IAEA

International Atomic Energy Agency

IAEA TECDOC SERIES

No. 2073

# Modelling the Contribution of Nuclear Energy to Economic Development

## A User's Guide to the Extended Input–Output Model for Sustainable Power Generation

# MODELLING THE CONTRIBUTION OF NUCLEAR ENERGY TO ECONOMIC DEVELOPMENT

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA, PLURINATIONAL STATE OF
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CABO VERDE
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
COMOROS
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DJIBOUTI
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ESWATINI
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GAMBIA
GEORGIA
GERMANY
GHANA
GREECE
GRENADA
GUATEMALA
GUINEA
GUYANA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS, KINGDOM OF THE
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORTH MACEDONIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAINT KITTS AND NEVIS
SAINT LUCIA
SAINT VINCENT AND THE GRENADINES
SAMOA
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
TOGO
TONGA
TRINIDAD AND TOBAGO
TUNISIA
TÜRKİYE
TURKMENISTAN
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VANUATU
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA-TECDOC-2073

# MODELLING THE CONTRIBUTION OF NUCLEAR ENERGY TO ECONOMIC DEVELOPMENT

## A USER'S GUIDE TO THE EXTENDED INPUT–OUTPUT MODEL FOR SUSTAINABLE POWER GENERATION

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2024

For further information on this publication, please contact:

Planning and Economic Studies Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org


Printed by the IAEA in Austria
October 2024
https://doi.org/10.61092/iaea.oh1h-o5bc

**IAEA Library Cataloguing in Publication Data**

Names: International Atomic Energy Agency.
Title: Modelling the contribution of nuclear energy to economic development / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2024. | Series: IAEA TECDOC series, ISSN 1011-4289 ; no. 2073 | Includes bibliographical references.
Identifiers: IAEAL 24-01715 | ISBN 978-92-0-133324-7 (paperback : alk. paper) | ISBN 978-92-0-133224-0 (pdf)
Subjects: LCSH: Nuclear energy — Economic aspects. | Electric power production. | Energy policy.

# FOREWORD

In the face of growing demand for low carbon and sustainable energy worldwide, an increasing number of Member States considers nuclear power as part of their response to the global climate change challenge and national energy security considerations. A decision to invest in a nuclear power plant affects a country's gross domestic product, employment, balance of payments and price stability, among other macroeconomic indicators. These effects are associated with the construction, operation and maintenance of nuclear power plants, thus generating economic growth and creating new employment opportunities. In addition to studies on energy demand and supply options, the IAEA therefore encourages Member States to conduct a macroeconomic impact assessment to better understand potential aggregate and sectoral impacts of introducing or extending national nuclear energy programmes.

Over several decades, the IAEA has developed a set of energy models to provide a systematic framework for analysis in the context of the energy decision making process. The existing IAEA modelling tools belong to the partial equilibrium model class, which is characterized by a detailed representation of the energy sector. As standard practice, however, partial equilibrium models disregard interrelationships with other economic sectors and therefore are less suitable to account for economy wide effects. The analysis of potentially important benefits or detriments requires the application of the model type that goes beyond the energy system view.

To fill this gap and address Member States' needs in terms of approaches to economic evaluation, the IAEA launched a coordinated research project covering the assessment of the economic effects associated with the development of nuclear power programmes and a new model — the Extended Input–Output Model for Sustainable Power Generation (EMPOWER) — to support macroeconomic impact analysis.

This publication provides an extended description of EMPOWER, presents data requirements and discusses illustrative case studies, including how it works with the Model for Energy Supply Strategy Alternatives and their General Environmental Impacts energy planning tool. It exemplifies the state of the art in assessing macroeconomic impacts of nuclear energy programmes based on the input–output framework. The publication is intended to support the application of models to advance the understanding of economy wide and sectoral impacts of building and operating nuclear power plants in interested Member States.

The IAEA wishes to thank the experts involved in the model development for their contributions. The IAEA officers responsible for this publication were V. Alexeeva, S. Dardour and N. Mberia of the Division of Planning, Information and Knowledge Management.

