation of the representative average.
[b] We compute the average of the four years 2017 to 2019 and 2021. We consider the year 2020 as not representative for electricity consumption of because of the Covid19 pandemic and the worldwide lock-down.
[c] We simplify by assuming a uniform electricity price for industries and households, since we do not consider subsidies.

2.3 Food and agriculture

To represent **food as the F-pillar in the WEFE nexus** in the REWEFE model, we consider four items: agriculture and food processing, each as activities and commodities. Agriculture represents the food pillar within the primary sector, aggregating agriculture, fishery and forestry. Food processing represents the food pillar in the secondary economic sector, aggregating the production of various processed food commodities and beverages (e.g., sugar and rum). In Reunion Island, the dominant impacts of the food pillar on water management result from a narrow set of agri-food subsectors: sugar cane cropping, and the processing of sugar and rum. Other agri-food systems also use water and contribute to water pollution (e.g., fruit and vegetable cropping, fishery, cattle), but to a lesser extent. For the WEFE nexus analysis with the REWEFE model, we consider that the representation of agriculture and food processing activities and commodities is sufficient. However, a more detailed disaggregation of the agri-food sector may be required to address other research questions, e.g., investigating Reunion Island's options for food self-sufficiency.

Table 12 provides an overview of the different aspects considered in the data and in the REWEFE model. For the data research and processing, we differentiate three activities, agriculture, industry and services, as economic activities, and households and the government as economic agents. We obtain the information for the agriculture and food processing sector from the SAM-Omega and SAM-GetRun-NRJ. Section 4.1 describes the relative economic shares of the agri-food sector in the REWEFE-SAM.

Table 12: Agricultural and food production and usage considered in the model

Production & services	Activities and agents				
	Agriculture	Industry	Services	Households	Government
Agricultural production (incl. sugar cane, banana, cereals, fruit and vegetable, also fishery)	Usage as intermediate commodity			Usage as final consumption	NA
Food processing industry (incl. sugar production, rum production, other foods and beverages)	Usage as intermediate commodity			Usage as final consumption	NA

2.4 Ecosystems and environment

To represent **ecosystems as the second E-pillar in the WEFE nexus**, we consider the emission of water pollutants, the emission of CO_2, and the physical quantities of water resources. The information on emissions and water quantities is not directly integrated into the CGE model but is instead externally linked to the model database as so-called "satellite accounts". The information from physical flows and emissions accounts are linked to the CGE model. Table 13 shows the groups of emissions (pollutants and CO_2) and the physical water flow attributed to the economic activities and the agents.

Table 13: Emission and physical water flows in the CGE model

Emission and physical flow	Activities and agents				
	Agriculture	Industry	Services	Households	Government
Active substances and other micro pollutants	Emission by pesticides application				
Heavy metals		Emission by traffic			
Nitrogen	Emission by agricultural production	Emission by sugar and rum industry		Emission by water usage	
Phosphorous		Emission by sugar and rum industry		Emission by water usage	
Suspended solids		Emission by sugar and rum industry		Emission by water usage	
CO_2 emissions		Electricity production, petrol usage		Petrol usage	
Surface water	Extraction for irrigation	Extraction for industrial usage	and water supply		
Ground water	Extraction for irrigation	Extraction for industrial usage	usage and water supply		

2.4.1 Water pollutants and indicators/parameters

In the REWEFE model, we consider ecosystems as being impacted by economic activities and consumption, which cause emissions of pollutants and greenhouse gases. We assume that simulated economic scenarios create changes in economic activities and household consumption. These changes in activities cause changes in pollutants and emissions to the environment (e.g., to water and the atmosphere). To represent the ecosystem-pillar we research information about emissions of water pollutants and CO_2 emissions in Reunion Island. We compile these data from different sources in one database which we use as a base for the satellite accounts to the REWEFE-SAM. The emission of pollutants can be classified by the originating activity, by the type of pollutant, and by the transport of pollution.

Table 14 presents the pollutants, emissions and pathways. While agricultural and wastewater emissions represent the node between food and water and ecosystems, the emissions from residences and traffic cannot be clearly reduced to only one nexus node. Thus, we indicate them as “WEF-E node”. In total we consider around 150 pollutants/pathway combination originated by 7 origins. We differentiate 51 substances and water quality parameters, i.e., active substances and other chemicals, heavy metals, nitrogen, phosphate and oxygen demand, and CO_2 emissions. For all pollutants and water quality indicators we record the physical information as kilogram emissions in the year 2016. We assume these data to be a representative proxy for the REWEFE-SAM. We derive the information and data of water pollutant and water quality indicators based on the reports from Office de l’Eau (2019b, c, d, e) and by data received by Defrance (2025).

Table 14: Sources of pollution and pathways considered: economic sectors

Pollutant/indicator	Source	Path/transport of pollution	Sink	Number of pollutants/ parameters	WEFE Nexus node
Active substances plant protection	agri	soil	sw	25	F-Ec
Active substances plant protection	agri	wind	sw	25	F-Ec
Nitrogen from fertilisation	agri		sw	1	F-Ec
Nitrogen from fertilisation	agri		seaw	1	F-Ec
Quantity of emissions of macro pollutants from the sugar and rum industry in the year 2016	food		sw	5	F-Ec
Urban industry and residency	oind	urban run-off	sw	17	WEF-Ec
Highway traffic	trans	Wash-off	sw	4	WEF-Ec

Table 15: Sources of pollution and pathways considered: households via wastewater

Pollutant/indicator	Source	Path/ transport of pollution	Sink	Number of pollutants/ parameters	WEFE Nexus node
Quantity of discharged water via ANC in 2017				1	W-Ec
Quantity of emissions of nitrogen (NH_4)[a] via ANC to groundwater in 2017	sanc		gw	1	W-Ec
Quantity of emissions of phosphorous via ANC to groundwater in 2017	sanc		gw	1	W-Ec
Quantity of emissions of nitrogen (NH_4) via ANC to surface water in 2017	sanc		sw	1	W-Ec
Quantity of emissions of phosphorous via ANC to surface water in 2017	sanc		sw	1	W-Ec
Quantity of emissions of micropollutants (cd, cr, cu, ni, pb, zn) via ANC to groundwater	sanc		gw	6	W-Ec
Quantity of emissions of micropollutants (cd, cr, cu, ni, pb, zn) via ANC to surfacewater	sanc		sw	6	W-Ec
Quantity of discharged water via collective systems in 2017	saco		sw	1	W-Ec
Quantity of emissions of macro pollutants at waterbody level	saco		sw	5	W-Ec
Note: [a] Converted from NH_4 to NH_4-N by multiplying with 0.776.					

Table 16: Sources of pollution, pathways and sinks: emission to coastal waters and sea

Pollutant/indicator	Source	Path/ transport of pollution	Sink	Number of pollutants/ parameters	WEFE Nexus node
Quantity of emissions of nitrogen to costal water	agri		seaw	1	F-Ec
Quantity of emissions of micro pollutants at waterbody level	saco		Sw	12	W-Ec
Quantity of emissions of nitrogen to costal and transition water bodies	saco		Sw, seaw	1	W-Ec
Quantity of DCO to costal and transition water bodies	saco		Sw, seaw	1	W-Ec

Table 17: Pollutant considered

Group of pollutants	Number
Active substances and chemicals	27
Nitrogen and Phosphate	2
Oxygen demand and suspended solids	3
Heavy metals	8
Total number of indicators	40

2.4.2 Greenhouse gas emissions

To represent the emission of greenhouse gases we compute the CO_2 emissions resulting from thermic production of electricity. This indicator represents a WEFE nexus node between energy and ecosystems (E-Ec). Table 18 presents the CO_2 emissions as resulting from the thermic production of electricity by petrol and by coal. While for the water pollutants and indicators we extract the physical quantities directly from the data source, we compute an emission factor to derive from the production of electricity the CO_2 emissions as physical quantities (i.e., CO2eq). We base the computation on the document “GetRun-NRJ -- Manuscript” (shared by energy economists at the University of Reunion Island). The document provides emission factors for the fossil fuel inputs petrol and coal.

Table 18: Sources of pollution and pathways considered

Origin of pollutant	Fossil fuel input	Emission factor [kg CO2eq / EUR output]	Factor demand [EUR input / EUR output]	Emission factor [kg CO2eq / EUR input]
Thermic production of electricity	Petrol	5,81	0,28	1,63
	Coal	7,91	0,55	4,34

Equation 1 symbolises the conversion of the emission factor related to the fossil fuel input into an emission factor related to the electricity output for the example of electricity produced from petrol. The conversion for electricity based on coal works correspondingly. Thus, we compute the emission factor for electricity production from petrol based thermic production as:

$$EF_{aelpe} = \frac{EF_{cpete} \times CI_{cpete,aelpe}}{XS_{cpete,aelpe}} \quad , \qquad \text{Eq. 1}$$

With

EF_{aelpe} : emission factor of thermic electricity production with petrol as input per value output (unit: kg CO_2eq per EUR electricity output),

EF_{cpete} : emission factor of thermic electricity production with petrol as input per value input of petrol (unit: kg CO_2eq per EUR petrol input),

$CI_{cpete,aelpe}$: value of intermediate demand of petrol based thermic electricity production (unit in EUR),

$XS_{cpete,aelpe}$: value of output electricity from petrol based thermic electricity production (unit in EUR).

In addition to the CO_2 emissions from the energy sector, we compute the CO_2 emissions resulting from the final consumption of petrol by households and the intermediate consumption by the non-electricity activities (e.g., transport). We compute the CO_2 emissions by applying emission factors to the final consumption and the intermediate demand. The applied emission factors were published by Solaymani and Kari (2014) and have already been used by Henseler and Maisonnave (2018).

3. EXTENSION OF THE SAM

Section 3 presents the rules applied for developing the Social Accounting Matrix (SAM) for the REWEFE model. The reader learns in an introduction the basic principles of a SAM (Section 3.1) and the different options on how to extend a SAM (Section 3.2). Furthermore, the section presents step-by-step how we split the SAM for Reunion Island to consider the four WEFE nexus pillars in the CGE model. For more detailed explanations about the SAM as a data base of CGE models, see, for example, (e.g., Breisinger et al, 2009).

3.1 Introduction to a SAM

A social accounting matrix (SAM) is a consistent macroeconomic accounting system to be used for macroeconomic analysis. It is used as the model database for a CGE model but can also be used by other analytical approaches (e.g., multiplier analysis). This section presents how we extend an existing SAM of Reunion Island to a SAM representing the WEFE nexus in the REWEFE model. Our description is limited to the basics to provide a basic understanding of the exercise presented in this study.

3.1.1 Basics of a SAM

A social accounting matrix (SAM) consists of rows and columns that represent different economic accounts. The accounts comprise activities, commodities, production factors, agents, and other accounts (e.g., tax accounts, trade margins). The cells where the accounts in row and column intersect are filled with monetary values. These values represent the monetary flows between the accounts. Interpreting the matrix in the direction from row to column reads like: “Row X provides a value Y which is being received by column Z”. Interpreting the matrix in the direction from column to row reads like: “Column Z purchases a value Y provided by row X”. Not all cells are filled with values because in the economy monetary values flow only from certain accounts (rows) to certain accounts (cols). A SAM is usually symmetric with the same number of rows and columns. In a SAM, the row names are mirrored as column names. However, asymmetric SAMs also exist, in which the number of columns exceeds the number or rows, called a rectangular or non-square SAM.

A consistent SAM is balanced, which means that the sum over a row equals the sum of the corresponding column and vice versa. It means that an account provides in the row direction the same value as the equivalent of the account receives. This balance represents a closed circular economy in which values are only transferred and transformed but cannot disappear or increase in total. In a SAM, the number of activities can equal the number of commodities, i.e., each activity produces one commodity. However, it is possible that the number of activities and commodities do not equal, e.g., if activities produce more than one commodity. A SAM can be used for different types of economic analysis, e.g., for input-output analysis, multiplier analysis and in CGE model analysis, where it serves as the database for the model calibration.

For a CGE model, the SAM is used as a consistent data set, representing the reference situation (also called “base” or “base situation”). The SAM is used to calibrate the model in its functional model parameters. Each cell in a SAM filled with values correspond in the CGE model to one model variable and one equation. The information flow is simplified: the value in the SAM cell (or account) is the starting value (or initial value) for the CGE model variable. The variable is computed in the CGE model by the equation. In a correctly specified (calibrated) CGE model, the model equation computes that the variable value equals the initial value, if the model simulates the reference situation.

The consistent framework of a SAM can be extended by satellite accounts, which are added as external information to the monetary values in a SAM. Satellite accounts are not integrated into the consistent framework of the balanced SAM, but they are added as external independent "satellites" to the SAM. For example, the environmental satellite accounts can represent environmental indicators external to the SAM but assigned to the integrated SAM accounts. The values in satellite accounts can differ from the monetary values normally expressed in currencies (e.g., Euro, US Dollar). Satellite accounts can contain data quantified also in non-monetary units (e.g., kilogram, cubic meters). Thus, a satellite account allows the addition of non-monetary data types (e.g., physical information or socioeconomic information). However, since satellite accounts are external and not integrated into the consistent framework of the SAM, these data are considered in a different way than the SAM data in the CGE model.

3.1.2 Reading a SAM

We illustrate reading a SAM by the example of accounts related to agriculture and food production. Figure 8 presents an exemplary SAM with representative accounts filled with artificial values. Since the values are artificial, we indicate generic "units" (in the sense of monetary units). Values in realistic SAMs are expressed in currencies, like M €, M USD, or other local currencies. We use this exemplary SAM to explain the basic principles. For ease of orientation in the matrix, the cells with the described values are framed. We explain the monetary flows for the exemplary accounts of agricultural activities and commodities, but the reading can be applied to other accounts.

Agricultural and food production activity (aagfo, in columns) demands as intermediate input from agri-food market (cagfo, in rows) a value of 165.5 units. This intermediate commodity can include for example cereals as agricultural commodity to produce bread as food commodity. The production activity demands 42.8 and 52.6 units of the production factor labour (flabo, in row) and capital (fcapi, in row). Labour includes the labour of the baker to produce the bread; capital can be the machines used for producing the bread (e.g., an oven). The commodity market of agrifood industry (cagfo, in columns) receives 317 units from the agrifood activity (aagfo, in column). This value includes for example bread which is sold on the market to the final consumers. The sum of the row of the agrifood sector comprises all commodities the activity aagfo produces for all markets, including production to other markets than the local agrifood market. For example, aagfo produces food commodities directly for the hotel industry included in the services (cserv, in columns). This sum of all the values produced by aagfo (in rows) for all markets (cagfo to cserv, in columns) equals the sum the aagfo industry (aagfo in column) pays for the production, i.e, the demand for intermediate commodities and production factors (cagfo to fcapi, in rows). In this way, the account agrifood industry is balanced. The sum of the row aagfo and the column aagfo are equals . This balance representsthat the total value in the account aagfo does not change; the total value is only transformed. During the production process, the values of intermediate commodities and production factors (i.e., the column aagfo) are transformed into a value of commodities (i.e., the row aagfo). In simple words: the baker uses labour, oven and flour to produce bread, which has the same value as the sum of the inputs.

The households (hous, in columns) consume 378 units from the agfo commodity market (cagfo, in row). They pay the purchased commodities by their income, which they earn from selling their production factors to the factor markets. This is represented by households (hous in row) providing 1236 units labour and 1132 units capital to the factor markets (flabo and fcapi in columns). Besides consuming, households also pay 210 units taxes (called transfers) to the government (hous in column and gove in rows). Vice versa, the households receive 618 units of subsidies/transfers from the government (e.g., social aids) (gove in column and hous in rows). Taxes and subsidies on commodities and activities are represented in the intersecting cells between the rows of commodities and a tax account ("taxe"). Activities or commodities pay taxes to the tax account ("taxe" in rows). Negative values represent subsidies (as inverted taxes), e.g., the negative value of a tax, e.g., 4.3 units of subsidies in column taxe and row cagfo. International trade is represented between the commodity markets and the rest of the world agent. The agrifood activity exports 43 units to the rest of the world (i.e., cagfo in row and rowe in column). Vice versa, the agrifood commodity market imports 158 units from the rest of the world as international trade partner (i.e., cagfo in column and rowe in row).

	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo					317,39	0,13	1,32		22,58						
aoind						202,75	0,02		30,28						
aelwa						2,14	182,20	2,85	4,23						
aserv					8,36	14,31	29,46		4225,39						
cagfo	165,57	4,92	1,60	141,13								378,36		-4,30	43,09
coind	39,73	110,44	48,37	408,30								501,19		282,82	16,18
celwa	2,49	3,76	55,21	21,82								65,85	0,16		
cwast															2,85
cserv	30,42	32,41	41,14	1104,38								1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	22,89	1129,43											
fcapi	52,62	25,52	19,45	1035,01											
hous										1236,14	1132,61		617,96		
gove												210,45		641,41	
taxe	7,77	14,98	2,77	437,45	246,17	492,07	-63,75		-496,06			711,56	-819,67	-15,34	808,04
rowe					158,45	695,63	0,05		46,59						

Figure 8: Exemplary SAM with artificial values

Note: a… = activities, c… = commodities, agfo = agriculture and food industry, oind = other industries, elwa = electricity and water services, wast = waste services, serv = services, flabo = factor labour, fcapi = factor capital, hous = households, gove = government, taxe = taxes and subsidies, rowe = rest of the world

3.1.3 WEFE nexus in a SAM

The WEFE nexus pillars (water, energy, food, and environment) can be represented in different ways in a SAM. Water can be represented as a factor (a form of natural capital) and thus intersects with activities like agri-food and the energy sector. Thus, in the SAM-section "factor demand," the nexus nodes between water and energy, and water and agrifood can be represented. Water can also be represented as an intermediate commodity and as a final consumption good (e.g., as piped water) (Section 0). The intermediate demand of activities for piped water represents a WEFE nexus node between water and the corresponding industry (agri-food or electricity). Being consumed by households as a final commodity represents an indirect nexus link. Households allocate part of their income to the consumption of water. If the consumption of water changes, it can influence the consumption of agri-food or energy commodities, since households adjust their consumption budget over the commodities.

Like water is an intermediate commodity, also electricity is demanded as an intermediate commodity by industries such as agri-food and the water sector, and thus representing the nexus nodes energy-food and energy-water. Like for water, the consumption of electricity by households (or government) can influence the consumption of the other pillars (water and food) and their production. The nexus pillar ecosystems cannot be directly represented in a SAM, if environmental accounts are not integrated within the SAM as monetary accounts. In most cases, environmental accounts are not considered in the SAM as integrated accounts. Therefore, satellite accounts are used to represent the pillar ecosystems in a CGE model.

3.2 Approaches to extend a SAM

3.2.1 Overview of approaches

If the research question requires information about an account which is not represented in the SAM, the SAM needs to be extended to make the simulation of the item possible in the CGE model. Concerning WEFE nexus research question, it is often the case that available SAMs consider water in one account aggregating water production and distribution services, wastewater management services, electricity production and distribution services, gas distribution and waste management services. This aggregate account summarises accounts that, as single disaggregated accounts, would have small values, at least in industrial economies.

In many industrial economies, water as an underpaid natural resource is not necessarily recorded in the economic statistics. Thus it is often aggregated with other accounts of comparable services and small values (e.g., electricity, gas and waste management services), which provides a more traceable figure. If, in terms of monetary values, water is of small importance for the economy, it is likely that water is not considered in the construction of a national (or regional) SAM. In some countries, where water is identified as a scarce resource, and where it represents an important monetary value for production and consumption, the monetary values representing water demand and consumption might be considered explicitly in SAMs. Extending an existing SAM without differentiated information for water, can be done using different approaches. Table 19 presents an overview of different approaches to extend a SAM, aligned with different advantages (pros) and disadvantages (cons).

Building an original new SAM is a way to create the database for a CGE model . This is the most sophisticated approach and goes beyond simply extending a SAM. Based on original statistical data, a completely consistent framework can be created in which the data of interest can be fully integrated. Thus, a new SAM represents a completely consistent framework including the accounts of interest. However, building a new SAM requires lots of resources and knowledge for researching and processing statistical data. This makes building an original new SAM expensive in terms of time and workload. Therefore, this approach is preferably applied if no other recent or older SAM exists or can be made available. Furthermore, if older or recent SAM already exist, the construction of a new SAM needs to be carefully evaluated. If for a region a SAM already exist (and is in use), the contribution of a newly constructed SAM can be small. Even worse, it also can create problems to choose between the existing and the new SAM to be used for research questions and policy decision support. And finally, the existence of two or more comparable SAMs could raise the question, how much the results differ, if SAMs are used with the same CGE model. Information on how to build original SAMs are provided in different papers (e.g., Breisinger et al., 2009).

Adding new accounts to an existing SAM allows for the inclusion of the new information separately from the existing framework and requires less work than building an original new SAM. However, adding new accounts, changes the balance of the SAM. New values are added in rows and columns, and changes the overall sum (i.e., the row sums and column sum) of the SAM. Thus, adding new accounts can require an extensive rebalancing of the original parts of the SAM, meaning changing the existing SAM for rebalancing purpose. If the modification to rebalance the SAM is significant and take place in many accounts, the existing SAM may be changed in its consistency framework. Therefore, this approach is applied only if the information of interest cannot be assumed to be included in existing accounts, which would allow for the method of "Splitting existing accounts".

When **splitting accounts in an existing SAM,** the information of interest is included in aggregate accounts and can be isolated from the aggregated account. It requires to know in which accounts the information is "hidden" (i.e., aggregated). In many SAMs, the value for water is aggregated together with electricity, gas and waste management services. By splitting the data of interest from an aggregate, account allows keeping the row and columns sum unaffected for most of the accounts. Thus, the need for rebalancing is reduced to a minimum and the original values of the non-split accounts remain unchanged. This approach can be applied if a recent and suitable SAM exist, and if the information splitting the accounts can be researched. Splitting accounts requires the smallest possible modification of a SAM to include new information.

Adding satellite accounts to an existing SAM means adding new information as "external" data to the SAM, which are not integrated in the SAM. Therefore, satellite accounts can also be in different units than monetary value (e.g., physical quantity units). Thus, the extension of the SAM by satellite accounts is flexible and does not require any change to the existing SAM. Satellite accounts are often used to represent biophysical, environmental or social indicators, which are not recorded in the economic statistics as values. Information from satellite accounts is differently treated in CGE models than the information in the integrated SAM. Table 19 presents an overview of the four approaches to extending a SAM. For more detailed information on satellite accounts see European Union (2025a).

Table 19: Approaches to extend a SAM

Approach	Pros	Cons	Application
Building an original new SAM	New consistent framework including consistently the new accounts and allowing the flexibility to customise the new SAM for own need.	Requires good knowledge and skills in researching and processing the statistical data. Thus, it requires expensive in terms of time and workload. Potential validation problems is other SAMs exist.	If no other recent or older SAM is existing or can be made available.
Adding new accounts to an existing SAM	Less work than building a new SAM	Requires rebalancing and changes the existing SAM	If data are not considered (hidden) in existing accounts

Splitting accounts in an existing SAM	Does not change the overall sum of the SAM. Requires less work for rebalancing than adding new accounts. Remains close as possible to the existing SAM.	Requires that information of interests is included in the existing accounts.	If a sufficiently suitable recent SAM exist
Adding satellite accounts	Allows adding information, which do not need to be consistent with the data in the SAM Adding information in units other than monetary values (e.g., quantities). The existing original SAM is not modified	The satellite accounts are not integrated part of the SAM. Satellite accounts need to be specifically included in the CGE model	If the information of interest is not included in the SAM (e.g. environmental indicators) If the information should be different than values (e.g., physical quantities)

3.2.2 Approaches selected for the WEFE-nexus SAM for Reunion Island

To represent the **WEFE nexus pillars water, energy and food** in the REWEFE model, we chose the approach of splitting existing accounts. For the study region Reunion Island, a recent, institutionalised and official SAM exist, which is frequently updated and used in policy support and which has been made available to the project InnWater. It is the SAM-Omega (see Croissant et al., 2023). By choosing the approach of splitting accounts in the existing SAM, we reduce the work compared to building an original new SAM or adding new accounts to an existing SAM. Furthermore, we develop an extended SAM while maintaining the consistency framework of the official SAM. Building a SAM different from the official SAM can create challenges to prove the validity and value-added of the new SAM. To include the information of the **WEFE nexus pillar "ecosystems",** we add satellite accounts to the existing SAM. Satellite accounts allow theinclusion of physical information on water quantities and emissions, which can be used as indicators in the CGE model.

Figure 9 and Figure 10 illustrate the splitting of the SAM. In the original SAM (Figure 9), the aggregate accounts containing electricity, water- and wastewater services are highlighted in green for the activities (aelwa) and commodities (celwa). In Figure 10, these accounts are split into yellow cells, representing the electricity services as activities (aelec) and commodities (celec). For the SAM of REU, we split the electricity activities into 3 different activities, however, for better overview, we restrict the presentation to one activity, which in the developed SAM will represent 3 activities of electricity production. The blue cells represent the new accounts for water and sanitary activity (awasa) and two accounts for water and sanitary commodities (cwadi and cwasa). Furthermore, we split the production factor capital (fcapi) into non-water capital (fcapi) and factor capital water (fcwat).

	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo					317,39	0,13	1,32		22,58						
aoind						202,75	0,02		30,28						
aelwa						2,14	182,20	2,85	4,23						
aserv					8,36	14,31	29,46		4225,39						
cagfo	165,57	4,92	1,60	141,13								378,36		-4,30	43,09
coind	39,73	110,44	48,37	408,30								501,19		282,82	16,18
celwa	2,49	3,76	55,21	21,82								65,85	0,16		
cwast															2,85
cserv	30,42	32,41	41,14	1104,38								1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	22,89	1129,43											
fcapi	52,62	25,52	19,45	1035,01											
hous										1236,14	1132,61		617,96		
gove												210,45		641,41	
taxe	7,77	14,98	2,77	437,45	246,17	492,07	-63,75		-496,06			711,56	-819,67	-15,34	808,04
rowe					158,45	695,63	0,05		46,59						

Figure 9: Exemplary SAM before splitting with aggregated accounts highlighted in green

	aagfo	aoind	acoal	aeptr	aebio	aehyd	aewin	aesol	awasa	aserv	cagfo	coind	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcnw	fswa	fgwa	hous	gove	taxe	rowe
aagfo											317,39	0,13	0,63	0,35	0,26	0,08		22,58								
aoind												202,75	0,01	0,01	0,00	0,00		30,28								
acoal												0,92	37,35					1,81								
aeptr												0,72	29,49					1,43								
aebio												0,10	4,07					0,20								
aehyd												0,08	3,24					0,16								
aewin												0,09	3,51					0,17								
aesol												0,24	9,68					0,47								
awasa														47,86	36,55	10,45	2,85									
aserv											8,36	14,31	14,12	7,74	5,91	1,69		4225,39								
cagfo	165,57	4,92	0,34	0,26	0,04	0,03	0,03	0,09	0,82	141,13													378,36		-4,30	43,09
coind	39,73	110,44	10,13	7,99	1,10	0,88	0,95	2,63	24,69	408,30													501,19		282,82	16,18
celec	0,42	1,20	3,70	2,92	0,40	0,32	0,35	0,96	9,02	21,82													30,29	0,16		
cwadi	0,80	1,32	4,05	3,19	0,44	0,35	0,38	1,05	9,86														17,78			
csaco	1,27	1,24	3,81	3,01	0,42	0,33	0,36	0,99	9,30														9,22			
csanc																							8,56			
cwast																										2,85
cserv	30,42	32,41	8,61	6,80	0,94	0,75	0,81	2,23	21,00	1104,38													1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	4,79	3,78	0,52	0,42	0,45	1,24	11,68	1129,43																
fcnw	49,51	25,47	4,06	3,20	0,44	0,35	0,38	1,05	9,22	1035,01																
fswa	2,05	0,05							0,38																	
fgwa	1,07		0,02	0,01	0,00	0,00	0,00	0,00	0,34																	
hous																			1236,14	1128,69				621,88		
gove																					2,48	1,44	210,45		641,41	
taxe	7,77	14,98	0,58	0,46	0,06	0,05	0,05	0,15	1,41	437,45	246,17	492,07	-30,56	-16,75	-12,79	-3,66		-496,06					711,56	-819,67	-15,34	808,04
rowe											158,45	695,63	0,02	0,01	0,01	0,00		46,59								

Figure 10: Exemplary SAM after splitting with the split accounts highlighted in yellow (electricity) and blue (water and wastewater services)

3.3 Splitting strategy

3.3.1 External information and proportions derived from the SAM

Before splitting the SAM, we define a strategy according to which we split the SAM. When splitting a SAM, one inserts external data into the SAM as the consistency framework. The inserted data potentially can disturb the balance of the SAM and create the need for re-balancing the SAM. The strategy aims to keep the consistency framework of the original SAM as much as possible. This means avoiding as much as possible rebalancing, and keep as close as possible to the original SAM. To reduce the need for rebalancing, we reduce the number of SAM sections where we insert the information of new data, i.e., where we split the accounts based on external information. The selection of split sections depends on two aspects: (i) which SAM sections are relevant to be split according to the research question and (ii) for which SAM sections sufficiently good data are available. Figure 11 presents schematically the split strategy for the SAM of Reunion Island. The red market elements indicate a split based on external data, the other colours (yellow, green, blue) indicate a split based on proportions derived from the SAM. In Steps 1a and 1b, we split in rows the final and intermediate consumption of electricity, water and sanitary services based on external data. In Step 2, we apply the new proportions to split the commodities in columns. In Step 3 split the aggregate activity of electricity and water services (aelwa) into two activities: electricity production (aelec) and water and sanitary services (awasa). We assign the commodities split in Step 2 correspondingly to the activity: electricity to aelec, water and wastewater services to awasa. In Step 4, we compute the proportion of the activities in the commodity market section (resulting from Step 3). We also apply the proportions to split the activities in columns. With this strategy, there is initially only one split based on external data (in Step 1a and b), and the other cells are then derived based on the new proportions.

In Step 5, we split the factor capital into non-water capital and water capital by inserting the absolute values for the water capital and subtracting it from the total capital. We compute the proportions of the capital demand and apply these proportions to split the section factor income (Step 6). Households do not own water as a capital, they own non-water capital and labour. Thus, we convert the factor income from water (which is first assigned to households) to factor income for the government. We rebalance the SAM by reducing the transfers from government to households by the same value. By converting the factor income for water to government income, we model the assumption that water is a common natural resource. In Step 7, we use the values of the domestic supply from the external SAM GetRun-NRJ to split the energy activities in rows by their domestic supply. Then, in Step 8, we use the resulting proportions of the domestic supply to split the energy activities in columns by their intermediate demand and taxes.

Note that it is also possible to split the SAM sections based on different external sources. Factor demands can split by applying proportions derived from Input-Output-Tables and taxes can be derived by proportions derived from tax statistics. With including more external empirical data into the split of the SAM, the split might be more empirically based but, the final SAM will be de-balanced and requires a re-balancing. De- and rebalancing changes the split SAM compared to the original SAM, while reducing the inclusion of external data and continuing with splits based on SAM proportions allows staying closer to the original SAM. Thus, with limited splitting at few selected points (accounts) and consecutive splitting based on resulting values, the SAM can be kept balanced. Note also, the split of accounts by using the same proportions can result in numerical issues for the solver to find a solution. In this case, values can be slightly modified to avoid exact proportional split. If the slight modification does not help, and the proportional split causes issues, it should be evaluated if empirical split (including more external data) might be preferable.

3.3.2 SAMs resulting from the splitting

In steps 1 to 5 we, include SAM external information to split selected accounts in a first instance and then use proportions to continue splitting in consecutive steps. This procedure results in SAMs with a different disaggregation of accounts. Figure 12 presents the different SAMs resulting from a stepwise procedure. SAM01 is the initial SAM without any split applied. For the REWEFE-SAM it represents the original SAM-Omega. SAM02 results from splitting the aggregate commodity (celwa, in light green) in rows into the commodities water, sanitary services (light blue) and electricity (light yellow), i.e., by their final and intermediate commodities for which we use external data. SAM03 results from the column - wise split of the commodities based on the proportions derived from the split of consumption. SAM04 and SAM05 result from split of the activities for electricity production and water and sanitary services. After splitting the commodities and activities, we change SAM05 to SAM06 by deleting the aggregate accounts which are split (i.e., the light green rows and columns).

We continue this procedure for the SAM07 by starting an initial split (based on external or derived data), with splitting first in rows, then in columns, and then deleting the aggregated accounts which we have split. Table 20 summarises the split activities and the information used. In Section 3.4, we describe in detail the practical splitting executed. In Appendix 8.3 we provide a GAMS code for splitting an exemplarily. SAM according to the method applied. The code can be used as support material for better understanding the applied method of splitting the SAM. Furthermore, this code can also be used as a template to write a splitting routing for other case studies. The code needs to be correspondingly customised to represent the SAM data and the corresponding split strategy, if different from the strategy chosen in this study.

	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo					317	0,13	1		23						
aoind						203	0		30						
aelwa						2	182	3	4						
aserv					8	14	29		4225						
cagfo	166	5	2	141								378		-4	43
coind	40	110	48	408								501		283	16
celwa	2	4	55	22								66	0,16		
cwast															3
cserv	30	32	41	1104								1119	1053	421	31
flabo	43	41	23	1129											
fcapi	53	26	19	1035											
hous										1236	1133		618		
gove												210		641	
taxe	8	15	3	437	246	492	-64		-496			712	-820	-15	808
rowe					158	696	0,05		47						

	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo					317	0,13	1		23						
aoind						203	0		30						
aelwa						2	182	3	4						
aserv					8	14	29		4225						
cagfo	166	5	2	141								378		-4	43
coind	40	110	48	408								501		283	16
celwa	2	4	55	22								66	0,16		
cwast															3
cserv	30	32	41	1104								1119	1053	421	31
flabo	43	41	23	1129											
fcapi	53	26	19	1035											
hous										1236	1133		618		
gove												210		641	
taxe	8	15	3	437	246	492	-64		-496			712	-820	-15	808
rowe					158	696	0,05		47						

	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo					317	0,13	1		23						
aoind						203	0		30						
aelwa						2	182	3	4						
aserv					8	14	29		4225						
cagfo	166	5	2	141								378		-4	43
coind	40	110	48	408								501		283	16
celwa	2	4	55	22								66	0,16		
cwast															3
cserv	30	32	41	1104								1119	1053	421	31
flabo	43	41	23	1129											
fcapi	53	26	19	1035											
hous										1236	1133		618		
gove												210		641	
taxe	8	15	3	437	246	492	-64		-496			712	-820	-15	808
rowe					158	696	0,05		47						

	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo					317	0,13	1		23						
aoind						203	0		30						
aelwa						2	182	3	4						
aserv					8	14	29		4225						
cagfo	166	5	2	141								378		-4	43
coind	40	110	48	408								501		283	16
celwa	2	4	55	22								66	0,16		
cwast															3
cserv	30	32	41	1104								1119	1053	421	31
flabo	43	41	23	1129											
fcapi	53	26	19	1035											
hous										1236	1133		618		
gove												210		641	
taxe	8	15	3	437	246	492	-64		-496			712	-820	-15	808
rowe					158	696	0,05		47						

Figure 11: Split strategy steps 1 to 8

SAM01	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo					317,39	0,13	1,32		22,58						
aoind						202,75	0,02		30,28						
aelwa						2,14	182,20	2,85	4,23						
aserv					8,36	14,31	29,46		4225,39						
cagfo	165,57	4,92	1,60	141,13								378,36		-4,30	43,09
coind	39,73	110,44	48,37	408,30								501,19		282,82	16,18
celwa	2,49	3,76	55,21	21,82								65,85	0,16		
cwast															2,85
cserv	30,42	32,41	41,14	1104,38								1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	22,89	1129,43											
fcapi	52,62	25,52	19,45	1035,01											
hous										1236,14	1132,61		617,96		
gove												210,45		641,41	
taxe	7,77	14,98	2,77	437,45	246,17	492,07	-63,75		-496,06			711,56	-819,67	-15,34	808,04
rowe					158,45	695,63	0,05		46,59						

SAM02	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo					317,39	0,13	1,32		22,58						
aoind						202,75	0,02		30,28						
aelwa						2,14	182,20	2,85	4,23						
aserv					8,36	14,31	29,46		4225,39						
cagfo	165,57	4,92	1,60	141,13								378,36		-4,30	43,09
coind	39,73	110,44	48,37	408,30								501,19		282,82	16,18
celwa	2,49	3,76	55,21	21,82								65,85	0,16		
celec	0,42	1,20		21,82								30,29	0,16		
cwadi	0,80	1,32										17,78			
csaco	1,27	1,24										9,22			
csanc												8,56			
cwast															2,85
cserv	30,42	32,41	41,14	1104,38								1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	22,89	1129,43											
fcapi	52,62	25,52	19,45	1035,01											
hous										1236,14	1132,61		617,96		
gove												210,45		641,41	
taxe	7,77	14,98	2,77	437,45	246,17	492,07	-63,75		-496,06			711,56	-819,67	-15,34	808,04
rowe					158,45	695,63	0,05		46,59						

SAM03	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo					317,39	0,13	1,32	0,63	0,35	0,26	0,08		22,58						
aoind						202,75	0,02	0,01	0,01	0,00	0,00		30,28						
aelwa						2,14	182,20	87,34	47,86	36,55	10,45	2,85	4,23						
aserv					8,36	14,31	29,46	14,12	7,74	5,91	1,69		4225,39						
cagfo	165,57	4,92	1,60	141,13												378,36		-4,30	43,09
coind	39,73	110,44	48,37	408,30												501,19		282,82	16,18
celwa	2,49	3,76	55,21	21,82												65,85	0,16		
celec	0,42	1,20		21,82												30,29	0,16		
cwadi	0,80	1,32														17,78			
csaco	1,27	1,24														9,22			
csanc																8,56			
cwast																			2,85
cserv	30,42	32,41	41,14	1104,38												1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	22,89	1129,43															
fcapi	52,62	25,52	19,45	1035,01															
hous														1236,14	1132,61		617,96		
gove																210,45		641,41	
taxe	7,77	14,98	2,77	437,45	246,17	492,07	-63,75	-30,56	-16,75	-12,79	-3,66		-496,06			711,56	-819,67	-15,34	808,04
rowe					158,45	695,63	0,05	0,02	0,01	0,01	0,00		46,59						

SAM04	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo					317,39	0,13	1,32	0,63	0,35	0,26	0,08		22,58						
aoind						202,75	0,02	0,01	0,01	0,00	0,00		30,28						
aelwa						2,14	182,20					2,85	4,23						
aelec						2,14		87,34					4,23						
awasa									47,86	36,55	10,45	2,85							
aserv					8,36	14,31	29,46	14,12	7,74	5,91	1,69		4225,39						
cagfo	165,57	4,92	1,60	141,13												378,36		-4,30	43,09
coind	39,73	110,44	48,37	408,30												501,19		282,82	16,18
celwa	2,49	3,76	55,21	21,82												65,85	0,16		
celec	0,42	1,20		21,82												30,29	0,16		
cwadi	0,80	1,32														17,78			
csaco	1,27	1,24														9,22			
csanc																8,56			
cwast																			2,85
cserv	30,42	32,41	41,14	1104,38												1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	22,89	1129,43															
fcapi	52,62	25,52	19,45	1035,01															
hous														1236,14	1132,61		617,96		
gove																210,45		641,41	
taxe	7,77	14,98	2,77	437,45	246,17	492,07	-63,75	-30,56	-16,75	-12,79	-3,66		-496,06			711,56	-819,67	-15,34	808,04
rowe					158,45	695,63	0,05	0,02	0,01	0,01	0,00		46,59						

Figure 12: SAMs resulting from the split

Steop05

	aagfo	aoind	aelwa	aelec	awasa	aserv	cagfo	coind	celwa	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo							317,39	0,13	1,32	0,63	0,35	0,26	0,08		22,58						
aoind								202,75	0,02	0,01	0,01	0,00	0,00		30,28						
aelwa								2,14	182,20					2,85	4,23						
aelec								2,14		87,34					4,23						
awasa											47,86	36,55	10,45	2,85							
aserv							8,36	14,31	29,46	14,12	7,74	5,91	1,69		4225,39						
cagfo	165,57	4,92	1,60	0,78	0,82	141,13												378,36		-4,30	43,09
coind	39,73	110,44	48,37	23,68	24,69	408,30												501,19		282,82	16,18
celwa	2,49	3,76	55,21			21,82												65,85	0,16		
celec	0,42	1,20		8,65	9,02	21,82												30,29	0,16		
cwadi	0,80	1,32		9,46	9,86													17,78			
csaco	1,27	1,24		8,92	9,30													9,22			
csanc																		8,56			
cwast																					2,85
cserv	30,42	32,41	41,14	20,14	21,00	1104,38												1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	22,89	11,20	11,68	1129,43															
fcapi	52,62	25,52	19,45	9,52	9,93	1035,01															
hous																1236,14	1132,61		617,96		
gove																		210,45		641,41	
taxe	7,77	14,98	2,77	1,36	1,41	437,45	246,17	492,07	-63,75	-30,56	-16,75	-12,79	-3,66		-496,06			711,56	-819,67	-15,34	808,04
rowe							158,45	695,63	0,05	0,02	0,01	0,01	0,00		46,59						

SAM06

	aagfo	aoind	aelec	awasa	aserv	cagfo	coind	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo						317,39	0,13	0,63	0,35	0,26	0,08		22,58						
aoind							202,75	0,01	0,01	0,00	0,00		30,28						
aelec							2,14	87,34					4,23						
awasa									47,86	36,55	10,45	2,85							
aserv						8,36	14,31	14,12	7,74	5,91	1,69		4225,39						
cagfo	165,57	4,92	0,78	0,82	141,13											378,36		-4,30	43,09
coind	39,73	110,44	23,68	24,69	408,30											501,19		282,82	16,18
celec	0,42	1,20	8,65	9,02	21,82											30,29	0,16		
cwadi	0,80	1,32	9,46	9,86												17,78			
csaco	1,27	1,24	8,92	9,30												9,22			
csanc																8,56			
cwast																			2,85
cserv	30,42	32,41	20,14	21,00	1104,38											1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	11,20	11,68	1129,43														
fcapi	52,62	25,52	9,52	9,93	1035,01														
hous														1236,14	1132,61		617,96		
gove																210,45		641,41	
taxe	7,77	14,98	1,36	1,41	437,45	246,17	492,07	-30,56	-16,75	-12,79	-3,66		-496,06			711,56	-819,67	-15,34	808,04
rowe						158,45	695,63	0,02	0,01	0,01	0,00		46,59						

SAM07

	aagfo	aoind	aelwa	aelec	awasa	aserv	cagfo	coind	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo							317,39	0,13	0,63	0,35	0,26	0,08		22,58						
aoind								202,75	0,01	0,01	0,00	0,00		30,28						
aelec								2,14	87,34					4,23						
awasa										47,86	36,55	10,45	2,85							
aserv							8,36	14,31	14,12	7,74	5,91	1,69		4225,39						
cagfo	165,57	4,92		0,78	0,82	141,13											378,36		-4,30	43,09
coind	39,73	110,44		23,68	24,69	408,30											501,19		282,82	16,18
celec	0,42	1,20		8,65	9,02	21,82											30,29	0,16		
cwadi	0,80	1,32		9,46	9,86												17,78			
csaco	1,27	1,24		8,92	9,30												9,22			
csanc																	8,56			
cwast																				2,85
cserv	30,42	32,41		20,14	21,00	1104,38											1119,30	1053,41	421,41	30,54
flabo	42,80	41,02		11,20	11,68	1129,43														
fcapi	52,62	25,52	19,45			1035,01														
fcnw	49,51	25,47		9,48	9,22	1035,01														
fswa	2,05	0,05			0,38															
fgwa	1,07			0,04	0,34															
hous															1236,14	1132,61		617,96		
gove																	210,45		641,41	
taxe	7,77	14,98		1,36	1,41	437,45	246,17	492,07	-30,56	-16,75	-12,79	-3,66		-496,06			711,56	-819,67	-15,34	808,04
rowe							158,45	695,63	0,02	0,01	0,01	0,00		46,59						

SAM08

	aagfo	aoind	aelwa	aelec	awasa	aserv	cagfo	coind	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcapi	fcnw	fswa	fgwa	hous	gove	taxe	rowe
aagfo							317,39	0,13	0,63	0,35	0,26	0,08		22,58									
aoind								202,75	0,01	0,01	0,00	0,00		30,28									
aelec								2,14	87,34					4,23									
awasa										47,86	36,55	10,45	2,85										
aserv							8,36	14,31	14,12	7,74	5,91	1,69		4225,39									
cagfo	165,57	4,92		0,78	0,82	141,13														378,36		-4,30	43,09
coind	39,73	110,44		23,68	24,69	408,30														501,19		282,82	16,18
celec	0,42	1,20		8,65	9,02	21,82														30,29	0,16		
cwadi	0,80	1,32		9,46	9,86															17,78			
csaco	1,27	1,24		8,92	9,30															9,22			
csanc																				8,56			
cwast																							2,85
cserv	30,42	32,41		20,14	21,00	1104,38														1119,30	1053,41	421,41	30,54
flabo	42,80	41,02		11,20	11,68	1129,43																	
fcapi	52,62	25,52	19,45			1035,01																	
fcnw	49,51	25,47		9,48	9,22	1035,01																	
fswa	2,05	0,05			0,38																		
fgwa	1,07			0,04	0,34																		
hous															1236,14	1132,61	1128,69				621,88		
gove																		2,48	1,44	210,45		641,41	
taxe	7,77	14,98		1,36	1,41	437,45	246,17	492,07	-30,56	-16,75	-12,79	-3,66		-496,06						711,56	-819,67	-15,34	808,04
rowe							158,45	695,63	0,02	0,01	0,01	0,00		46,59									

Figure 12: SAMs resulting from the split (cont.1)

Setp09

	aagfo	aoind	aelec	awasa	aserv	cagfo	coind	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcnw	fswa	fgwa	hous	gove	taxe	rowe
aagfo						317,39	0,13	0,63	0,35	0,26	0,08		22,58								
aoind							202,75	0,01	0,01	0,00	0,00		30,28								
aelec							2,14	87,34					4,23								
awasa									47,86	36,55	10,45	2,85									
aserv						8,36	14,31	14,12	7,74	5,91	1,69		4225,39								
cagfo	165,57	4,92	0,78	0,82	141,13													378,36		-4,30	43,09
coind	39,73	110,44	23,68	24,69	408,30													501,19		282,82	16,18
celec	0,42	1,20	8,65	9,02	21,82													30,29	0,16		
cwadi	0,80	1,32	9,46	9,86														17,78			
csaco	1,27	1,24	8,92	9,30														9,22			
csanc																		8,56			
cwast																					2,85
cserv	30,42	32,41	20,14	21,00	1104,38													1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	11,20	11,68	1129,43																
fcnw	49,51	25,47	9,48	9,22	1035,01																
fswa	2,05	0,05		0,38																	
fgwa	1,07		0,04	0,34																	
hous														1236,14	1128,69				621,88		
gove																2,48	1,44	210,45		641,41	
taxe	7,77	14,98	1,36	1,41	437,45	246,17	492,07	-30,56	-16,75	-12,79	-3,66		-496,06					711,56	-819,67	-15,34	808,04
rowe						158,45	695,63	0,02	0,01	0,01	0,00		46,59								

SAM10

	aagfo	aoind	aelec	awasa	aserv	cagfo	coind	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcnw	fswa	fgwa	hous	gove	taxe	rowe
aagfo						317,39	0,13	0,63	0,35	0,26	0,08		22,58								
aoind							202,75	0,01	0,01	0,00	0,00		30,28								
aelec							2,14	87,34					4,23								
acoal							0,92						1,81								
aeptr							0,72						1,43								
aebio							0,10						0,20								
aehyd							0,08						0,16								
aewin							0,09						0,17								
aesol							0,24						0,47								
awasa									47,86	36,55	10,45	2,85									
aserv						8,36	14,31	14,12	7,74	5,91	1,69		4225,39								
cagfo	165,57	4,92	0,78	0,82	141,13													378,36		-4,30	43,09
coind	39,73	110,44	23,68	24,69	408,30													501,19		282,82	16,18
celec	0,42	1,20	8,65	9,02	21,82													30,29	0,16		
cwadi	0,80	1,32	9,46	9,86														17,78			
csaco	1,27	1,24	8,92	9,30														9,22			
csanc																		8,56			
cwast																					2,85
cserv	30,42	32,41	20,14	21,00	1104,38													1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	11,20	11,68	1129,43																
fcnw	49,51	25,47		9,22	1035,01																
fswa	2,05	0,05		0,38																	
fgwa	1,07			0,34																	
hous														1236,14	1128,69				621,88		
gove																2,48	1,44	210,45		641,41	
taxe	7,77	14,98	1,36	1,41	437,45	246,17	492,07	-30,56	-16,75	-12,79	-3,66		-496,06					711,56	-819,67	-15,34	808,04
rowe						158,45	695,63	0,02	0,01	0,01	0,00		46,59								

SAM11

	aagfo	aoind	aelec	acoal	aeptr	aebio	aehyd	aewin	aesol	awasa	aserv	cagfo	coind	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcnw	fswa	fgwa	hous	gove	taxe	rowe
aagfo												317,39	0,13	0,63	0,35	0,26	0,08		22,58								
aoind													202,75	0,01	0,01	0,00	0,00		30,28								
aelec													2,14	87,34					4,23								
acoal													0,92						1,81								
aeptr													0,72						1,43								
aebio													0,10						0,20								
aehyd													0,08						0,16								
aewin													0,09						0,17								
aesol													0,24						0,47								
awasa															47,86	36,55	10,45	2,85									
aserv												8,36	14,31	14,12	7,74	5,91	1,69		4225,39								
cagfo	165,57	4,92	0,78	0,34	0,26	0,04	0,03	0,03	0,09	0,82	141,13													378,36		-4,30	43,09
coind	39,73	110,44	23,68	10,13	7,99	1,10	0,88	0,95	2,63	24,69	408,30													501,19		282,82	16,18
celec	0,42	1,20	8,65							9,02	21,82													30,29	0,16		
cwadi	0,80	1,32	9,46	4,05	3,19	0,44	0,35	0,38	1,05	9,86														17,78			
csaco	1,27	1,24	8,92	3,81	3,01	0,42	0,33	0,36	0,99	9,30														9,22			
csanc																								8,56			
cwast																											2,85
cserv	30,42	32,41	20,14	8,61	6,80	0,94	0,75	0,81	2,23	21,00	1104,38													1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	11,20	4,79	3,78	0,52	0,42	0,45	1,24	11,68	1129,43																
fcnw	49,51	25,47		4,06	3,20	0,44	0,35	0,38	1,05	9,22	1035,01																
fswa	2,05	0,05								0,38																	
fgwa	1,07			0,02	0,01	0,00	0,00	0,00	0,00	0,34																	
hous																				1236,14	1128,69				621,88		
gove																						2,48	1,44	210,45		641,41	
taxe	7,77	14,98	1,36	0,58	0,46	0,06	0,05	0,05	0,15	1,41	437,45	246,17	492,07	-30,56	-16,75	-12,79	-3,66		-496,06					711,56	-819,67	-15,34	808,04
rowe												158,45	695,63	0,02	0,01	0,01	0,00		46,59								

Figure 12: SAMs resulting from the split (cont.2)

SAM12	aagfo	aoind	acoal	aeptr	aebio	aehyd	aewin	aesol	awasa	aserv	cagfo	coind	celec	cwadi	csaco	csanc	cwast	cserv	flabo	fcnw	fswa	fgwa	hous	gove	taxe	rowe
aagfo											317,39	0,13	0,63	0,35	0,26	0,08		22,58								
aoind												202,75	0,01	0,01	0,00	0,00		30,28								
acoal												0,92	37,35					1,81								
aeptr												0,72	29,49					1,43								
aebio												0,10	4,07					0,20								
aehyd												0,08	3,24					0,16								
aewin												0,09	3,51					0,17								
aesol												0,24	9,68					0,47								
awasa														47,86	36,55	10,45	2,85									
aserv											8,36	14,31	14,12	7,74	5,91	1,69		4225,39								
cagfo	165,57	4,92	0,34	0,26	0,04	0,03	0,03	0,09	0,82	141,13													378,36		-4,30	43,09
coind	39,73	110,44	10,13	7,99	1,10	0,88	0,95	2,63	24,69	408,30													501,19		282,82	16,18
celec	0,42	1,20	3,70	2,92	0,40	0,32	0,35	0,96	9,02	21,82													30,29	0,16		
cwadi	0,80	1,32	4,05	3,19	0,44	0,35	0,38	1,05	9,86														17,78			
csaco	1,27	1,24	3,81	3,01	0,42	0,33	0,36	0,99	9,30														9,22			
csanc																							8,56			
cwast																										2,85
cserv	30,42	32,41	8,61	6,80	0,94	0,75	0,81	2,23	21,00	1104,38													1119,30	1053,41	421,41	30,54
flabo	42,80	41,02	4,79	3,78	0,52	0,42	0,45	1,24	11,68	1129,43																
fcnw	49,51	25,47	4,06	3,20	0,44	0,35	0,38	1,05	9,22	1035,01																
fswa	2,05	0,05							0,38																	
fgwa	1,07		0,02	0,01	0,00	0,00	0,00	0,00	0,34																	
hous																			1236,14	1128,69				621,88		
gove																					2,48	1,44	210,45		641,41	
taxe	7,77	14,98	0,58	0,46	0,06	0,05	0,05	0,15	1,41	437,45	246,17	492,07	-30,56	-16,75	-12,79	-3,66		-496,06					711,56	-819,67	-15,34	808,04
rowe											158,45	695,63	0,02	0,01	0,01	0,00		46,59								

Figure 12: SAMs resulting from the split (cont.3)

Table 20: SAMs resulting from the splitting and information used.

Step	Start SAM	Target SAM	Split action	SAM section split	Data used for split
SAM-Omega					
01	Base SAM			Base SAM is balanced SAM provided by the project Omega	
Water and electricity ac activities and commodities					
02	Base SAM	SAM02	Commodities water and electricity in rows	Split final and intermediate demand	**Empirical data**: special reports
03	SAM02	SAM03	Commodities water and electricity in cols	Domestic supply, taxes and exports	Proportions consumption SAM_02
04	SAM03	SAM04	Activities water and electricity in rows	Assigning values of domestic supply to activities	Values domestic supply from SAM03
05	SAM04	SAM05	Activities water and electricity in cols	Intermediate demand, factor demand, taxes	Proportions consumption SAM_03
06	SAM05	SAM06	Delete split rows and cols		
Production factor water factors					
07	SAM06	SAM07	Split factor in rows: Assign water values for capital and subtract from original capital to derive non-water capital	Factor demand	**Empirical data:** cost data computed
08	SAM07	SAM08	Split factor in cols: assign factor income for water to government, increase transfers from government to	Factor income	Values factor demand from SAM07

				households by factor income from water		
	09	SAM08	SAM09	Delete rows and cols for the aggregate split factor demand capital		
Energy activities						
	10	SAM09	SAM10	Split energy activities in rows	Domestic supply of electricity	**Empirical data**: values domestic supply from SAM GetRun-NRJ
	11	SAM10	SAM11	Split energy activities in cols	Intermediate demand and taxes	Proportions of domestic supply of SAM10
	12	SAM11	SAM12	Delete rows and cols for the split aggregated electricity activities		

3.4 Splitting the SAM accounts

The objective of the REWEFE-CGE model is the representation of the interactions between economic activities concerning the WEFE nexus pillars (water, food, energy, ecosystems), with specific focus on water uses, energy production and the environmental impacts of economic activities. For representing these intersections, the final consumption (by private households) and the intermediate consumption (by activities, the industrial sectors) are of high importance. Households and activities steer with their demand the production of water, food (agriculture), energy and the corresponding environmental impacts. The data of final and intermediate consumption are publicly available for Reunion Island. Thus, these data allow to deriving proportions to split existing aggregated accounts into the differentiated accounts of interest: water- and sanitary services and energy (electricity).

3.4.1 Electricity, water and sanitary services: final and intermediate consumption

Based on regional consumption data (presented in Section 0) we derive proportions for electricity consumption, water distribution, and sanitary services (collective and non-collective). We do not disaggregate the services gas distribution and waste management. We assume that these two items are aggregated together with water distribution and sanitary services. Gas distribution is marginal and its distribution is comparable to water distribution. Waste management is comparable to wastewater management. Thus, we assume waste management is aggregated with sanitary services. Only for the part of the account, indicated as exported in the original SAM, do we assume that the exported share represents waste, since electricity, gas, and water are not exported.

Table 21 presents the proportions computed for the intermediate and final consumptions for the commodities. We assume that services and government consume only electricity and that households are the unique consumer of non-collective wastewater disposal. Households consume the largest proportion (46%) of electricity and comparable shares for piped water services and wastewater services (including the non-collective disposal). For industries, the shares of the services are nearly balanced, while for agriculture the highest proportions are attributed to the intermediate consumption of water and wastewater treatment. We apply the computed proportions to split the intermediate and final consumption of the SAM.

Table 21: Proportions computed to split the aggregate account into electricity, water and sanitary services

	Unit	Activities and agents				
		Agriculture	Industry	Services	Households	Government
Electricity (celec)	%	17	32	100	46	100
Piped water (cwadi)	%	32	35	0	27	0
Collective wastewater treatment (csaco)	%	51	33	0	14	0
Non-Collective waste-water disposal (csanc)	%	0	0	0	14	0

To validate the split SAM, we compare the computed shares with statistical data obtained from the input-output-table (IOT) statistics provided by the French National Institute of Statistics and Economic Studies (INSEE), received with the help of data experts from Reunion Island. Table 22 compares the resulting split SAM after applying the split proportions in the SAM. Since the IOT-data are available for the aggregated intermediate consumption of all industries and for wastewater services, we aggregate the values of the split SAM similarly for “all activities” and for aggregate waste services (wast). The proportion of household consumption fits well with the statistical data by being only 3 to 4 percent under and overestimated for water distribution and wastewater treatment.

For the intermediate consumption of all industries, we find significant deviation between the estimated shares and the statistical values provided by the IOT. Compared to the IOT-data, we underestimate the share of electricity by 25 percentage points and we overestimate the shares of water and waste services by 11 to 13 percentage points. In the split SAM, the share of electricity consumption is still the largest compared to the similar shares of water and waste services, but at 64% it is less pronounced than in the IOT statistical table. Although the deviations are large (-25 percentage points for electricity, and +13 to 14 percentage points for water and waste), we consider our estimation to sufficiently represent the IOT.

First, the consumption for households fits quite well with the IOT data by INSEE, proving a good validity. Second, the proportions for the intermediate consumption are comparable in terms of distribution: the highest share corresponds to electricity (although underestimated compared to IOT) and water and wastewater services are similar in magnitude (although overestimated compared to the IOT).

A correction of the values could be undertaken by inserting weighting correction factors to increase the share of electricity and decrease the shares of waste and water services. However, with such a correction we move away from our empirical base, presented Section 0. Also, without considering further information, we cannot exclude that the underestimation of electricity or the overestimation of water and waste services could even represent the reality. We derived our data based on special reports on the costs related to water and waste. We do not know if these specific data were used for the computation of the IOT by INSEE. Thus, it is possible, although being the official data to be used for constructing a SAM, the IOT underestimates the value for water and waste services. The original SAM (i.e., SAM-Omega), which is based on the IOT, considers electricity, water and wastewater services, as an aggregate account. Therefore, an under- or over-estimation of the subaccounts cannot be detected in the original SAM. Further comparison with more disaggregated statistical data (disaggregated IOT will need to be used to confirm or object this hypothesis in future work).

Table 22: Validation of splitting the consumption by comparison with input-output-table data

		Unit	Activities and agents					
			Agriculture	Industry	Services	All activities	Households	Reference
Estimated values for consumption								
	elec	M€	3.8	66.8	211.0	281.6	246.2	
	wadi	M€	7.3	71.2	0.0	78.5	147.0	
	wast	M€	11.6	67.9	0.0	79.5	151.8	
	Total consumption	M€	22.8	205.9	211.0	439.6	545.0	
Share of estimated values								
	elec	%	17	32	100	64	45	
	wadi	%	32	35	0	18	27	
	wast	%	51	33	0	18	28	
Share of statistical values (IOT)								
	elec	%				72	46	INSEE
	wadi	%				13	30	INSEE
	wast	%				14	24	INSEE
Computed values and shares in the SAM								
	elwa	M€	4.1	381.5	114.1	499.8	395.2	
	elec	M€	0.7	123.7	114.1	238.6	178.5	
	wadi	M€	1.3	132.0	0.0	133.3	106.6	
	wast	M€	2.1	125.8	0.0	127.9	110.1	
	elec	%				48	45	
	wadi	%				27	27	
	wast	%				26	28	

Difference between SAM proportions and statistical proportions (IOT)								
	elec	%p				-25	0	
	wadi	%p				13	-3	
	wast	%p.				11	4	

3.4.2 Electricity, water and sanitary services: production, taxes and imports

We **derive the production** by summing up the final and intermediate consumption, since the production supplies these values. We compute the shares of values compared to the total. We proportionally split the aggregate of production into the target accounts. We also use these proportions to split the production of other activities than aelwa. By applying this numerical split, we maintain the balance of the SAM. For most of the activities, it is not clear how the activities can provide the production even of the aggregate commodity celwa. With some values being with less than one, very small, we suspect that these could be residual values, resulting from an estimation procedure, distributing residuals over the cells. Assuming numerical consistency, we can also split them pragmatically to maintain the balance of the original SAM as much as possible. We maintain the value produced by the activity aelwa for the export market and assume that this value represents exported waste, since neither electricity nor water is exported from Reunion Island to the rest of the world.

We split **taxes, subsidies and imports** by applying the proportions of the production. This split is a numerical split that we maintain the balance of the SAM and avoid rebalancing. We consider the numerical approach as legitimate, since we can assume that all services theoretically can be taxed or subsidised. The numerical split of imports and import taxes, however, is purely numerical since only waste management might be imported. With less than 0.3 the imports and import taxes of aggregate elwa is marginal, thus, the numerical split can be maintained. We continue with splitting the aggregate activity aelwa into the target accounts aelec and awasa.

3.4.3 Splitting activities: electricity and water

For splitting the activities of electricity and water, we follow proportional shares of the SAM. We split the **production** by assigning the commodity celec to the sector aelec and the commodities awadi, asaco and asanc to the activity awasa. We assign the exported commodity “xlewa” to awasa, assuming the xelwa is exported waste and we aggregate this waste to the water service sectors. We split the **intermediate consumption** proportionally to the sum of production of both sectors aelec and awasa. With this numerical split, we maintain the balance of the SAM. We assume simply that the inputs which can be used for electricity production can also be used for the production of wasa (water distribution, sanatary and waste management). We split the **factor demand labour and capital** proportionally to the sum of production of both sectors aelec and awasa. This split is numerical to keep the SAM balanced. We split the **taxes and subsidies** proportionally to the sum of production of both sectors aelec and awasa. The proportional split applied to split the activities for electricity and water is pragmatic and allows for maintaining the balance of the SAM. However, in future work, these splits can be more refined to obtain a more empirically based split.

3.4.4 Splitting factors: surface water and ground water

We split the production factor capital fcapi into fcanw (capital not water), fgwa (factor groundwater) and fswa (factor surface water). For the splitting of the intermediate and final consumption of water and electricity, we derived proportion to split the account (See Section 3.3). For including the factor demand for raw water, we include directly the absolute value to derive separate the factors ground water and surface water from the aggregate capital. We split the factors into the two natural capital types: ground- and surface water, and non-water capital (aggregating e.g., machines, land, livestock).

The rationale behind this method is: According to INSEE, water as a natural resource is not included in the IOT by INSEE. Since the base SAM-Omega is based on INSEE data, we cannot expect that raw water be included in the accounts. Thus, a plausible strategy would be adding the computed values as new accounts into the SAM. This approach, however, would de-balance the SAM and its consistency (e.g., the ratio between labour and capital demand). To maintain the balance and consistency, we assume that raw water is included in the capital accounts and subtract the absolute value from the capital accounts. The value of raw water is small compared to the values of other more expensive capital (e.g., land, machines). Thus, the modification of the original capital account is not big, but the small modification allows representing ground- and surface water.

Based on the regional data researched for raw water extraction quantities and costs, we differentiate between groundwater (GW) and surface water (SW). The activity awasa demands groundwater and surface water, processes them and distributes them as cwadi. The activity aagri uses groundwater and a big quantity of surface water for irrigation. For the other industries, we assume that they demand only groundwater, which is normally cleaner than surface water and can be extracted without facing extraction restrictions during dry periods. Only thermic electricity production uses surface water for cooling. However, the assumptions are simplified.

Table 23 presents the split share for the activities demanding raw water as a production factor. For most of the activities, the share of raw water is with comparably small compared to the non-water capital and approximates only for the water and sanitary activities 10% of the total of capital.

Table 23: Splitting production factor water based on absolute values, share of total capital demand and values of raw water.

			Activities				
		Unit	Agriculture	Food	Other indu	Electricity	Water and sanitary
Proportions							
	Capital (non-water)	%	94.39	93.23	99.81	99.67	90.06
	Groundwater	%	0.51	6.77	0.19	0.00	4.67
	Surface water	%	5.13	0.00	0.00	0.33	5.27
Values							
	Groundwater	M €	1.21	5.17	0.30	0.00	2.01
	Surface water	M €	12.28	0.00	0.00	0.24	2.26

3.4.5 Splitting activities: energy

For representing the **production of electricity (i.e., the energy activities)** we base ourselves on the source provided by energy economists of the University of Reunion Island (see Section 2.2), which provides information on six electricity-producing activities. We apply the same principles as those used for splitting the energy and water commodities (see Section 3.3). We split the **production (the domestic supply)** according to the proportions provided by Garabedian et al. (2020). We use these proportions also for numerically splitting **the intermediate demand** of the energy activities and obtain consistency between the domestic supply and the intermediate demand. In the SAM GetRun-NrJVs (GetRun-NRJ - SAM, n.d.), the proportions of intermediate demand are partially uniform between energy activities and intermediate commodities. Uniform proportions indicate a numerical split of the intermediate demand. Thus, we assume that the numerical split based on the production of domestic supply provides a comparably good representation, being consistent within the **original SAM-Omega**.

In the SAM GetRun-NRJ, the proportions of intermediate demand are uniform for the fossil fuels (acoal and apetr) and similar for the renewable energies (aebio, aehyd, aewin, aesol). In a later step, we can aggregate the activities into three groups of electricity production activities: **fossil fuels** (thermic petrol and coal-based energy), **biomass-based energy** and other **renewable energies** (e.g., hydroelectricity, wind and solar energy). Reducing the number of activities to the minimum level of information required is a measure to reduce the complexity of the model. It is applied if a higher differentiation does not provide better information. With the differentiation into fossil fuel based (thermic electricity production), biomass based and renewable energies, we represent different WEFE nexus pillars or nodes. The food and energy node is represented by biomass-based energy, which requires agricultural inputs. The nexus node between energy and water is represented by the raw water demand **as cooling water** for thermic electricity production.

To represent the demand for cooling water by thermic electricity production, we split the factor demand for surface water. We assume that primarily **surface water is used as cooling water** (see

Section 2.1). We split the demand for surface water between the two fossil fuels according to their proportions of production. Correspondingly, we split the demand for the other production factors labour and non-water capital. We split the values for **taxes, subsidies and production** according to the same principles as the intermediate demand.

3.5 Environmental indicators

The SAM is an integrated system of monetary values representing the macroeconomy of the study region. Emission and pollution indicators represent physical information about the physical quantities emitted by activities. As physical quantities, we cannot include this information directly into the SAM, which consists of monetary values. Thus, we link this information separately to the SAM as "satellite accounts".

3.5.1 Emission satellite accounts

For integrating the **physical emissions of economic activities,** we assign the information of the satellite accounts to the corresponding entries in the SAM. "Satellite accounts provide a framework linked to the two central (national or regional) accounts, allowing attention to be focused on a certain field or aspect of economic and social life in the context of national accounts; common examples are satellite accounts for the environment, or tourism, or unpaid household work […]. [Satellite accounts] are closely linked to the main system but are not bound to employ exactly the same concepts or restrict themselves to data expressed in monetary terms. Satellite accounts are intended for special purposes such as monitoring the community's health or the state of the environment. […] Satellite accounts can meet specific data needs by providing more detail, by rearranging concepts from the central framework or by providing supplementary information. They can range from simple tables to an extended set of accounts in special areas like for e.g., environment or education." (European Union, 2025b).

Table 24 provides an overview of which items of the SAM accounts are linked to the satellite accounts, respectively the ecological indicators and the corresponding ecological indicators. The table also presents the underlying assumptions on which we define the corresponding linkage between satellite account and SAM.

Table 24: Sources of pollution and pathways considered

Origin of pollutant	Pollutant	Pathway	SAM item	Assumption
Agriculture	Active substances from crop protection	Soil erosion	Production of agricultural commodities	Agricultural production applies pesticides and thus creates emission of active substances
		Wind transport	Production of agricultural commodities	
	Nitrogen emissions from fertilisation	Emission to surface water	Production of agricultural commodities	Agricultural production applies nitrogen fertiliser and thus creates emission of nitrogen to surface and costal water
		Emission to costal water		
Urban activities	Households, industries, littering	Surface run-off	Production of other industries	Other industries produce the commodities, which are consumed by households and with then create pollution (e.g., by littering to the environment)
Traffic	Emissions from vehicles (CO2 emissions represented in non-electricity activities)	Atmosphere, Surface run-off	Production of transport sector	The transport service public and private create the emissions from vehicles
Households	Non-collective wastewater discharge	Wastewater discharge	Production of non-collective wastewater service	Households demand the service for non-collective and collective wastewater discharge and emit correspondingly the pollutants
	Collective wastewater	Wastewater discharge and treatment	Production of collective wastewater service	
	Consumption of petrol	Fossil fuel consumption	Final consumption of petrol	Households use petrol as energy source and emit correspondingly CO_2
Electricity	Thermic (petrol)	Atmosphere	Production of electricity by using petrol	The production of electricity based on fossil fuels requires burning fossil fuels which creates CO_2 emissions
	Thermic (coal)	Atmosphere	Production of electricity by using coal	
Non-electricity activities and services	Petrol intermediate consumption	Atmosphere	Activities' usage of fossil fuel petrol	The production of production and services requires burning fossil fuels which creates CO_2 emissions

To compute the **CO_2 emissions** from fossil fuel-based electricity production we apply the emission factor (Eq 1) to the value of electricity resulting as an output from the fossil fuel-based electricity sectors. We compute the CO_2 emissions according to Eq 1 as:

$$CO2eq_{aelpe} = EF_{cpete} \times XS_{cpete,aelpe} \quad , \qquad \text{Eq 1}$$

With

$CO2eq_{aelpe}$: CO2 emissions, unit in kg CO2eq,

EF_{aelpe} : emission factor of thermic electricity production with petrol as input per value output unit: kg CO2eq per EUR electricity output,

$XS_{cpete,aelpe}$: value of output electricity from petrol based thermic electricity production, unit in EUR.

To represent the CO_2 emissions from other activities (e.g., from transport, industrial production, agriculture) and from households, we apply the emission factors provided by Solaymani and Kari (2014) to the intermediate and final consumption of petrol as done in Henseler and Maisonnave (2018).

$$CO2eq_{aelpe} = EF_{cpete} \times CI_{cpete,non\text{-}aelpe} \quad , \qquad \text{Eq 2}$$

And

$$CO2eq_{aelpe} = EF_{cpete} \times C_{cpete,hous} \quad , \qquad \text{Eq 3}$$

With

$CO2eq_{aelpe}$: CO2 emissions, unit in kg CO2eq,

EF_{aelpe} : emission factor petrol usage as intermediate input or final consumptions unit: kg CO2eq per EUR,

$CI_{cpete,non\text{-}aelpe}$: intermediate consumption of petrol (cpete) by non-electricity (non-aelpe) activities, unit in EUR.

$C_{cpete,hous}$: final consumption of petrol (cpete) by households (hous), unit in EUR.

3.5.2 SEEA-W satellite accounts

To link the environmental satellite account to the SAM and to the CGE model, we organise the data according to the physical flows and emission accounts by United Nations (2012), i.e., the System of Environmental-Economic Accounting for Water (SEEA-W). Within the SEEA-W system, “the emission accounts provide information by industry, households and government on the amount of pollutants added to wastewater, which is discharged into the environment, with or without treatment, or discharged into a sewage network.” (United Nations 2012: 25). The physical supply “describes the flows of water within the economy, such as the distribution of water from one industry to another or to households, and with the rest of the world; [… and …] flows from the economy to the environment” (United Nations 2012: 25).

The physical use describes the water flows from “the environment to the economy, such as water abstraction by industries and households [… and …] flows within the economy, such as water received from other industries, households and the rest of the world.” (United Nations 2012: 25). We combine the information of the environmental satellite accounts according to SEEA-W (United Nations 2012) as a hybrid account for supply and use of water (United Nation 2012: 75). Figure 13 presents the SAM extended by the environmental satellite account according to SEEA-W at the margins of the split SAM in pink and dark blue. Note that the water quantities and emissions are assigned to the production of commodities, but the figures represent quantities, not values (like in the SAM). Water quantities are expressed in million cubic meters, emissions are expressed as tonnes of pollutant or emitted substances, or indicator. Thus, these data are still not an integrated part of the economic SAM, which consists of value data (in million euros). The linkage between the data of the environmental satellite accounts and the CGE model is explained in Section4.2￼.

	aagfo	aoind	aelec	awasa	aserv	cagfo	coind	celec	cwadi	csawa	cserv	flabo	fcapi	hous	gove	taxe	rowe	PWSU	PWUS	STOW	LOSW	EMIS
aagfo						317,4	0,1	0,6	0,3	0,3	22,6											
aoind							202,8	0,0	0,0	0,0	30,3											
aelec							2,1	87,3		47,0	4,2											
awasa									47,9	10,5												
aserv						8,4	14,3	14,1	7,7		4225,4											
cagfo	165,6	4,9	0,8	0,8	141,1									378,4		-4,3	43,1					
coind	39,7	110,4	23,7	24,7	408,3									501,2		282,8	16,2					
celec	0,4	1,2	8,6	9,0	21,8									30,3	0,2							
cwadi	0,8	1,3	9,5	9,9										17,8								
csaco	1,3	1,2												17,8			2,9					
cserv	30,4	32,4	20,1	21,0	1104,4									1119,3	1053,4	421,4	30,5					
flabo	42,8	41,0	11,2	11,7	1129,4																	
fcapi	52,6	25,5	9,5	9,9	1035,0																	
hous												1236,1	1132,6		618,0							
gove														210,5		641,4						
taxe	7,8	15,0	1,4	1,4	437,5	246,2	492,1	-30,6	-16,7	-16,4	-496,1			711,6	-819,7	-15,3	808,0					
rowe						158,4	695,6	0,0	0,0	0,0	46,6											
GWex						8,7			99,5									108,2				
SWex						44,6	0,5		324									374,5				
PWsu									142,4									142,4				
PWus						1,6			218,8					78,8					299,2			
WWsu										78,8								78,8				
PWst									0,4											0,4		
PWlo									69,3												69,3	
acti						4,9				0												4,9
mipo						0				4,8	0,2											5,1
nitr	#					2,8				1119,4												1122,1*
phos						0,2				181,4												181,6
oxyg						55,2				2292,8												2348
sups						11,6				265,3												277
CO2eq	#	#		#	#			1,7														1,7*

Figure 13: SAM extended by satellite accounts according to SEEA-W

Note: a… = activitiy (e.g., aagri = agricultural activity); c… = commody (e.g., cagri = agricultural commodity); agri = agriculture; food = food processing (incl. sugar, rhum); oind = other industry (e.g., manufacturing and refinery); cons = construction; tran = transport; admi = public administration; sefi = financial services; senf = non-financial services; celec = commodity/service electricity distribution; aelhy = activity electricity production based on renwable energy (incl. hydroenergy); aelpe = activity electricity production based on fossil energy (incl. petrol based); awasa = activity water production and distribution, sanitary services and waste management services; cwadi = commodity/service water distribution; csaco = collective sanitary services/waste water treatment; csanc = non-collective sanitary services; cwast = commodity/service waste and wastemanagemen; hous = household; gove = government; flabo = production factor labour; fcapi = production factor capital; fcanw = production factor capital, which is not water (e.g., machines, buildings, liverstock, land); fgwa = production factor capital ground water; fswa = production factor capital surface water;
GWex = groundwater extraction; SWex = surface water extraction; PWsu = piped water supply; PWus = piped water usage; WWsu = waste water supply; PWst = piped water stockage; PWlo = piped water losses; acti = (in Figure SAM extended by satellite accounts according to SEEA-W) active ingredients and other chemicals
mipo = micro polltants; nitr = nitrogen emissions ; phos = phosphate emissions ; oxyg = oxigen demand;
susp = suspende matter; CO_2eq = CO_2 emissions;
# = the emission values for nitrogen from agricultural production and for CO2 emissions from other industries than electricity are not indicated in this presentation. * = the sums of the nitrate and CO2 emissions are excluding the emissions from agricultural nitrogen emissions and CO2 emissons from non-electricity producing activities.

3.6 Constructing a river basin SAM

The construction (or the extension) of a SAM requires the availability of macroeconomic data. At national level, the data to build a SAM represent the economy of the corresponding country. These data are regularly surveyed and often being made available by statistical offices. The data include: the integrated economic accounts (to define monetary flows between agents and consumption), national input-output tables (to define intermediate demand and production), the balance of payments (to define the monetary flow between the country and the rest of the world), different types of microeconomic surveys (labour force or household surveys) and other sources informing on specific markets or agents (e.g., agricultural surveys, tax and trade statistics). In a first step, the integrated economic accounts, the national input-output-tables and the balance of payments are used to compile a macro-SAM, i.e., a consistent representation of monetary flows at an aggregated level. Micro-economic survey data and specific reports support the differentiation of the macroeconomic SAM into a SAM with different agents. Detailed instructions on how to build a country SAM are provided by Breisinger et al. (2009). For many countries, SAMs are made available, either by the national agencies or by research institutions. Research institutions are, for example, the Global Trade Analysis Project (GTAP), which constructs database for trade analysis, covering countries worldwide, or the International Food Policy Research Institute (IFPRI), which constructs SAMs for Southern countries.

At the regional level, the construction of a SAM is challenging. Constructing a regional SAM requires the availability of the economic data for the corresponding region. Economic data are surveyed for administrative regions, according to country specific regional statistic systems. In Europe, the administrative regions are differentiated according to the Nomenclature of Territorial Units for Statistics (NUTS) classification, dividing EU countries into 3 level: NUTS1 (major socio-economic regions), NUTS2 (basic regions for regional policies) and NUTS3 (small regions, for specific analysis). The NUTS classification is used for collecting, developing and harmonising European regional statistics, for socioeconomic analysis and for framing European regional policies (Eurostat, 2024). Based on the NUTS system also regional SAMs are constructed for EU regions, e.g., for NUTS2 regions in Europe (Mueller and Ferrari, 2013; Garcia Rodriguez et al., 2023). While the data to construct a regional SAM can be available (e.g., for European NUTS2 regions), the development of a regional CGE model creates the challenge of modelling trade flows and the flows of production factors between the modelled region and the neighbouring regions. If data on interregional trade flows and flows of production factors are not available, assumptions need to be made to represent the flow of trade and factors. While at national level trade statistics and stocks of production factors are statistically tracked, flows between neighbouring regions (e.g., labour commuting) are difficult to track.