*EDITORIAL NOTE*

CONTENTS


1. INTRODUCTION ........................................................ 1
   1.1. BACKGROUND ........................................................ 1
   1.2. OBJECTIVE ........................................................ 3
   1.3. SCOPE ........................................................ 3
   1.4. STRUCTURE ........................................................ 3

2. METHODOLOGY FOR IMPACT ASSESSMENTS ........................................................ 5
   2.1. MODELLING TOOLS FOR ASSESSING MACROECONOMIC IMPACTS ........................................................ 5
   2.2. EMPOWER: TECHNICAL DESCRIPTION ........................................................ 6
      2.2.1. Mechanism I: Direct and indirect effects ........................................................ 8
      2.2.2. Mechanism II: Induced effects (endogenous private consumption) ........................................................ 8
      2.2.3. Mechanism III: Feedback from the labour market ........................................................ 9
      2.2.4. Mechanism IV: Feedback from financing of an investment during the construction phase (ex-ante) ........................................................ 11
      2.2.5. Mechanism V: Feedback from new electricity generation ........................................................ 12
      2.2.6. Mechanism VI: Feedback from ex-post financing of the investment ........................................................ 14
      2.2.7. Mechanism VII: Feedback on exports due to domestic prices changes ........................................................ 14
      2.2.8. Summary of equations and mechanisms ........................................................ 15

3. EMPOWER: MODEL IMPLEMENTATION ........................................................ 19
   3.1. GENERAL STRUCTURE ........................................................ 19
   3.2. MODULAR AND SUBMODULAR STRUCTURE ........................................................ 21
   3.3. DATA REQUIREMENTS ........................................................ 23
   3.4. SCENARIO SPECIFICATION ........................................................ 25
   3.5. MODEL RESULTS ........................................................ 27
   3.6. TUTORIAL ........................................................ 28
   3.7. FILE ORGANISATION AND BUILT-IN CHECKS ........................................................ 29

4. STEP BY STEP PROCEDURE IN EMPOWER APPLICATION ........................................................ 31
   4.1. FILE 1: AGGREGATION SCHEMES ........................................................ 31
      4.1.1. Step1.1: Define sectoral correspondence and aggregation codes (Sheet: Select_Class) ........................................................ 31
      4.1.2. Step1.2: Define correspondence and aggregation codes for value-added categories (Sheet: Select_Class) ........................................................ 32
      4.1.3. Step1.3: Define correspondence and aggregation codes for final demand categories (Sheet: Select_Class) ........................................................ 33
      4.1.4. Use allocation examples (Sheets: Appx_Eurostat, Appx_WIOD16, Appx_OECD) ........................................................ 34
      4.1.5. Include additional information as an advanced user (Sheets: AdminTut and AdminCalc) ........................................................ 34
   4.2. FILE 2: AGGREGATION OF INPUT-OUTPUT-TABLE ........................................................ 34
      4.2.1. Step 2.1: Load correspondence and aggregation codes (Sheet: Select_Class) ........................................................ 35