Constructing SAMs for river basins extends the challenges of a regional SAM by the problem of spatial congruency of geographical and administrative borders. A river basin is a natural spatial unit that is defined by geographic borders (e.g., water bodies). In rare cases, the borders of the river basin as natural spatial unit are congruent with the borders of administrative regions. The study region Reunion Island is such a case. As a volcanic island distanced by 2000 km from the mainland (Mozambique), Reunion Island is an isolated surface which also operates as a separate river basin and ecosystem. At the same time, it is a French overseas department classified as NUTS2 region for which statistical data are collected.[3] By being significantly distanced from other regions, trade flows and migration of production factors can be assumed to be statistically tracked. Thus, Reunion Island represents an ideal study case with coinciding administrative and river basin borders and with recorded information on trade and factor flows.

For most of the river basins worldwide, the natural borders of the river basin do not coincide with the administrative borders for which economic data are collected. The administrative coverage does not equal the geographical coverage. Nevertheless, river basin SAMs can be constructed if economic data are available for the administrative regions covering approximately the surface of the river basin territory. Principally two situations apply for such cases: situation one, the river basin lies in one administrative region, but the river basin territory does not cover

[3] The statistical national office INSEE collects the statistical data for French regions based on which the regional SAM for the river basin Reunion Island can be constructed, also for other islands of the French oversea territories, see the project OMEGA (Croissant et al., 2023).

the region completely. Situation two, the river basin lies in more than one administrative region and covers partially one or more administrative regions. Eventually the river basin territory covers one or more administrative regions completely. In both situations, the administrative regions for which economic data are available over- or underestimate the territory of the river basin.

To support the task "Replication assessment throughout Europe" (Task 6.3 in WP6), we develop a questionnaire for the replication assessment, which surveys the criteria to assess the possibility of replication. The data availability for constructing a river basin SAM could be surveyed by this questionnaire. The questionnaire is presented in the Section Annex 8.3.6. Following guideline can support the analysis of data to define the possibility of deriving a river basin SAM, if macroeconomic data for administrative regions are available.

Guideline for estimation data for a river basin SAM

For analysing the regional coverage between administrative regions and river basin territory, one may use a geographic mapping software (e.g., a GIS system) and geographic reference shapefiles. One compares the geographic layers of the administrative regions with the region of the river basin and can virtually identify the coverage between river basin territory and administrative borders.

-1-Identify the smallest administrative regions, which cover the river basin territory (e.g., NUTS3 or NUTS2). Are the economic data required for building a SAM (hereafter "SAM data") available for these smallest administrative regions?

-2- Identify the next larger administrative region which covers fully or partially the river basin territory (e.g., NUTS2 or NUTS1). Are the economic data required for building a SAM available for these regions?

-3- If the SAM data are available for the smallest administrative region, aggregate the data for all these regions, which are covered completely by the river basin. And continue with 3.1.

-4- If the SAM data are only available for the next biggest region, continue with 4.1.

-3.1- Identify the regions, which are covered only partially by the river basin territory.

-3.2- Analyse as good as possible, how important the partially covered parts are and evaluate the options for how to consider these parts.

-3.2.1- If the part represents only a small share of the administrative region (e.g., <25% of the surface of the partially covered region) and if no significant economic activity takes place in this part, then consider ignoring this part. You accept the underestimation of the river basin territory because the share is small and not of economic relevance.

-3.2.2- If the part represents a large share (e.g., > 75% of the surface of the partially covered administrative region), check if the not-covered part of the administrative region is of economic relevance. If the not-covered part is not of economic relevance, consider including the full region. It can be assumed that adding a small share of an economically not relevant part only creates small overestimation.

-3.2.3- Under- or over-estimations cannot be accepted when significant economic activity takes place in ignored areas or is counted as part of the river basin even though it does not belong to the river basin. Also, excluding or including entire administrative regions or large shares can result in significant under- or over-estimations. In these cases, it may be necessary to count only a weighted part of the administrative region towards the river basin territory. To design and choose a suitable weighting requires detailed information about the region. Weighting can, for example, be based on surface area, number of inhabitants or the extent of industrial land use. Weighting regional shares can be work-intensive and might require the definition of many assumptions. Therefore, in most cases, it is preferable to accept small under- or over-estimations for efficiency, rather than pursue higher regional precision through complex weighting procedures.

-3.2.4- If it is decided which economic data from partially covered regions should be included, all data can be aggregated and defined as the river-basin SAM. Continue with 5.

-4.1- If the bigger administrative regions provide the SAM data, one evaluates by how much the SAM overestimates the data of the river basin if the full region is considered. One analyses the area which is not part of the river basin territory.

-4.1.1- If the area not covered by the river basin territory is small and without relevant economic activity (including residential activities), the area can be included, and the overestimation can be evaluated as small.

-4.1.2- If the area not covered by the river basin is small but with relevant economic activity (including residential activities), the economic data can be estimated and subtracted. For example, if a specific factory is located in the part not covered by the river basin territory, the contribution of the factory to the total region can be estimated and subtracted. If residential areas are not covered by the river basin territory, the value of households can be corrected by these data. Continue with 5.

-5- If the river basin SAM should be equipped with environmental indicators (e.g., as satellite accounts), the modeller should ensure that all sources relevant for pollution for the river basin are included. Even sources outside of the river basin territory borders can be relevant and should at least be known and mentioned. For instance, point pollution sources can emit a part of the pollutants loads into the river basin. Diffuse pollution sources (e.g., intensive agricultural production) close to the river basin border can have impacts on the water bodies in the river basin. Also, intensively water-using industries can have impacts on the bordering water body (i.e., the river basin of interest). These aspects might be difficult to quantify, however, they should at least be qualitatively considered and described as factor of potential insecurity.

-6- If the river basin territory can be at the same time covered by smaller and larger administrative regions, one can carry out the approximation both bottom-up (from smaller) and top-down (from larger) regions. The results of both approximations can be compared, and the difference used to quantify potential misestimations.

-7- While the guideline to approximate can support river basin SAM construction, it does not provide for handling interregional flows of trade and factors. The model specification must address these aspects with appropriate assumptions.

The guideline presented here supports the estimation of a SAM for a river basin territory. However, the modeller might keep in mind that the CGE model framework is designed as a policy simulation tool at the macroeconomic scale. The precision of this tool is limited due to its degree of aggregation and its complexity. It allows for economy-wide analysis, but results should be interpreted with care, focusing on directions and magnitudes rather than precise values. Keeping this in mind, before taking measures to approximate the SAM as close as possible to the natural borders of a river basin (or any other natural region), one might evaluate if a less precise regional approximation could offer sufficiently robust results for a representative CGE model. The two questions are: Does an over- or under-estimated SAM based on consistent statistical data provide results comparable to a SAM which is carefully adjusted to the borders of a natural river basin? How big is the additional value-added resulting from a better approximation to a natural river basin territory than accepting over- or under-estimated administrative regions? As CGE model results are usually presented as percentage change, a rule of thumb is that over- and underestimations not significantly affecting main proportions can be accepted.

4. DESCRIPTION OF THE SAM AND CGE MODEL

4.1 The SAM

The disaggregated WEFE-Nexus SAM (i.e., the REWEFE-SAM) represents the macroeconomic situation of the river basin Reunion Island in the base year. For information about the basic principles of a SAM, see Section 3. We analyse the structure of the REWEFE-SAM by interpreting so-called structure tables. Structure tables display the relative shares of accounts related to a specific section (e.g., contribution of activities to value added or to the production of commodities). The analysis of the structure tables provides relevant information: First, it presents the structure of the economy in the base year, identifying which accounts are important (e.g., accounts with high proportions) and which are less relevant (i.e., accounts with small proportions). It also describes the interconnections between activities, commodities and agents. Second, this analysis helps to identify values, which could be not plausible and could raise questions or require corrections. Third, knowledge of the structure of the SAM helps explain the results after scenario simulation. For instance, if during the scenario simulation, the reaction of the model is small, it can be that the shock targets an account that is of small value. The organisation of the analysis presented here follows the organisation of the CGE model equations: value added and production, income, spending and demand and trade. We also analyse the proportions of emissions as information of the satellite accounts, which are not integrated into the SAM.

4.1.1 Value added and production

In the REWEFE-SAM the value added informs about the value of factors (e.g., labour and capital) used by the activities to produce. The share of value added of the sectors related to the value of value added informs about how many factors are used in which sectors and thus, how important each activity is for the economy. In simple terms, it represents the contribution of an activity to the whole output. In the SAM, the share of value added is highest for the services (aadmi, asefi, asenf), followed by construction, transport and other industries (cons, tran, oind). Agricultural and food processing activities (aagri, afood) account for only around 2% of the total value added and are thus less relevant, and the activities of energy and water sanitary contribute with around 1% each to the total value added.

The higher the share of value added of an activity, the more production factors are used and the more factor income is paid to the factor owners (i.e., the households). Thus, impacts on activities with high share of value added can imply high impact on the income of households. Depending on their production systems, the activities use proportions of the factors labour and capital. Agricultural activities are capital-intensive because they depend a lot on land or livestock as capital for production. Food processing activities are more labour-intensive, while the factor demand is nearly balanced for electricity activities (aelhy, aelpe) and water distribution activities (awasa).

The capital demand includes the demand for non-water capital (fcanw) and the demand for the natural resources groundwater (fgwa) and surface water (fswa). The water distribution service demands 2.1% of groundwater (fgwa) and 2.4% of surface water (fswa), to produce piped water (see Section 3.4.4). For agricultural production, nearly 4% account for the usage of surface water, for irrigation in crop production (e.g., sugar cane). Only a small share accounts for groundwater (fgwa). The food processing activity demands 2% of its factors as surface water (fgwa). The other industries (oind) and electricity production (i.e., thermic production) demand small shares with only 0.1 and 0.2% of their factor demand. These figures show that the sectors most depending on raw water as a production factor are agriculture and water distribution. However, with less than 5 and 3% of sectors total factor demand, the importance of demand for raw water is relatively small.

Table 25: Structure table of value added and factor demand

	VAshare	flabo	capital	fcanw	fgwa	fswa
aagri	2.2	24.5	75.5	71.2	0.4	3.9
afood	1.8	70.1	29.9	27.9	2.0	
aoind	2.8	61.7	38.3	38.3	0.1	
aelhy	0.3	54.1	45.9	45.9		
aelpe	0.9	54.0	46.0	45.8		0.2
awasa	0.7	54.1	45.9	41.4	2.1	2.4
acons	5.9	57.6	42.4	42.4		
atran	3.9	68.0	32.0	32.0		
aadmi	32.8	71.0	29.0	29.0		
asefi	24.9	17.7	82.3	82.3		
asenf	23.9	58.4	41.6	41.6		

Note: a… = activitiy (e.g., aagri = agricultural activity); c… = commody (e.g., cagri = agricultural commodity); agri = agriculture; food = food processing (incl. sugar, rhum); oind = other industry (e.g., manufacturing and refinery); cons = construction; tran = transport; admi = public administration; sefi = financial services; senf = non-financial services; celec = commodity/service electricity distribution; aelhy = activity electricity production based on renwable energy (incl. hydroenergy); aelpe = activity electricity production based on fossil energy (incl. petrol based); awasa = activity water production and distribution, sanitary services and waste management services; cwadi = commodity/service water distribution; csaco = collective sanitary services/waste water treatment; csanc = non-collective sanitary services; cwast = commodity/service waste and wastemanagemen; hous = household; gove = government; flabo = production factor labour; fcapi = production factor capital; fcanw = production factor capital, which is not water (e.g., machines, buildings, liverstock, land); fgwa = production factor capital ground water; fswa = production factor capital surface water;

The share of intermediate demand presents how much the activities demand for each commodity (Table 26). Most of the shares appear as plausible. Thus, agricultural and food processing activities (aagri, afood) demand mostly agricultural and food commodities (cagri, cfood). Construction activities demand many other commodities (coind) and commodities/services from the construction activities (ccons), while transport (atran) demands high shares of petrol (cpete), transport (ctran) and financial services (csefi). The financial, non-financial and public services (asefi, asenf, aadmi) demand the services provided by their respective activities (csefi, csenf, cadmi). In this SAM, the intermediate demand of the electricity and water distribution activities (aelhy, aelpe, awasa) is less differentiated because we rely on the shares of the original SAM-Omega. Referring to the original values of the aggregate activities (electricity and water) allows us to maintain a balanced SAM, without modifying it too much.

However, further differentiation of these shares can be envisaged in future development of this prototype, to achieve better representativeness.

Table 26: Structure table of intermediate demand

	aagri	afood	aoind	aelhy	aelpe	awasa	acons	atran	aadmi	asefi	asenf
cagri	20.8	25.7	1.3	0.2	0.2	0.2	0.3		0.1	0.0	0.6
cfood	25.6	50.4	1.9	0.9	0.9	0.9	0.7	2.4	14.2	1.3	13.6
cpetr	6.6	0.6	1.8	2.4	2.4	2.4	1.5	17.5	2.1	0.7	1.9
coind	35.1	9.0	71.1	30.7	30.7	30.7	51.1	8.6	23.8	5.8	16.2
celec	0.2	0.3	0.8	28.6	28.6	28.6	0.2	0.3	3.1	0.7	1.3
cwadi	0.4	0.3	0.9	4.0	4.0	4.0	0.2	0.3			
csaco	0.7	0.3	0.8	5.1	5.1	5.1	0.2	0.3			
ccons	0.5	0.1	0.3	2.5	2.5	2.5	25.8	0.3	4.1	2.3	0.7
ctran	0.3	2.3	3.3	2.5	2.5	2.5	2.2	38.3	7.2	2.9	10.8
cadmi	0.4	0.6	1.2	1.9	1.9	1.9	0.8	4.4	9.4	1.4	1.8
csefi	6.2	5.7	7.8	9.0	9.0	9.0	9.4	15.2	18.3	64.5	27.1
csenf	3.1	4.7	8.8	12.2	12.2	12.2	7.8	12.6	17.7	20.5	26.1

Note: a… = activitiy (e.g., aagri = agricultural activity); c… = commody (e.g., cagri = agricultural commodity); agri = agriculture; food = food processing (incl. sugar, rhum); oind = other industry (e.g., manufacturing and refinery); cons = construction; tran = transport; admi = public administration; sefi = financial services; senf = non-financial services; celec = commodity/service electricity distribution; aelhy = activity electricity production based on renwable energy (incl. hydroenergy); aelpe = activity electricity production based on fossil energy (incl. petrol based); awasa = activity water production and distribution, sanitary services and waste management services; cwadi = commodity/service water distribution; csaco = collective sanitary services/waste water treatment; csanc = non-collective sanitary services; cwast = commodity/service waste and wastemanagemen; hous = household; gove = government; flabo = production factor labour; fcapi = production factor capital; fcanw = production factor capital, which is not water (e.g., machines, buildings, liverstock, land); fgwa = production factor capital ground water; fswa = production factor capital surface water;

The share of production shows how much the activities contribute to the production of commodities (

Table 27). The highlighted cells indicate the highest shares of each activity. These cells combine to a quasi-diagonal, indicating that the activities mainly produce their corresponding commodities. For example, the renewable and fossil fuel energy activities (aelhy, aelpe) contribute respectively 20% and 66% to the production of electricity. The water and sanitary activity contributes a major share to the production of the three commodities: water distribution, collective, and non-collective wastewater services (cwadi, csaco, csanc). The SAM contains many values, that are not easily explained by economic production logic. For instance, agriculture (aagri) is shown as contributing 4% to the production of transport. Such value, and others in this SAM, result from numerical splits in the original SAM-Omega. By defining the original SAM-Omega as the consistency framework, we try to maintain these numerical splits and values for the share of production. Like with the intermediate consumption, in further development these values can be adjusted for better accuracy.

Table 27: Structure table of production shares

	cagri	cfood	coind	celec	cwadi	csaco	csanc	ccons	ctran	cadmi	csefi	csenf
aagri	74.7	5.1	3.6			4.0		0.3	3.7	0.0	0.3	1.3
afood	1.8	28.0	3.7	0.6	0.6	4.3	0.6	0.2	3.7	0.0	0.3	0.9
aoind	1.8	5.1	45.5	0.0	0.0	4.0	0.0	0.6	4.7	0.0	0.3	1.9
aelhy	7.0	20.3	14.6	20.1		16.2		1.0	14.9	0.1	1.0	1.3
aelpe	3.5	10.2	7.6	65.5		8.1		0.8	7.5	0.1	0.5	0.8
awasa	1.8	5.1	3.6		85.5	37.8	85.5	0.2	3.7	0.0	0.3	0.3
acons	1.8	5.1	4.5	0.0	0.0	4.1	0.0	94.0	3.8	0.0	0.3	0.7
atran	1.8	5.1	3.8	0.0	0.0	4.0	0.0	0.2	46.1	0.0	0.8	0.6
aadmi	2.4	5.1	3.6	13.7	13.7	9.4	13.7	0.7	4.0	99.4	1.1	0.9
asefi	1.8	5.1	3.6	0.1	0.1	4.1	0.1	1.4	3.7	0.2	94.2	1.0
asenf	1.8	6.0	5.8	0.0	0.0	4.1	0.0	0.5	4.2	0.1	1.1	90.3

Note: a… = activitiy (e.g., aagri = agricultural activity); c… = commody (e.g., cagri = agricultural commodity); agri = agriculture; food = food processing (incl. sugar, rhum); oind = other industry (e.g., manufacturing and refinery); cons = construction; tran = transport; admi = public administration; sefi = financial services; senf = non-financial services; celec = commodity/service electricity distribution; aelhy = activity electricity production based on renwable energy (incl. hydroenergy); aelpe = activity electricity production based on fossil energy (incl. petrol based); awasa = activity water production and distribution, sanitary services and waste management services; cwadi = commodity/service water distribution; csaco = collective sanitary services/waste water treatment; csanc = non-collective sanitary services; cwast = commodity/service waste and wastemanagemen; hous = household; gove = government; flabo = production factor labour; fcapi = production factor capital; fcanw = production factor capital, which is not water (e.g., machines, buildings, liverstock, land); fgwa = production factor capital ground water; fswa = production factor capital surface water;

4.1.2 Income and spending

The share of income indicates from which source households receive their income: from labour, capital or transfers (from other households, the government or the rest of the world) (Table 28). High shares of income received from labour and capital, mean that shocks affecting the activities with high shares of value added, can impact the household income. Since households use their income to consume commodities, such shocks can induce further economic impacts, through the consumption channel. In the REWEFE-SAM, the shares of income from capital and labour are comparable at around 40%, while the income from transfers accounts for 20%. Transfers include money received from the government (e.g., social aids), from other households (e.g., private support) or from the rest of the world (e.g., remittances from abroad). Transfers are not directly impacted by shocks on the production; thus, they represent a less reactive compartment of the household income.

The government receives transfers from households and from the rest of the world, adding up to nearly 20% of its income. Its main source of income is various forms of taxation, which together sum to approximately 80%. The tax income is composed primarily of social fees (40%), with7 to 10% coming from taxes on value added, production, imports and other commodities. The government uses a share of 14.6% of income to pay for subsidies on production and commodities. Since subsidies are paid from the income, they are indicated as negative income (i.e., expenses).

Table 28: Structure table of income

	hous	gove
Labour	41.4	
Capital	37.8	
Transfer	20.8	21.1
Income fm tax of income		78.9
Tax on VA		7.8
Tax as social fees		40.7
Tax on production		12.4
Tax on commodities		10.7
Tax on imports		7.2
Subsidies on production and commodities		-14.6
Subsidies on production		-6.7
Subsidies on commodities		-7.9

Households and government use the income mainly for consumption. Households pay a share of 7% in taxes, while the government pays transfers to the households and the rest of the world (Table 29). Furthermore, households and government save and invest money, which is represented in the REWEFE-SAM as an aggregated account of savings and investments. Households save and invest nearly 24% of their income, while the government shows nearly 33% negative savings. Negative savings corresponds to debts, meaning the government lacks 33% of income to be at zero savings and zero debt.

Table 29: Structure table of spendings

	hous	gove
Consumption	69.1	42.2
Taxes	7.1	
Transfers		24.9
Saving Investment	23.8	-32.9

4.1.3 Final demand

The structure of final demand (or consumption) by households and government shows which commodities are mostly consumed by each agent (Table 30). In the REWEFE-SAM, the government has the highest demand (97%) for public administration services. Households demand major shares of financial and non-financial services (csefi, csenf) followed by other commodities (coind) and food (cfood). The final demand for electricity (celec) and water related services (cwadi, csaco, csanc) is small, at between 0.7 and 1.5% small, compared to the rest of consumption. This small share of consumption indicates that changes in the commodities of electricity or water might not result in big changes in households' overall consumption.

Table 30: Structure table of final demand

	hous	gove
cagri	4.5	
cfood	13.9	
cpetr	2.0	
coind	22.3	
celec	1.5	0.01
cwadi	0.9	
csaco	0.4	
csanc	0.4	
ccons	0.9	
ctran	5.5	
cadmi	8.7	96.6
csefi	19.9	0.09
csenf	19.1	3.3

4.1.4 Imports and exports

The structure of trade informs shows how the economy depends on imports and exports and thus provides insights into how trade flows can be affected if the commodities or their world prices are shocked. The import and export shares represent the shares of the commodities in total imports and exports (

Table 31). The most important import commodities are other commodities (coind) with approximately 70% of all imports, followed by food (cfood) and petrol (cpetr). The export shares are highest for food (cfood), for example, sugar and rum, accounting for more than 40%. The import penetration shows the proportion of imports in relation to total supply on the domestic market. The export intensity quantifies the share of exports in total domestic production. The highest shares of imports range from 5 to 7% for agri-food commodities, petrol and other commodities. Exports are most relevant for food production, at 5%.

Table 31: Structure table of international trade

	Import Share % of total imports	Export Share % of total export	Market penetration % of supply	Export intensity % of production
cagri	2	2.3	5	1.8
cfood	15.6	44.2	6.1	5.1
cpetr	6.5		6.7	
coind	70.7	17.5	6.5	3.6
celec				
cwadi				
csaco		3.1		4
csanc				
ccons	0	1.2		0.2
ctran	4	23.7	4.5	3.7
cadmi		0.4		
csefi	0.2	2.6	0.2	0.3
csenf	0.9	5	0.6	0.3

4.1.5 Pollution and emission

The analysis of the pollutants allows us to evaluate the importance of sources and paths for certain sinks. Shares of different sources are only comparable for emission into surface water, since emissions into groundwater are only considered for non-collective wastewater discharge (ACN). For agricultural emissions of active substances from agrichemicals, we find that the majority of the emissions are transported by wind and only 10% by soil (Table 32). The emissions from other economic sectors show that ACN is particularly relevant for the emission of nitrogen and phosphor into surface water (

Table 33).

Table 32: Shares of emissions from agricultural plant protection into surface water by wind or soil erosion in per cent

Pollutant/Indicator	wind	soil
s_2_4_d	90.9	9.1
s_2_4_mcpa	90.7	9.3
aclonifen	90.9	9.1
azoxystrobine	90.8	9.2
bentazone	90.8	9.2
bifenox	93.3	6.7
boscalid	91	9
chlorprophame	92.6	7.4
chlorpyriphosethyl	90.9	9.1
cypermethrine	90.9	9.1
cyprodinyl	90.9	9.1
dicofol	91	9
diflufenicanil	90.9	9.1
glyphosate	90.9	9.1
imidaclopride	90.5	9.5
iprodione	90.9	9.1
isoproturon	90.3	9.7
linuron	90.9	9.1
metaldehyde	90.9	9.1
metazachlore	90.7	9.3
nicosulfuron	88.9	11.1
oxadiazon	90.9	9.1
pendimethaline	90.9	9.1
tebuconazole	91	9
copper	90.9	9.1

Table 33: Percentage of emissions of selected pollutants by sources to surface water

Pollutant/Indicator	cfood	csaco	csanc	ctran
cadmium		51.7	14.9	33.4
chrome		88.7	11.3	
copper		28.2	65.1	6.6
lead		15.4	84.6	
nickel		68.7	31.3	
zinc		79.5	10.7	9.8
nitrogen_total*	1.4	15.7	82.9	
phosphor_total	0.6		99.4	
dbo	4.3	95.7		
dco	3.8	96.2		
mes	4.2	95.8		
Notes: dbo = * excluding nitrogen emissions resulting from agricultural production. In later revisions the nitrogen emissions from agriculture were added. dbo = Biologic oxygen demand; dco = Chemical oxygen demand; mes = suspended solids (MES);				

4.2 Specification of the CGE model

To simulate the pillars of the WEFE nexus in the REWEFE-CGE model, we specify the standard model PEP-1-1 to represent the economic situation of Reunion Island and the intersectoral linkages considering the WEFE nexus. The specification consists of four procedures for specifying the PEP-1-1 standard model (Decaluwé et al, 2013) as a Reunion Island WEFE nexus CGE model. We call the model "REWEFE-CGE model" or simply "REWEFE model". We (i) include water and sanitary services as activity and as commodities, and we represent the electricity production by different activities. We (ii) specify the production function to represent ground- and surface-water as production factors; we (iii) specify the labour market to consider unemployment and we (iv) link environmental indicators to the REWEFE-CGE model following the SEEA-W approach.

4.2.1 Specification of activities, commodities, factors and agents

For representing the WEFE nexus in the REWEFE model, we extend the model by simulating additional activities and commodities. Table 34 compares the number of items of the PEP-1-1 model in its standard specification with the specified WEFE nexus CGE model (i.e., the REWEFE-CGE model). We specify the REWEFE model to represent the items presented in Section 4.1 in the REWEFE-SAM. For the specification, we edit the model sets, the model code and the corresponding functional parameters. This step of specification does not require methodological development, because the PEP-1-1 standard model is developed to be applied to SAMs containing various activities, commodities and agents.

The specified model represents an aggregated water and sanitary sector, which produces four commodities: piped water, collective wastewater treatment services, non-collective sewage discharge, and waste services. The activity water and sanitary services demands raw water (i.e., ground- and surface-water) as production factor to produce piped water. Also, the agricultural sector and other industrial sectors use raw water as input for production (e.g., for irrigation). As primary energy, we consider the petrol as an imported commodity for intermediate and final consumption. As secondary energy, we model three activities to produce electricity from different primary energy sources: electricity based on the fossil fuels petrol and coal, on biomass and on renewable energies (e.g., wind, water, solar). Thus, via different activities, the model can choose between the sources of primary energy to produce electricity. The produced electricity is used as energy input for production (i.e., as an intermediate input) and for final consumption by households. Fossil fuel-based electricity production uses petrol and coal as inputs. The biomass-based electricity production uses biomass from agri-food production as fuel. Thus, this energy activity represents a linkage between the energy and food pillar of the WEFE-nexus. The renewable energy activity consists of other renewable energy forms besides biomass-based energy, like hydroelectricity, wind and solar energy.

Table 34:Number of items in the PEP-1-1 standard model and in the REWEFE-CGE model

	PEP-1-1 standard	REWEFE-CGE
Activities	4	11
Commodities	5	14
Labour types	2	1
Capital types	2	3
Agents	7	3

4.2.2 Specification of the production function

One important specification of the REWEFE model concerns the production function. As presented in Section 1.2.3, the production function defines the interdependencies between the production factors and the outputs of the activities. The interdependencies can schematically be presented by a production tree (see Section 1.2.3). Figure 14 presents the production with water and electricity as intermediate commodities and factors in the standard specification of the PEP-1-1 model. Raw water as capital type (W_1 and W_2) is combined with non-water in a composite of capital and water (KW). As a commodity (piped water) water is consumed as an intermediate commodity (W_3). Energy in form of electricity is consumed by the activities as an intermediate commodity. The final consumption of water and electricity by the agents (households and government), is not represented in the production tree.

The challenge of the PEP-1-1 standard specification of the production tree is, the two raw water types (W_1 and W_2) are substitutable by non-water capital (e.g., machines, land, livestock). In this formulation, the three production factors capital (K), groundwater (W_1) and surface water (W_2) can substitute each other with equal flexibility. This means that groundwater, surface water and non-water capital can substitute each other with the same flexibility. Translated into a real production situation this means, a shortage of non-water capital like machines or livestock can be substituted by ground- or surface water with the same flexibility; a shortage of groundwater (or surface water) can be substituted by non-water capital or surface water (or groundwater). While the substitution of one raw water type by the other can be realistic, the substitution of non-water capital by a raw water type and vice versa, is technically not plausible. In specific cases, technologies (as non-water capital) can partially substitute the factor demand for raw water, if, for example, the access to water pipes substitutes the extraction of water. Or a water saving technology can reduce the demand for water. However, water as a production factor cannot be substituted by another primary factors (labour or capital).

To avoid the equal substitutability between capital and raw water, we specify the production function according to Figure 15. The intermediate commodities are still included through a Leontief function, meaning that the proportion for the demand of the intermediate consumptions are fixed. One unit of output requires the same proportions of input from piped water, electricity and other intermediate commodities. For the primary production factors, we change the specification at the third level. We compose labour (L) and capital (K) into a labour-capital bundle (LK) and we compose ground water (W_1) and surface water (W_2) into a raw water bundle (WC). In this specification, ground- and surface water can substitute each other to feed into the raw water composite, while there is no substitution between capital and water, or vice versa. Furthermore, this structure maintains the substitutability between the primary factors labour and capital separated. The labour-capital bundle (LK) and the raw water composite (WC) combine into the labour-capital-water bundle (LKW). By defining a small value for the elasticity of substitution between labour-capital bundle (LK) and the raw water composite (WC) we specify that a substitution between capital-labour and raw water is hardly possible.

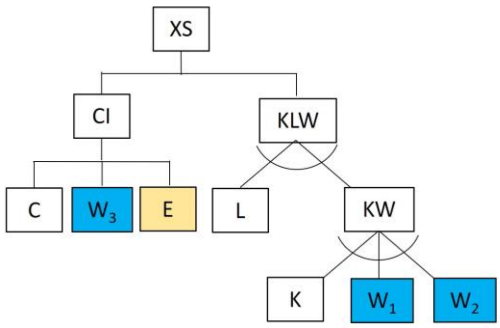

Figure 14: Production tree with water and energy in the PEP-1-1 standard model.

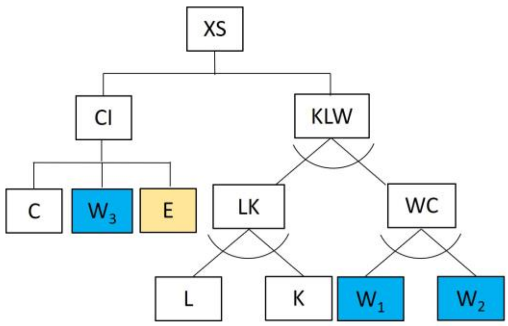

Figure 15: Production tree with water and energy in the specified REWEFE-CGE model

Note:
XS = output of production;
CI = intermediate consumption;
C = other intermediate commodities as input;
W_3 = water as intermediate commodity (e.g., piped water);
E = Energy as intermediate commodity (e.g., electricity);
KLW = value added resulting from capital (K), labour (L) and water (W);
L = labour (L) as primary production factor or as composite of different labour types;
K = capital (K) as single production factor or as composite of different capital types;
KW = as capital composite with capital (K) and water (W) as natural capital production factor;
LK = value added resulting from labour (L) and capital (K);
WC = raw water composite as a production factor;
W_1 = raw water type 1 as a production factor (e.g., groundwater);

W_2 = raw water type 2 as a production factor (e.g., surface water).

The Equation blocks 1 and 2 present selected equations specified in the production and price functions. Equation block 1 presents the specification of the PEP 1-1 standard production function and related prices in algebraic notation. Equation 2 presents the specified form in the REWEFE-CGE model. Section Annex 8.4.2 presents the complete algebraic notation of the specified REWEFE-CGE model.

Equation 1 and 2 represent the first two levels, combining the value added (VA) of the primary production factors (KLW) and intermediate demand (CI) into output (XS). Equation 9 represents the intermediate demand from activities. The three equations follow a Leontief functional form. Equations 3 and 4 represent the composition of labour and capital into value added (KLW), defined as a CES functional form. Equation 5 and 6 define the substitution between labour types and the demand for labour types from activities. In the REWEFE-CGE model, we consider only one type of labour. Therefore, in Figure 14 and Figure 15, we do not display the labour types as branches of the tree. The illustration of labour types would correspond to the branch representing different types of capital. Equation 7 represents the substitution between the different capital types: non-water capital (K), groundwater (W_1) and surface water (W_2) in a CES functional form. Equation 8 defines the activity specific demand for capital types per activity. Equation 10 and 11 define the industry unit costs and the price of industry value added, as well as the demand for composite labour and capital, which are defined by Equations 1, 3, 4, 5, 7, and 8.

Equation block 1: Production function, value added and factor prices in the PEP-1-1 standard model

Production function

Value added demand in industry *j* (Leontief)

$$VA_j = v_j XST_j \qquad \textit{Eq. 1}$$

Total intermediate consumption demand in industry *j* (Leontief)

$$CI_j = io_j XST_j \qquad \textit{Eq. 2}$$

CES between of composite labour and capital

$$VA_j = B_j^{VA}\left[\beta_j^{VA} LDC_j^{-\rho_j^{VA}} + \left(1-\beta_j^{VA}\right) KDC_j^{-\rho_j^{VA}}\right]^{-\frac{1}{\rho_j^{VA}}} \qquad \textit{Eq. 3}$$

Relative demand for composite labour and capital by industry *j* (CES)

$$LDC_j = \left\{\left[\frac{\beta_j^{VA}}{(1-\beta_j^{VA})}\right]\left[\frac{RC_J}{WC_J}\right]\right\}^{\sigma_j^{VA}} KDC_j \qquad \textit{Eq. 4}$$

CES between labour categories

$$LDC_j = B_j^{LD}\left[\beta_j^{LD} LD_{l,j}^{-\rho_j^{LD}} + (1-\beta_j^{LD}) LD_{l,j}^{-\rho_j^{LD}}\right]^{-1/\rho_j^{LD}} \qquad \textit{Eq. 5}$$

Demand for type l labour by industry *j* (CES)

$$LD_{l,j} = \left[\frac{\beta_j^{LD} WC_j}{WTI_{l,j}}\right]^{\sigma_j^{LD}} B_j^{LD\left(\sigma_j^{LD}-1\right)} LDC_j \qquad \text{Eq. 6}$$

CES between capital categories

$$KDC_j = B_j^{KD}\left[\sum_k \beta_j^{KD} KD_{k,j}^{-\sigma_j^{KD}}\right]^{-1/\sigma_j^{KD}} \qquad \text{Eq. 7}$$

Demand for type *k* capital by industry *j* (CES)

$$KD_{k,j} = \left[\frac{\beta_j^{KD} RC_j}{RTI_{k,j}}\right]^{\sigma_j^{KD}} B_j^{KD\left(\sigma_j^{KD}-1\right)} KDC_j \qquad \text{Eq. 8}$$

Intermediate consumption of commodity *i* by industry *j* (Leontief)

$$DI_{i,j,} = aij_{i,j} CI_j \qquad \text{Eq. 9}$$

Industry unit cost and factor prices

Industry *j* unit cost

$$PP_j XST_j = PVA_j VA_j + PCI_j CI_j \qquad \text{Eq. 10}$$

Price of industry *j* value added

$$PVA_j VA_j = WC_j LDC_j + RC_j KDC_j \qquad \text{Eq. 11}$$

With

VA_j: Value added of industry j

v_j: Coefficient (Leontief - value added)

XST_j: Total aggregate output of industry j

CI_j: Total intermediate consumption of industry j

io_j: Coefficient (Leontief - intermediate consumption)

LDC_j: Industry j demand for composite labour

KDC_j: Industry j demand for composite capital

B_j^{VA}: Scale parameter (CES - value added)

β_j^{VA}: Share parameter (CES - value added)

ρ_j^{VA}: Elasticity parameter (CES - value added)

RC_j: Rental rate of industry j composite capital

$LD_{l,j}$: Demand for type l labour by industry j

WC_j: Wage rate of industry j composite labour

B_j^{LD}: Scale parameter (CES - composite labour)

B_j^{KD}: Scale parameter (CES - composite capital)

$\beta_{k,j}^{KD}$: Share parameter (CES - composite capital)

σ_j^{KD}: Elasticity (CES - composite capital)

$KD_{k,j}$: Demand for type k capital by industry j

$RTI_{k,j}$: Rental rate paid by industry j for type k capital including capital taxes

$DI_{i,j}$: Intermediate consumption of commodity i by industry j

$aij_{i,j}$: Input-output coefficient

PP_j: Industry j unit cost including taxes directly related to the use of capital and labour but excluding other taxes on production

PCI_j: Intermediate consumption price index of industry j

$WTI_{l,j}$: Wage rate paid by industry j for type l labour including payroll taxes

β_j^{LD}: Share parameter (CES - composite labour)

σ_j^{LD}: Elasticity (CES - composite labour)

PVA_j: Price of industry j value added (including taxes on production directly related to the use of capital and labour)

Equation 1, 2, 7 to 10 are equivalent to equations from Equation block 2. Equation 7 and 8 refer to non-water capital instead of all capital types, as in Equation block 1. Equation 3a describes the level 2 and 3 in Figure 18 and combines water (WC) and non-water factors (LK). Equations 3.1 and 3.2 define the substitution between raw water types (W_1 and W_2) and the specific demand by activities. Equation 3.4 defines the value added resulting from labour and capital. Equation 4 defines the demand for non-water capital by activities. Equations 11.1 and 11.2 compute the price of industry value added by considering the prices and the demand for non-water capital (*PNWAT* and *NWAT*) and water (*PWAT* and *WAT*), in addition to the capital composite.