4.2.2. Step 2.2: Provide IOT data by component (Sheets: IM_Dom, IM_Imp, IM_VA, FD_Dom, FD_Imp and FD_VA) .................. 35
4.2.3. Step 2.3: Generate EMPOWER IOT (Sheet: Output_IOT) ......... 35
4.3. FILE 3: DATA COMPOSITION .......................................................... 36
4.3.1. Step 3.1: Load Step2 data (Sheet: Data A) ................................ 36
4.3.2. Step 3.2: Include information on labour and capital compensation in value-added block (Sheet: Data B) ........................................ 37
4.3.3. Step 3.3: Include information on disposable income of private households (Sheet: Data B) ........................................................ 38
4.3.4. Step 3.4: Include labour market data (Sheet: Data C) ................ 39
4.3.5. Step 3.5: Include information on public expenditures (Sheet: Data D) .......................................................................................... 40
4.3.6. Step 3.6: Further Sheets (Sheet: Check, AdminCalc, AdminTut) ...................................................................................... 40
4.4. FILE 4: SCENARIO DATA ................................................................. 40
4.4.1. Step 4.1: Load MESSAGE information (Sheet: Description) ..... 41
4.4.2. Step 4.2: Load previous information (Sheet: Growth (ABCD)) .. 41
4.4.3. Step 4.3: Define a time span (Sheet: Growth (ABCD)) ............. 41
4.4.4. Step 4.4: Sectoral growth assumptions (Sheet: Growth (ABCD)) ...................................................................................... 42
4.4.5. Step 4.5: Include aggregated construction costs (Sheet: ConstCosts (A)) ........................................................................... 43
4.4.6. Step 4.6: Disaggregate construction costs by sector (Sheet: ConstCosts (A)) ........................................................................... 44
4.4.7. Step 4.7: Fuel mix of electricity generation (Sheet: Operation energy (A)) ................................................................................. 45
4.4.8. Step 4.8: Costs of electricity generation (Sheet: Operation energy (A)) ............................................................................................. 46
4.4.9. Step 4.10: Supply costs of electricity generation (Sheet: Operation energy (A)) ................................................................................. 47
4.4.10. Step 4.10: Allocation of physical fuels to economic sectors (Sheet: Operation costs_structure (A)) ...................................... 47
4.4.11. Step 4.6: Disaggregation of operation costs to economic sectors (Sheet: Operation Costs_Structure (A)) ..................................... 48
4.4.12. Step 4.12: Include household income parameters (Sheet: Income consumption (B)) ....................................................................... 48
4.4.13. Step 4.13: Labour market parameters (Sheet: Labour market (C)) ...................................................................................... 49
4.4.14. Step 4.14: Set financing parameters (Sheet: Financing (D)) ....... 52
4.5. FILE 5: MASTERFILE ......................................................................... 53
4.5.1. Step 5.1: Load data and scenarios (Sheet: SetUp) ....................... 53
4.5.2. Step 5.2: Balance IOT (Sheet: SetUp) ........................................ 54
4.5.3. Step 5.3: Handle control panels (Sheets: Ctrl CON and Ctrl OPR) ...................................................................................... 55
4.5.4. Step 5.4: Run scenarios (Sheet: Ctrl CON and Ctrl OPR) ........... 58
4.5.5. Step 5.5: Aggregated results (Sheet: Ctrl CON & Ctrl OPR) ...... 59
4.6. FILE 6: VISUALIZATION ................................................................... 62
4.6.1. Step 6.1: Load results (Sheet: Description) ................................ 62
4.6.2. Step 6.2: Visualize key macroeconomic variables (Sheet: Graphs CON1 / Graphs OPR1) ............................................................ 62

4.6.3. Step 6.3: Visualize sectoral results (Sheets: Sector CON / Sector OP) ........ 64
4.6.4. Step 6.4: Identify sectors with strongest impacts (Sheet: Graphs CON2 / Graphs OP2) ........ 64
4.7. ADDITIONAL FILE 7: STEP1B IMPORT MATRIX GENERATION 65

5. ILLUSTRATIVE CASE STUDIES ........ 69

5.1. INTERPRETATION OF IMPACT ANALYSIS VS. SCENARIO ANALYSIS ........ 71
5.2. DATA SOURCES FOR THE CASE STUDIES ........ 72
5.3. CASE STUDY NUC: POWER PLANT INVESTMENT — AN IMPACT ANALYSIS ........ 73
5.3.1. STEP 1: Definition of the IOT aggregation scheme ........ 73
5.3.2. STEP 2: IOT aggregation ........ 74
5.3.3. STEP 3: Additional data ........ 75
5.3.4. STEP 4: Scenario definition ........ 77
5.3.5. STEP 5: Model run ........ 82
5.3.6. STEP 6: Results and interpretation ........ 83
5.4. CASE STUDY ENE: COMPARING ENERGY SYSTEM DEVELOPMENT SCENARIOS ........ 90
5.4.1. MESSAGE model description ........ 90
5.4.2. MESSAGE case study ........ 91
5.4.3. File “MESSAGE input for EMPOWER” ........ 102
5.4.4. How to include MESSAGE results in EMPOWER ........ 103
5.4.5. Results and interpretation ........ 104

SUMMARY ........ 109

REFERENCES ........ 111

LIST OF ABBREVIATIONS ........ 113

CONTRIBUTORS TO DRAFTING AND REVIEW ........ 115

# 1. INTRODUCTION

## 1.1. BACKGROUND

Decisions to initiate and invest into a nuclear energy programme will produce important sectoral and economy-wide (macroeconomic) effects beyond the energy sector. Investments in energy infrastructures, in general, and nuclear power plants (NPP), in particular, tend to stimulate construction, manufacturing and service sectors, thus generating economic growth through the entire economy. The effects on the labour market are thus central to the dynamics of local and regional economic growth. These effects include initial direct effects of economic activities related to the investment and secondary or ‘ripple’ effects triggered by these initial activities. A joint report by the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) explores the effects of nuclear energy programmes on employment [1].

The IAEA has been providing integrated support for nuclear power infrastructure development to Member States considering adoption of nuclear energy as part of their energy mix. Towards this end, the Agency has developed a comprehensive guide for nuclear power programme development and the related Integrated Nuclear Infrastructure Review service (the Milestones Approach [2]), that helps Member States assess the progress in developing their nuclear infrastructure. The IAEA Milestones Approach encourages Member States to quantify potential impacts from investments into a nuclear power programme, including but not limited to employment generation. In particular, the Milestones Approach recommends conducting a macroeconomic assessment, complementing studies on energy demand, supply and options analysis, and incorporating it into the comprehensive report [2].

Over the last few decades, the IAEA has developed a wide range of integrated energy planning tools to inform decision-making in the power sector [3]. The existing IAEA modelling tools belong to a particular class of models namely partial equilibrium models, which are characterized by a detailed representation of the energy sector. Although widely used to provide a reliable and robust assessment of alternative paths for the development of the energy sector, partial equilibrium models disregard interrelationships with other sectors in the economy and therefore are less suitable to account for economy-wide effects.

An evaluation of the impacts of nuclear power on the national economy requires the development and/or adoption of macroeconomic models appropriate to the country’s conditions. In response to an increasing number of requests from Member States, the IAEA initiated the development of an innovative tool to support national efforts for macroeconomic impact analysis, the **E**xtended Input-Output **M**odel for Sustainable **Power** Generation (EMPOWER) [4]. In addition, the IAEA kicked-off a Coordinated Research Project (CRP) focused on Assessing the National and Regional Economic Effects of Nuclear Programmes (2014–2018) to explore these issues further and to test the newly developed model by interested MSs [5]. This publication presents an outcome from these activities — the EMPOWER code as it stands in January 2022 (this version will be referred to as “Rev. 7” throughout the document).

The mathematical and non-mathematical formulation of EMPOWER is based on the recommendations provided by external experts who participated in several meetings organized by the IAEA since late 2012. The model development was led by Kurt Kratena and Mark Sommer from Austria [4].

In the early phase of the model development, two consultancy meetings — *Roadmap for Development of the IAEA Planning and Economic Studies Section's (PESS) Tools* and *Methods for economic impact assessment of an NPP Programme* — were conducted. Experts from Belarus, Croatia, Ghana, Indonesia, Morocco, Nigeria, Poland, Republic of Korea, Russian Federation, Viet Nam, United States of America, and the OECD/NEA defined modelling needs from a policy maker's perspective and discussed methods and potential challenges, in particular data constraints. They subsequently submitted a number of recommendations for the model development.

In particular, participants in both meetings agreed that, in the context of different levels of complexity among the model types, the question of marginal value of introducing additional model components involves multiple trade-offs. It therefore becomes a question of balancing a choice between a simple, yet easy to understand framework, and potentially a more complex model, containing a larger number of equations and data points.

Against that background, meeting participants recommended to develop a simple but flexible input-output model, using the Excel software package, which would allow both an *ex-ante* and *ex-post* assessment of macroeconomic effects associated with construction and operation of nuclear power plants. Following these recommendations, the current version of EMPOWER has been developed and tested within the IAEA Coordinated Research Project on Assessing the National Economic Effects of Nuclear Programmes from 2014 to 2018 [5].

This CRP brought together unified participants from twelve Member States — Croatia, Germany, Indonesia, Malaysia, Poland, Russian Federation, Republic of Korea, South Africa, Tunisia, Uruguay, Vietnam, and United States of America — with an objective to review the model development and conduct a cross-check assessment of EMPOWER with both country-specific data sets and country-specific quantitative models. Multiple cross-check studies conducted over four years from 2014 to 2018 with different prototype versions of EMPOWER allowed to converge towards a submodular structure of the model. The latter is particularly favourable when different types of data constraints apply.

The application of EMPOWER to different datasets at the level of individual Member States has demonstrated reasonable consistency across participating Member States in the calculation of the effects on gross domestic product, sectoral production, and employment. In addition, several Member States have tested the plausibility of the results obtained with EMPOWER based on the application of supplementary country-specific quantitative tools. These cross-checks showed that different results may be obtained according to how individual macroeconomic models at the country-level are formulated.