Equation block 2: Production function, value added and factor prices in the REWEFE-CGE model

Value added demand in industry *j* (Leontief)

$$VA_j = v_j XST_j \qquad \textit{Eq. 1}$$

Total intermediate consumption demand in industry *j* (Leontief)

$$CI_j = io_j XST_j \qquad \textit{Eq. 2}$$

CES between of composite water and non-water factors

$$VA_j = B_j^{VA}\left[\beta_j^{VA} WAT_j^{-\rho_j^{VA}} + \left(1-\beta_j^{VA}\right) NWAT_j^{-\rho_j^{VA}}\right]^{-\frac{1}{\rho_j^{VA}}} \qquad \textit{Eq. 3a}$$

Relative demand for composite water and non-water factors by industry *j* (CES)

$$WAT_j = \left\{\left[\frac{\beta_j^{VA}}{\left(1-\beta_j^{VA}\right)}\right]\left[\frac{PNWAT_J}{PWAT_J}\right]\right\}^{\sigma_j^{VA}} NWAT_j \qquad \textit{Eq. 3.1}$$

Demand for composite water by industry *j* (CES)

$$WAT_j = B_j^{WAT_{mult}} \times B_j^{WAT}\left[\sum_{k_{wat}} \beta_j^{WAT} KD_{k_{wat},j}^{-\sigma_j^{KD}}\right]^{-1/\sigma_j^{KD}} \qquad \textit{Eq. 3.2}$$

Demand for water type (*k_wat*) by industry *j* (CES)

$$KD_{k_{wat},j} = \left[\frac{\beta_j^{WAT} PWAT_j}{RTI_{k_{wat},j}}\right]^{\sigma_j^{KD}} B_j^{WAT\left(\sigma_j^{KD}-1\right)} WAT_j \qquad \textit{Eq. 3.3}$$

CES between of composite labour and non-water capital

$$NWAT_j = B_j^{NWAT}\left[\beta_j^{NWAT} LDC_j^{-\rho_j^{NWAT}} + \left(1-\beta_j^{NWAT}\right) KDC_j^{-\rho_j^{NWAT}}\right]^{-1/\rho_j^{NWAT}} \qquad \textit{Eq. 3.4}$$

Relative demand for composite labour and capital by industry *j* (CES)

$$LDC_j = \left\{\left[\frac{\beta_j^{NWAT}}{(1-\beta_j^{NWAT})}\right]\left[\frac{RC_J}{WC_J}\right]\right\}^{\sigma_j^{NWAT}} KDC_j$$ *Eq 4a*

CES between labour categories

$$LDC_j = B_j^{LD}\left[\sum_l \beta_j^{LD} LD_{l,j}^{-\sigma_j^{LD}}\right]^{-1/\sigma_j^{LD}}$$ *Eq. 5a*

Demand for type *l* labour by industry *j* (CES)

$$LD_{l,j} = \left[\frac{\beta_j^{LD} WC_j}{WTI_{l,j}}\right]^{\sigma_j^{LD}} B_j^{LD\left(\sigma_j^{LD}-1\right)} LDC_j$$ *Eq 6a*

CES between non-water capital categories

$$KDC_j = B_j^{KD}\left[\sum_{k_{nwat}} \beta_j^{KD} KD_{k_{nwat},j}^{-\sigma_j^{KD}}\right]^{-1/\sigma_j^{KD}}$$ *Eq. 7*

Demand for non-water capital by industry *j* (CES)

$$KD_{k_{nwat},j} = \left[\frac{\beta_{k_{nwat},j}^{KD}\ RC_j}{RTI_{k_{nwat},j}}\right]^{\sigma_j^{KD}} B_j^{KD\left(\sigma_j^{KD}-1\right)} KDC_j$$ *Eq. 8*

Intermediate consumption of commodity *i* by industry *j* (Leontief)

$$DI_{i,j,} = aij_{i,j} CI_j$$ *Eq. 9*

Prices

Industry *j* unit cost

$$PP_j XST_j = PVA_j VA_j + PCI_j CI_j$$ *Eq. 10*

Price of industry *j* value added

$$PVA_j VA_j = PWAT_j WAT_j + PNWAT_j NWAT_j$$ *Eq.11.1*

$$PNWAT_j NWAT_j = WC_j LDC_j + RC_j KDC_j$$ *Eq. 11.2*

With

$WATj$: Industry j demand for composite water (i.e., WC: water composite)

$NWATj$: Industry j demand for composite non water factors (i.e., composite LK: labour and capital)

$KDwat,j$: Demand for type water by industry j

β_j^{WAT}: Share parameter (CES - composite capital: water)

β_j^{NWAT}: Share parameter (CES - composite non water capital)

B_j^{WAT}: Scale parameter (CES - value added water composite)

$B_j^{WATmult}$: Multiplier to modify scale parameter (CES - value added water composite)

B_j^{NWAT}: Scale parameter (CES - value added non-water composite)

ρ_j^{NWAT}: Elasticity parameter (CES - composite non-water capital)

σ_j^{NWAT}: Elasticity (CES - composite non-water capital)

$PNWATj$: Rate of industry j composite non water capital (i.e., composite LK: labour and capital)

$PWATj$: Rate of industry j composite water (i.e., composite WC: ground and surface water)

4.2.3 Specification of the labour market

The PEP-1-1 standard model represents the labour market under the assumption of full employment. The labour supply is exogenously fixed based on the population that can work. The demand for labour quantity (working hours) is a variable that changes according to the model simulation. It is assumed that the value of labour demanded by the labour market equals the labour supplied (i.e., zero unemployment). This means, that the price for the factor labour, i.e., the wage rate, changes accordingly. If the labour demand increases, the wage rate increases and if the labour demand decreases, the wage rate decreases. Thus, in simulations the value of demanded labour corresponds to the value of supplied labour. This specification implies two challenges: First, simulations which change the labour demand can result in strong changes in wage rates and corresponding strong changes in value added, household income consumption, and GDP. Second, the hypothesis of full employment does not hold for many countries, since often a part of the population is unemployed.

In Reunion Island the unemployment rate is at nearly 20% (INSEE, 2024). In a situation with unemployment, the labour supply is higher than the labour demand in the reference situation. This means, that in scenarios with increased labour demand, this labour demand can be covered by workers who are unemployed and who start working again. The buffer of unemployed labour allows the model a smoother adjustment without strong changes of wage rates. To represent these effects of unemployment, we specify the REWEFE-CGE model correspondingly. Equation blocks 3 and 4 present the equations for the labour market in the standard model and in the specified REWEFE-CGE model (with unemployment). Equation 3 defines the labour market equilibrium without unemployment as labour supply equals labour demand, while the labour supply is fixed as the labour supply in the base situation (Equation 4).

Equation block 3: Labour market in the PEP-1-1 standard model

Wage rate of industry *j* composite labour

$$WC_j = \frac{\sum_l WTI_{l,j} \times LD_{l,j}}{LDC_j} \quad \textit{Eq. 1}$$

Wage rate paid by industry *j* for type *l* labour including payroll taxes

$$WTI_{l,j} = W_l(1 + ttiw_j) \quad \textit{Eq. 2}$$

Labour supply equals labour demand

$$LS_l = \sum_j LD_{l,j}$$ *Eq. 3*

Labour supply is exogenously fixed (closure rule)

$$LS_l = LSO_l$$ *Eq. 4*

With

VA_j: Value added of industry j

v_j: Coefficient (Leontief - value added)

XST_j: Total aggregate output of industry j

CI_j: Total intermediate consumption of industry j

io_j: Coefficient (Leontief - intermediate consumption)

LDC_j: Industry j demand for composite labour

KDC_j: Industry j demand for composite capital

B_j^{VA}: Scale parameter (CES - value added)

β_j^{VA}: Share parameter (CES - value added)

ρ_j^{VA}: Elasticity parameter (CES - value added)

RC_j: Rental rate of industry j composite capital

$LD_{l,j}$: Demand for type l labour by industry j

WC_j: Wage rate of industry j composite labour

$WTI_{l,j}$: Wage rate paid by industry j for type l labour including payroll taxes

β_j^{LD}: Share parameter (CES - composite labour)

σ_j^{LD}: Elasticity (CES - composite labour)

B_j^{LD}: Scale parameter (CES - composite labour)

B_j^{KD}: Scale parameter (CES - composite capital)

$\beta_{k,j}^{KD}$: Share parameter (CES - composite capital)

σ_j^{KD}: Elasticity (CES - composite capital)

$KD_{k,j}$: Demand for type k capital by industry j

$RTI_{k,j}$: Rental rate paid by industry j for type k capital including capital taxes

$DI_{i,j}$: Intermediate consumption of commodity i by industry j

$aij_{i,j}$: Input-output coefficient

PP_j: Industry j unit cost including taxes directly related to the use of capital and labour but excluding other taxes on production

PCI_j: Intermediate consumption price index of industry j

PVA_j: Price of industry j value added (including taxes on production directly related to the use of capital and labour)

We specify the labour market including unemployment by changing Equation 3 to 3a. In this specification, the labour supply is reduced by the unemployment rate (un_l), which itself is a variable. The variable unemployment rate can adjust. If the unemployment rate reaches zero, the equilibrium is in full employment. The adjustment of the wage rate (W_l) is steered by a new Equation 5. Equation 5 defines a wage curve that determines how the wage rate adjusts and prevents excessive wages fluctuations.

Equation block 4: Labour market in the specified REWEFE-CGE model

Wage rate of industry *j* composite labour

$$WC_j = \frac{\sum_l WTI_{l,j} \times LD_{l,j}}{LDC_j}$$ *Eq. 1.1*

Wage rate paid by industry *j* for type *l* labour including payroll taxes

$$WTI_{l,j} = W_l(1 + ttiw_j)$$ *Eq. 2*

Labour supply equals labour demand equilibrium with unemployment

$$LS_l(1 - un_l) = \sum_j LD_{l,j}$$ *Eq. 3a*

Labour supply is exogenously fixed (closure rule)

$$LS_l = LSO_l$$ *Eq. 4*

Wage curve

$$\frac{W_l}{PIXCON} = A_l^{WC} {un_l}^{\sigma^{WC}}$$ *Eq.5*

With

un_l: Unemployment rate by type of labour *l*

$ttiw_{l,j}$: Tax rate on type *l* worker compensation in industry *j*

W_l: Wage rate of type *l* labour

$PIXCON$: Consumer price index

σ_l^{WC}: Elasticity parameter for wage curve

A_l^{WC}: Scale parameter wage curve

σ_l^{WC}: Elasticity parameter for wage curve

A_l^{WC}: Scale parameter wage curve

4.2.4 Link between CGE and SEEA-W emission and flow accounts

Based on Equation 1 below, we compute the change in quantities of emitted water pollutant, water quality indicators and emitted GHG emissions as CO_2eq. The comparison between the base situation without any change and the situation in the scenarios provides the difference between the two situations. The presentation in percentage change makes the changes comparable and in line with the presentation of other results of the CGE model.

$$INDIperc = \frac{INDIscen - INDIbase}{INDIbase} \times 100 \quad ,$$ Eq. 1

With

INDIperc: percentage change of the indicator (unit: percent),

INDIscen: level of indicator in the scenario (scen) (unit: kg or kg CO2eq, for variables of the CGE model million Euros),

INDIbase: level of indicator in the calibrated reference base situation (base) (unit: kg or kg CO2eq, for Variables of the CGE model million Euros).

While some of the CGE model variables can be aggregated (as monetary values) and the changes can be computed for the aggregate, this possibility is limited for the environmental variables. Aggregation is only possible across the same pollutants type An aggregation over different pollutants is not interpretable because the impacts differ between the pollutants. Particularly for active substances from plant protection, the impacts on the environment are specific and heterogenous. They depend on where they are emitted to the aquatic systems – an aspect which cannot be captured with the aggregation of the CGE model. Thus, the level of emission does not inform sufficiently about the impacts and a change can only be interpreted as an increasing or decreasing pressure.

The REWEFE-CGE incorporates the ecosystems pillar by the emission of pollutants and greenhouse gas CO_2 emitted by electricity production and usage of fossil fuels. With high number of pollutants, the REWEFE model presents a considerable set of environmental indicators for different economic activities. For the prototype of the REWEFE-CGE model, we follow the InnWater project proposal by linking the physical flows and emissions accounts according to the SEEA-W accounts to the CGE model (InnWater Consortium 2022: 35). In further research the representation of the ecosystem pillar can be elaborated.

In further improvements of the REWEFE-CGE model, the set of pollutants can be extended and specified. Furthermore, the "soft" linkage between the CGE model and the indicators can be turned into a more integrated linkage. Currently, the change in values is transmitted as a shock to the indicators, assuming that the data approximate the quantity. A better approximation can be reached by attempting the differentiation between price and quantity effects. As satellite accounts, the environmental indicators are not an integrated part of the CGE model framework. In a more sophisticated formulation, environmental indicators can be integrated into the REWEFE-CGE. Following approaches can be considered for further implementation of the ecosystem pillar in the REWEFE model.

Emission trade systems: emission trading systems (ETS) are represented in CGE models to analyse impacts on emission trade markets. Thus, with emission trading systems such an implementation is already established in CGE model frameworks. However, such an implementation would require assuming and defining an emission trade system for Reunion Island, which does not correspond to the current situation. As a French department, the GHG emissions of Reunion Island are accounted with those of France and contribute only marginally to the total emissions of France. For water pollutants, trading systems do not exist and thus are difficult to justify. Other environmental aspects established in CGE models are the consideration of environmental taxes (Pigou taxes) and payments for environmental services (PES). These approaches could be considered by payments linked to the emissions. Emission trading systems and environmental taxes would need to be calibrated for the base situation.

Implementation of a **damage function**: the impacts of CO_2 emissions and pollutants can be considered in a damage curve estimating the negative impacts resulting from more emissions and pollutants. In a damage function, the denaturation of ecosystems caused by emissions and pollutants is represented as a reduction of productivity of the impacted sectors. For instance, if water pollutants reduce the quality of the marine ecosystems, the productivity of the tourism sector might reduce, since ecosystems become less attractive for tourists and consequently the tourism sector suffers. Thus, the reduction in tourism demand can represent the impacts of denaturation. In simple words: increased pollution reduces tourism output or the demand for tourism services. The challenge of this implementation is the empirical estimation of the effects (e.g., in the literature). Without quantitative empirical information of impacts of pollutant on ecosystems and ecosystems damages on activities, such an implementation is based on ad-hoc assumptions. Particularly, the impacts of pollutants are difficult to estimate, since their impacts depend on many different circumstances.

Ecosystems as **natural capital**: If the value of ecosystems as capital for activities is quantified, the ecosystems can be implemented into the CGE as a factor, natural capital, with a productive function for activities (e.g., tourism). The output of ecosystems or landscapes can also be defined as commodity (service) for residencies (as spare time service) and tourists. Negative impacts of pollution can be reflected by reducing the productivity of the capital or the demand for the commodity. Like for the estimation of a damage function, the empirical quantification of the capital value of ecosystems goes beyond the scope of this work. The work package WP5 Subtask 5.2.1 addresses the empirical estimation of "the willingness to pay for water, sanitation and environmental improvements (contingent evaluation)." (InnWater Consortium 2022: 37).

Representation of **ecosystem aspects in scenarios:** The outcome of the empirical survey of WP5 Subtask 5.2.1 can provide the perceived value of a natural capital (or natural asset), e.g., coral reefs. However, it will be challenging to derive an estimation of the capital value at the macroeconomic scale. Nevertheless, empirical data from contingent evaluation can be used to support scenario definition, through which, environmental aspects can be represented in the CGE model. The academic literature provides examples. For example, Banerjee et al. (2017) define a scenario based on results from contingent valuation surveys to simulate the demand for tourist attraction in Dominican Republic (Banerjee et al. 2017).

Representation in the **microsimulation model (MSM):** Further development of ecosystem aspects could include the differentiation of households to improve the linkage between the CGE model and the MSM. Based on available microeconomic data, the household in the CGE model could be differentiated into poor and rich, or high and low water consuming (and polluting) households. With such a differentiation, the CGE model could better consider the socioeconomic aspects, compared to the uniform representative of the current REWEFE-CGE prototype. The differentiated representation of households could also consider environmental perception and behaviour. For such an extension, microeconomic data would need to inform about environmental perception and behaviour.

4.2.5 Model closure

The macroeconomic closure (also called "model closure", "macro closure" or "closure rules") defines the macroeconomic settings in which the CGE model is embedded. The closure rules are assumptions for different parameters, which are either exogenously fixed or defined as flexible reactive model variables. Depending on which variables are exogenously fixed, the CGE model has specific options to react. Therefore, the closure rules are important for scenario design. The closures rules determine the macroeconomic situation one intends to simulate in the scenario. Thus, the closure rules need to be considered during the interpretation because they significantly drive the results. Closure rules need to be treated carefully if scenario results are compared. The comparability of scenario results requires identical closure rules. However, sometimes the closure rules can be part of a scenario assumption, which makes comparison of results across models with different closures challenging. For more information about model closure, see Laborde Debucquet and Traoré (2017).

For the prototype model of REWEFE-CGE model, we define the following macroeconomic closure rules. The world prices are endogenously fixed. We assume that Reunion Island cannot influence the world prices (small country assumption). The minimum consumption of households is fixed, meaning households do not change their minimum demand. The current account balance and the changes in stocks are fixed, which does not allow the model to adjust by these variables. Governmental spending is fixed assuming that the structure of the government and its expenses do not change. Also, all tax rates are fixed at their base levels. The supply of labour and capital are fixed. When simulating a scenario, we change the values of certain fixed variables. For example, for simulating changes in the world price, we increase the exogenously fixed world market prices. We do the same when simulating shocks to the supply of production factors or to tax rates. Finally, we define the exchange rate as fixed at a value of 1. The exchange rate serves as the numeraire, a price which is set to one, as the reference for the changes of other prices.

4.2.6 Calibration and simulation

The **calibration of a CGE model** is the process of specifying the data base (the SAM), the functional forms and the functional parameters so that the CGE model, without a simulated shock, reproduces exactly the base situation of the SAM. In other words: a calibrated CGE model exactly replicates the base situation if no shock is simulated. During the calibration process, the CGE model is run to replicate the base situation without any shock and the results are compared with the base situation. If the values of the simulated variables differ, the model is not correctly specified in its functional forms or values of functional parameter. Then, the model functions are not consistent with the model database. The correct calibration of a CGE model is an essential precondition to use the CGE model for simulating scenarios. The results of a non-calibrated model cannot be interpreted since it cannot be assumed that changes in variables follow the underlying microeconomic theory.

The practical execution of the calibration process depends on the specific CGE standard model used. For the PEP-1-1 standard model, the literature provides documents instructing the user how to calibrate the CGE model. **The model documentation** by Decaluwé et al. (2013) explains in detail all model functions and the derivation f functions calibrating the model (i.e., the calibration functions). Thus, the model documentation provides the methodological background of the PEP-1-1 standard model and the model database. The **model user guide** by Robichaud et al. (2013) provides instructions for the practical usage of the PEP-1-1 model as applied model to country study cases. The model user guide, called **Debugator** by Maisonnave et al. (2013) instructs the user on how to correctly calibrate the PEP-1-1 model and how to find and correct typical errors in the calibration process. Additionally, to these documentation and instruction materials, the research network Partnership for Economic Policy (PEP) offers the PEP standard models as downloadable template models and various documentation and instruction materials online (see PEP, 2024a). Partnership for Economic Policy (PEP) also offers online training courses in which users are taught CGE modelling at a basic or advanced level (PEP, 2024 b, c). For more details see PEP (2024 a, b, c).

The **simulation of an economic shock** changes either a functional parameter or a fixed variable to mimic a change in the economy. This shock disturbs the equilibrium of the CGE model in its calibrated situation. Despite the disturbed equilibrium, the shocked CGE model needs to be solved. This means that the values of the variables are varied until that point that the CGE model finds a new equilibrium. All the markets in the model with their supply, demand and prices, can be changed to find a new equilibrium under the shock. Thus, the change of the market variables creates changes for the interlinked agents and activities. During the solving process, a mathematical solver varies the free model variables according to solving algorithms until the new equilibrium is found. At the end of this process, the free model variables have changed their values to achieve a new model equilibrium in the shock scenario. During the solving process, all free variables are impacted with different magnitude. The change in free model variables represents the model results. The model results identify which variables change in which direction (increasing, decreasing) and in which magnitude (significantly, small, or marginally/negligibly).

The complex system of CGE models is composed of many equilibriums (markets) allowing for the change of many variables. Therefore, the resulting changes are often relatively small. CGE model adjusts with prices and quantities on the supply and demand side, whereas variables are represented in values as (i.e., quantities multiplied by prices). In comparison: in PE models, the number of variables to adjust is limited and the models are exogenously constrained. Thus, the solving space in a PE is smaller and the changes in free variables are bigger in PE models than in CGE models. The PE model has fewer variables to adjust, therefore the adjustable variables react stronger. This is the reason why, PE models often react more sensitive to economic shocks than CGE models. Also, in a PE model the variables represent physical quantities separated from prices and not combined as values combined of prices and quantities.

In CGE models, the possibility of changing the variables is so great that at many different positions (markets) the variables can be adjusted. Thus, the results are relatively small. For example, a percentage change of (plus or minus) 10% or higher is extreme for a CGE model and should alert the user. A percent change between 1% and 5% is high. A change ranging between 0.1% to 1% is for macroeconomic variables significant. Changes less than 0.1% need to be evaluated and can still be interesting to report. Depending on the variable a change of this magnitude can be considered as marginal. Changes below 0.01% are difficult to interpret. They can indicate a trend of model reaction but also can result from an overall adjustment within the CGE model. It is furthermore important, CGE model results are interpreted simultaneously and not isolated for single variables. Only the simultaneous analysis and interpretation allow understanding how the complex model system reacts and how it simulates the economic system under an economic shock.

5. SCENARIOS

To test the CGE model and to illustrate its possibilities of application, we simulate academic scenarios based on ad-hoc assumptions. We design the academic scenarios to cover different research questions of potential interest for researchers and policy makers. Scenarios for applied research and policy support require a design which is empirically founded. For the illustrative usage, we choose an ad-hoc definition. We leave the design of applied scenarios as a task for the applied policy analysis exercise within the project framework InnWater. In collaboration with stakeholders and policy experts, scenarios will be redefined during a co-modelling process (Mabugu et al., 2022). As academic scenarios, the scenario design remains simple, allowing us to limit the complexity and maintain the illustrative character. Despite their exemplary ad-hoc character, the scenarios can be starting points for discussion with stakeholders and for designing applied scenarios of direct policy interest.

5.1 Water Scarcity

The academic scenario "**Water Scarcity**" simulates a situation of water scarcity. **The availability of ground- and surface water is reduced by 5% each.** The **Water Scarcity** scenario is an academic scenario for climate change impacts, expecting that the variability in precipitation results in less filled ground- and surface water bodies. For Reunion Island, the situation of physical water scarcity may not be the most relevant scenario. However, water scarcity can also simulate that the availability of water with the required high quality is reduced (e.g., if surface water is too polluted), or that ecosystem requirements constrain the water quantity which can be extracted (e.g., if the water level of natural habitats should not be changed too much). If environmental constraints by pollution or ecosystems reduce the water availability, the economic effects and mechanisms are comparable with the situation where the availability of ground- and surface water is reduced by decreased precipitation. **To simulate the reduction of water availability, we shock the model by reducing the supply of natural capital ground- and surface water as production factors.** We defined the magnitude of 5% reduction ad-hoc for ground- and surface water. For an applied policy scenario, the shock should represent the reduction of water which can be expected in future based on empirical information. Eventually, the reduction can be specified separately for the availability of ground- and surface water. **The information derived from this academic scenario is: what happens if ground- and surface water availability is reduced by 5%.**

The magnitude of a 5% decrease in raw water availability, can be compared to a to a medium scenario according to Leroux et al. (2023) for the period 2041-2070. Leroux et al. (2023) forecast the regional annual changes in anomalies of precipitation for an optimistic and a pessimistic scenario, (i.e., the scenarios SSP1-2.6 and SSP5-8.5) (Leroux et al., 2023: 156, 158). Leroux et al. (2023) present the changes at spatial scale on a 3**x**3 km grid. Upscaling the Leroux's et al. (2023) spatial data to a Reunion Island wide change results in a change of -1.81% in the optimistic scenario (SSP1-2.6) and -7.23% in the pessimistic scenario (SSP5-8.5). For a description of how we derived the global data from the spatial data, see Appendix Section 5.1. The mean of the upscaled forecasted scenario values is -5.02% change in precipitation. If we assume that the changes in precipitation transmit directly to levels of surface and groundwater, then the ad-hoc scenario of 5% decrease in raw water is comparable to the mean of the optimistic and the pessimistic scenario, empirically simulated by Leroux et al. (2023).

5.2 Reduced Leakage

The scenario **“Reduced Leakage” simulates that the losses of piped water by leakages are reduced.** The current losses of piped water during distribution account for approximately 40%. We assume that the reasons for these leakages are partially fixed (e.g., by repair of water pipes) and thus more water reaches the consumers. **In this scenario, we shock the model by increasing the factor productivity of ground- and surface water by 0.5%.** The assumed increase in factor productivity is defined ad-hoc. For a policy relevant scenario, the potential efficiency gains would need to be empirically based (e.g., estimated by experts). Furthermore, we do not consider the costs associated with the repair of the infrastructure (e.g., fixing the water pipes). Also, these costs would need to be empirically supported and implemented within the model simulation (e.g., as increased governmental spending). Finally, scenarios which simulate spending to improve economic performance are more relevant if the simulation considers potential funding options. Such funding options could be the increase in water tariffs to cover the costs of investment via increased governmental income. **In its current design, the academic scenario Reduced Leakage informs about what happens if the productivity of the piped water sector is increased by 0.5%.**

5.3 Sewage Disposal

Scenario “Sewage Disposal” simulates that households which discharge their wastewater by non-collective installations switch to collective wastewater discharge. Non-collective (or autonomous) sewage disposal installations emit more pollutants than the collective sewage disposal systems. Thus, shifting households from autonomous to collective sewage disposal systems reduces the emissions of pollutants. **To simulate the scenario Sewage Disposal, we shock the model by increasing the tariff for non-collective sewage disposal by 5% and decreasing the tariff for collective sewage disposal by 5%.** The change in tariffs incentivises the households to switch from autonomous to collective systems. Like in the other academic scenarios, we define the increase of the tariff ad-hoc. We also do not consider the cost for the infrastructure required to connect the households with autonomous sewage discharge to the collective discharge system. For an applied policy scenario design, the expected costs for the installation of connections to collective systems and the realistic magnitude of change in tariffs need to be empirically supported. As for the scenario “Reduced Leakage” the analysis of potential funding mechanism are of policy interest. **In its current design the scenario Sewage Disposal informs about what happens if the tariff for non-collecting discharge systems is increased by 5% and the tariff for collective discharge system is decreased by 5%.**

5.4 Water Price Increase

The Scenario “Water Price Increase” simulates an increase in piped water tariff by 5%. Increasing the water tariff can have two objectives. First, to increase the efficiency of usage fand to reduce its consumption. Since water is often under-priced, the consumer does not undertake measures to save water. Second, increasing a tariff increases the income for the government and creates fiscal resources which can be reallocated. The tariff of piped water is perse a relevant topic. The current tariff's model does not incentive households to save water and technical installations in households do not facilitate water saving behaviour. The applied policy scenario needs to be refined by empirically-based magnitudes of water tariffs and eventual reallocation mechanisms (if possible). **Thus, the current design of the scenario Water Price Increase simulates the increase in piped water tariff and informs about the impacts if the piped water price is increased by 5%.**

5.5 Oil Price Increase

The scenario Oil Price Increase simulates an increase in world crude oil price by 5%. Increases in world oil prices impact the whole economy via the activities using petrol as input for production and households using petrol for mobility. The increase in world oil prices illustrates the WEFE nexus linkages between energy, the economy and other WEFE nexus pillars: water, food and ecosystems. Increasing world crude oil prices is a global price shock that frequently occurs and even at higher magnitudes (e.g., due to the Russia-Ukraine war). As an oil importer, Reunion Island depends on the world energy trade. As for the other academic scenarios, the magnitude of the price shock is defined ad-hoc and would need to be empirically supported. For a more realistic representation of a global shock (e.g., a global trade shock) also the increase of other world market prices can be simulated (e.g., increasing world food and agricultural products). **In its current definition, the scenario Oil Price Increase informs about what happens if world oil prices increase by 5%.**

5.6 Scenario implementation and refinement

Table 35 provides an overview of the scenarios with their technical implementation in the model and potential extensions to represent more applied scenarios. To simulate the academic scenarios, we shock different model parameters by modifying their value from the value they have obtained in the reference situation (the calibrated situation). Where *KD* represents the availability of capital ground- and surface water, *B_WAT* represents the capital productivity in the activity awasa, *ttic* represents tariff rates for commodities, which are increased or reduced and *PWX* and *PWM* represent the world market prices for exports and imports. The potential refinements indicate the aspects to be considered to make the scenarios more applied and relevant for research and policy making. We also indicate potential data sources to support the scenario refinement and guide the scenario design.

In the report « Etat des lieux 2019 : Analyse prospective des pressions et des enjeux à l'horizon 2027 » The Office de l'eau Réunion presents estimations on scenario impacts and cost estimates (Office de l'Eau, 2019d). Thus, this report can provide empirical data to refine the scenarios to make them more applied. As it was published in 2019, since then scenario impacts, cost estimates and research priorities could have changed. Therefore, the refinement of the scenarios towards an applied policy relevant tool is better supported by policy experts and stakeholders in a stakeholder-oriented co-modelling process (Mabugu et al., 2023).

Table 35: Overview of the academic scenarios with implementation and potential extensions.

	Shocked parameter	Ad-hoc defined shock in code	Potential refinement	Example for data source for empirical scenarios
Water Scarcity	Factor supply	KD.fx("fgwa") × 0.95; KD.fx("fswa") × 0.95;	Empirically based reduction specific for ground- and surface water	· Office de l'Eau (2019d: 16) Decrease of precipitation in South-East of or REU by 6 to 8%. · Office de l'Eau (2019d: 39) Estimated irrigation water demand increase by 2030 by 1.6 times · Office de l'Eau (2019d: 36): Reduction of consumption by 5% · Leroux et al. (2023): Anomaly in precipitation on REU between -2% and -7% in the period 2040-2070.
Reduced Leakage	Productivity of capital	B_WAT("awasa") × 1.075; shifter of scaling increases factor productivity by 0.5%	Empirically based increase of productivity; estimated costs for improving performance;	· Office de l'Eau (2019d: 70) water distribution system: 280 M€;
Sewage Disposal	Tax rate on commodity csaco & csanc	ttic.fx("csaco") - 0.05; ttic.fx("csanc") + 0.05;	Empirically based tariff changes; estimated costs for connection of households to collective systems; funding mechanism;	· Office de l'Eau (2019d: 77-80) investment for improving collective sewage disposal = 270 M€; · Office de l'Eau (2019d: 81) Investment for improving non-collective sewage disposal= 200 M €; · Office de l'Eau (2019: 51-54): number of users of non-collective sewage disposal
Water Price Increase	Water tariff for pipded water	ttic.fx("cwadi") + 0.05;	Empirically based tariff changes, funding mechanism	· Office de l'Eau (2019d: 82-83): Estimation of need for subventions; Office de l'Eau (2019: 68-69): Estimation of need for 1.7 G€;
Oil Price Increase	World market price for crude oil	PWX.fx('cpetr') × 1.05; PWM.fx('cpetr') × 1.05;	Empirically based increase of world market prices; increase of prices of other commodities (e.g., food, agricultural products)	· World Bank (2023b) · OECD/FAO (2023)

6. RESULTS AND DISCUSSION

In Section 6, we analyse and discuss the results of the simulated scenarios **per indicators** for all scenarios. In applied policy analysis, this way of presenting results is used if alternative and comparable scenarios are compared, e.g., to assess which alternative policy is (more or less) favourable. If the scenarios are independent and based on different story lines (like the academic scenarios), the results are usually analysed **per scenario** for all indicators consecutively. Analysing per scenario allows us to maintain the context of each scenario story line and avoids mixing different scenario assumptions. By presenting the results per indicator, we compare scenarios which are not linked to each other, allowing us to (i) illustrate the changes of the indicators and (ii) present comparatively the model reactions by different scenarios. Thus, we follow an illustrative approach to demonstrate and explain how the model reacts under different shocks and how to interpret the indicators.

6.1 Macroeconomic indicators

The changes in macroeconomic (aggregated) indicators inform about how the economy adjusts to the economic shocks. We sort the description of the result according to the illustrative purpose.

6.1.1 Oil Price Increase

Figure 16 presents the changes of the macroeconomic indicators in the simulated scenarios as a percentage change compared to the base. The percentage change informs on the reaction of the economy at an aggregate scale if the scenario shock applies. The indicator “GDP real” represents the change in real GDP as an aggregated indicator for the reaction of the whole economy. The change in GDP is with -0.3% highest for the scenario **Oil Price Increase**, where world crude oil price increase. Reunion Island depends as an oil importer strongly on the world oil prices. Increasing world prices create increased production cost for all industries using oil (or petrol) as a direct source of energy (e.g., transportation) and as an input for production, i.e., petrol based thermic electricity production. Thus, from the production side, the increased petrol price impacts the economy negatively through all petrol- and electricity-using activities. Furthermore, the price increase impact households via the consumption of petrol for private transport and electricity as energy.

The prices for commodities increase if their production depends on petrol. Thus, the households reduce their total consumptions of these commodities but also other commodities. The households pay more for petrol and electricity and can afford less consumption of other commodities. This effect is indicated: the indicator “household consumption” decreases by about 0.2%. Decreased household consumption results in decreased demand for all commodities and less overall domestic demand from the producing activities. The activities reduce their production (driven both by increased energy costs and decreased demand). The decrease in production is indicated by the change in output, intermediate demand and value added, decreasing by 0.15%, 0.2% and 0.1%. The indicator value added presents the change of the combined demand for production factors capital and labour. Since production reduces, also the demand for labour reduces. A decreased labour demand means a decreased employment of workers and in a decrease in wages. More workers become unemployed and employed workers earn less. These reactions of the labour markets are reflected by an increase in the indicator unemployment rate by 0.8%[4]. Lost jobs and decreased wages, reduce the household income. Reduced household income weakens household consumption. The decreased demand for production factors (e.g., crude oil) results in a decrease in imports (-0.3%), while the reduce production results in a decrease of exports (-0.2%). In summary, all these negative impacts caused by the increase in world crude oil prices explain the overall negative impact on the whole economy indicated by the decreasing GDP.

6.1.2 Water Price Increase

While the scenario **Oil Price Increase** creates by the increase of world oil price a strong impact on all activities, markets and households, the scenario of **Water Price Increase** results in less strong impacts on less indicators. **Water Price Increase** simulates an increase in water tariff by 5%, meaning the price of piped water increases as an intermediate commodity (used as input factor for production) and as final consumption commodity by households. In scenario **Oil Price Increase**, the price of the input and final commodity petrol increases the production costs and household expenditures. In **Water Price Increase**, the higher water price increases the production cost for activities, reduces output, value added and exports on the supply side. Reduced production decreases the demand for labour and increase the unemployment rate. Households face reduced employment and earn less income. Thus, also the demand side decreased in terms of consumption and imports. Different to the increased price of petrol (in scenario **Oil Price Increase**) the impact of price increase for piped water is less strong, because piped water represents less costs as intermediate commodity for the industries than crude oil.

The different model reaction can be explained by information provided in the analysis of the structure tables presented in Section 4.1. Table 26 shows that intermediate consumption of water ranges between 0.2 to 0.9% for most of the activities, while share of petrol accounts between 2 to 17% for most of the activities. Also, the share in piped water of household consumption (see Table 30) is 0.9%, smaller than for petrol (2%) or for electricity (1.5%), summing up to 3.5% of final consumption commodities affected by the petrol price. Another difference between scenarios **Water Price Increase** and **Oil Price Increase** is that the tariff for piped water is increased through taxes. The increased taxes, paid by both activities and households for the piped water, generate additional tax income for the government. Therefore, governmental income increases by 0.25% and increases the budget for the government. In applied policy assessments, the question of interest would be how the government could spend this money additionally received from the consumers. The money received could be used to compensate for the negative economic impacts. Tax income could be reallocated to support policies, (e.g., installing consumer subsidies) or by compensating for negative external impacts, e.g., environmental impacts.

[4] The indicator unemployment is indicated as a rate (i.e., percent of population unemployed). Since the change in the unemployment rate is a change between two rates, the more consistent unit to describe the change is percentage points. To simplify the analysis, we describe in this paper, the change of unemployment rate in percent changes like the other indicators.

6.1.3 Sewage Disposal

In the scenario **Sewage Disposal** a reallocation is roughly mimicked by increasing the tariff for the more polluting usage of non-collective sewage disposal installations and decreasing the tariff for collective wastewater treatment. This price incentivises households to switch from the more polluting and more expensive autonomous disposal system to the less polluting collective disposal system. However, the money the government spends on reducing the tariff for the collective discharge creates more losses in the governmental income than the increase in tariffs for the non-collective discharge. Therefore, the net-effect on the governmental income is negative and governmental income, decreases by nearly 0.1%. Nevertheless, the general impacts of this policy are neutral to positive: slightly increasing GDP, production, and exports and decreasing unemployment. This effect appears if government injects money into the economy and reduces the governmental income, which is missing for public spending (e.g., public services). Besides the economic results for this scenario the development of the environmental indicators is of interest, presented in Section 6.5.

6.1.4 Water Scarcity and Reduced Leakage

While the scenarios **Sewage Disposal, Water Price Increase and Oil Price Increase** shock tariff rates and international trade, the scenarios **Water Scarcity** and Reduced Leakage shock the production side by factor scarcity and factor productivity. The magnitudes of the two simulated shocks cause marginal changes, which hardly can be identified at the macroeconomic (i.e., aggregated) level. The explanation for this weak reaction is similar to the explanation for the smaller impact of water price increase, compared to the petrol price increase. In **Water Scarcity,** the production factors ground- and surface water reduce by 5%, while in **Reduced Leakage** the productivity of both factors increases by 0.5%. The shocks are presenting opposite directions. In the **Water Scarcity** scenario, the supply of the production factor water reduces and increases the price for of the production factor. In **Reduced Leakage,** lower quantities of raw water are required to produce the same quantity of piped water. As a reaction, the factor prices for raw water decrease. While **Water Scarcity** impacts the economy negatively, the overall impacts of the **Reduced Leakages** on the economy are positive, caused by more productive production factors of raw water.

The changes resulting from the negative shock of water scarcity and the positive shock of increased productivity are small. These small changes, are due to the small share that ground- and surface water represent among all production factors. Table 25 shows that ground- and surface water contribute to the value added of agriculture, water services and food industry by 4 to 5% and 2%. respectively Thus, for the activities where water is of highest relevance as a production factor, the share of contribution to the value added is relatively small compared to other capital and labour. Thus, the impact on the production is limited. Also, the impacts of the commodity piped water carry over only modestly. Piped water is of small relevance for intermediate and final consumption (see Table 26). Furthermore, the impact on the whole economy is very small because the activities with high water demand (e.g., water sector and agriculture) contribute with less than 5% only a small share to the total value added (Table 25). Thus, information on the economic impacts of the productivity shocks cannot be gained from the analysis of the aggregated economy and requires a more differentiated analysis at activity and commodity level.

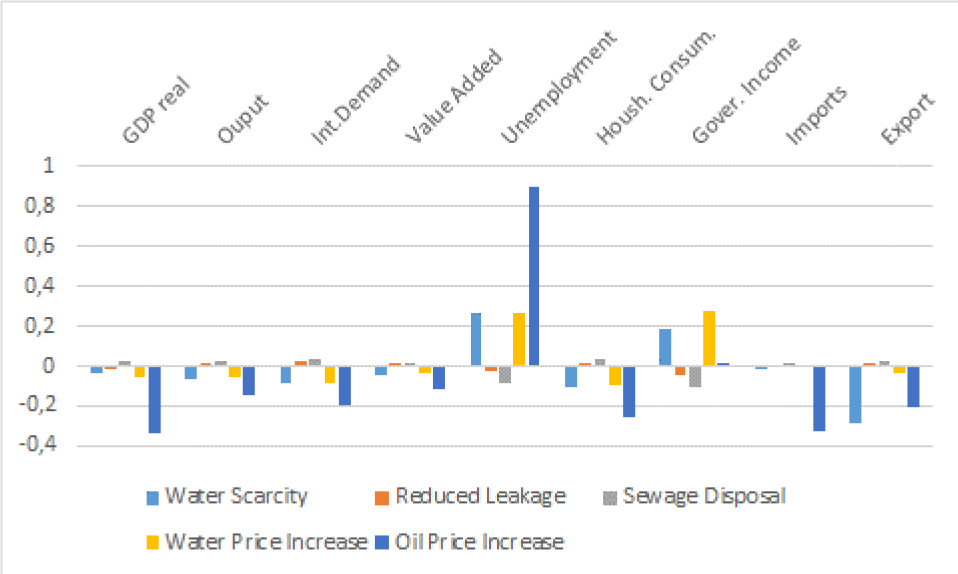

Figure 16: Impact on macroeconomic indicators in %-change from the base

6.2 Production and consumption

The changes in production and consumption indicate how the activities adjust their output supply to the economic shock and how consumers adjust their consumption in response to changes in prices and income.