In June 2019, the final version of EMPOWER model has been reviewed at the IAEA Technical Meeting *Measuring the Macroeconomic Impacts of a Nuclear Power Plant Programme* by policymakers, regulatory officials, and energy planners from 14 Member States and three international organizations. The meeting concluded with a recommendation to apply EMPOWER for the macroeconomic assessment of NPP programmes. A *Technical Meeting to Review the IAEA's Methodologies and Analytical Tools*, also held in June 2019, recommended to apply EMPOWER to study in an illustrative example macroeconomic impacts resulting from a more comprehensive strategy, including a nuclear and non-nuclear scenario. The final Section in this publication contains the details of this exercise.

## 1.2. OBJECTIVE

The purpose of this publication is to provide a practical guide covering the use of EMPOWER as well as the underlying mathematical and non-mathematical formulations, relevant components, and data requirements. The specific objectives of this publication include:

— To enhance the capability of Member States in conducting macroeconomic impact assessments of nuclear projects through the introduction of state-of-the-art economic modelling techniques with EMPOWER.
— To improve the capability of Member States in developing consistent databases and in closing potential data gaps at the country's (or regional) level.
— To achieve a better understanding of the potential contribution of nuclear energy to the social-economic development at the national level with illustrative examples.

## 1.3. SCOPE

The report describes the approaches that can be utilised in assessing the impacts of nuclear power plant construction and operation on an economy and explains the approach applied in EMPOWER. It outlines the structure of the tool and data required for analysis. It also explains the process of creating an EMPOWER case study through a step-by-step description of the modelling procedure. The report further demonstrates the application of the tool using two illustrative case studies.

The report provides a detailed description of the following topics:

— Non-technical introduction to the structure of EMPOWER.
— Mathematical formulation of EMPOWER.
— Data requirements and data preparation routines in EMPOWER.
— Running individual submodules of EMPOWER.
— Interpreting results and preparing graphs in EMPOWER.
— Illustrative case studies with EMPOWER.

The report is intended for analysts, stakeholders and decision-makers exploring ways to develop energy policies and strategies at the governmental level as well as at ministries leading or contributing to energy planning studies.

## 1.4. STRUCTURE

After describing this publication's general context, objectives, and scope, Section 2 presents the methodological framework for macroeconomic impact analysis of nuclear programs. It also includes a description of the model implemented in the Agency's EMPOWER tool. Section 3 then details the implementation of the model based on the integrated Visual Basic for Applications. Section 4 explains individual steps related to the data transfer, scenario definition and result calculation by using Excel's built-in tools.

EMPOWER can support macroeconomic assessments of any type of energy investments, including nuclear power capacity addition and expansion, and a more comprehensive energy strategy. Therefore, Section 5 presents an illustrative analysis of macroeconomic impacts at the national level and details how EMPOWER can be applied for two cases: investment into a single energy technology (nuclear energy) and investment into a comprehensive energy strategy. It provides recommendations for the application of EMPOWER, particularly related to the data requirements and results' interpretation. Based on a defined set of data and further assumptions, EMPOWER simulates the impact on GDP, domestic production activities, employment, and several other economic indicators for each year of defined construction and the operation phases. Section 6 provides a summary.

# 2. METHODOLOGY FOR IMPACT ASSESSMENTS

## 2.1. MODELLING TOOLS FOR ASSESSING MACROECONOMIC IMPACTS

The joint report of the NEA and the IAEA, focusing on employment effects of nuclear energy programs [1], describes the three types of approaches that can be applied in analysing the effects of nuclear energy programmes on a given economy:

- Traditional input-output models (IOMs).
- Econometric input-output models (IO-E).
- Computable general equilibrium (CGE) models.

The first type of approach (IOMs) considers the dependencies between the different sectors of the economy and describes them in the form of a system of linear equations linking changes in the inputs or outputs of the economic sectors to their impacts on the whole economy. A conventional IOM is characterized by a number of features (assumptions). For example, production technologies are specified with constant returns to scale, thereby no substitution among inputs is possible. Moreover, this type of model assumes that productive resources such as capital, labour, or natural resources are available without any limitation [6].

Furthermore, each sector's final demand for goods and services is exogenously specified in a conventional IOM. A system of linear production functions is used to estimate primary and intermediate inputs needed to meet this demand. This type of model is typically open, so there are no feedback loops linking primary inputs to the final demand. Often, those models are also static, meaning they do not consider intertemporal distribution of investment impacts.

More advanced IOMs have been developed to overcome these limitations when analysing analyse the macroeconomic impacts of various investment activities. For instance, some IOMs establish feedback relationships between primary inputs and household consumption by specifying households as "an industry" that procures food, consumer goods and services as inputs and provides labour as outputs. This specification makes it possible to assess the macroeconomic impacts of an increase in household consumption resulting from increased demand for labour. Another improvement is the "dynamization" of a standard IOM that includes a more realistic representation of the evolution of an economy over time.

The second modelling approach is IO-E models, which combine IOMs with macroeconomic models. This approach aims to better represent the relationships between supply and demand in the overall economy. A typical IO-E model uses econometric models to estimate the different components of the final demand such as household consumption, government expenditures, savings or investments over time. This approach, therefore, makes it possible to update the IOM according to the evolution of various macroeconomic drivers (e.g., employment, wages, and labour force).

CGE models represent the third type of macroeconomic impact assessment methodologies. A CGE model assumes that the interactions of producers and consumers lead to a status of overall general equilibrium in the economy in which all markets clear – there are no surpluses or shortages, and prices, as well as quantities, do not change. The CGE framework assumes that:

- Producers will opt for the quantities of inputs and outputs that minimise their production costs.

— Consumers will purchase consumer goods and services while maximising their utility.

The three types of models differ in several dimensions, for example, in how they describe production and consumption functions or their treatment of supply constraints, price responses, and changes in the economy over time. Most IOMs ignore constraints on the availability of productive resources, contrary to IO-E and CGE models. The behaviours of producers and consumers are described by a system of linear equations in IOMs but are based on non-linear specifications in the OI-E and CGE models.

Input-output models (IOMs and IO-Es) have often been favoured in economic impact studies, at least the ones dealing with the introduction of nuclear power, because of their flexibility in introducing investment options and available alternatives, their ability to consider market and non-market systems simultaneously, and the possibility of factor substitution in response to price changes. Moreover, these models offer greater transparency and ease of implementation than CGE. Indeed, input-output require less input data, the solution path is traceable, and the computation process is more straightforward to implement than in the case of CGE models where tools like GAMS or GEMPACK are used to solve a complex set of equations. The interpretation of the results is also less complicated and does not require a deep knowledge of the underlying equations and economic assumptions (e.g., closure rules). However, IO-based models are demand determined. This means, if it is not explicitly built in, they do not take into account limitations in production or scarcity of factors e.g., labour. This supply restriction is a strong feature of CGE models where scarcity of factors is reflected in increases in the price system. The IAEA's tool EMPOWER described in the next few paragraphs also belongs to this class of models, which is described based on references [4] and [5].

## 2.2. EMPOWER: TECHNICAL DESCRIPTION

EMPOWER is an extended input-output framework that uses an input-output table (IOT) as its primary data source. IOT represents the monetary relationships among predefined sectors in a given economy. IOTs describe the monetary relationships between economic sectors, i.e., the inputs demanded by different sectors for the production of goods and services, as well as the composition and volume of output demanded by public and private consumers, for gross investment and exports. While the structure of IOTs is defined in the Systems of National Accounts [7], IOTs are typically prepared by National Statistical Offices.

EMPOWER can be applied to study the macroeconomic effects of investments in the energy sector, including the construction and operation of nuclear power plants. Both key phases - construction and operation - can be simulated. Four consecutive levels of economic feedback mechanisms could be accounted for depending on the availability of data and the interests of the model users. These mechanisms are simulated in four consecutive submodules (Table 1) which can be executed separately. They cover (i) indirect effects linked to up-stream production impacts, (ii) induced effects that consider the reaction of households to changes in disposable income, (iii) labour market response to take into account the scarcity of labour supply and (iv) feedback related to financing options available for the investment. Details to the underlying mechanisms are outlined in the next Section. The model can be also applied to quantify macroeconomic effects associated with decommissioning and long-term management of radioactive waste.