6.2.1 Oil Price Increase

Figure 17 presents the impact on the production of the activities, and Figure 18 presents complementarily, the impact on household consumption of the commodities. In the scenario **Oil Price Increase**, particularly the activities depending on petrol reduce their output. These are mainly the thermic electricity production (aelpe) and transport (atran) (Figure 17). The decrease in production results from an increase in production costs, increased consumer prices, and corresponding decreased demand by industries (as intermediate commodity) and households (as final consumption commodity). Figure 18 shows that in scenario **Oil Price Increase,** the demand for the commodities transport and petrol (ctran and cpetr) by households is reduced. An intersectoral impact can be observed since also the output of water and wastewater services is also reduced (Figure 17), because these activities use energy in the form of electricity. The production of piped water and wastewater services (awasa) is also impacted due to high dependency on petrol and electricity inputs.[5]

[5] For the electricity producing activities (aelhy, aelbi, aelpe) and for the water and sanitary services (awasa) the share of intermediate demand is 2.4% for petrol and 28% for electricity. For the development of this protype model we split the aggregated account according to the proportion of the SAM as to equal shares for electricity and water. In future development of the prototype model, a better differentiated split can be considered.

6.2.2 Water Price Increase

The increase in the water tariff in the scenario **Water Price Increase** creates a significant 4% decrease in demand for piped water . The reduced consumption results from reducing the wastage of piped water, as higher prices incentivise more efficient usage of piped water. The simulation of this scenario shows that a price increase in water can reduce water consumption, however, without substantial impacts on the consumption of other commodities. The decrease in output of the electricity producing activities results from the intersectoral linkages between electricity and water. Water production requires electricity, and reduced water production requires less electricity as intermediate consumption by the water sector.

6.2.3 Sewage Disposal

The tariff policy to switch from non-collective to collective wastewater treatment creates an increase in output of the sanitary sector, which demands electricity for its production. As a result, electricity-producing activities increase their output (see Figure 17). Figure 18 shows that households reduce consumption of non-collective discharge (csanc) by 3% and increase consumption of collective wastewater treatment services (csaco) by about 4.5%.

6.2.4 Reduced Leakage

Increasing the factor productivity of raw water stimulates the output of the water service sector, as more piped water can be produced from less input. The intersectoral impacts of this scenario are limited. The price of piped water decreases but the increase in factor productivity (by 0.5%) and the share of intermediate consumption are so small (see Table 26), that this reduction in production cost does not lead to increased output in other sectors. For final consumption by households, we assume that households already consume more piped water than economically efficient. In the base scenario, households waste piped water because it is too cheap. Since the level of piped water consumption is beyond the optimum, a decrease in prices does not increase wastage. Water is not perceived as a valuable or scarce resource.

6.2.5 Water Scarcity

The reduction of raw water resources impacts the output of water demanding activities, such as agriculture, food industry, and water industries. Also, electricity producing activities are negatively impacted. These reactions illustrate the intersectoral linkages between water and food (represented by agricultural and food industries) and water and energy (electricity producing activities). The impact on households' consumption is negligible, suggesting (Figure 18) that the reduced domestic supply is offset by imports, to maintain the level of household consumption of food and agricultural products.

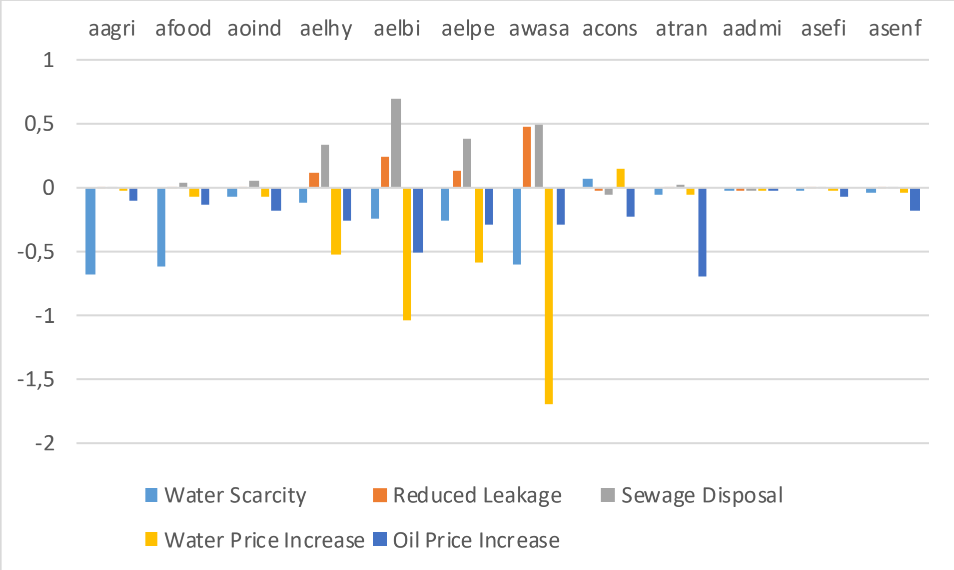

Figure 17: Impact on activities production in %-change from the base

Note: a… = activities, c… = commodities, agfo = agriculture and food industry, oind = other industries, elwa = electricity and water services, wast = waste services, serv = services.

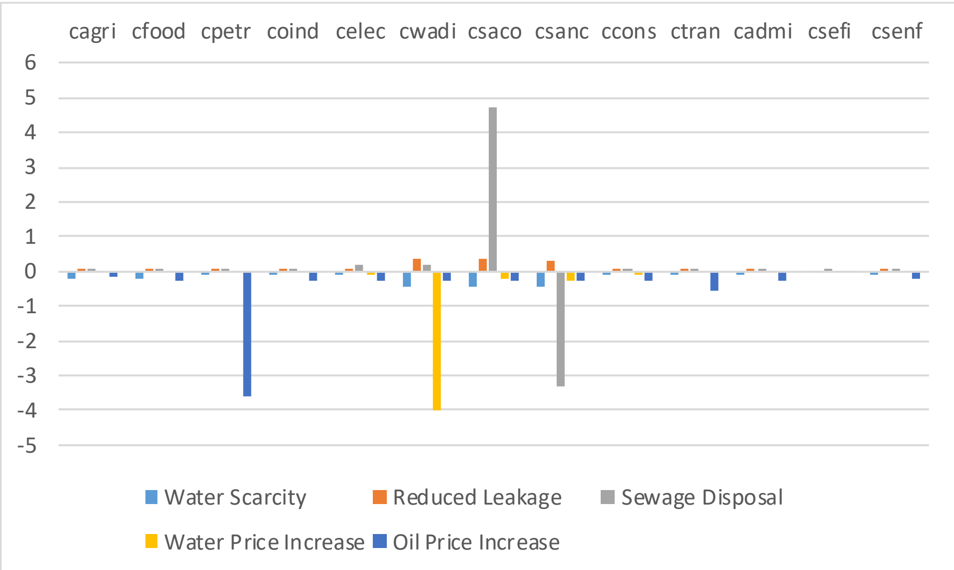

Figure 18: Impact on household consumption in %-change from the base

Note: a… = activities, c… = commodities, agfo = agriculture and food industry, oind = other industries, elwa = electricity and water services, wast = waste services, serv = services.

6.3 Imports and exports

The changes in imports and exports indicate how the economy adjusts to the international markets following the economic shocks (Figure 19 and Figure 20). As can be expected, the scenario **Oil Price Increase** creates the highest impact on trade changes. Petrol imports reduce by 1.5% and other affected sectors also reduce imports to compensate for economic losses caused by production costs. As a reaction to the increased production in transport services, the model simulates an import of these transport services. Exports reduce correspondingly for transport as mainly affected activity.

Scenarios **Reduced Leakage** and **Sewage Disposal** show only marginal changes in international trade (less than 0.1%). The reason is that the increase in productivity is only 0.5%, and the services which are shocked are defined as non-tradable commodities and the marginal changes observed are only second round impacts. The scenario of **Water Scarcity** increases the import of agricultural and food commodities, which partially explains how household consumption can be maintained. Also, exports of agri-food commodities reduce by 0.7 and 0.8%. Thus, supply gaps from local production are filled by adjusted international trade: more imports from abroad and less exports increase the food supply on domestic markets.

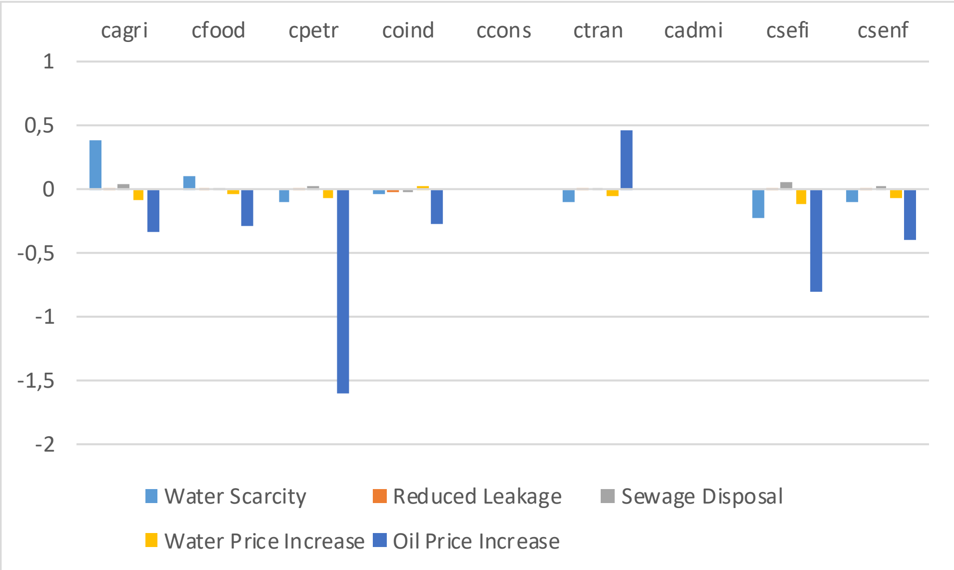

Figure 19: Impact on imports in %-change from the base

Note: a… = activities, c… = commodities, agfo = agriculture and food industry, oind = other industries, elwa = electricity and water services, wast = waste services, serv = services.

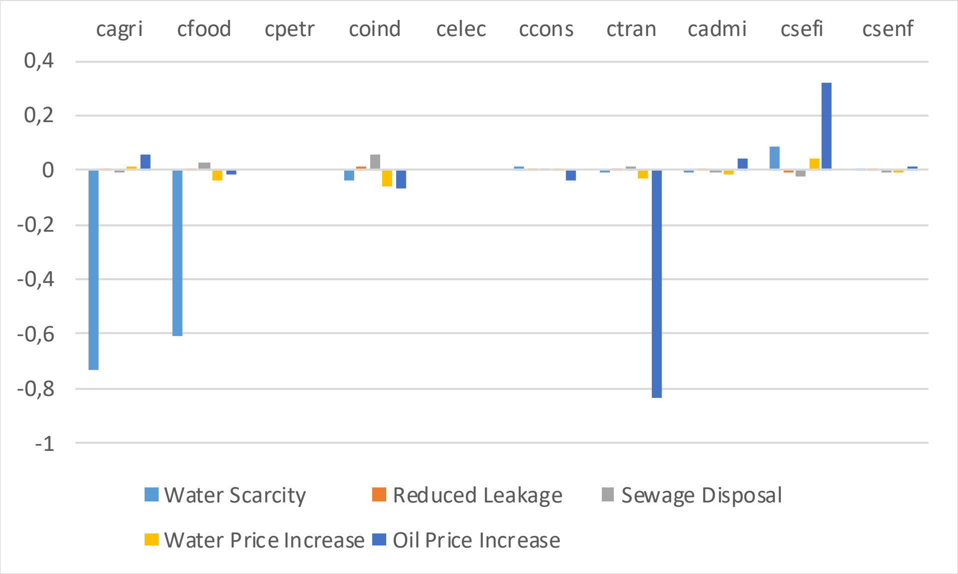

Figure 20: Impact on exports in %-change from the base

Note: a… = activities, c… = commodities, agfo = agriculture and food industry, oind = other industries, elwa = electricity and water services, wast = waste services, serv = services.

6.4 Commodity and factor prices

In a CGE model, the adjustment mechanism operates via the changes of three model variables: supply, demand and prices. By changing these variables, the CGE model finds a new equilibrium after an economic shock. The prices equalise between supply and demand and thus are sensitive to shocks. Furthermore, prices in an equilibrium model are all normalised to a value of one in the base situation. Therefore, percentage changes of prices in the scenario are related to the same base. Both the interlinkage between supply and demand and the normalised nature make prices an informative variable in a CGE model. The change prices can reflect both: the economic shock itself and the economy's adjustment to the shock. Here we present two types of prices relevant for the simulated scenarios and their interpretation: the consumer price (what the consumer pays for the commodities) and the factor prices for capital (the value of the production factor that activities pay for using capital in production).

Figure 21 shows the change in consumer prices. In the scenario **Oil Price Increase,** the import price for petrol increases by 5%. The magnitude of the shock on the import price is directly translated into the consumer price, which also rises by 5%. The price transmission to the commodity directly impacted (i.e., the transport commodity) is relatively weak, indicating that adjustments also occur on the supply or demand side. In the analysis of the changes of consumption and production we see that the output of transport and the final consumption reduce both in the shock situation. The decreased supply and demand result in a devaluation of the price of non-water capital in the activities, which are impacted by the increased petrol prices, e.g. for the transport sector. The value of capital decreases since the commodity market finds new equilibrium in a less favourable situation in terms of supply and demand than in the base situation.

Figure 22 shows the change in price of the production factor non-water-capital. The value of the factor non-water capital decreases in a sector where commodities have increased in price, caused decreased in demand and supply (e.g., the transport sector). Figure 23 and Figure 24 show only a marginal decrease in the value for ground- and surface water in activities affected by the petrol price increase and using raw water as an input, e.g., the agriculture and food sector.

In **Water Price Increase** scenario, the 5% rise in piped water price is transmitted to a 6% increase in consumers priceFigure 21). The prices for non-water capital decreases for the water service sector, mainly due to the price increase and reduced demand for piped waterFigure 22). Capital values for ground- and surface water also decrease in the sector experiencing the price increase Figure 23 Figure 24).

In the **Sewage Disposal** scenario, the tariff for non-collective sewage disposal is increased and the tariff for collective water treatment is decreased, which is translated into a consumer price increase for both commodities (i.e., csanc and csaco) (Figure 21). The net impact on the sector is positive, indicated by an increased value of non-water capital, as the net-demand for both commodities increases (Figure 22). Switching from the cheaper (and more polluting) autonomous discharge installation to the more expensive (but less polluting) collective system increases the net output of the water and sanitary sector. The capital prices for both raw water types increase only marginally (Figure 23 and Figure 24).

In **Reduced Leakage** scenario, the productivity of raw water capital is increased to simulate the reduction of piped water losses. With less raw water input, the water sector can provide more piped water. The increase in productivity leads to only a marginal decrease in consumer price, making piped water even cheaper than in the base situation, but no creating additional demand (Figure 21). The non-water capital price in the piped water activity increases slightly due to higher productivity and output (Figure 22). The capital rent of ground and surface water decreases significantly, as the increased productivity decreases the demand of these factors in production (Figure 23 and Figure 24).

In **Water Scarcity** scenario, the scarcity of raw water causes only a minimal increase in the commodity prices of goods whose production depends on raw water. For agricultural and food products, increased imports offset any domestic supply shortfall, preventing major price rises, while piped water remains a cheap, price-inelastic commodity (Figure 21). The decrease in non-water capital prices results from decreased production in the impacted sectors (Figure 22). The raw water scarcity leads to an increase in capital rent for raw water, indicating that this production factor becomes more valuable even though the scarcity has limited effects on producing sectors themselves. The value of capital rent increases for the sectors which depend on raw water as input: agriculture, food industry and water services (Figure 23 and Figure 24). The increase in the rant for raw water is relatively high and represents that under water scarcity the extraction of ground- and surface water become significantly more expensive (e.g., by wells requiring deeper drilling to reach lower groundwater levels).

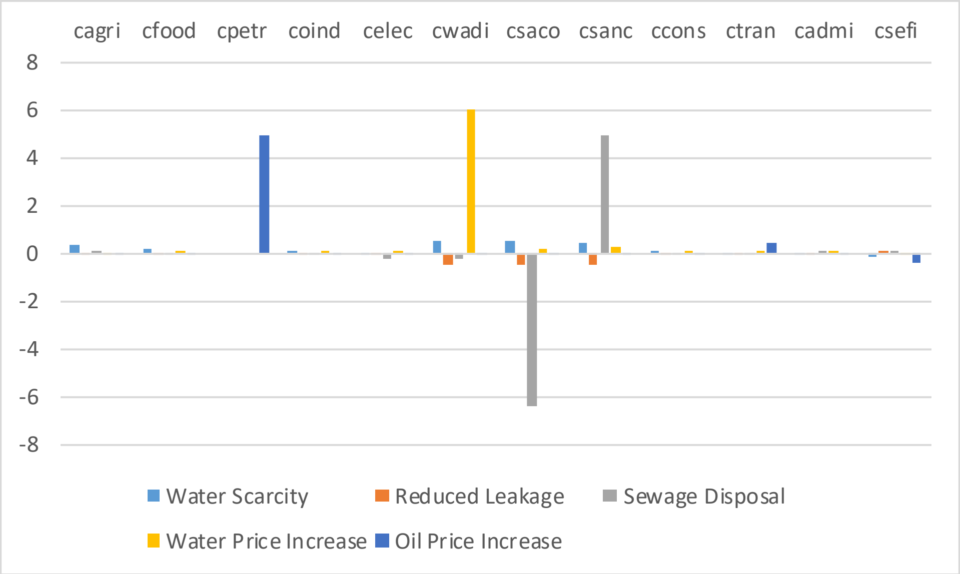

Figure 21: Impact on consumer prices in %-change from the base

Note: a… = activities, c… = commodities, agfo = agriculture and food industry, oind = other industries, elwa = electricity and water services, wast = waste services, serv = services.

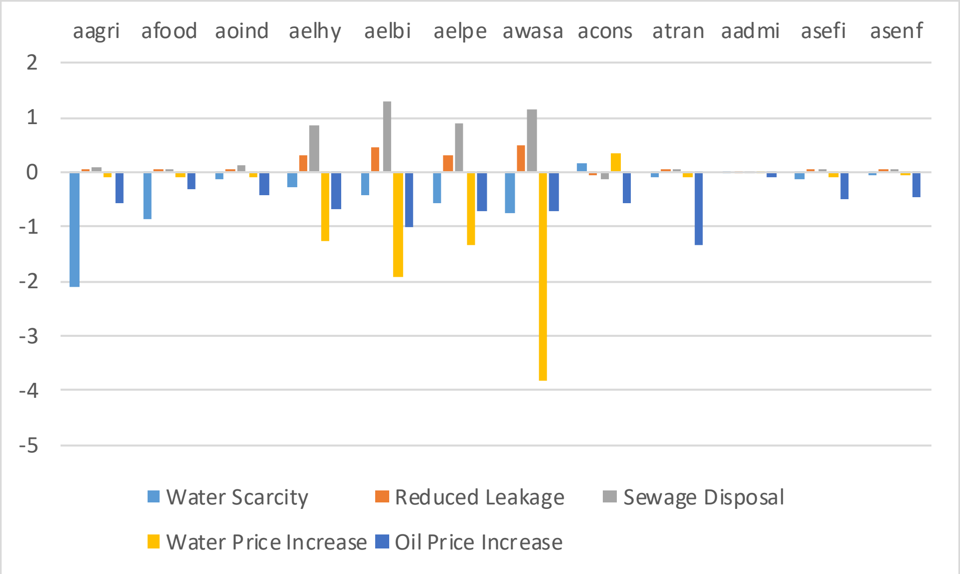

Figure 22: Impact on factor prices for non-water capital in %-change from the base

Note: a… = activities, c… = commodities, agfo = agriculture and food industry, oind = other industries, elwa = electricity and water services, wast = waste services, serv = services.

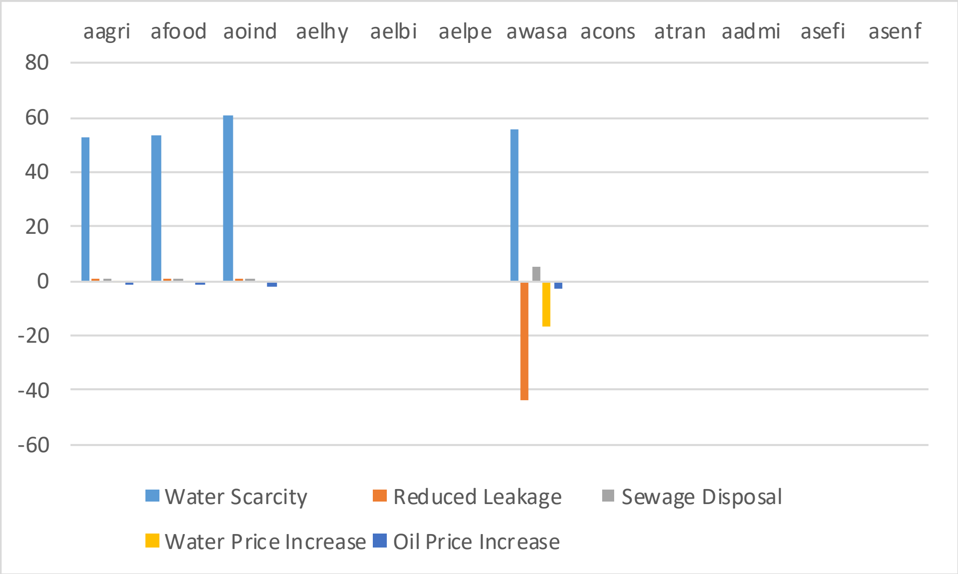

Figure 23: Impact on factor price for groundwater in %-change from the base

Note: a… = activities, c… = commodities, agfo = agriculture and food industry, oind = other industries, elwa = electricity and water services, wast = waste services, serv = services.

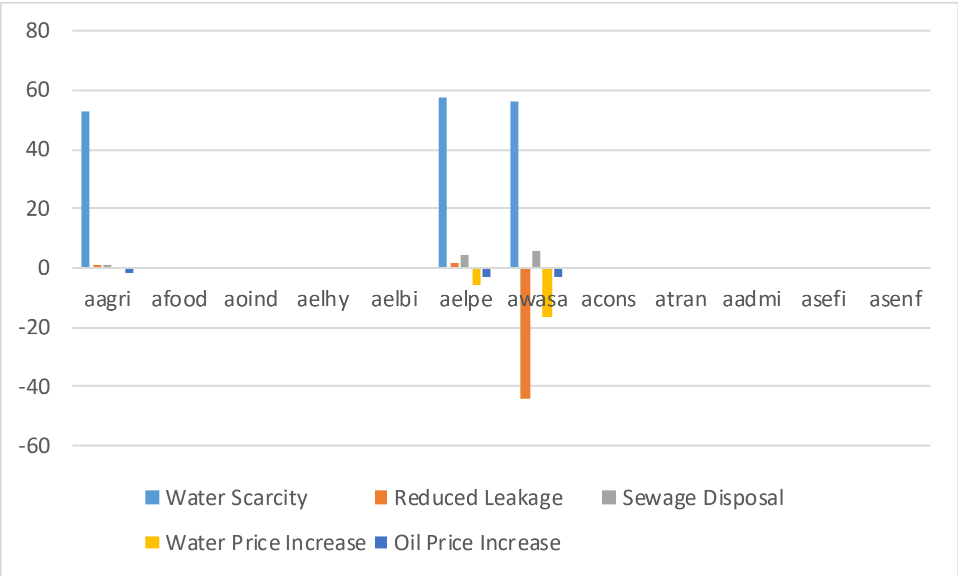

Figure 24: Impact on factor prices of surface water in %-change from the base

Note: a… = activities, c… = commodities, agfo = agriculture and food industry, oind = other industries, elwa = electricity and water services, wast = waste services, serv = services.

6.5 SEEA-W environmental indicators

The changes in model variable indicators result directly from the CGE model and its mechanism. The SEEA-W environmental indicators provide information that does not directly result from the outputs of the CGE model. These indicators are linked to the CGE model by accounting for the changes in activity or consumption level (Section 4.2.4). For environmental assessments, this information helps quantify changes in pollutants and extraction quantities. Although not directly linked, the SEEA-W environmental indicators can be interpreted in the context of the simulated shocks. Figure 25 presents the impacts on the SEEA-W environmental indicators.

In the **Oil Price Increase** scenario**,** the petrol price increase leads to reduced pollution from activities and agents. Since the production of all sectors decreases, the demand for thermic electricity decreases and CO_2 emissions decrease.[6] The impacts on the emissions of pollutants are minor in the **Reduced Leakage** and **Water Price Increase scenarios**. In **Reduced Leakage,** the emissions rise because the production and consumption are stimulated, by lower prices for the production factor water, whose productivity is higher. For **Water Price Increase,** the intermediate consumption of water decreases due to higher water prices, and thus, reduced output from activities leads to less emissions. Also, the quantity of consumed piped water (usag_PW) decreases by 2%. The **Sewage Disposal** scenario generates positive environmental impacts by decreasing the polluting non-collective sewage discharge and replacing it with collective wastewater discharge.

The emissions of nitrogen and phosphorous (from non-collective discharge) decrease significantly by 2 and 3%. With more households connected to the collective wastewater treatment network, the indicator of oxygen demand (DBO and DCO) increases compared to the base with fewer users. With more households connected to the collective sewage disposal network, more organic matter is emitted to the water, requiring more oxygen to break it down. The same applies to the suspended solids (MES), which also increase as more households are connected to the system. The **Water Scarcity** scenario creates a slight reduction of emissions by negatively impacting production. As a production factor for agriculture, the emissions of agricultural nitrogen (Nagri) decrease because of reduced agricultural activity and lower fertiliser use.

[6] Note, that the change in CO_2 emissions presented here refer to the emissions from thermic electricity production. The indicator quantifying the CO_2 from other activities (e.g., the transport sector) and households are implemented in the model but not displayed here.

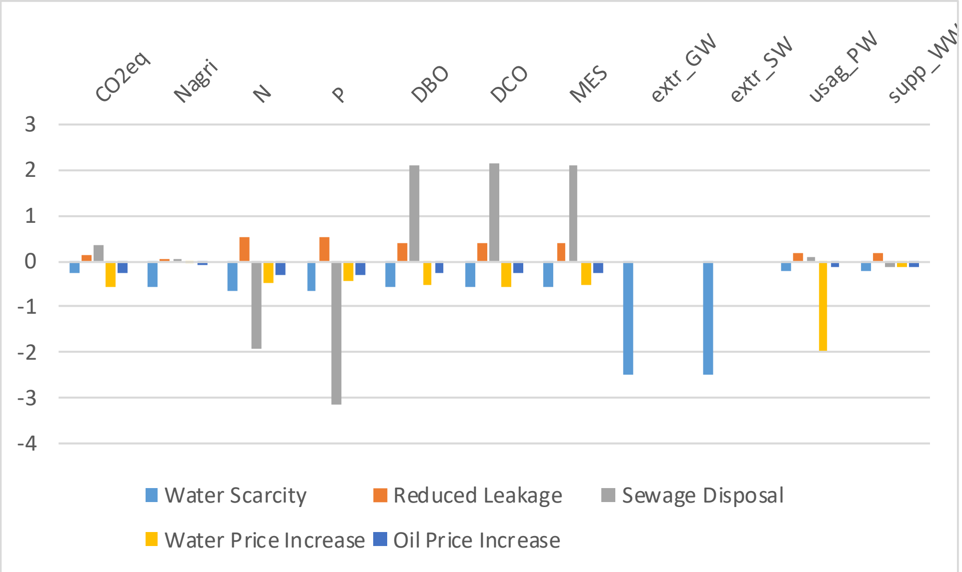

Figure 25: Impact on environmental indicators in %-change from the base

Note: CO2eq = CO_2 emissions, Nagri = nitrogen emissions from agriculture, N = nitrogen emissions from households and industry, P = phosphor, DBO = biologic oxygen demand, DCO = chemical oxygen demand; MES = suspended solids, extr_GW = extraction groundwater, extr_SW = extraction surface water, usag_PW = usage piped water, supp_WW = supply wastewater

7. THE DIGITAL PLATFORM

Within Work package WP4, Task 4.4, the developed REWEFE-CGE model will be included in the digital platform as a policy decision support tool. The implementation will present CGE model results and enable linkage to a household water demand microsimulation model (MSM).

7.1 Linkage between CGE and microsimulation model

Within the digital platform the REWEFE-CGE model is linked to the microsimulation model (MSM) to analyse the macroeconomic impacts at household level. The MSM is a water demand model, representing the individual households and their economic behaviour with respect to water consumption. The MSM is described in detail in Paul (2024). The CGE model computes indicators at macroeconomic scale, which are then transferred to the MSM for more detailed analysis at the household level. By transferring changes in these indicators to the MSM, the shock is transmitted from the macroeconomic CGE model to the functions of the MSM (i.e., the shock transmission). This allows for a detailed simulation of household-level responses. Such a top-down, sequential macro-micro-simulation is frequently used in economic modelling research and extensively described in the academic literature (e.g., Cockburn et al., 2014; Colombo et al., 2010).

Figure 26 presents schematically the linkage between a CGE model and an MSM. The CGE model (on the left) simulates the shock and computes changes of variables for the macroeconomic analysis. Selected variables, like the percentage change in consumption spending or the consumer price index, are transferred to the MSM. The MSM includes the information in its model functions (e.g., in the household demand function). The demand function simulates household demand subject to different economic variables like the household income, the consumption and the consumer prices of water and non-water commodities. The changes of these variables simulated by the CGE model are included in the MSM model, which simulates the changed household behaviour driven by the economic shock. An MSM can also include production functions. Thus, also variables influencing the water supply, or water production costs can be transferred from the CGE model to the MSM. For example, the change in electricity price simulated by the CGE can be transmitted to the production function of the MSM, where it drives the production costs for water and thus, the water price. Based on the results of the simulation with the MSM socioeconomic indicators can be computed, e.g., for poverty analysis or for water specific socioeconomic indicators, like affordability of water, water poverty, etc.

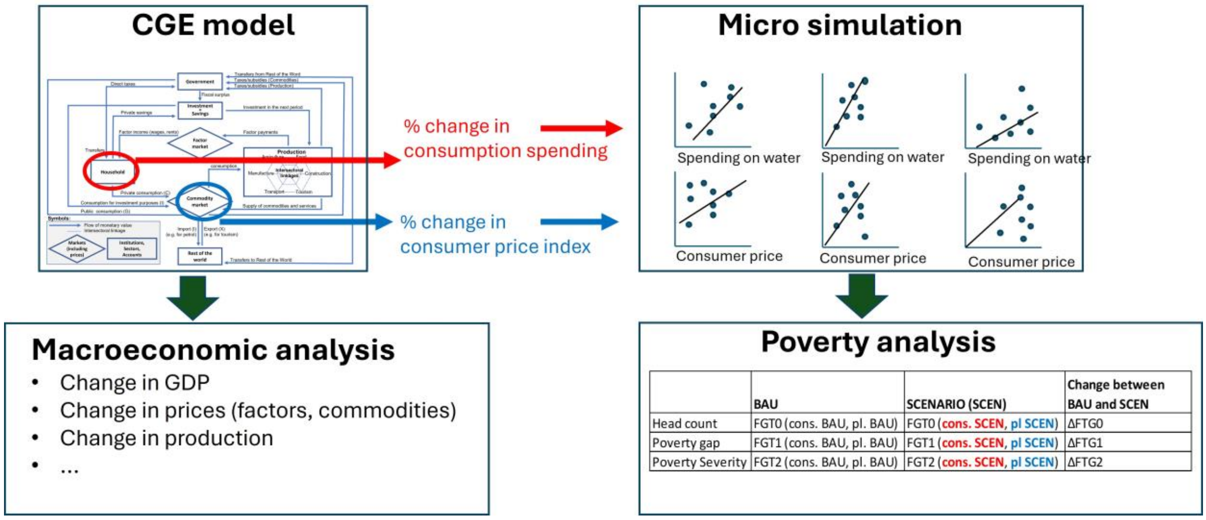

Figure 26: Schematic illustration of the linkage between the CGE model and the MSM

For example, in a scenario, in which the water tariff is increased as a policy instrument, the CGE model calculates an increase in the water consumer price (e.g., by 6%). By transferring the relative change in water price to the MSM, the same proportional increase is applied to all individual households represented in the MSM. The MSM differentiates the households by their socioeconomic attributes (e.g., level of water consumption and household income). Thus, the water price increase is applied to the demand functions of all households represented in the MSM. The increase in water price creates different reactions among the households in the MSM, e.g., for poor and rich households. For poor households, the increase in water price is more impactful than for rich households, who more easily can compensate for price increases. Poor households might need to adjust their consumption of water or other commodities; rich households do not need to adjust. Thus, poor households are more at risk of experiencing poverty, for example water poverty. Thus, although the price increase for water, provided by the CGE model, is the same on the macroeconomic scale, the socioeconomic impacts among households simulated by the MSM are heterogeneous. The CGE model with one representative household cannot capture the heterogeneity among households. The MSM captures the socioeconomic differences between households and allows the computation of indicators, to assess the distributive impacts (e.g., for poverty analysis).

Equation 1 presents a water demand function as presented by Paul (2024: 32, Equation 4.1). This functional form is presented in the literature as a general form to determine consumed water at a tariff block *j*. Here, it is specified for the base consumption at the first tariff block 1 as:

$$q_{ij}^{d} = \underline{q}_i + \alpha \times \frac{R_i - (F + \pi_1 \underline{q}_i) + D_j}{\pi_j} - \alpha \times \frac{p_2 \underline{q}_{i2}}{\pi_j} \qquad \text{Eq.1}$$

with

q_{ij}^{d} : water demand of household i
R_i : the income of household *i*,
$\underline{q}_i$: its basic consumption of tap water of household i
$\underline{q}_{i2}$: basic consumption for the "other goods" (composite good)
p_2 : the price of this composite good "other goods"
$\alpha \in [0,1]$: a preference parameter.

D_j : Nordin's D function (also called the "Difference variable").
F: the amount of the subscription, which is interpreted as an access fee to the EP / EPA service (fixed cost of consumption) that the subscriber (household) has to pay to start consuming tap water,
π_j : the unit price per m^3 per tariff block *j*, with *j* = 1, i.e., the first tariff block.

Equation 2 presents one approach to link the CGE and the MSM by shock transmission. Equation 2 contains the CGE result variables (i.e., the changes in prices, consumption quantities and household income) applied to the corresponding elements in the equation of the MSM model (Eq. 1). The presented shock transmission is oriented to common macro-micro simulation approaches and here applied to the generic form of a water demand function. Defining the operational model linkage between REWEFE-CGE model and the MSM on the digital platform requires the transmission to the specified functional form of the water demand function as described in detail in Paul (2024). Furthermore, linking the REWEFE-CGE and the MSM requires testing, validation, and if needed, refinement of the model linkage.

In this presentation of macro-micro linkage between CGE and MSM, the demand function of the MSM differs from the demand function in the CGE model. The water demand function in the CGE model simulates the water consumption by a representative household for a global water tariff (e.g., at macroeconomic level). The MSM represents the water consumption by individual households for differentiated water tariffs and considers various socioeconomic variables. Thus, the demand functions in the two models are not consistent. Nevertheless, the approach is legitimate, since both models simulate the consumption at different economic levels: the CGE model at the macroeconomic (aggregated) level and the MSM at the microeconomic (individual) level.

$$q_{ij}^{d} = ConsPW \times \underline{q}_i + \alpha \times \frac{IncoHH \times R_i - (F + \pi_1 \underline{q}_i) + D_j}{PricPW \times \pi_j} - \alpha \times \frac{PricNPW \times p_2 \times ConsNPW \times q_{i2}}{PricPW \times \pi_j} \qquad \text{Eq. 2}$$

with

$ConsPW$: change in consumption of piped water (computed by the CGE model)
$PricPW$: change in price for piped water (computed by the CGE model)
$ConsNPW$: change in consumption of non-water commodities (computed by the CGE model)
$PricNPW$: change in price for non-water commodities (computed by the CGE model)
$IncoHH$: change in household income (computed by the CGE model)

Figure 27 presents the results of the indicators linking CGE model and MSM. Consistent with the presentation of other results, the transmission indicators are presented as percent changes and require a transformation as multiplicators. The indicators *ConsPW* and *PricPW* correspond to the CGE results presented in Sections 6.2 and 6.4, which represent the change in consumer price and consumption of piped water. As previously noted, the price for piped water increases significantly in the scenario “Water price increase,” driven by the increase in the piped water tariff rate. The resulting increase in consumer price causes a decrease in consumption. The indicators *ConsNPW* and *PricNPW* represent the changes for the total of non-water commodities. The total of commodities does not show significant reaction, since the share of piped water in total consumption and the impact of shocks on non-water commodities is small. Only in the scenario

"Oil price increase" does the increased oil price result in a small decrease in consumption of non-piped water commodities. Household income (IncHH) is also decreased in the scenario "Oil Price Increase", since labour demand decreases (Section 6.1). The price of electricity can influence the production cost of water and thus may also affect the water price. The changes in electricity price (PricELEC) in the five academic scenarios are very small.

The linked model framework combining the REWEFE-CGE model and MSM enables distributional analysis and considers macroeconomic and socioeconomic aspects. Due to the aggregated nature of CGE models, analysis of socioeconomic aspects and individual-level results is underrepresented in CGE literature. Linking the REWEFE-CGE model and MSM helps address this gap. Extensions of the REWEFE-CGE model could improve the degree of implementation, e.g., by differentiating the household agent into different household types (e.g., according to region, income level, house size or water consumption level). With this differentiation, the REWEFE-CGE model would better consider the socioeconomic aspects than the uniform representative household used in the current prototype. Differentiation into household types in the REWEFE-CGE model enables shock transmission at a higher level of disaggregation. However, this extension to household types requires an appropriate empirical database (e.g., household survey) and is beyond the scope of the current prototype's development.

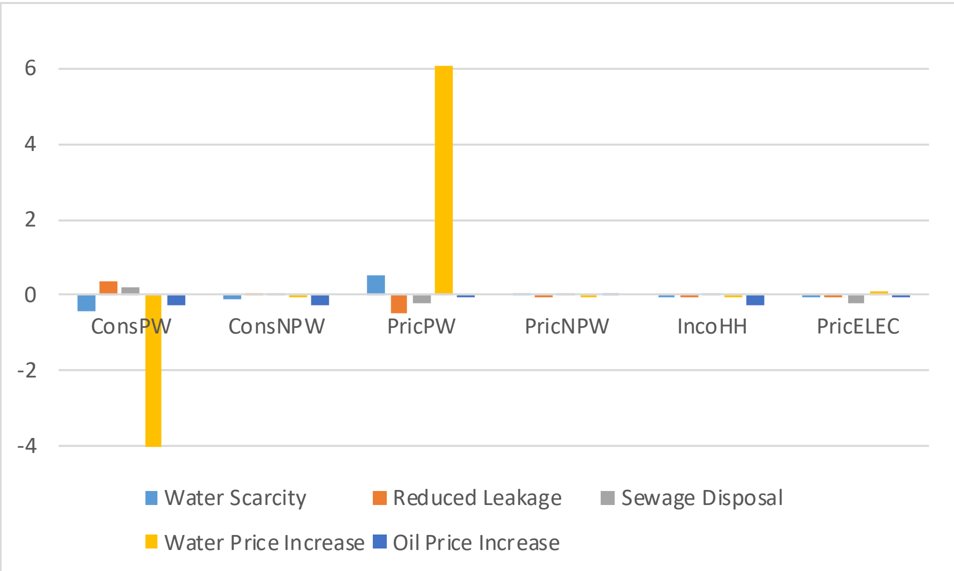

Figure 27: Impact on exchange variables between the REWEFE-CGE model and MSM in %-change from the base

7.2 Presentation of CGE model results

The REWEFE-CGE model provides multiple indicators, each allowing for specific interpretation as a stand-alone indicator and in the context of other indicators. Therefore, the interpretation of the REWEFE-CGE model is complex. The challenge of presenting CGE model results to users is to present a useful selection of results in a structured way that provides a good overview and facilitates the interpretation. To present the CGE model results on the digital platform, we suggest a display structured in four sections: the model info, the scenario info, the model results, and the microsimulation model data. Figure 28 presents an indicative layout for displaying the model results. Table 36 presents the suggested indicator groups and data, with a short text explaining the reasoning for the display.