TABLE 1. FOUR LEVELS OF ECONOMIC FEEDBACK IN EMPOWER SUBMODULES.

| Submodule | | Construction phase | | Operation phase |
|---|---|---|---|---|
| A | | (A) Indirect effects of investment | | (A) Indirect effect of operation |
| AB | + | (B) Induced effects | + | (B) Induced effects |
| ABC | + | (C) Labour market response | + | (C) Labour market response |
| ABCD | + | (D) Financing of investment in the construction phase | + | (D) Financing of investment in the operation phase |

EMPOWER is built around a classical input-output framework in which a new project is introduced (see Ref. [6]). The final demand approach is used to include new activities (e.g., construction or operation of new NPPs) in which the focus is on goods for final demand (which are not used to produce other goods) rather than on goods which serve as input to subsequent production processes and represent intermediate demand (see Ref. [8] for details). EMPOWER can be applied to assess macroeconomic effects of structural changes in the economy related to the introduction of nuclear power in a given country for the first time or associated with an expansion of a country's nuclear fleet. EMPOWER is flexible enough to evaluate economy-wide effects associated with construction, operation, and long-term operation.

EMPOWER goes beyond the traditional "static" IOMs that do not consider the effect of introducing a new industry on incomes and thus underestimate the short-term impacts. EMPOWER provides mechanisms to keep track of effects - and avoid overestimating them - by taking into account changes in wages due to increased labour demand. In EMPOWER, price-quantity relationships are described by elasticities (the relative change in an economic variable in response to a unitary change in another) between prices and demands for consumption, exports, and labour. Finally, EMPOWER makes it possible to take into account the feedback effects from public-private partnerships in situations where the government finances part of the investment. In this sense, EMPOWER can be seen as a reasonable compromise between a quasi-realistic representation of national economies on the one hand and technical challenges that a dynamic EGC entails, for example, on the other hand.

The solving mechanism of EMPOWER is to apply a set of equations. The set of equations is distinct for each phase, construction and operation. The equation system is in balance in the reference situation of each construction and operation year, i.e., where no change in electricity production is simulated. By introducing interruptions which is on one hand be the additional demand due to the construction and on the other a change in the structure of electricity generation, the equation system is partly unbalanced. By repeatedly iterating through the equations, the system converges towards another equilibrium. The difference between the reference equilibrium and the new equilibrium reflects the effect of the interruption. In EMPOWER the applied equations are distributed amongst seven sets of equations. Each set represents an economic feedback mechanism. The following seven Sections (2.2.1 – 2.2.7) outline the equations applied. The last Section (2.2.8) summarizes the features of the mechanisms and explains the concept of submodules. EMPOWER's submodules are a set of mechanisms that is applied in a consecutive way in order to decompose economic feedback effects.

### 2.2.1. Mechanism I: Direct and indirect effects

EMPOWER (Eq. 1) is based primarily on an input-output equation:

$$\mathbf{x} = \mathbf{A}^{\mathrm{d}}\mathbf{x} + \mathbf{c}^{\mathbf{priv}} + \mathbf{f}^{*} + \mathbf{f}^{\mathrm{new}} \quad (1)$$

where $\mathbf{x}$ is the column vector of gross output, $\mathbf{A}^{\mathrm{d}}$ is the matrix of input-output coefficients (technical coefficients) for domestic intermediate demand, $\mathbf{f}^{*}$ is the column vector of other (exogenous) final demand and $\mathbf{f}^{\mathrm{new}}$ (direct effects) is the column vector of demand from the new activity (e.g., the nuclear power plant investments during construction phase). $\mathbf{c}^{\mathbf{priv}}$ is the column vector of private consumption and is determined by equation (3) which is described in detail in the following Section. In Eq. (1) all variables are defined in **nominal values** at current prices.

Matrix $\mathbf{A}^{\mathrm{d}}$ in Eq. (1) is derived by dividing the elements of domestic intermediate demand by its column sum, i.e., the sector's output $\mathbf{x}$. Another matrix $\mathbf{A}^{\mathrm{m}}$ can be prepared for imported intermediate demand. This treatment of imports assumes that all imports are — in principle — non-competitive. Dealing with competitive imports could be introduced by specifying the import shares of demand (intermediate as well as final) as endogenous. In the baseline case with the original IOT, $\mathbf{f}^{\mathrm{new}}$ contains only zero elements, i.e., it describes the situation in the absence of nuclear power investments.