The section "model info" presents an explanatory text about the data presented and a table listing the most important information about the model. This information is important to correctly describe the data origin and the basic assumptions. The section "scenario info" presents information on the simulated scenario and the model closure. It presents the rationale of the scenario as the scenario narrative (i.e., the story line). The scenario shock itself is presented graphically as a bar chart, and numerically in a table format. The bar chart is a simple visualisation allowing for fast comparison between multiple variables. The results table allows for a detailed presentation in numerical format.

The structure of presenting "model results" allows for a structured interpretation of the model results. The presentation follows a top-down approach, starting with the aggregated macroeconomic results and continuing with more disaggregated results of production, consumption, prices, etc. The results are presented as a bar chart and as a results table, and they are accompanied by an explanatory text, providing information on the meaning of the results to support the interpretation. Specific grouping of indicators allows comparing the indicators for specific interest (e.g., the WEFE nexus indicators). The last section presents the microsimulation model data, representing the transmission shock which links the CGE model and the MSM. It follows the same structure as the results presentation: an explanatory text, the variable values presented as a graph, and the values presented in a table format. This section is of particular relevance if the user is interested in the linked model application CGE and MSM.

Layout (indicative): suggestion vertical presentation (alternatively in the sections some elements could be organised horizontally)

MODEL INFO

Exlanatory text: Model assumptions

The model metadate are essential to correctly interpret the results. The comparative static temporal resultion means that the model simulates only from one year to the other. The model assumptions determine which of the economic variables are not a result of the model but assume from outside the model. E.g., the assumption of a fixed governmental spending means that the government does not allocate money to households. The assumption of a fixed world commodity price means that, the world price are determined, and they can be used for as mimicking a simulation (e.g., an increase in food prices).

Table: Model and scenario metadata

Model name	InnWater macroeconoomic simulation model
Model type / standard model	PEP-1-1 (single country, static), reference to documentation
Temporal resolution	Comparative static
Regional resolution	Riverbasin of Reunion Island
Scenario name	Test scenario 20% increase in food prices and 10% decrease in water supply
Citation of results	InnWaterPlattform, ...
Closures	
Assumption on **world commodity** prices	Fixed (simulated)
Assumption on **governmental spendings**	Fixed
Assumption on **labour supply**	Fixed
Assumption on **capital supply**	Fixed (simulated)

SCENARIO INFO

Explanatory text for scenario name: Test scenario 10% increase in food prices and 5% decrease in water supply

This scenario assumes that world food prices increase by 10% driven by global food crises (e.g., caused by military conflicts or harvest losses of big food supplier e.g., caused by droughts). At the same time climate change creates locally a drought situation in Reunion Island reducing the availabliliy of ground and surface water by 5% and impacting all Industries requiring water for their production and increasing the price for households.

Figure: Scenario shocks "Testscenario 10% …."

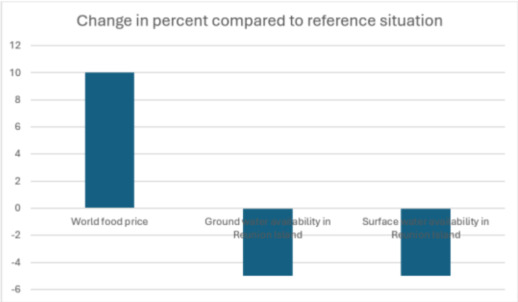

Table: Scenario shocks "Testscenario 10% …."

	Change in percent compared to reference situation
World food price	10
Ground water availability in Reunion Island	-5
Surface water availability in Reunion Island	-5

MODEL RESULTS

Macroeconomic indicators (aggregated)

Explanatory text for macroindicators: Test scenario 10% increase in food prices and 5% decrease in water supply

The macroeconomic indicators inform as aggregated indicators about the development in the economy. Each indicator presents specific information, e.g., GDP presents the impact on the development of the whole economy, whereas export and imports inform about the development of the international trade.

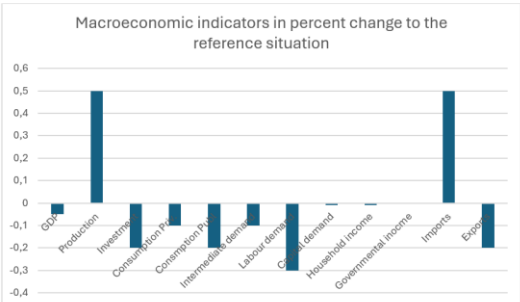

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Table: Macro indicators "Testscenario 10% …."

Indicator	Macroeconomic indicators in percent change to the reference situation
GDP	-0,05
Production	0,5
Investment	-0,2
Consumption Priv.	-0,1
Consmption Publ	-0,2
Intermediate demand	-0,1
Labour demand	-0,3
Capital demand	-0,01
Household income	-0,01
Governmental inocme	-0,002
Imports	0,5
Exports	-0,2
Consumer price index (pp)	0.1

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Activity and commodity indicators

Production volumes (disaggregated)

Explanatory text for production: Test scenario 10% increase in food prices and 5% decrease in water supply

The change in production inform about…. TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT

Final consumption volumes (disaggregated)

Explanatory text for production: Test scenario 10% increase in food prices and 5% decrease in water supply

The change in production inform about…. TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT

Figure: Production "Testscenario 10% ...."

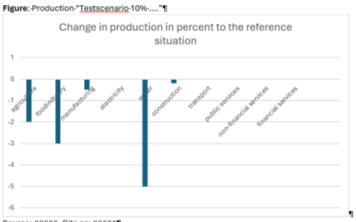

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Table: Production "Testscenario 10% ...."

Sector	**Change in production in percent to reference situation**
agriculture	-2
foodindustry	-3
manufacturing	-0,5
electricity	0,001
water	-5
construction	-0,2
transport	-0,01
public services	0,0001
non-financial services	0,0001
financial services	0,0001

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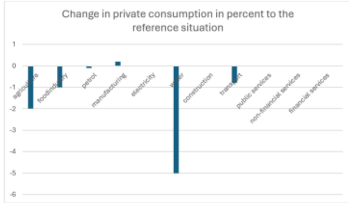

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Table: Consumption "Testscenario 10% ...."

Commoditiy	**Change in private consumption in percent to reference situation**
agriculture	-2
foodindustry	-1
petrol	-0,1
manufacturing	0,2
electricity	0,001
water	-5
construction	-0,001
transport	-0,8
public services	0,0001
non-financial services	0,0001
financial services	0,0001

Source: #####. Cite as: #####

Import volumes (disaggregated)

Explanatory text for production: Test scenario 10% increase in food prices and 5% decrease in water supply

The change in production inform about .... TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT

Figure: Production "Testscenario 10% ...."

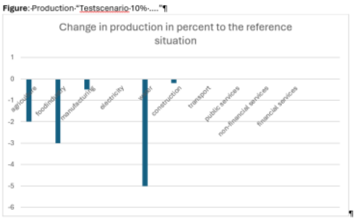

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Table: Production "Testscenario 10% ...."

Sector	**Change in production in percent to reference situation**
agriculture	-2
foodindustry	-3
manufacturing	-0,5
electricity	0,001
water	-5
construction	-0,2
transport	-0,01
public services	0,0001
non-financial services	0,0001
financial services	0,0001

Source: #####, Cite as: #####

Export volumes (disaggregated)

Explanatory text for production: Test scenario 10% increase in food prices and 5% decrease in water supply

The change in production inform about .... TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT TEXT

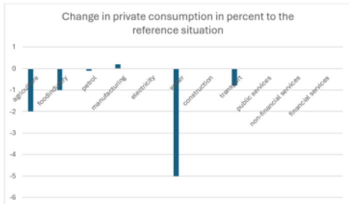

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Table: Consumption "Testscenario 10% ...."

Commoditiy	**Change in private consumption in percent to reference situation**
agriculture	-2
foodindustry	-1
petrol	-0,1
manufacturing	0,2
electricity	0,001
water	-5
construction	-0,001
transport	-0,8
public services	0,0001
non-financial services	0,0001
financial services	0,0001

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Other indicator groups ...

MICROSIMULATION MODEL

Explanatory text transfer data:

The transfer data link the macroeconomic CGE model with the microsimulation model. The change of following indicators is transmitted, increasing price for commodities shocks the consumption of households.....

Figure: Transfer data "Testscenario 10% ...."

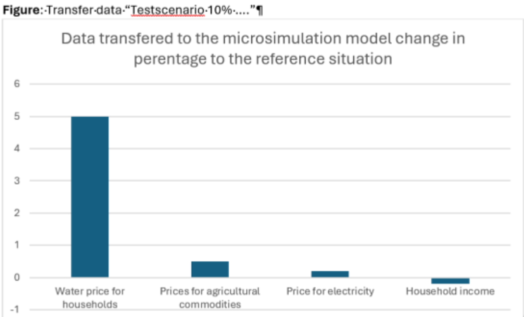

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Table: Transfer data "Testscenario 10% ...."

	Data transfert the microsimulation model change in percentage to the reference situation
Water price for households	5
Prices for agricultural commodities	0,5
Price for electricity	0,2
Household income	-0,2

Source: #####, Cite as: #####

Figure 28: Indicative layout for displaying the CGE model results on the digital platform

Table 36: Info and indicators displayed for the CGE model results (indicative)

Group	Indicator(s)	Rationale
Section Meta data		
Model info		Info of type of model, underlying assumptions and citation
Scenario info		Info of the scenario assumptions and citation
Section Model results		
Macroeconomic indicators	Different macro indicators	Impact on the macroeconomy
Activity and commodity indicators	Production volume	Impact on the activities
	Final Consumption volume	Impact on the consumption and the commodity markets
	Import volume	Impact on trade
	Export volume	Impact on trade
Commodity and factor prices	Consumer prices	Impact on the commodity market
	Capital rental rate and wage rate	Impact on the factor markets
	Ground water rental rate	Impact on the factor price of raw water
	Surface water rental rate	Impact on the factor price of raw water
Income	Government income	Impact on the different sources of income
	Household income	Impact on the different sources of income
WEFE nexus	W-Pillar	Impact on selected indicators of water
	E-pillar	Impact on selected indicators of electricity
	F-pillar	Impact on selected indicators of the agriculture and food sector and commodities
	Ec Pillar	Impact on CO_2 emissions and pollution
Microsimulation model	Shock transmission data	Impact on the variables transmitted to the MSM for understanding the shock transmission

CONCLUSION

This study presents the prototype of a CGE model simulating the WEFE nexus in Reunion Island, i.e., the "Reunion Island WEFE nexus CGE model" (REWEFE-CGE model). The study region, Reunion Island, provides statistical data at the same coverage for a geographic region (i.e., the Reunion Island River basin) and an administrative region, i.e., the French Department of Reunion Island. The geographic congruency between the river basin and administrative region allows for the representativeness of economic data for the river basin. In extensive data research, processing, and estimation, we built a Social Accounting Matrix (SAM) representing the WEFE nexus in Reunion Island (i.e., the REWEFE-SAM). Based on this SAM, we specify the static single-country standard model (PEP-1-1) to represent the four WEFE nexus pillars: water, energy, food, and ecosystems. We test the model in five academic scenarios of potential interest for regional policymakers of Reunion Island water governance. We illustrate the model reactions by interpreting the different test scenarios.

The study presents the development of the REWEFE-CGE model. As one of the first WEFE nexus CGE models, it considers all four WEFE-nexus pillars: water, energy, food, and ecosystems. The literature presents only a few studies covering three or more WEFE nexus pillars. Thus, covering four pillars, the REWEFE-CGE model is part of the pioneering works in macroeconomic modelling of the WEFE nexus. Due to the aggregated nature (i.e., macroeconomic analysis scale), socioeconomic aspects in WEFE nexus CGE analysis are underrepresented. The linkage to a microsimulation model (MSM) allows for the analysis of socioeconomic aspects. The REWEFE-CGE model is developed and specified for the study region, Reunion Island. However, the methods, approaches, and guides presented in this study can be applied to other study regions. Thus, this study guides the replication of building a WEFE-CGE model for study regions where the required data are available. The study provides the following value-added to academic research and policy decision support in Europe[7]:

- to extend the representation of WEFE nexus pillars to all four pillars;
- to provide researchers and analysts guidance on how to build a CGE model for another river basin;
- to policymakers and practitioners, the insight of developing and applying a CGE model;
- to support the linkage between the modelling research, policymakers, and stakeholders on a topic that requires understanding linkages from all perspectives: the WEFE nexus.

We learn from developing the REWEFE-CGE model that selecting suitable study regions is essential for data availability and identical coverage between river basin and administrative regions. The REWEFE-CGE model offers different functions and scenario options, which still need further exploration and testing. The simulated test scenarios require careful interpretation since they are defined as ad-hoc scenarios and are not based on empirical data or expert knowledge. Based on the results, it can be concluded that the impacts of shocks on availability and water productivity are relatively small for the whole economy. Price instruments can contribute to water-saving behaviour and change from polluting autonomous to collective sewage disposal systems. Global economic shocks on energy prices impact the economy significantly. For all scenarios, analysing the environmental impacts requires a specific focus. The environmental

[7] The approach is not limited to European regions and can be applied to any region for which the corresponding data are available.

satellite accounts can support translating the results of a macroeconomic sectoral model into quantity-based information.

CGE models are developed as macroeconomic experimental laboratories to understand how the macroeconomic system could react when the economic situation changes. Based on economic statistical data and rigorous macro- and micro-economic theory, CGE models can indicate the percentage change in values. However, the results should be interpreted holistically, mainly to understand the economic mechanism by interpreting first the tendency of indicator development (i.e., whether they are increasing, decreasing or stable). Interpretation of the percentage changes should focus on small, large, and extreme magnitude rather than precise numerical values. This careful interpretation also translates to the environmental satellite accounts, whose quantitative nature invites us to interpret the absolute changes in absolute terms. A more integrated representation of the ecosystem pillar should be envisaged in further research.

Certain caveats are unavoidable for a CGE model as a model type. A CGE model provides a holistic picture and wide-ranging information, including the interconnectivity of activities, agents and markets, but its macroeconomic scale and complexity mean it cannot provide precise, small-scale, sharply interpretable results. This caveat requires at least three measures: First, sufficient explanation and training for the user using CGE models to avoid misunderstanding and misinterpretation. Second, other quantitative or qualitative tools must be employed complementarily to improve the information from the CGE model. Linking the REWEFE-CGE model to an MSM on the Digital Platform is one such approach to provide additional information at disaggregated agent scales. Finally, the aggregate nature of a CGE model does not allow conclusions for individuals or groups below the aggregation of activities, commodities, or agents. Further disaggregation of the representation of economic items in the CGE model is required if the results and their interpretation do not satisfy the research question. For example, a more precise representation of households could be reached by differentiating the household agent into different household types according to income, size or water usage. The food pillar could be further differentiated into agricultural commodities and activities. Currently implemented by satellite accounts as an external extension, the ecosystem pillar can be integrated into the REWEFE-CGE model.

Developed as a prototype, the REWEFE-CGE model needs to be further tested and validated by users and in collaboration with stakeholders. The REWEFE-CGE can be used as a macroeconomic laboratory to simulate empirical and expert knowledge-based scenarios. In experimental practice, the REWEFE-CGE model can be validated and further revised and improved; pointedly stated by Lemelin and Savard (2022): “CGE (and other) models are useful to contribute insights to the policy debate […] while leaving some room for improvement — no model is perfect, no model is complete. It would be fair to say that every model should be considered as a work in progress” (Lemelin and Savard, 2022: 771).

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8. ANNEXES

Glossary

Account in a Social Accounting Matrix (SAM): An account in a Social Accounting Matrix (SAM) represents a component of the economy where flows of income or expenditure are recorded. Common accounts include: the activities (representing production processes), the commodities: goods and services exchanged in the economy, factors of production (labour and capital earning income), institutions (households, firms, and government receiving and spending income) and the rest of the World (capturing trade and financial flows with other economies). Each account tracks inflows (receipts) and outflows (expenditures), ensuring consistency and balance across the economic system.

CES (Constant Elasticity of Substitution) production function: The CES (Constant Elasticity of Substitution) production function in a Computable General Equilibrium (CGE) model is a flexible functional form used to represent production, where inputs (e.g., labour and capital) can substitute for one another with a constant elasticity of substitution. In CGE models, the CES function allows modelling different substitution possibilities between inputs, accommodating varying degrees of flexibility in input use compared to the fixed proportions in Cobb-Douglas functions.

Cobb-Douglas production function: The Cobb-Douglas production function in a Computable General Equilibrium (CGE) model is a functional form used to represent production, where output depends on inputs (e.g., labour and capital) combined with fixed input shares and constant returns to scale. In CGE models, the Cobb-Douglas function assumes fixed factor shares and unitary elasticity of substitution, making it straightforward and commonly used for modelling production and utility.

Co-modelling (also stakeholder oriented modelling or participative modelling): Here in the sense of stakeholder-oriented co-modelling is an approach that involves engaging relevant stakeholders in the development and use of models to ensure that their perspectives, knowledge, and interests are incorporated. It aims to improve the relevance, legitimacy, and effectiveness of the model by aligning it with the needs and concerns of those directly affected by the outcomes, fostering collaboration and shared decision-making.

Economic shock: An economic shock in a Computable General Equilibrium (CGE) model is a sudden change in external or internal economic conditions that disrupts the equilibrium. It is typically modelled as an exogenous change in variables such as: policy shocks (e.g., tax rates, tariffs, subsidies), demand shocks (e.g., changes in consumer preferences or export demand), or supply shocks (e.g., changes in productivity, resource availability, or input prices). The shock impacts the model's parameters or variables, causing adjustments across markets until a new equilibrium is reached. CGE models are used to analyse the effects of such shocks on the economy. An economic shock can also represent an "environmental" shock, if for example factor supply (like for raw water) reduces because of climatic change.

Elasticity of substitution: Elasticity of substitution in a Computable General Equilibrium (CGE) model measures the responsiveness of the ratio of two inputs or goods to changes in their relative prices. It indicates how easily one input (e.g., labour) in production can be substituted for another (e.g., capital) when their relative prices change. A higher elasticity implies that inputs (or goods) can be substituted more easily, while a lower elasticity suggests more rigid production or consumption relationships.

Elasticity: Elasticities in a Computable General Equilibrium (CGE) model refer to the responsiveness of one variable to changes in another. Specifically, they measure how sensitive the supply, demand, or substitution between goods and factors is to changes in prices, income, or other economic variables. Common elasticities used in CGE models include: price elasticity of demand (the responsiveness of the quantity demanded to changes in price), elasticity of substitution (in production: the degree to which one input can be substituted for another; in consumption: the degree to which one commodity can be substituted for another). Elasticities are key parameters that influence how shocks or policy changes affect the economy in CGE modelling.

Input-output analysis: The input-output analysis is an economic method used to study the interdependencies between different sectors of an economy. It examines how the output of one industry serves as an input for another, helping to analyse the flow of goods and services, measure the economic impact of changes in demand or production, and understand the structure of an economy.

Input-output tables: Input-output tables are structured representations of an economy that show the flow of goods and services between different sectors. They detail how the output of one sector serves as input for another, helping to analyse the interrelationships and dependencies within the economy, and to measure the direct and indirect effects of economic activities.

Integrated economic accounts: Integrated economic accounts are comprehensive systems that combine various economic data, such as national income, production, consumption, and wealth, into a unified framework. They provide a detailed and consistent view of an economy's overall structure, capturing the relationships between different sectors, activities, and agents to support economic analysis and policymaking.

Leontief production function: The Leontief production function in a Computable General Equilibrium (CGE) model is a functional form used to represent production with fixed input proportions, meaning inputs must be used in strict ratios to produce output. In CGE models, the Leontief function assumes no substitution between inputs, reflecting rigid production technologies and perfect complementarity of factors.

Macroeconomic analysis: a macroeconomic analysis is the study of the behaviour, performance, and structure of an economy at the aggregate level. It examines broad economic indicators such as: output (e.g., GDP growth), unemployment (e.g., labour market trends), inflation (e.g., price levels) and fiscal and monetary policies (e.g., government spending, interest rates). The goal is to understand and evaluate the overall functioning of the economy, identify trends, and assess the impact of policies or external shocks on economic stability and growth.

Microeconomic analysis: Microeconomic analysis refers to the study of individual economic units, such as households, firms, and persons, and how they make decisions regarding resource allocation, production, consumption, and pricing. It focuses on understanding the behaviour and interactions of these entities within markets.

Model closure: Model closure in a Computable General Equilibrium (CGE) model refers to the set of assumptions or rules that determine how the model is balanced, ensuring that all markets clear and all variables are determined. It defines how the model handles different economic relationships, such as savings, investment, government policies, trade and factor supply by specifying how certain variables (e.g., prices, quantities) are endogenously or exogenously determined within the model.

Multiplier analysis: Multiplier analysis is an economic technique used to measure the impact of an initial change in spending or investment on the overall economy. It calculates the total increase in economic activity resulting from that initial change, reflecting how initial expenditures generate additional rounds of income and spending throughout the economy.

Numeraire: Numeraire in a Computable General Equilibrium (CGE) model refers to the reference good or price used to normalise the system, allowing for the measurement of all other prices and variables. It serves as a standard unit of value, typically set to 1, to simplify the model and make comparisons between different goods or services in the economy.

Rebalancing a Social Accounting Matrix (SAM): Rebalancing a Social Accounting Matrix (SAM) refers to the process of adjusting the matrix to restore consistency and equilibrium among the economic transactions represented within it. This often involves modifying the entries to correct imbalances, such as discrepancies between income and expenditure flows, ensuring that the matrix accurately reflects the relationships and interactions between various sectors, institutions, and agents in the economy.

Section in a Social Accounting Matrix (SAM): A section in a Social Accounting Matrix (SAM) refers to a grouping of related accounts that represent specific economic activities or entities within the matrix. Common sections include production activities (representing industries or sectors), commodities (goods and services), factors of production (labour and capital), institutions (households, firms, and government) and external accounts (transactions with the rest of the world). Each section organises data to show the interactions and flow of income or expenditure between accounts, facilitating analysis of the economic structure and interdependencies.

Shock transmission: The shock transmission in a Computable General Equilibrium (CGE) model refers to the process through which an economic shock propagates through interconnected markets and sectors in the economy. When a shock occurs (e.g., a change in policy, productivity, or global demand), it affects key variables like prices, wages, and outputs in one market or sector, triggering adjustments in others due to interdependencies. These adjustments continue until a new equilibrium is reached. CGE models capture this transmission by accounting for linkages between production, consumption, supply, and demand. Shocks can be transmitted directly, e.g., as change of factor price to factor demand, or indirectly from as a change of factor price, via the change of factor demand, to the factor income on the factor market and finally to the impact on the factor income of the factor owning agent and its consumption.

Structure table: Structure tables of a Social Accounting Matrix (SAM) refer to tables that display the relationships and flows between different accounts (e.g., production sectors, households, government, and external sectors) in the economy. For example, they outline how income is generated and distributed across various sectors and institutions, showing the interdependencies of economic activities. Structure tables help organise and summarise data, the data of a SAM enabling analysis of how changes in one part of the economy (like production or consumption) affect others.

8.1 Methodology background

8.1.1 Introduction to CGE models

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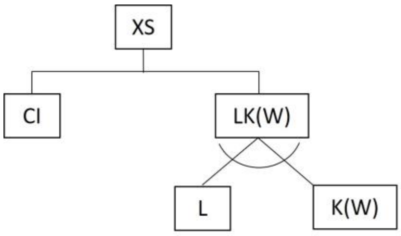
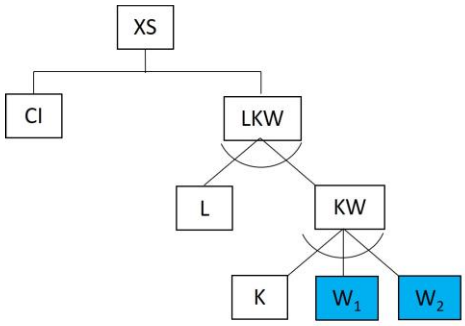
8.1.2 Literature review

Presentation of different types of production tree in CGE models

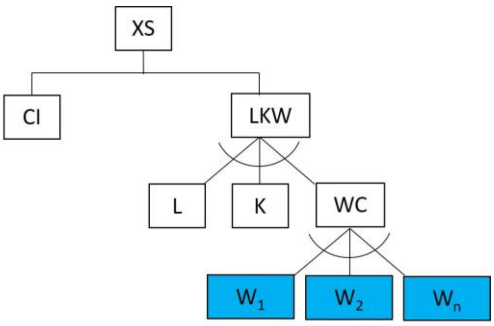
Production trees with only water



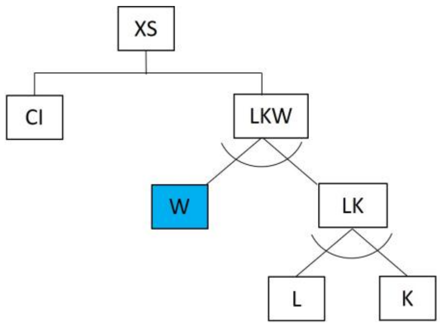
Legend
XS = output of production
CI = intermediate consumption
LK(W) = value added (VA) resulting form labour (L) capital (K) and water (W). Water is included within the capital aggregate, which is indicated by „(W)"
L = labour single primary production factor, or as a composite of different labour types
K(W) = capital as a primary production factor including in the aggregate water (W), or as composite of different capital types



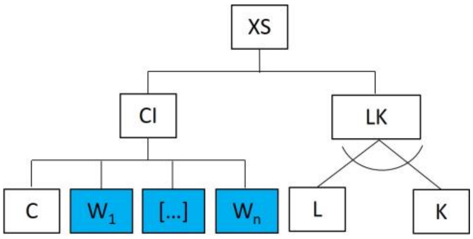
Legend
XS = output of production
CI = intermediate consumption
LKW = value added (VA) resulting form labour (L) capital (K) and water (W)
L = labour as single primary production factor, or as a composite of different labour types
KW = capital (K) and water (W) bundel
K = capital (K) a single primary production factor or as composite of different capital types.
W_1 = Water as production factor in different water types W_1 and W_2, for example groundwater and surface water



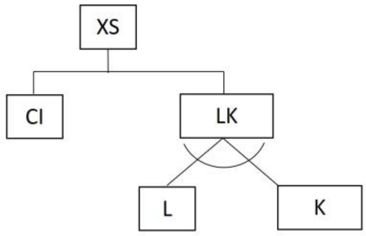
Legend
XS = output of production
CI = intermediate consumption
LKW = value added (VA) resulting form labour (L) capital (K) and water (W)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types
KC = water composite consisting of different water types
W_n = water as production factor in different water types W_1 and , W_2 , W_n (e.g., groundwater, surface water, sea water, brakish water, recycled water, …)



Legend
XS = output of production
CI = intermediate consumption
LKW = value added (VA) resulting form labour (L) capital (K) and water (W)
W = water as production factor as one type or as coposite of different water types W_1 and , W_2 , W_n (e.g., groundwater, surface water, sea water, brakish water, recycled water, …)
LK = bundel of labour (L) and capital (K)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types

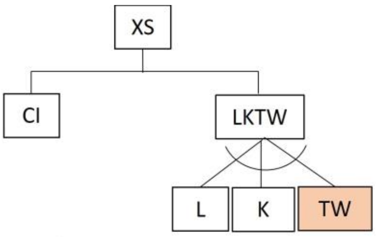


Legend
XS = output of production
C I = composite intermediate input
C = other intermediate input commodities
C = intermediate commodities
W_n = water as intermediate commodity in different water types W_1 and , W_2 , W_n (e.g., piped water, industrial water, …)
LK = value added (VA) resulting form labour (L) capital (K)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types

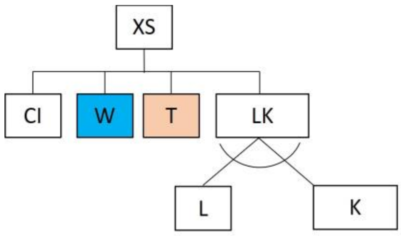


Legend
XS = output of production
C I = composite intermediate input
C = other intermediate input commodities
LK(W) = value added (VA) resulting form labour (L) capital (K) and water (W). Water is included within the capital aggregate, which is indicated by „(W)"
L = labour single primary production factor, or as a composite of different labour types
K = capital as a primary production factor
W = water as production factor

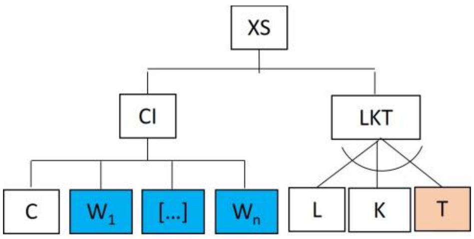
Production trees with Water and Land



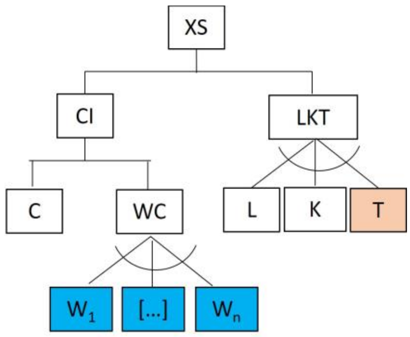
Legend
XS = output of production
CI = intermediate consumption
C = intermediate commodities
W_n = water as intermediate commodity in different water types W_1 and , W_2 , W_n (e.g., piped water, industrial water, …)
LKTW = value added (VA) resulting form labour (L) capital (K), land-water factor (TW)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types
TW = land-water factor, representing land which on which water is used or available (e.g., irrigated agricultural land, wet-lands, …)



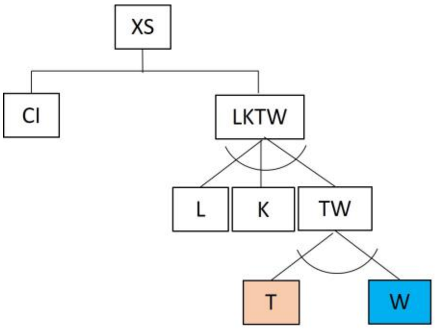
Legend
XS = output of production
CI = intermediate consumption
W = water as production factor
T = land as production factor
LK = value added (VA) resulting form labour (L) capital (K)
L = labour single primary production factor, or as a composite of different labour types
K = capital as a primary production factor



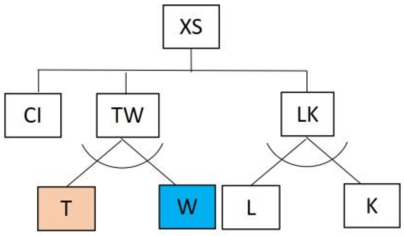
Legend
XS = output of production
CI = intermediate consumption
C = intermediate commodities
W_n = water as intermediate commodity in different water types W_1 and , W_2 , W_n (e.g., piped water, industrial water, …)
LKT = value added (VA) resulting form labour (L) capital (K) and land (T)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types



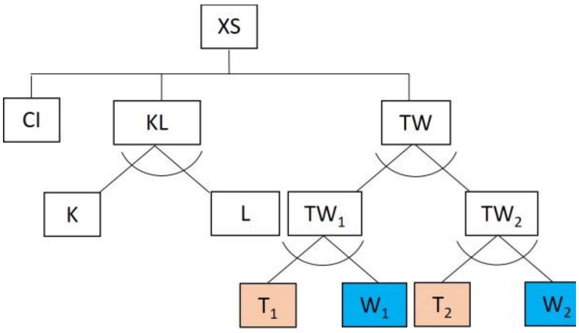
Legend
XS = output of production
C I = composite intermediate input
C = other intermediate input commodities
C = intermediate commodities
W_n = water as intermediate commodity in different water types W_1 and , W_2 , W_n (e.g., piped water, industrial water, …)
LKT = value added (VA) resulting form labour (L) capital (K) and land (T)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types



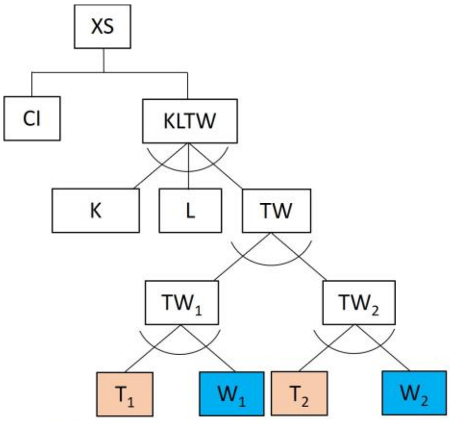
Legend
XS = output of production
CI = intermediate consumption
LKTW = value added (VA) resulting form labour (L), capital (K), land-water factor (TW)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types
TW = land-water factor, representing land which on which water is used or available
T = land
W = water



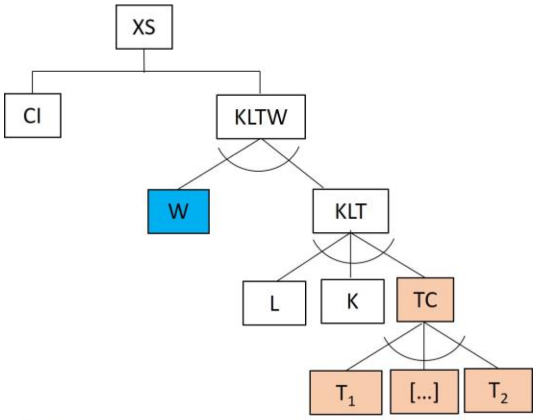
Legend
XS = output of production
CI = intermediate consumption
TW = land (T) water (W) composite
T = land as production factor
W = water as production factor
LK = value added (VA) resulting form labour (L) capital (K)
L = labour single primary production factor, or as a composite of different labour types
K = capital as a primary production factor



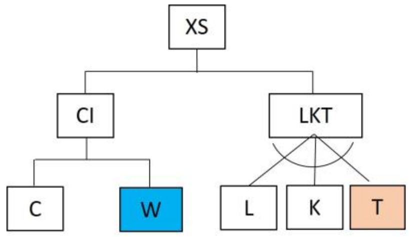
Legend
XS = output of production
CI = intermediate consumption
KL = value added (VA) from capital (K) and labour (L)
TW = composite of land (T) and water (W)
T_n = landtype (T) which composes with specific water usages (W_n), e.g., irrigated land, industrial land
W_n = water as an production factor in different water types which compose with land types Tn, e.g., irrigation water, industrial water.



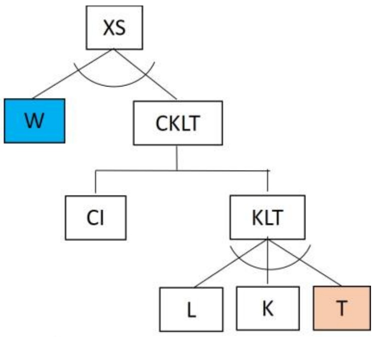
Legend
XS = output of production
CI = intermediate consumption
KL = value added (VA) from capital (K) and labour (L)
TW = composite of landtpyes (T_n) and water types (W_n)
T_n = landtype (T) which composes with specific water usages (W_n), e.g., irrigated land, industrial land
W_n = water as an production factor in different water types which compose with land types Tn, e.g., irrigation water, industrial water.



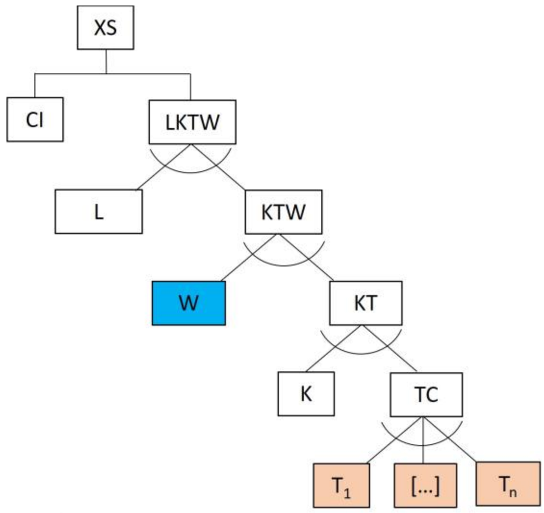
Legend
XS = output of production
CI = intermediate input
KLTW = value added (VA) resulting from capital (K), labour (L) land (T) and water (W)
KLT = composite of labour (L), capital (K) and land (TC)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types
TC = comosite of land with different land types
T_n = landtype which composes with specific water usages, e.g., irrigated land, industrial land



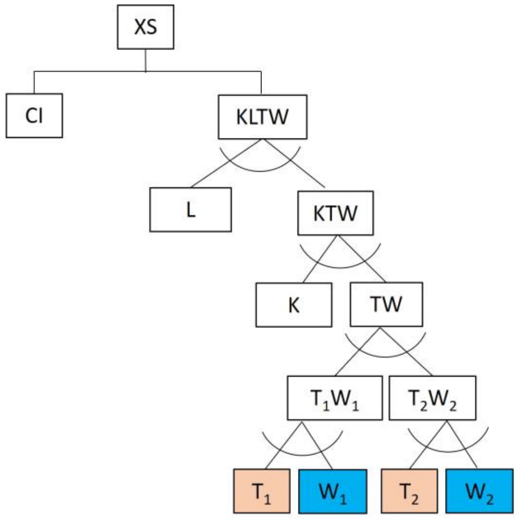
Legend
XS = output of production
CI = intermediate consumption
W = water as production factor
LKT = value added (VA) resulting form labour (L) capital (K) and land (T).
L = labour single primary production factor, or as a composite of different labour types
K = capital as a primary production factor



Legend
XS = output of production
W = water
CI = intermediate input
CKLT = value added (VA) resulting from intermediate input (CI), labour (L) capital (K), land (T)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types
T = land

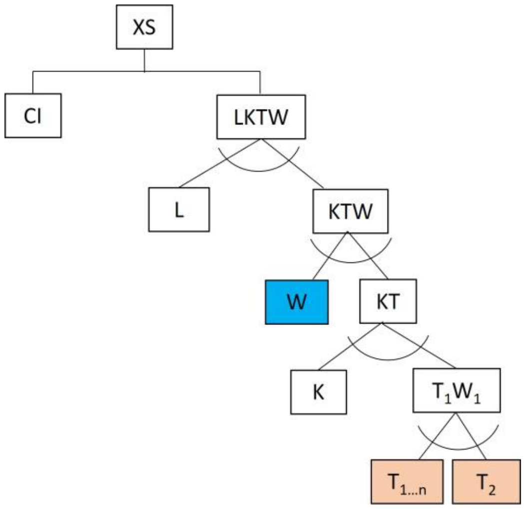


Legend
XS = output of production
CI = intermediate consumption
C = intermediate commodities
LKTW = value added (VA) resulting form labour (L) capital (K), land-water factor (TW)
L = labour as single primary production factor, or as a composite of different labour types
KTW = composite of capital (K), land (T) and water (W)
W_n = water as production factor single or in different water types W_1 and , W_2 , W_n (e.g., groundwater, surface water, ...)
KT = composite of capital (K) and land (T)
K = capital (K) a single primary production factor or as composite of different capital types
TC = composite of land
Tn = different land types (e.g., irrigated land, rainfed land, ...)



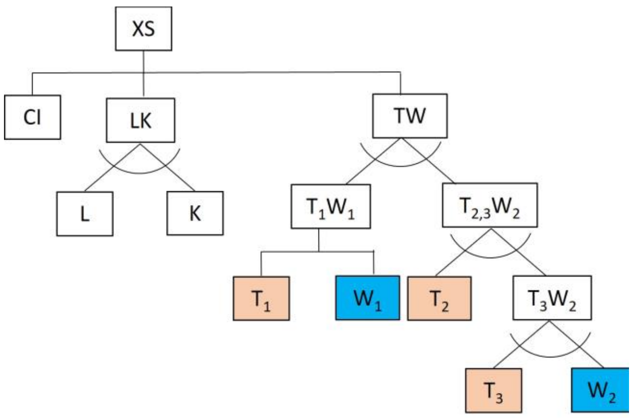
Legend

XS = output of production
CI = intermediate consumption
C = intermediate commodities
KLTW = value added (VA) resulting from capital (K), labour (L) land (T) and water (W)
L = labour as single primary production factor, or as a composite of different labour types
KTW = composite of capital (K), land (T) and water (W)
K = capital (K) a single primary production factor or as composite of different capital types
TW = land (T) and water (W)
T_n = landtype (T) which composes with specific water usages (W_n), e.g., irrigated land, industrial land
W_n = water as an production factor in different water types which compose with land types Tn, e.g., irrigation water, industrial water.



Legend

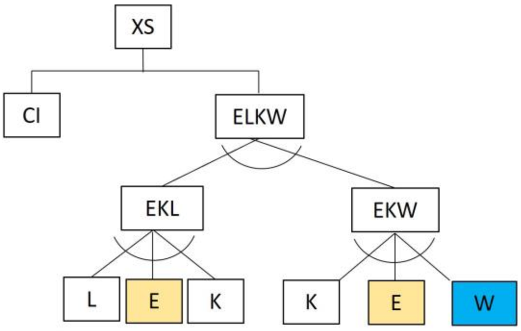
XS = output of production
CI = intermediate consumption
C = intermediate commodities
KLTW = value added (VA) resulting from capital (K), labour (L) land (T) and water (W)
L = labour as single primary production factor, or as a composite of different labour types
KTW = composite of capital (K), land (T) and water (W)
K = capital (K) a single primary production factor or as composite of different capital types
TW = land (T) and water (W)
T_n = landtype which composes with specific water usages, e.g., irrigated land, industrial land



Legend

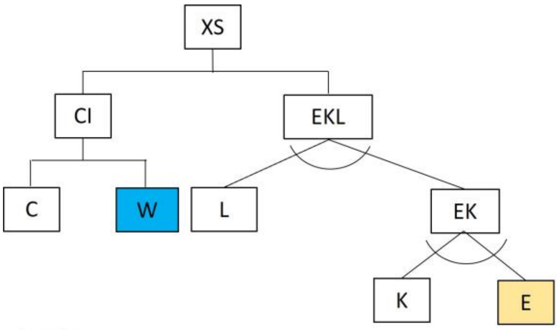
XS = output of production
CI = intermediate consumption
LK = value added from labour (L) and capital (K)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types
TW = composite of land (T) and water (W)
T_1W_1 = industrial land (T_1) and industrial water (W_1)
$T_{2,3}W_2$ = agricultural pasture land (T_2) irrigated land (T_3) and irrigation water (W_2)

Production trees with water and electricity



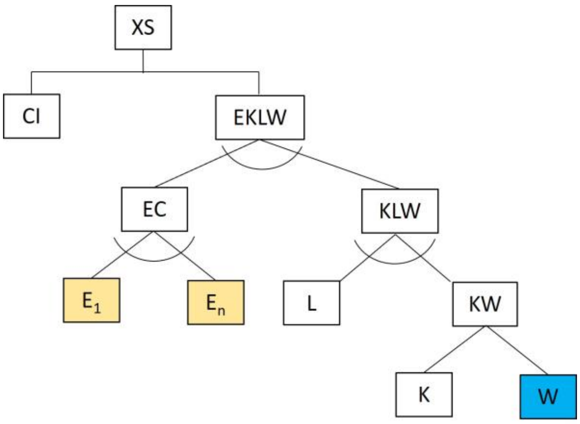
Legend

XS = output of production
CI = intermediate consumption
C = intermediate commodities
KL = value added (VA) resulting capital (K) and labour (L) water (W)
EKLW = value added (VA) resulting from energy (E), labour (L), capital (K), water (W)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types
E = energy as production factor or as composite of different energy types
W = water as production factor or as composite of different water types



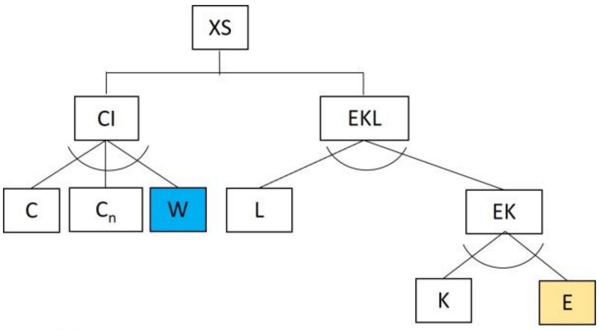
Legend

XS = output of production
C I = composite intermediate input
C = other intermediate input commodities
W = water as an intermediate commodity
EKL = value added (VA) resulting from energy (E), capital (K) and labour (L)
L = labour as single primary production factor, or as a composite of different labour types
EK = composition of energy (E) and capital (K)
K = capital (K) a single primary production factor or as composite of different capital types
E = energy as production factor or as composite of different energy types



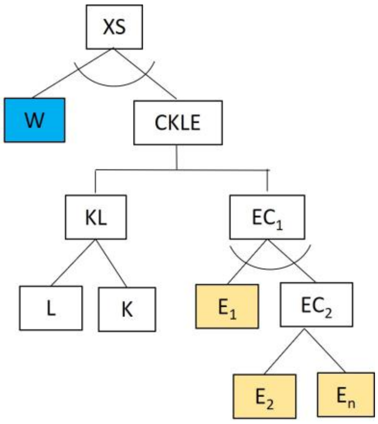
Legend

XS = output of production
CI = intermediate consumption
EC = composite of energy (E)
E_n = energy types (E_n) e.g.,
EKLW = value added (VA) resulting from energy (E), capital (K), labour (L) and water (W)
KLW = value added (VA) resulting from capital (K), labour (L) and water (W)
KW = value added (VA) resulting from capital (K) and water (W)
K = capital (K) a single primary production factor or as composite of different capital types
W = water as an intermediate commodity

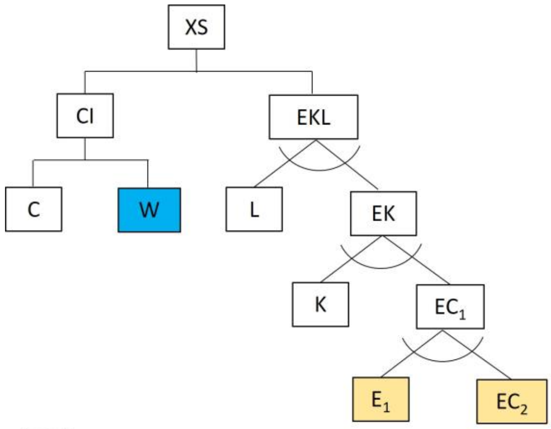


Legend

XS = output of production
CI = intermediate consumption
C_n = intermediate commodities (E_n)
W = water as an intermediate commodity
EKL = value added (VA) resulting from energy (E), capital (K) and labour (L)
L = labour as single primary production factor, or as a composite of different labour types
EK = value added (VA) resulting from energy (E) and capital (K)
K = capital (K) a single primary production factor or as composite of different capital types
E = energy

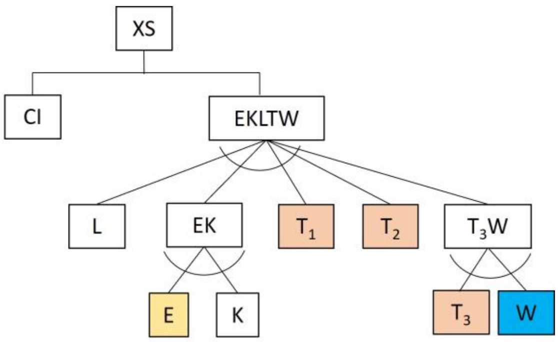


Legend
XS = output of production
W = water
CKLT = value added (VA) resulting from intermediate input (CI), labour (L) capital (K), energy (E)
LK = value added composite from labour (L) and capital (K)
L = labour as single primary production factor, or as a composite of different labour types
K = capital (K) a single primary production factor or as composite of different capital types
EC_1 = energy composite with electricity (E_1) and fuel energy composite (EC_2)
E_n = energy fuel composite, e.g., coal, petrol,...



Legend
XS = output of production
C I = composite intermediate input
C = other intermediate input commodities
W = water as an intermediate commodity
EKL = value added (VA) resulting from labour (L) and capital (K) and energy (E)
K = capital (K) a single primary production factor or as composite of different capital types
EC = composite of energy (E)
E_n = energy types (E_n)

Production trees with water and electricity and land



Legend
XS = output of production
CI = intermediate consumption
EKLTW = value added (VA) resulting from energy (E), capital (K) and labour (L), land (T) and water (W)
L = labour as single primary production factor, or as a composite of different labour types
EK = composite of energy (E) and capital (K)
E = composite of energy (E)
K = capital (K)
TW = composite of land (T) and water (W)
T_n = land types, e.g, industrial land, agricultural land
T_3 = land type with water usage, e.g., irrigated land
W = water as an production factor, e.g., irrigation water

8.2 Data

8.2.1 Water and sanitary services

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8.2.2 Energy and electricity

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8.2.3 Food and agriculture

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8.2.4 Ecosystems and environment

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8.2.5 Water extraction cost

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8.2.6 Ecosystems and environment

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8.2.7 SEEA-W

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8.3 Extension of the SAM

8.3.1 Reading a SAM

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8.3.2 Approaches of extending a SAM

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8.3.3 Splitting strategy

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8.3.4 Splitting the SAM accounts

GAMS code for splitting an exemplary SAM. Copy and paste the GAMS code in the Box below to a GAMS file.

Box: GAMS code for splitting a SAM

```
* GAMS code to for splitting a SAM  with water and energy accounts
* Date: 2025-02-05
* Author: Martin Henseler, within the project
* InnWater  (https://www.innwater.eu/)
*
* Call: HORIZON-CL6-2022-GOVERNANCE-01 Project 101086512
* This project has received funding from the European Union's Horizon EUROPE research and innovation program under grant agreement No. 101086512.
* This project was funded by UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee [grant number 10066637].
*
* Citation:
* Henseler, Martin (2025) Split SAM REWEFE - GAMS code to split a SAM into water and energy. GAMS code version 2025-02-05.
* Contact: Email: martin.henseler@univ-rouen.fr or dr.martin.henseler@gmail.com
*------------------------------------------------------------------------------

scalar thre_show "threhold for magnitude of difference to be shown" /0.0000000000000000000000001/;

set rows "global set SAM accounts"
/
aagfo
aoind
aelwa
aelec
acoal
aeptr
```

```
aebio
aehyd
aewin
aesol
awasa
aserv
cagfo
coind
celwa
"celec"
"cwadi"
"csaco"
"csanc"
"cwast"
cserv
xagfo
xoind
xelwa
xserv
flabo
fcapi
fcnw
fswa
fgwa
trmg
hous
gove
taxe
rowe
/;
alias(rows,cols,rows_j,cols_j);

* define the examplary artificial SAM from excel and convert into gdx
table sam_00(rows,cols) "the artificial example SAM the original SAM"
```

	aagfo	aoind	aelwa	aserv	cagfo	coind	celwa	cserv	flabo	fcapi	hous	gove	taxe	rowe
aagfo	0.000000000000	0.000000000000	0.000000000000	0.000000000000	317.393591514771	0.128920350867	1.317822648823	22.577123165735	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000
aoind	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	202.752756070498	0.020621584066	30.275411258453	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000
aelwa	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	2.143601974574	185.055612791828	4.230954782370	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000
aserv	0.000000000000	0.000000000000	0.000000000000	0.000000000000	8.356175561321	14.311523476326	29.460252072656	4225.392874522910	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000
cagfo	165.571662250410	4.917204948114	1.602020993269	141.131371790921	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	378.356687414837	0.000000000000	-4.299832642756	43.089234225712
coind	39.734923632392	110.437300235296	48.373323310212	408.299002528418	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	501.190040455745	0.000000000000	282.818051845955	16.183710598995
celwa	2.489526435359	3.763520657222	55.211370068780	21.820951871442	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	65.853523632041	0.156292934702	0.000000000000	2.854326701496
cserv	30.419212968998	32.414025841343	41.135396914301	1104.379628880390	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	1119.296538492350	1053.409659605970	421.413547334880	30.539763179907
flabo	42.803814152763	41.021807989764	22.887294238430	1129.428091189800	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000
fcapi	52.624543755741	25.517034681606	19.452643331950	1035.010840922740	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000
hous	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	1236.141007570760	1132.605062692030	0.000000000000	617.959831462703	0.000000000000	0.000000000000
gove	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	210.450969846397	0.000000000000	641.409586375813	0.000000000000
taxe	7.773774484533	14.977894559670	2.768120525202	437.450938282876	246.173565612378	492.072508918956	-63.750044241285	-496.057172099777	0.000000000000	0.000000000000	711.558141717490	-819.665227947793	-15.338996481000	808.038852435123
rowe	0.000000000000	0.000000000000	0.000000000000	0.000000000000	158.445016292036	695.627042149051	0.045247444954	46.588581255192	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000

```
;

*scalar thre_show /0.01/;

* check balance of the original SAM (sam00)
parameter
chck_bala_sam00_rows(rows)      "rowsum"
chck_bala_sam00_cols(cols)      "colsum"
chck_bala_sam00_diff(rows)      "difference rowsum minus colsum"
chck_bala_sam00_diff_show(rows) "show differences gt threshold"
;
chck_bala_sam00_rows(rows) = sum(cols, sam_00(rows,cols));
chck_bala_sam00_cols(cols) = sum(rows, sam_00(rows,cols));
chck_bala_sam00_diff(rows) =  chck_bala_sam00_rows(rows)   - chck_bala_sam00_cols(rows) ;
chck_bala_sam00_diff_show(rows)$(chck_bala_sam00_diff(rows) gt thre_show) =  chck_bala_sam00_diff(rows);
display chck_bala_sam00_diff_show;

*#################################################################################
*#*#* Split 01: Final consumptions

parameter  sam_00_01(rows,cols) "the artificial example SAM split for final and intermediate consumption"
;
sam_00_01(rows,cols) = sam_00(rows,cols);
* define the exported commodity as cwaste and substraact it from the supply
sam_00_01("cwast","rowe") =  sam_00("celwa","rowe");
sam_00_01("aelwa","cwast") = sam_00("celwa","rowe");
* make cwast be displayed as empty col
sam_00_01("aelwa","celwa") =  sam_00("aelwa","celwa") - sam_00("celwa","rowe");
* deleted the cells which we moved
sam_00_01("celwa","rowe") =  0;

parameter sam_00_elwa_00(rows,cols) "the artificial example SAM imported in short format unchanged"  ;
sam_00_elwa_00(rows,cols) =  sam_00_01(rows,cols)   ;

table split_prop_cons(rows,cols) "proportions to split the consumption based on external data in percent"
           aagfo    aoind  aelwa  aserv   hous   gove
celec        17       32    32     100     46     100
cwadi        32       35    35     0       27     0
csaco        51       33    33     0       14     0
csanc        0        0     0      0       13     0
;
* convert propotions into index
split_prop_cons(rows,cols) = split_prop_cons(rows,cols)/100;

* compute shares propotions for split 01 = split final consumption into electricity (celec) and 3 water services (cwadi, csaco, csanc)
sam_00_01("celec","aagfo") =  sam_00("celwa","aagfo") * split_prop_cons("celec","aagfo");
sam_00_01("cwadi","aagfo") =  sam_00("celwa","aagfo") * split_prop_cons("cwadi","aagfo");
sam_00_01("csaco","aagfo") =  sam_00("celwa","aagfo") * split_prop_cons("csaco","aagfo");
sam_00_01("csanc","aagfo") =  sam_00("celwa","aagfo") * split_prop_cons("csanc","aagfo");

sam_00_01("celec","aoind") =  sam_00("celwa","aoind") * split_prop_cons("celec","aoind");
sam_00_01("cwadi","aoind") =  sam_00("celwa","aoind") * split_prop_cons("cwadi","aoind");
sam_00_01("csaco","aoind") =  sam_00("celwa","aoind") * split_prop_cons("csaco","aoind");
sam_00_01("csanc","aoind") =  sam_00("celwa","aoind") * split_prop_cons("csanc","aoind");

sam_00_01("celec","aelwa") =  sam_00("celwa","aelwa") * split_prop_cons("celec","aelwa");
sam_00_01("cwadi","aelwa") =  sam_00("celwa","aelwa") * split_prop_cons("cwadi","aelwa");
sam_00_01("csaco","aelwa") =  sam_00("celwa","aelwa") * split_prop_cons("csaco","aelwa");
sam_00_01("csanc","aelwa") =  sam_00("celwa","aelwa") * split_prop_cons("csanc","aelwa");

sam_00_01("celec","aserv") =  sam_00("celwa","aserv") * split_prop_cons("celec","aserv");
sam_00_01("cwadi","aserv") =  sam_00("celwa","aserv") * split_prop_cons("cwadi","aserv");
sam_00_01("csaco","aserv") =  sam_00("celwa","aserv") * split_prop_cons("csaco","aserv");
sam_00_01("csanc","aserv") =  sam_00("celwa","aserv") * split_prop_cons("csanc","aserv");

sam_00_01("celec","hous") =  sam_00("celwa","hous") *   split_prop_cons("celec","hous");
sam_00_01("cwadi","hous") =  sam_00("celwa","hous") *   split_prop_cons("cwadi","hous");
sam_00_01("csaco","hous") =  sam_00("celwa","hous") *   split_prop_cons("csaco","hous");
sam_00_01("csanc","hous") =  sam_00("celwa","hous") *   split_prop_cons("csanc","hous");

sam_00_01("celec","gove") =  sam_00("celwa","gove") *   split_prop_cons("celec","gove");
sam_00_01("cwadi","gove") =  sam_00("celwa","gove") *   split_prop_cons("cwadi","gove");
sam_00_01("csaco","gove") =  sam_00("celwa","gove") *   split_prop_cons("csaco","gove");
sam_00_01("csanc","gove") =  sam_00("celwa","gove") *   split_prop_cons("csanc","gove");

* set to zero after split
sam_00_01("celwa",cols) = 0;

parameter sam_00_elwa_01(rows,cols) "the artificial example SAM split in rows elwa comm";
sam_00_elwa_01(rows,cols) =  sam_00_01(rows,cols)   ;

* check balance of the SAM after split  01
parameter
chck_bala_sam_00_01_rows(rows)      "rowsum"
chck_bala_sam_00_01_cols(cols)      "colsum"
chck_bala_sam_00_01_diff(rows)      "difference rowsum minus colsum"
chck_bala_sam_00_01_diff_show(rows)   "show differences gt threshold"
;
chck_bala_sam_00_01_rows(rows) = sum(cols, sam_00_01(rows,cols));
chck_bala_sam_00_01_cols(cols) = sum(rows, sam_00_01(rows,cols));
chck_bala_sam_00_01_diff(rows) =  chck_bala_sam_00_01_rows(rows)   - chck_bala_sam_00_01_cols(rows) ;
chck_bala_sam_00_01_diff_show(rows)$(chck_bala_sam_00_01_diff(rows) gt thre_show) =  chck_bala_sam_00_01_diff(rows);
display chck_bala_sam_00_01_diff_show;

*#################################################################################
*#*#* Split 02: Production

* proportions of total consumption to split the production of water services
parameter tota_cons(rows);
```

```
tota_cons("celec") = sum(cols, sam_00_01("celec",cols));
tota_cons("cwadi") = sum(cols, sam_00_01("cwadi",cols));
tota_cons("csaco") = sum(cols, sam_00_01("csaco",cols));
tota_cons("csanc") = sum(cols, sam_00_01("csanc",cols));

parameter split_prod(rows) "proportions of total consumption to split the production";
split_prod(rows)$(tota_cons(rows)) =  tota_cons(rows)/sum(rows_j, tota_cons(rows_j)) ;

set s_acti(rows) "all activities"
/
"aagfo"
"aoind"
"aelwa"
"aserv"
/;

set s_taxe_rowe(rows) "taxes and rest of the world"
/
"taxe"
"rowe"
/ ;

* assing for split 02 = split the production of the commodities celec, cwadi, csaco, csanc
parameter sam_00_02(rows,cols) "split commodities in cols (i.e. production)";
sam_00_02(rows,cols)                  = sam_00_01(rows,cols) ;
sam_00_02(rows,cols)$(split_prod(cols))  = sam_00_01(rows,"celwa") * split_prod(cols);

* set to zero after split
sam_00_02(rows,"celwa") = 0;
display split_prod;

* check balance of the SAM after split  02 (production)
parameter
chck_bala_sam_00_02_rows(rows)      "rowsum"
chck_bala_sam_00_02_cols(cols)      "colsum"
chck_bala_sam_00_02_diff(rows)      "difference rowsum minus colsum"
chck_bala_sam_00_02_diff_show(rows)  "show differences gt threshold"
;
chck_bala_sam_00_02_rows(rows) = sum(cols, sam_00_02(rows,cols));
chck_bala_sam_00_02_cols(cols) = sum(rows, sam_00_02(rows,cols));
chck_bala_sam_00_02_diff(rows) =   chck_bala_sam_00_02_rows(rows)   - chck_bala_sam_00_02_cols(rows) ;
chck_bala_sam_00_02_diff_show(rows)$(chck_bala_sam_00_02_diff(rows) gt thre_show) =  chck_bala_sam_00_02_diff(rows);
display chck_bala_sam_00_02_diff_show;

*####################################################################################
*#*#* Split 03: Activities into activities aelec and awasa

parameter sam_00_elwa_02(rows,cols) "the artificial example SAM split in cols elwa comm"   ;
sam_00_elwa_02(rows,cols)  =  sam_00_02(rows,cols)    ;

parameter sam_00_03(rows,cols) "split activities in rows (i.e. production)";
sam_00_03(rows,cols) =  sam_00_02(rows,cols) ;

* assign the commodities to the two acitivities elec and wasa
sam_00_03("aelec","celec") =  sam_00_02("aelwa","celec") ;
sam_00_03("awasa","cwadi") =  sam_00_02("aelwa","cwadi") ;
sam_00_03("awasa","csaco") =  sam_00_02("aelwa","csaco") ;
sam_00_03("awasa","csanc") =  sam_00_02("aelwa","csanc") ;
sam_00_03("awasa","cwast") =  sam_00_02("aelwa","cwast") ;

* assing the less plausible production to aelec
sam_00_03("aelec","cagfo") =  sam_00_02("aelwa","cagfo") ;
sam_00_03("aelec","coind") =  sam_00_02("aelwa","coind") ;
sam_00_03("aelec","cserv") =  sam_00_02("aelwa","cserv") ;

* set to zero after split
sam_00_03("aelwa",cols) = 0;

parameter sam_00_elwa_03(rows,cols) "the artificial example SAM split in rows elwa acti"   ;
sam_00_elwa_03(rows,cols)  =  sam_00_03(rows,cols)    ;

parameter tota_prod_aelec  "sum of all production from aelec";
tota_prod_aelec = sum( cols,   sam_00_03("aelec",cols));

parameter tota_prod_awasa "sum of all production from awasa"; ;
tota_prod_awasa = sum( cols,   sam_00_03("awasa",cols));

parameter tota_prod_aelwa "sum or all production from aelwa, water and elec";
tota_prod_aelwa =  tota_prod_aelec + tota_prod_awasa;

parameter split_acti_cols(cols)"proportions of production from aelec and awasa";
split_acti_cols("aelec")   =    tota_prod_aelec / tota_prod_aelwa;
split_acti_cols("awasa")   =    tota_prod_awasa / tota_prod_aelwa;
sam_00_03(rows,"aelec") =  sam_00_02(rows,"aelwa")  * split_acti_cols("aelec") ;
sam_00_03(rows,"awasa") =  sam_00_02(rows,"aelwa")  * split_acti_cols("awasa") ;
* set to zero after split
sam_00_03(rows,"aelwa") = 0;

* check balance of the SAM after split  03 (activities: aelec and awasa)
parameter
chck_bala_sam_00_03_rows(rows)      "rowsum"
chck_bala_sam_00_03_cols(cols)      "colsum"
chck_bala_sam_00_03_diff(rows)      "difference rowsum minus colsum"
chck_bala_sam_00_03_diff_show(rows)   "show differences gt threshold"
;
chck_bala_sam_00_03_rows(rows) = sum(cols, sam_00_03(rows,cols));
chck_bala_sam_00_03_cols(cols) = sum(rows, sam_00_03(rows,cols));
chck_bala_sam_00_03_diff(rows) =   chck_bala_sam_00_03_rows(rows)   - chck_bala_sam_00_03_cols(rows) ;
chck_bala_sam_00_03_diff_show(rows)$(chck_bala_sam_00_03_diff(rows) gt thre_show) =  chck_bala_sam_00_03_diff(rows);
display chck_bala_sam_00_03_diff_show;

parameter sam_00_elwa_04(rows,cols) "the artificial example SAM split in cols elwa acti"   ;
sam_00_elwa_04(rows,cols)  =  sam_00_03(rows,cols)    ;

*####################################################################################
*#*#* Split 04: Production factors raw water: fswa and fgwa

parameter sam_00_04(rows,cols) "split factors";
sam_00_04(rows,cols) =  sam_00_03(rows,cols) ;

table fact_wate_valu(rows,cols) "computed capital value of raw water usage by activity"
            aagfo        aoind                aelec            awasa
fswa         2.048569678    0.050087278            0              0.377324162
fgwa         1.06518945     0                    0.040069823       0.335584764
;

* assign water capital values
sam_00_04("fswa",cols)  =  fact_wate_valu("fswa",cols);
sam_00_04("fgwa",cols)  =  fact_wate_valu("fgwa",cols);

* compute non-water capital split captial in rows
sam_00_04("fcnw",cols)  =  sam_00_03("fcapi",cols)  -   sam_00_04("fswa",cols) - sam_00_04("fgwa",cols) ;

*delete all rows and cols not needed
sam_00_04("fcapi",cols) = 0;

parameter sam_00_fact_01(rows,cols) "the artificial example SAM split in rows wate factors"   ;
sam_00_fact_01(rows,cols)  =   sam_00_04(rows,cols)    ;

* compute non-water capital split captial in cols
* assign incomme from non-water capital to hous
sam_00_04("hous","fcnw")  =  sam_00_04("hous","fcapi") -  sum(cols, sam_00_04("fswa",cols) + sam_00_04("fgwa",cols));
* delete capital income
sam_00_04("hous","fcapi")  =    0;

* assign incomme from water capital to government
sam_00_04("gove","fswa")  =   sum(cols, sam_00_04("fswa",cols));
sam_00_04("gove","fgwa")  =   sum(cols, sam_00_04("fgwa",cols));
* move facpi to fcnw
sam_00_04("gove","fcnw")  =   sam_00_04("gove","fcapi");
```

```
sam_00_04("gove","fcapi")  = 0;

* rebalance the gove and hous account by tranfering the captial income from water to
sam_00_04("hous","gove")  =    sam_00_04("hous","gove")  +    ( sam_00_04("gove","fswa") +  sam_00_04("gove","fgwa") );

*delete all rows and cols not needed
sam_00_04(rows,"fcapi") = 0;
sam_00_04("fcapi",cols) = 0;

* check balance of the SAM after split 04 (Production factors raw water: fswa and fgwa)
parameter
chck_bala_sam_00_04_rows(rows)      "rowsum"
chck_bala_sam_00_04_cols(cols)      "colsum"
chck_bala_sam_00_04_diff(rows)      "difference rowsum minus colsum"
chck_bala_sam_00_04_diff_show(rows)  "show differences gt threshold"
;
chck_bala_sam_00_04_rows(rows) = sum(cols, sam_00_04(rows,cols));
chck_bala_sam_00_04_cols(cols) = sum(rows, sam_00_04(rows,cols));
chck_bala_sam_00_04_diff(rows) =   chck_bala_sam_00_04_rows(rows)   - chck_bala_sam_00_04_cols(rows) ;
chck_bala_sam_00_04_diff_show(rows)$(chck_bala_sam_00_04_diff(rows) gt thre_show) =  chck_bala_sam_00_04_diff(rows);
display chck_bala_sam_00_04_diff_show;

parameter sam_00_fact_02(rows,cols) "the artificial example SAM split in cols wate factors"    ;
sam_00_fact_02(rows,cols)  =   sam_00_04(rows,cols)    ;

*#####################################################################################
*#*#* Split 05: Production of electricity by energy activities

* split energy activities: split production
parameter  split_prod_elec(rows)
     /
acoal  =    0.42762557 ,
aeptr  =    0.33759387 ,
aebio  =    0.04658263 ,
aehyd  =     0.03710540 ,
aewin  =    0.04023135 ,
aesol  =    0.11086118
      /;

set s_ener_rows(rows)
/
acoal
aeptr
aebio
aehyd
aewin
aesol
/ ;
alias(s_ener_rows, s_ener_cols);

parameter sam_00_05(rows,cols) "split energy activities";
sam_00_05(rows,cols) =  sam_00_04(rows,cols) ;

* split the supply to the domestic market for celec and other commm  in rows
sam_00_05(s_ener_rows,cols)$( split_prod_elec(s_ener_rows) gt 0) = sam_00_04("aelec",cols)  *  split_prod_elec(s_ener_rows);

* delete  row aelec
sam_00_05("aelec",cols) =   0;

parameter sam_00_ener_01(rows,cols) "the artificial example SAM split in rows ener acti"   ;
sam_00_ener_01(rows,cols)  =   sam_00_05(rows,cols)    ;


*#####################################################################################
*#*#* Split 06: Intermediate demand by energy activities

parameter sam_00_06(rows,cols) "split energy activities";
sam_00_06(rows,cols) =   sam_00_05(rows,cols);

* not used: split energy activities: intermediate demand and other comm in cols
* attention: this table represents the emprical base according to which
* the intermediate demand could be split. However, splitting according to these
* proportions will create an unbalanced SAM. Thus, we split consistent to the SAM
* and by this we stay closer to the original SAM
table split_ener_cols(rows,cols)  "proportions derived from SAMomega"
        acoal   aeptr   aebio   aehyd   aewin   aesol
*intermediate demand
cagfo   0.325   0.325   0.350   0.000   0.000   0.000
coind   0.325   0.325   0.000   0.000   0.175   0.175
celec   0.325   0.325   0.140   0.140   0.035   0.035
cserv   0.325   0.325   0.088   0.088   0.088   0.088
*factors
*       acoal   aeptr   aebio   aehyd   aewin   aesol
flabo   0.3250  0.3250  0.0292  0.0292  0.0271  0.2645
fcapi   0.0354  0.6146  0.1511  0.0096  0.0356  0.1537
fswa    0.5588  0.4412  0.0000  0.0000  0.0000  0.0000
* taxes
*       acoal   aeptr   aebio   aehyd   aewin   aesol
taxe    0.5147  0.1353  0.1001  0.2405  0.0053  0.0042
;

set s_ener(cols) /acoal ,  aeptr ,  aebio  ,  aehyd  ,  aewin  ,  aesol/;

* used: split energy activities: intermediate demand and other comm in cols
* split according to the proportions of production to keep consistency the empirical split according to the data looks artificial
* thus we splitt accroding to the produciotn to avoid de-balancing
sam_00_06(rows,s_ener_cols)$(split_prod_elec(s_ener_cols) gt 0) = sam_00_05(rows,"aelec")  *  split_prod_elec(s_ener_cols);

* delete  col aelec
sam_00_06(rows,"aelec") =   0;

* check balance of the SAM after split 05 and 06 (Production of electricity by energy activities)
parameter
chck_bala_sam_00_06_rows(rows)      "rowsum"
chck_bala_sam_00_06_cols(cols)      "colsum"
chck_bala_sam_00_06_diff(rows)      "difference rowsum minus colsum"
chck_bala_sam_00_06_diff_show(rows)  "show differences gt threshold"
;
chck_bala_sam_00_06_rows(rows) = sum(cols, sam_00_06(rows,cols));
chck_bala_sam_00_06_cols(cols) = sum(rows, sam_00_06(rows,cols));
chck_bala_sam_00_06_diff(rows) =   chck_bala_sam_00_06_rows(rows)   - chck_bala_sam_00_06_cols(rows) ;
chck_bala_sam_00_06_diff_show(rows)$(chck_bala_sam_00_06_diff(rows) gt thre_show) =  chck_bala_sam_00_06_diff(rows);
display chck_bala_sam_00_06_diff_show;

execute_unload "sam_show.gdx" sam_00_01, sam_00_02, sam_00_03, sam_00_04, sam_00_05, sam_00_06;

parameter sam_00_ener_02(rows,cols) "the artificial example SAM split in cols ener acti"   ;
sam_00_ener_02(rows,cols)  =   sam_00_06(rows,cols)    ;

* write SAM sections with the corresponding splits for illuatration
parameter
 sam_00_D42_A_01_elwa(rows,cols)
 sam_00_D42_A_02_elwa(rows,cols)
 sam_00_D42_A_03_elwa(rows,cols)
 sam_00_D42_A_04_elwa(rows,cols)
 sam_00_D42_A_05_elwa(rows,cols)
 sam_00_D42_A_06_elwa(rows,cols)

 sam_00_D42_B_01_fact(rows,cols)
 sam_00_D42_B_02_fact(rows,cols)
 sam_00_D42_B_03_fact(rows,cols)
 sam_00_D42_B_04_fact(rows,cols)

 sam_00_D42_C_01_ener(rows,cols)
 sam_00_D42_C_02_ener(rows,cols)
 sam_00_D42_C_03_ener(rows,cols)
 sam_00_D42_C_04_ener(rows,cols)
      ;

sam_00_D42_A_01_elwa(rows,cols)    =  sam_00_elwa_00(rows,cols);
```

```
sam_00_D42_A_02_elwa(rows,cols)   = sam_00_elwa_01(rows,cols);
sam_00_D42_A_02_elwa("aelwa",cols) = sam_00_elwa_00("aelwa",cols) ;
sam_00_D42_A_02_elwa(rows,"aelwa") = sam_00_elwa_00(rows,"aelwa") ;
sam_00_D42_A_02_elwa("celwa",cols) = sam_00_elwa_00("celwa",cols);
sam_00_D42_A_02_elwa(rows,"celwa") = sam_00_elwa_00(rows,"celwa") ;

sam_00_D42_A_03_elwa(rows,cols)   = sam_00_elwa_02(rows,cols);
sam_00_D42_A_03_elwa("aelwa",cols) = sam_00_elwa_00("aelwa",cols) ;
sam_00_D42_A_03_elwa(rows,"aelwa") = sam_00_elwa_00(rows,"aelwa") ;
sam_00_D42_A_03_elwa("celwa",cols) = sam_00_elwa_00("celwa",cols);
sam_00_D42_A_03_elwa(rows,"celwa") = sam_00_elwa_00(rows,"celwa") ;

sam_00_D42_A_04_elwa(rows,cols)   = sam_00_elwa_03(rows,cols);
sam_00_D42_A_04_elwa("aelwa",cols) = sam_00_elwa_00("aelwa",cols) ;
sam_00_D42_A_04_elwa(rows,"aelwa") = sam_00_elwa_00(rows,"aelwa") ;
sam_00_D42_A_04_elwa("celwa",cols) = sam_00_elwa_00("celwa",cols);
sam_00_D42_A_04_elwa(rows,"celwa") = sam_00_elwa_00(rows,"celwa") ;

sam_00_D42_A_05_elwa(rows,cols)   = sam_00_elwa_04(rows,cols);
sam_00_D42_A_05_elwa("aelwa",cols) = sam_00_elwa_00("aelwa",cols) ;
sam_00_D42_A_05_elwa(rows,"aelwa") = sam_00_elwa_00(rows,"aelwa") ;
sam_00_D42_A_05_elwa("celwa",cols) = sam_00_elwa_00("celwa",cols);
sam_00_D42_A_05_elwa(rows,"celwa") = sam_00_elwa_00(rows,"celwa") ;

sam_00_D42_A_06_elwa(rows,cols)   = sam_00_elwa_04(rows,cols);

sam_00_D42_B_01_fact(rows,cols)   = sam_00_elwa_04(rows,cols);

sam_00_D42_B_02_fact(rows,cols)   = sam_00_fact_01(rows,cols);
sam_00_D42_B_02_fact("fcapi",cols) = sam_00_elwa_00("fcapi",cols) ;
sam_00_D42_B_02_fact(rows,"fcapi") = sam_00_elwa_00(rows,"fcapi") ;
sam_00_D42_B_02_fact("fcapi",cols) = sam_00_elwa_00("fcapi",cols);
sam_00_D42_B_02_fact(rows,"fcapi") = sam_00_elwa_00(rows,"fcapi") ;

sam_00_D42_B_03_fact(rows,cols)   = sam_00_fact_02(rows,cols);
sam_00_D42_B_03_fact("fcapi",cols) = sam_00_elwa_00("fcapi",cols) ;
sam_00_D42_B_03_fact(rows,"fcapi") = sam_00_elwa_00(rows,"fcapi") ;
sam_00_D42_B_03_fact("fcapi",cols) = sam_00_elwa_00("fcapi",cols);
sam_00_D42_B_03_fact(rows,"fcapi") = sam_00_elwa_00(rows,"fcapi") ;

sam_00_D42_B_04_fact(rows,cols)   = sam_00_fact_02(rows,cols);

sam_00_D42_C_01_ener(rows,cols)   = sam_00_fact_02(rows,cols);

sam_00_D42_C_02_ener(rows,cols)   = sam_00_ener_01(rows,cols)   ;
sam_00_D42_C_02_ener("fcapi",cols) = 0 ;
sam_00_D42_C_02_ener(rows,"fcapi") = 0 ;
sam_00_D42_C_02_ener("aelec",cols) = sam_00_elwa_04("aelec",cols) ;
sam_00_D42_C_02_ener(rows,"aelec") = sam_00_elwa_04(rows,"aelec") ;
sam_00_D42_C_02_ener("celec",cols) = sam_00_elwa_04("celec",cols) ;
sam_00_D42_C_02_ener(rows,"celec") = sam_00_elwa_04(rows,"celec") ;

sam_00_D42_C_03_ener(rows,cols)   = sam_00_ener_02(rows,cols)   ;
sam_00_D42_C_03_ener("fcapi",cols) = 0 ;
sam_00_D42_C_03_ener(rows,"fcapi") = 0 ;
sam_00_D42_C_03_ener("aelec",cols) = sam_00_elwa_04("aelec",cols) ;
sam_00_D42_C_03_ener(rows,"aelec") = sam_00_elwa_04(rows,"aelec") ;
sam_00_D42_C_03_ener("celec",cols) = sam_00_elwa_04("celec",cols) ;
sam_00_D42_C_03_ener(rows,"celec") = sam_00_elwa_04(rows,"celec") ;

sam_00_D42_C_04_ener(rows,cols)   = sam_00_ener_02(rows,cols)   ;

execute_unload "D4_2_SAM_examples_20250205.gdx"
sam_00_D42_A_01_elwa,
sam_00_D42_A_02_elwa,
sam_00_D42_A_03_elwa,
sam_00_D42_A_04_elwa,
sam_00_D42_A_05_elwa,
sam_00_D42_A_06_elwa,
sam_00_D42_B_01_fact,
sam_00_D42_B_02_fact,
sam_00_D42_B_03_fact,
sam_00_D42_B_04_fact
sam_00_D42_C_01_ener,
sam_00_D42_C_02_ener,
sam_00_D42_C_03_ener,
sam_00_D42_C_04_ener
;

execute_unload "D4_2_SAM_examples_20250205.gdx" sam_00_elwa_00, sam_00_elwa_01, sam_00_elwa_02, sam_00_elwa_03, sam_00_elwa_04, sam_00_fact_01,sam_00_fact_02, sam_00_ener_01, sam_00_ener_02;

* end of code
```

8.3.5 Environmental indicators

This section is intentionally left blank.

8.3.6 Constructing a river basin SAM

Questionnaire for the replication assessment

InnWater Project Work Package 6

Replication assessment

Feasibility to replicate the CGE modelling on the replication sites: Seine and Corsica

First draft version

Date: 12/06/2024

Introductory information: to build a SAM at national level macro-economic statistics can be used (e.g., the integrated economic national accounts, input-output tables, …) Regions at smaller spatial scale these data might be available in a different regional data collections or even not available. River basins are defined according to their natural borders, which are only in few cases matching with administrative borders. Therefore, it can be challenging to collect the macroeconomic data required to build a CGE model database (i.e. a SAM). This questionnaire supports to evaluate the data availability for building CGE models for river basin regions.

No	Question/answer	Source (incl. URL)
1	**Availability of existing SAM**	
1.1	Is a SAM existing and available which represents the exactly the river basin? If yes continue with 2.1.	
	Answer:	
1.2	Is a SAM existing which partially represents the RB, or which covers more than the RB? If yes continue with 2.1.	
	Answer:	
1.3	Is no SAM existing, which partially or approximately represents the RB? If yes continue with 3.1.	
	Answer:	
2	**Existing SAM exactly or partially covering the RB region**	
2.1	**Representativeness of existing SAM: area coverage**	
2.1.0	Is the SAM representing (a) exactly representing, (b) partially representing the RB or (b) covering more than the RB? If (a) continues with 2.2, if (b) or (c) continue with 2.1.1.	
	Answer:	
2.1.1	If the SAM represents partially the RB, how much of the RB is covered by the SAM in terms of area, economic activities and the WEFE relevant activities is covered? Please explain for each item: aera, economic activities, WEFE-pillars	
	Answer:	
2.1.2	How much would you estimate the overall representativeness of the SAM for the RB expressed in percent, with 100% i.e. fully representative, with <100% underrepresented,	
2.1.3	If the SAM represents approximately but more than the RB, by how much does the SAM overestimate the RB in terms of area, economic activities and the WEFE relevant activities? Please explain for each item: aera, economic activities, WEFE-pillars	
2.1.4	How much would you estimate the overall representativeness of the SAM for the RB expressed in percent, with 100% i.e. fully representative, with >100% overestimation.	
2.1.5	If the SAM represents partially the RB, how much of the RB is covered by the SAM in terms of area, economic activities and the WEFE relevant activities is covered, in percentage?	

2.2	**Representativeness of existing SAM: time/period/base year**
2.2.0	When is the base year of the SAM: (a) less than 5 years older than current, (b) between 5 and 10 years older than current or (c) more than 10 years older than the current? Please, indicate if (a), (b) or (c) and the year.
2.2.1	Can the SAM be still considered as representative for the current situation? Please explain if yes or no and why? (e.g., representative because the economic structure has not changed significantly since the SAM base year, or not representative because some activities have been expanded significantly after the base year).
2.2.2	If the SAM is not anymore representative, can the SAM still provide useful information (e.g., on intermediate consumption)? If yes, which information can be useful, if not, why can the SAM not be used.
2.2.3	If the SAM is outdated can an update of the SAM be possible?
2.3	**Representativeness of existing SAM: account coverage**
2.3.1	How many and which accounts are represented by the SAM in terms of
	Answer: (a) activities: ###insert### (b) commodities: ###insert### (c) production factors ###insert### (d) economic agents (household, governments, rest of work): ###insert### (e) tax and other agents: ###insert### (f) other accounts: ###insert###
2.3.2	Which WEFE-relevant activities and commodities does the SAM represent? Please, list and describe them.
	Answer:
2.3.3	Are WEFE-relevant activities and commodities are aggregated represented in the SAM and if yes in which form?
2.3.4	Can the WEFE-relevant activities be disaggregated? Which data can be used to disaggregate the aggregated accounts?
3	**Building original SAM**
3.1	**Data availability to build an original SAM**

3.1.1	Which administrative unit(s) contain the RB? (e.g., regions, departments). Please name them and indicate the corresponding **NUTS** (Nomenclature of Territorial Units for Statistics) level (e.g., NUTS1, NUTS2, NUTS3).
3.1.2	Which administrative units are laying within the RB (e.g., counties, districts, communities)? Please name them and indicate the corresponding NUTS level, with corresponding description for the case (e.g., NUTS3 or LAU (Local Administrative Units), e.g. communes).
3.2	**Statistical spatial units**
3.2.1	**Aggregation bottom-up**: Which is the **largest administrative unit** which can be aggregated to **represent most precisely** the RB if aggregated (i.e., it is in line with the RB natural borders)? For example several hundred community level data (e.g. communes) can be aggregated to represent the RB in its natural borders? Please, list them in a summarized way (e.g., all communities of NUTS2 region X, 50% of communities of the department Y, … etc.)
3.2.2	**Coverage top-down**: Which is the **smallest administrative unit** which can be aggregated to **represent the RB with smallest overestimation possible** (i.e., it is not in line with the RBs natural borders but overestimates the area smallest as possible)? For example some few department level data (NUTS3) or region data represent the area of the RB and some more area, which represents the administrative region but are not in line with the natural borders?
3.3	**Spatial data availability**
3.3.1	**Data availability aggregation bottom-up**: which economic data are available for the **largest administrative unit** which can be aggregated to **represent most precisely** the RB (3.2.1)? Which data can be used to build a SAM in terms of activities, commodities, agents and taxes and other accounts? Which data are not available and need to be derived based on data and assumptions?
3.3.2	**Data availability coverage top-down**: which economic data are available for **smallest administrative unit** which can be aggregated to **represent the RB with smallest overestimation possible** (3.2.2)? Which data can be used to build a SAM in terms of activities, commodities, agents and taxes and other accounts? Which data are not available and need to be derived based on data and assumptions?
3.3.3	**Over-/under-estimation coverage top-down**: How much do you estimate the representativeness of the SAM if the data representing the **smallest administrative unit** are aggregated to **represent the RB with smallest over-/under-estimation possible** (3.2.2)? Estimate the over-/over-estimation of different aspects in %.with 100% i.e. fully representative, with >100% overestimation, with with <100% underestimation Indicate local extreme overestimation, e.g., if a industrial production site not located within the natural borders of the RB contribute a lot to production and pollution within the administrative unit. e.g.,

- for surface = 90%
- production of agriculture = 80%
- population = 105%
- pollution = 102%

3.3.4	Is a **mixed approach** between the two approaches a possible, i.e., to apply **coverage top-down** for areas which slightly over/under-estimate **and aggregation bottom-up** for RB zones which otherwise significantly over/under-estimate. If yes, for how many LAU regions data need to be researched.
3.4	**Data sources**
3.4.1	**Data sources and derivations Aggregation bottom-up**: Indicate the potential data source for **non-**WEFE-nexus accounts in the SAM (e.g., production, final consumption, intermediate consumption) and indicate for which accounts statistical data are available and accessible and which data require and derivation based on other data and on assumptions.
3.4.2	**Data sources and derivations Aggregation bottom-up**: Indicate the potential data source for **WEFE-nexus accounts** in the SAM (e.g., production, final consumption, intermediate consumption) and indicate for which accounts statistical data are available and accessible and which data require and derivation based on other data and on assumptions.
3.4.3	**Data sources and derivations Coverage top-down**: Indicate the potential data source for **non-WEFE-nexus** accounts in the SAM (e.g., for water production, final consumption, intermediate consumption) and indicate for which accounts statistical data are available and accessible and which data require and derivation based on other data and on assumptions.
3.4.4	**Data sources and derivations Coverage top-down**: Indicate the potential data source for **WEFE-nexus accounts** in the SAM (e.g., for water: production, final consumption, intermediate consumption) and indicate for which accounts statistical data are available and accessible and which data require and derivation based on other data and on assumptions.
3.5	**Estimation of feasibility building a new SAM**
3.5.1	Which of the assessed approaches (**Aggregation bottom-up or Coverage top-down)** is the more promising and why?
3.5.2	Indicate for which of the approaches (**Aggregation bottom-up or Coverage top-down)** the data availability is better
3.5.3	Indicate much time the approaches (**Aggregation bottom-up and Coverage top-down)** would require collecting all the data to construct an original SAM?

4	**Research question for the replication sites**
4.1	Which 3 to 5 research questions concerning water management and WEFE-nexus are of highest interest for • The government • The citizens • Different industries (e.g., agriculture, water supplier) • Other stakeholders (e.g. environmentalists)
4.2	Which of the research questions (4.1) can be addressed by using a CGE model? Which cannot be addressed by using a CGE model?

8.4 Description of the SAM and CGE model

8.4.1 The SAM

This section is intentionally left blank.

8.4.2 Specification of the CGE model

The following sections (S1 to S4) present algebraically the developed CGE model, the REWEFE-CGE model. For detailed explanation of the methodological background see Decaluwé et al. (2013). Note, that the formulation presented here differs from the PEP-1-1 standard model by the adjusted elements as explained in Section 2.

S1.1 Production

$$VA_j = v_j XST_j \quad \text{Eq. 1}$$

$$CI_j = io_j XST_j \quad \text{Eq. 2}$$

$$VA_j = B_j^{VA}\left[\beta_j^{VA} WAT_j^{-\rho_j^{VA}} + (1-\beta_j^{VA})\, NWAT_j^{-\rho_j^{VA}}\right]^{-\frac{1}{\rho_j^{VA}}} \quad \text{Eq. 3}$$

$$WAT_j = \left\{\left[\frac{\beta_j^{VA}}{(1-\beta_j^{VA})}\right]\left[\frac{PNWAT_J}{PWAT_J}\right]\right\}^{\sigma_j^{VA}} NWAT_j \quad \text{Eq. 4}$$

$$WAT_j = B_j^{WAT_{mult}} \times B_j^{WAT}\left[\sum_{k_{wat}} \beta_{k_{wat}}^{WAT} KD_{k_{wat},j}^{-\sigma_j^{KD}}\right]^{-1/\sigma_j^{KD}} \quad \text{Eq. 5}$$

$$KD_{k_{wat},j} = \left[\frac{\beta_j^{WAT} PWAT_j}{RTI_{k_{wat},j}}\right]^{\sigma_j^{KD}} B_j^{WAT(\sigma_j^{KD}-1)} WAT_j \quad \text{Eq. 6}$$

$$NWAT_j = B_j^{NWAT}\left[\beta_j^{NWAT} LDC_j^{-\rho_j^{NWAT}} + (1-\beta_j^{NWAT}) KDC_j^{-\rho_j^{NWAT}}\right]^{-1/\rho_j^{NWAT}} \quad \text{Eq. 7}$$

$$LDC_j = \left\{\left[\frac{\beta_j^{NWAT}}{(1-\beta_j^{NWAT})}\right]\left[\frac{RC_J}{WC_J}\right]\right\}^{\sigma_j^{NWAT}} KDC_j \quad \text{Eq. 8}$$

$$LDC_j = B_j^{LD}\left[\sum_{l} \beta_j^{LD} LD_{l,j}^{-\sigma_j^{LD}}\right]^{-1/\sigma_j^{LD}} \quad \text{Eq. 9}$$

$$LD_{l,j} = \left[\frac{\beta_j^{LD} WC_j}{WTI_{l,j}}\right]^{\sigma_j^{LD}} B_j^{LD(\sigma_j^{LD}-1)} LDC_j \quad \text{Eq. 10}$$

$$KDC_j = B_j^{KD}\left[\sum_{k_{nwat}} \beta_j^{KD} KD_{k_{nwat},j}^{-\sigma_j^{KD}}\right]^{-1/\sigma_j^{KD}} \quad \text{Eq. 11}$$

$$KD_{k_{nwat},j} = \left[\frac{\beta_{k_{nwat},j}^{KD} RC_j}{RTI_{k_{nwat},j}}\right]^{\sigma_j^{KD}} B_j^{KD(\sigma_j^{KD}-1)} KDC_j \quad \text{Eq. 12}$$

$$DI_{i,j,} = aij_{i,j} CI_j \quad \text{Eq. 13}$$

S1.2 Income and Savings

S1.2.1 Households

$$YH_h = YHL_h + YHK_h + YHTR_h \quad \text{Eq. 14}$$

$$YHL_h = \sum_l \lambda_h^{WL} W_l \sum_j LD_{l,j}$$ Eq. 15

$$YHK_h = \sum_k \lambda_k^{RK} \left(\sum_j R_{k,j} KD_{k,j} \right)$$ Eq. 16

$$YHTR_h = \sum_{ag} TR_{h,ag}$$ Eq. 17

$$YDH_h = YH_h - TDH_h - TR_{'gvt',h}$$ Eq. 18

$$CTH_h = YDH_h - SH_h - \sum_{agng} TR_{agng,h}$$ Eq. 19

$$SH_h = sh1_h \; YDH_h$$ Eq. 20

S1.2.2Firms

$$YF = YFK + YFTR$$ Eq. 21

$$YFK = \sum_k \lambda_f^{RK} \left(\sum_j R_{k,j} KD_{k,j} \right)$$ Eq. 22

$$YFTR = \sum_{ag} TR_{f,ag}$$ Eq. 23

$$YDF = YF - TDF$$ Eq. 24

$$SF = YDF - \sum_{ag} TR_{ag,f}$$ Eq. 25

S1.2.3 Government

$$YG = YGK + TDHT + TDF + TPRODN + TPRCTS + YGTR$$ Eq. 26

$$YGK = \lambda_{'gvt'}^{RK} \left(\sum_j R_j KD_j \right)$$ Eq. 27

$$TDHT = \sum_h TDH_h$$ Eq. 28

$$TDFT = \sum_f TDF_f$$ Eq. 29

$$TPRODN = TIPT + TIWT + TIKT$$ Eq. 30

$$TIWT = \sum_{l,j} TIW_{l,j}$$ Eq. 31

$$TIKT = \sum_{k,j} TIK_{k,j}$$ Eq. 32

$$TIPT = \sum_{j} TIP_j$$ Eq. 33

$$TPRCTS = TICT + TIMT + TIXT$$ Eq. 34

$$TICT = \sum_{i} TIC_i$$ Eq. 35

$$TIMT = \sum_{i} TIM_i$$ Eq. 36

$$TIXT = \sum_{i} TIX_i$$ Eq. 37

$$YGTR = \sum_{agng} TR_{gvt,agng}$$ Eq. 38

$$TDH_h = PIXCON^n ttdh0_h + ttdh1_h YH_h$$ Eq. 39

$$TDF_f = PIXCON^n ttdf0_h + ttdh1_f YFK_f$$ Eq. 40

$$TIW_{l,j} = ttiw_{l,j} W_l LD_{l,j}$$ Eq. 41

$$TIK_{k,j} = ttik_{k,j} R_{k,j} kD_{k,j}$$ Eq. 42

$$TIP_j = ttip_j PP_j XST_j$$ Eq. 43

$$TIC_i = ttic_i \left[\left(PL_i + \sum_{ij} PC_{ij} tmrg_{ij,i} \right) DD_i \left((1 + ttim_i) PWM_i e + \sum_{ij} PC_{ij} tmrg_{ij,i} \right) IM_i \right]$$ Eq. 44

$$TIM_i = ttim_i PWM_i \ e \ IM_i$$ Eq. 45

$$TIX_i = ttix_i \left(PE_i + \sum_{ij} PC_{ij} tmrg^x_{ij,i} \right) EXD_i$$ Eq. 46

$$SG = YG - \sum_{agng} TR_{agng,gvt} - G$$ Eq. 47

S1.2.4 Rest of the World

$$YROW = e\sum_{i} PWM_i IM_i + \lambda_{row}^{RK}\left(\sum_{j} R_j KD_j\right) + \sum_{agd} TR_{row,agd}$$ Eq. 48

$$SROW = YROW - \sum_{i} PE_i^{FOB} EX_i - \sum_{agd} TR_{agd,row}$$ Eq. 49

$$SROW = -CAB$$ Eq. 50

S1.2.5 Transfers

$$TR_{agng,'h} = \lambda_{agng,h'}^{TR} YDH_h$$ Eq. 51

$$TR_{gvt,h} = PIXCON^n tr0_h tr1_h YH_h$$ Eq. 52

$$TR_{ag,f} = \lambda_{ag,f}^{TR}\ YDF_f$$ Eq. 53

$$TR_{agng,gvt} = PIXCON^n TR_{agng,gvt}^0$$ Eq. 54

$$TR_{agd,row} = PIXCON^n TR_{agd,row}^0$$ Eq. 55

S1.3 Demand

$$PC_i\ C_{i,h} = PC_i C_{i,h}^{MIN} + \gamma_{i,h}^{LES}\left(CTH_h - \sum_{ij} PC_{ij} C_{ij,h}^{MIN}\right)$$ Eq. 56

$$GFCF = IT - \sum_{i} PC_i VSTK_i$$ Eq. 57

$$PC_i INV_i = \gamma_i^{INV} GFCF$$ Eq. 58

$$PC_i CG_i = \gamma_i^{GVT} G$$ Eq. 59

$$DIT_i = \sum_{j} DI_{i,j}$$ Eq. 60

$$MRGN_i = \sum_{ij} tmrg_{i,ij} DD_{ij} + \sum_{ij} tmrg_{i,ij} IM_{ij} + \sum_{ij} tmrg_{i,ij}^{x} EXD_{ij}$$ Eq. 61

S1.4 Producer supplies of products and international trade

$$XST_j = B_j^{XT}\left[\sum_{i} \beta_{j,i}^{XT} XS_{j,i}^{\rho_j^{XT}}\right]^{\frac{1}{\rho_j^{XT}}}$$ Eq. 62

$$XS_{j,i} = \frac{XST_j}{\left(B_j^{XT}\right)^{1+\sigma_j^{XT}}} \left[\frac{P_{j,i}}{\beta_{j,i}^{XT}\ PT_j}\right]^{\sigma_j^{XT}}$$ Eq. 63

$$XS_{j,i} = B_{j,i}^{X} \left[\beta_{j,i}^{X} EX_{j,i}^{\rho_{j,i}^{X}} + \left(1 - \beta_{j,i}^{X}\right) DS_{j,i}^{\rho_j^X}\right]^{\frac{1}{\rho_j^X}}$$ Eq. 64

$$EX_{j,i} = \left[\frac{1 - \beta_{j,i}^{X}}{\beta_{j,i}^{X}} \frac{PE_i}{PL_i}\right]^{\sigma_{j,i}^{X}} DS_{j,i}$$ Eq. 65

$$EXD_i = EXD_i^{O} \left(\frac{e\ PWX_i}{PE_i^{FOB}}\right)^{\sigma_i^{XD}}$$ Eq. 66

$$Q_i = B_i^{M} \left[\beta_i^{M} IM_i^{-\rho_i^M} + \left(1 - \beta_i^{M}\right) DD_i^{-\rho_i^M}\right]^{\frac{-1}{\rho_i^M}}$$ Eq. 67

$$IM_i = \left[\frac{\beta_i^{M}}{1 - \beta_i^{M}} \frac{PD_i}{PM_i}\right]^{\sigma_i^{M}} DD_i$$ Eq. 68

S1.5 Prices

S1.5.1 Production

$$PP_j XST_j = PVA_j VA_j + PCI_j CI_j$$ Eq. 69

$$PT_j = \left(1 + ttip_j\right) PP_j$$ Eq. 70

$$PCI_j CI_j = \sum_i PC_i DI_{i,j}$$ Eq. 71

$$PVA_j VA_j = PWAT_j WAT_j + PNWAT_j NWAT_j$$ Eq. 72

$$PNWAT_j NWAT_j = WC_j LDC_j + RC_j KDC_j$$ Eq. 73

$$WTI_j = W_l\left(1 + ttiw_{l,j}\right)$$ Eq. 74

S1.5.2 Production International Trade

$$RTI_j = R_{k,j}\left(1 + ttik_{k,j}\right)$$ Eq. 75

$$R_{k,j} = Rk_k$$ Eq. 76

$$P_{j,i} = \frac{PE_i EX_{j,i} + PL_i DS_{j,i}}{XS_{j,i}}$$ Eq. 77

$$PE_i^{FOB} = \left(PE_i + \sum_{ij} PC_{ij} tmrg_{ij,i}^{x} \right) (1 + ttix_i)$$ Eq. 78

$$PD_i = (1 + ttic_{i,}) \left(PL_i + \sum_{ij} PC_{ij} tmrg_{ij,i} \right)$$ Eq. 79

$$PM_i = (1 + ttic_i) \left((1 + ttim_i)\ e\ PWM_i + \sum_{ij} PC_{ij} tmrg_{ij,i} \right)$$ Eq. 80

$$PC_i = \frac{PM_i IM_i + PD_i DD_i}{Q_i}$$ Eq. 81

S1.5.3 Production Price indexes

$$PIXGDP = \sqrt{\frac{\sum_j \left(PVA_j + \frac{TIP_j}{VA_j} \right) VA_j^O AO_j}{\sum_j \left(PVA_j^O\ VA_j^O + TIP_j^O \right)} \frac{\sum_j \left(PVA_j VA_j + TIP_j \right)}{\sum_j \left(PVA_j^O + \frac{TIP_j^O}{VA_j^O} \right) VA_j}}$$ Eq. 82

$$PIXCON = \frac{\sum_i PC_i \sum_h C_{i,h}^O}{\sum_i PC_{i,h}^O \sum_h C_{ij,h}^O}$$ Eq. 83

$$PIXINV = \prod_i \left(\frac{PC_{i,}}{PC_i^O} \right)^{\gamma_i^{INV}}$$ Eq. 84

$$PIXGVT = \prod_i \left(\frac{PC_i}{PC_i^O} \right)^{\gamma_i^{GVT}}$$ Eq. 85

S1.6 Equilibrium

$$Q_i = \sum_h C_{i,h} + CG_i + INV_i + VSTK_i + DIT_i + MRGN_i$$ Eq. 86

$$LS_l = \left(\sum_j LD_{l,j} \right) \Big/ \left(\frac{1}{un_l} \right)$$ Eq. 87

$$\sum_j KD_{k,j} = KS_j$$ Eq. 88

$$IT = \sum_h SH_h + \sum_f SF_f + SG + SROW$$ Eq. 89

$$\sum_j DS_{j,i} = DD_i \quad \text{Eq. 90}$$

$$\sum_j EX_{j,i} = EXD_i \quad \text{Eq. 91}$$

S1.7 Gross domestic product

$$GDP^{BP} = \sum_j PVA_j VA_j + TIPT \quad \text{Eq. 92}$$

$$GDP^{MP} = GDP^{BP} + TPRCTS \quad \text{Eq. 93}$$

$$GDP^{IB} = \sum_j W_l LD_{l,j} + \sum_{k,j} R_{k,j} KD_{k,j} + TPRODN + TPRCTS \quad \text{Eq. 94}$$

$$GDP^{FD} = \sum_i PC_i [C_i + CG_i + INV_i] + \sum_i PE_i^{FOB} EXD_i - e \sum_i PWM_i IM_i \quad \text{Eq. 95}$$

S1.8 Volume variables computed from price indeces

$$CTH_h^{REAL} = \frac{CTH_h}{PIXCON} \quad \text{Eq. 96}$$

$$G^{REAL} = \frac{G}{PIXGVT} \quad \text{Eq. 97}$$

$$GDP^{BP_{REAL}} = \frac{GDP^{BP}}{PIXGDP} \quad \text{Eq. 98}$$

$$GDP^{MP_{REAL}} = \frac{GDP^{MP}}{PIXCON} \quad \text{Eq. 99}$$

$$GFCF^{REAL} = \frac{GFCF}{PIXINV} \quad \text{Eq. 100}$$

S1.9 Wage curve

$$\frac{W_l}{PIXCON} = A_l^{WC} {un_l}^{\sigma^{WC}} \quad \text{Eq. 101}$$

S2. Sets

S2.1 Industries and Commodities

All industries:

$i, ij \in J$ = {aagri, afood, aoind, aelhy, aelbi, aelpe, awasa, acons, atran, aadmi, asefi, asenf}

aagri "agriculture and fishery and forestry" afood "agrifood and other agri-industry"

aoind "other industries"

aelhy "electricity from other renew"

aelbi "electricity from biomass"

aelpe "electricity from fossil"

awasa "water distribution and sanitary"

acons "construction sector"

atran "transport sector"

aadmi "administration public services"

asefi "services financial"

asenf "services non-financial"

All commodities:

$i, ij \in I = \{$ cagri, cfood, cpetr, coind, celec, cwadi, csaco, csanc, ccons, ctran, cadmi, csefi, csenf$\}$

cagri "agriculture and fishery and forestry"

cfood "agrifood and other agri-industry"

cpetr "petrol products"

coind "other industries"

celec "electricity"

cwadi "water piped water"

csaco "water sanitary collective"

csanc "water sanitary non-collective"

ccons "construction"

ctran "transport service"

cadmi "administration public services"

csefi "services financial"

csenf "services non-financial"

S2.2 Production factors

Labour categories: $l \in L = \{flabo\}$

flabo representative labour type

Capital categories: $k \in K = \{CAP\}$

fcanw "factor capital non water"

fgwa "factor capital ground water"

fswa "factor capital surface water"

S2.3 Agents

All agents: $ag, agj \in AG = H \cup \{F, GVT, ROW\} = \{hous, gove, rowe\}$

hous "agent household, one representative household"

gove "agent government"

rowe "agent rest of the world"

Households categories: $h, hj \in H \subset AG = \{hous\}$

Non-governmental agent: $agng \in AGNG \subset AG = H \cup \{ROW\} = \{\{hous, rowe\}\}$

Domestic agents: $agd \in AGD \subset AG = H \cup \{GVT\} = \{\{hous, gove\}\}$

S3. Variables

S3.1 Volume variables

$C_{i,h}$:	Consumption of commodity i by type h households
$C_{i,h}^{MIN}$:	Minimum consumption of commodity i by type h households
CG_i:	Public consumption of commodity i
CI_j:	Total intermediate consumption of industry j
CTH_h^{REAL}:	Real consumption expenditures of household h
DD_i:	Domestic demand for commodity i produced locally
$DI_{i,j}$:	Intermediate consumption of commodity i by industry j
DIT_i:	Total intermediate demand for commodity i
$DS_{j,i}$:	Supply of commodity i by sector j to the domestic market
$EX_{j,i}$:	Quantity of product i exported by sector j
EXD_i:	World demand for exports of product i
G^{REAL}:	Real government expenditures
$GDP^{BP,REAL}$:	Real GDP at basic prices
$GDP^{MP,REAL}$:	Real GDP at market prices
$GFCF^{REAL}$:	Real gross fixed capital formation
IM_i:	Quantity of product i imported
INV_i:	Final demand of commodity i for investment purposes (GFCF)
$KD_{k,j}$:	Demand for type k capital by industry j
KDC_j:	Industry j demand for composite capital
KS_k:	Supply of type k capital
$LD_{l,j}$:	Demand for type l labour by industry j
LQ_j:	Industry j demand for skilled labour
LNQ_j:	Industry j demand for unskilled labour
LDC_j:	Industry j demand for composite labour
LS_l:	Supply of type l labour
$MRGN_i$:	Demand for commodity i as a trade or transport margin
Q_i:	Quantity demanded of composite commodity i
VA_j:	Value added of industry j
$VSTK_i$:	Inventory change of commodity i
$XS_{j,i}$:	Industry j production of commodity i
XST_j:	Total aggregate output of industry j

S3.2 Price variables

e:	Exchange rate (price of foreign currency in local currency)
$P_{j,i}$:	Basic price of industry j's production of commodity i
PC_i:	Purchaser price of composite commodity i (including all taxes and margins)
PCI_j:	Intermediate consumption price index of industry j
PD_i:	Price of local product i sold on the domestic market (including all taxes and margins)
PE_i:	Price received for exported commodity i (excluding export taxes)

PE_i^{FOB}: FOB price of exported commodity i (in local currency)
$PIXCON$: Consumer price index
$PIXGDP$: GDP deflator
$PIXGVT$: Public expenditures price index
$PIXINV$: Investment price index
PL_i: Price of local product i (excluding all taxes on products)
PM_i: Price of imported product i (including all taxes and tariffs)
PP_j: Industry j unit cost including taxes directly related to the use of capital and labour but excluding other taxes on production
PT_j: Basic price of industry j's output
PVA_j: Price of industry j value added (including taxes on production directly related to the use of capital and labour)
PWM_i: World price of imported product i (expressed in foreign currency)
PWX_i: World price of exported product i (expressed in foreign currency)
$R_{k,j}$: Rental rate of type k capital in industry j
RC_j: Rental rate of industry j composite capital
RK_k: Rental rate of type k capital (if capital is mobile)
$RTI_{k,j}$: Rental rate paid by industry j for type k capital including capital taxes
W_l: Wage rate of type l labour
WC_j: Wage rate of industry j composite labour
$WTI_{l,j}$: Wage rate paid by industry j for type l labour including payroll taxes

S3.3 Nominal (value) variables

CAB: Current account balance
CTH_h: Consumption budget of type h households
G: Current government expenditures on goods and services
GDP^{BP}: GDP at basic prices
GDP^{FD}: GDP at purchasers' prices from the perspective of final demand
GDP^{IB}: GDP at market prices (income-based)
GDP^{MP}: GDP at market prices
$GFCF$: Gross fixed capital formation
IT: Total investment expenditures
SF: Savings of type f businesses
SG: Government savings
SH_h: Savings of type h households
$SROW$: Rest-of-the-world savings
TDF_f: Income taxes of type f businesses
$TDFT$: Total government revenue from business income taxes
TDH_h: Income taxes of type h households
$TDHT$: Total government revenue from household income taxes
TIC_i: Government revenue from indirect taxes on product i
$TICT$: Total government receipts of indirect taxes on commodities
$TIK_{k,j}$: Government revenue from taxes on type k capital used by industry j
$TIKT$: Total government revenue from taxes on capital
TIM_i: Government revenue from import duties on product i
$TIMT$: Total government revenue from import duties
TIP_j: Government revenue from taxes on industry j production (excluding taxes directly related to the use of capital and labour)
$TIPT$: Total government revenue from production taxes (excluding taxes directly related to the use of capital and labour)
$TIW_{l,j}$: Government revenue from payroll taxes on type l labour in industry j
$TIWT$: Total government revenue from payroll taxes
TIX_i: Government revenue from export taxes on product i
$TIXT$: Total government revenue from export taxes
$TPRCTS$: Total government revenue from taxes on products and imports
$TPRODN$: Total government revenue from other taxes on production
$TR_{ag,agj}$: Transfers from agent agj to agent ag

YDF_f:	Disposable income of type f businesses
YDH_h:	Disposable income of type h households
YF_f:	Total income of type f businesses
YFK_f:	Capital income of type f businesses
$YFTR_f$:	Transfer income of type f businesses
YG:	Total government income
YGK:	Government capital income
$YGTR$:	Government transfer income
YH_h:	Total income of type h households
YHK_h:	Capital income of type h households
YHL_h:	Labour income of type h households
$YHTR_h$:	Transfer income of type h households
$YROW$:	Rest-of-the-world income

S3.4 Rates and intercepts

$sh0_h$:	Intercept (type h household savings)
$sh1_h$:	Slope (type h household savings)
$tr0_h$:	Intercept (transfers by type h households to government)
$tr1_h$:	Marginal rate of transfers by type h households to government
$ttdf0$:	Intercept (income taxes of type f businesses)
$ttdf1$:	Marginal income tax rate of type f businesses
$ttdh0_h$:	Intercept (income taxes of type h households)
$ttdh1_h$:	Marginal income tax rate of type h households
$ttic_i$:	Tax rate on commodity i
$ttik_{k,j}$:	Tax rate on type k capital used in industry j
$ttim_i$:	Rate of taxes and duties on imports of commodity i
$ttip_j$:	Tax rate on the production of industry j
$ttiw_{l,j}$:	Tax rate on type l worker compensation in industry j
$ttix_i$:	Export tax rate on exported commodity i
un_l:	Unemployment rate by type of labour l

S4. Parameters

$aij_{i,j}$:	Input-output coefficient
B_j^{KD}:	Scale parameter (CES - composite capital)
B_j^{LD}:	Scale parameter (CES - composite labour)
β_i^M:	Scale parameter (CES - composite commodity)
B_j^{VA}:	Scale parameter (CES - value added)
$B_{j,i}^X$:	Scale parameter (CET - exports and local sales)
B_j^{XT}:	Scale parameter (CET - total output)
$\beta_{k,j}^{KD}$:	Share parameter (CES - composite capital)
β_i^M:	Share parameter (CES - composite commodity)
β_j^{VA}:	Share parameter (CES - value added)
$\beta_{j,i}^X$:	Share parameter (CET - exports and local sales)
η:	Price elasticity of indexed transfers and parameters
$frish_h$:	Frisch parameter (LES function)
γ_i^{GVT}:	Share of commodity i in total current public expenditures on goods and services
γ_i^{INV}:	Share of commodity i in total investment expenditures
$\gamma_{i,h}^{LES}$:	Marginal share of commodity i in household h consumption budget
io_j:	Coefficient (Leontief - intermediate consumption)
K^{MOB}:	Flag parameter (1 if capital is mobile)
$\lambda_{ag,k}^{RK}$:	Share of type k capital income received by agent ag
$\lambda_{ag,agj}^{TR}$:	Share parameter (transfer functions)
$\lambda_{h,l}^{WL}$:	Share of type l labour income received by type h households
ρ_j^{KD}:	Elasticity parameter (CES - composite capital)
ρ_i^M:	Elasticity parameter (CES - composite commodity)

ρ_j^{VA}: Elasticity parameter (CES - value added)
$\rho_{j,i}^{X}$: Elasticity parameter (CET - exports and local sales)
ρ_j^{XT}: Elasticity parameter (CET - total output)
σ_j^{KD}: Elasticity (CES - composite capital)
σ_i^{M}: Elasticity (CES - composite commodity)
σ_j^{VA}: Elasticity (CES - value added)
$\sigma_{j,i}^{X}$: Elasticity (CET - exports and local sales)
σ_j^{XT}: Elasticity (CET - total output)
σ_i^{XD}: Price elasticity of the world demand for exports of product i
$\sigma_{i,h}^{Y}$: Income elasticity of consumption
$tmrg_{i,ij}$: Rate of margin i applied to commodity ij
$tmrg_{i,ij}^{X}$: Rate of margin i applied to exported commodity i
v_j: Coefficient (Leontief - value added)
β_j^{LD}: Share parameter (CES - composite labour)
ρ_j^{LD}: Elasticity parameter (CES - composite labour)
σ_j^{LD}: Elasticity (CES - composite labour)

8.5 Scenarios

8.5.1 Water Scarcity

To upscale the spatial data provided by Leroux et al. (2023) we translate the data display in the maps presented in Figure 29 into EXCEL. Based on the spatial reference data and the spatial change in anomalies we compute the spatial precipitation under anomaly scenario (Figure 30). We sum up the precipitation over all grids 3 times 3 km grids and compare the global precipitation with the sum of grids in the reference situation.

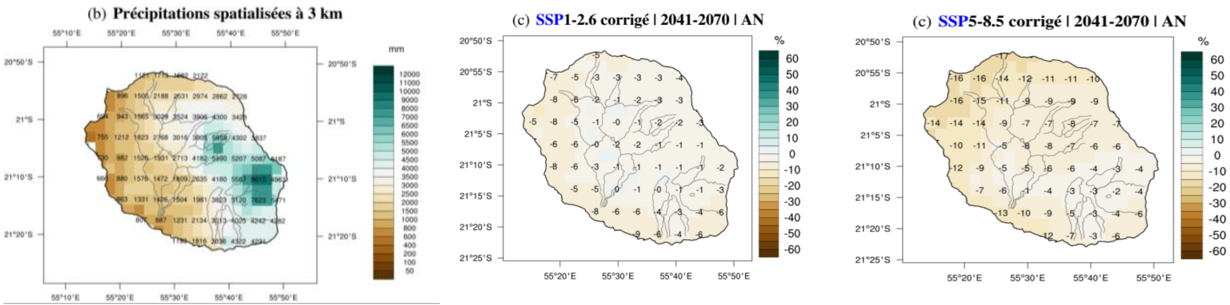

Figure 29: Reference and anomalies in spatial precipitation

Notes: Reference spatial precipitation (left), anomaly in annual precipitation in the optimistic scenario (SSP1-2.6) (middle) and in the pessimistic scenario (SSP5-8.5) (right). Source: Leroux et al. (2023: 73, 156,158)

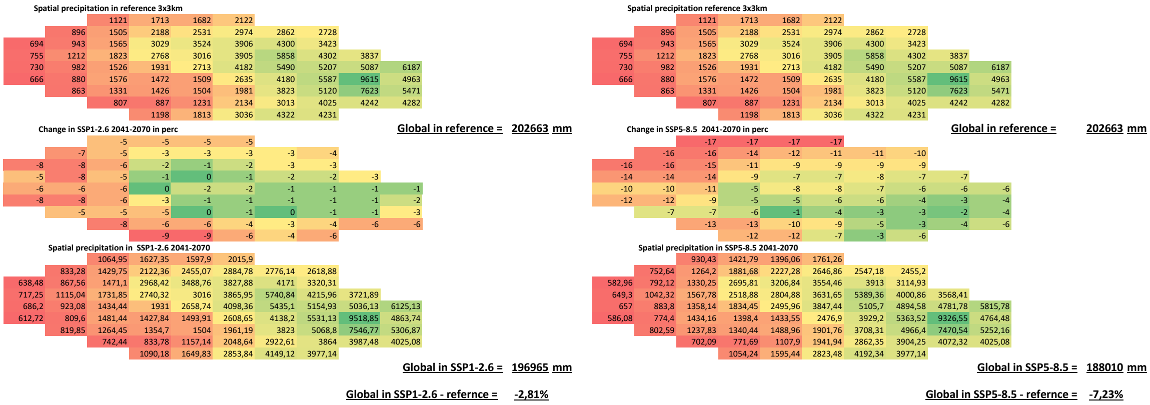

Figure 30: Stylised shape of REU in EXCEL and computation of the global anomaly of precipitation

Notes: Left: optimistic scenario (SSP1-2.6); right: pessimistic scenario (SSP5-8.5).

8.5.2 Reduced Leakage

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8.5.3 Sewage Disposal

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8.5.4 Water Price Increase

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8.5.5 Oil Price Increase

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8.6 Results and discussion

8.6.1 Macroeconomic indicators

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8.6.2 Production and consumption

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8.6.3 Imports and exports

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8.6.4 Commodity and factor prices

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8.6.5 SEEA-W environmental indicators

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8.7 CGE model on the digital platform

8.7.1 Linkage between CGE and microsimulation model

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8.7.2 Presentation of the CGE model results

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