Eq. (1) can then be used to assess direct and indirect impacts of the investment in nuclear energy by inserting the basic data of the nuclear plant's construction into $\mathbf{f}^{\mathrm{new}}$. This will initiate the basic output loop of the model: the nuclear energy investments $\mathbf{f}^{\mathrm{new}}$ results in a new output vector $\mathbf{x}$, which in turn is inserted into $\mathbf{A}^{\mathrm{d}}\mathbf{x}$ to derive another revised output vector $\mathbf{x}$ that reflects the resulting change in output, and so on. This iteration converges to the same solution for the output vector $\mathbf{x}$, as the solution using the Leontief inverse $[\mathbf{I} - \mathbf{A}^{\mathrm{d}}]^{-1}$ (where $\mathbf{I}$ is the identity matrix) (see Ref. [6]. Therefore, Eq. (1) serves to quantify *direct* ($\mathbf{f}^{\mathrm{new}}$) and *indirect effects* via the IO linkages. The difference between the output vectors in the baseline case and in the construction scenario shows the impacts of the NPP investment on output volumes as a sum of direct and indirect effects.

### 2.2.2. Mechanism II: Induced effects (endogenous private consumption)

The first extension of the core model in Eq. (1) estimates the induced impacts of NPP construction or operation associated with direct and indirect effects of increasing personal incomes through employment creation. The latter, in turn, leads to higher household expenditures on goods and services purchased from different sectors, which requires that the information about the value-added components in the IOT matches the data covering households' disposable income from the national accounts. The minimum disaggregation in the value-added part of the IOT comprises wages, operating surplus and net taxes (i.e., taxes minus subsidies). The shares of these value-added components are linked to the sectoral output by technical coefficients in the same way inputs are tied to outputs. Eq. (2) is used to calculate the disposable income of households.

$$Y = \mathbf{l}w f_{\mathrm{w,hh}}(1 - t_{\mathrm{hh}})\mathbf{x} + \mathbf{s} f_{\mathrm{s,hh}}(1 - t_{\mathrm{hh}})\mathbf{x} + Y_{\mathrm{oth}} \quad (2)$$

where $Y$ is the disposable income, $\mathbf{l}$ is a row vector of employment per unit of output coefficients, $w$ contains the industry wage rates, $f_{\mathrm{w,hh}}$ is an adjustment factor[1], $t_{\mathrm{hh}}$ is the average tax rate on disposable income of households, $\mathbf{x}$ is the column vector of gross output, $\mathbf{s}$ is a row vector of operating surplus per unit of output, $f_{\mathrm{s,hh}}$ is the share of gross operating surplus accruing to households and $Y_{\mathrm{oth}}$ contains other components of disposable household income that are not covered by the former. In Eq. (2) $\mathbf{l}wf_{\mathrm{w,hh}}(1-t_{\mathrm{hh}})$ represents net wages (gross wages minus corresponding taxes plus subsidies) and $\mathbf{s}f_{\mathrm{s,hh}}(1-t_{\mathrm{hh}})$ represents net operating surplus accruing to households (gross operating surplus accruing to households minus corresponding taxes plus subsidies).

The adjustment factor $f_{\mathrm{w,hh}}$ corrects possible differences between wages in the IOT and those reported in the national accounts. The adjustment factor $f_{\mathrm{s,hh}}$ captures the share of operating surplus accruing to households as disposable income. An average tax rate $t_{\mathrm{hh}}$ on the disposable income $Y$ is assumed, reflecting taxes and transfers (summed up to net taxes) paid by households. Other components of disposable household income ($YD_{\mathrm{oth}}$) are specified exogenously in this model, e.g., net income from abroad, profits and rents. Wages and operating surplus link household incomes to the IOM.

Next, total private consumption is calculated according to Eq. (3) from the disposable income ($YD$) by adopting a simple Keynesian consumption function in which the level of consumer spending is determined by three factors: disposable income, autonomous consumption (consumption in the absence of income) and the marginal propensity to consume (the fraction of the extra income spent). Eq. (3) uses a fixed marginal propensity to consume. The consumption vector $\mathbf{c}^{\mathbf{priv}}$ is determined by multiplying total consumption by a column vector of domestic budget shares $\mathbf{b}_{\mathrm{hh}}^{\mathrm{d}}$.

$$\mathbf{c}^{\mathbf{priv}} = [exp(const_{\mathrm{cp}} + m^{pc}(\log(Y))]\mathbf{b}_{\mathrm{hh}}^{\mathrm{d}} \tag{3}$$

where $\mathbf{c}^{\mathbf{priv}}$ is the vector of private consumption, $const_{\mathrm{cp}}$ is the constant calibrated to the respective base year, $m^{pc}$is the marginal propensity to consume, $Y$ is the disposable income and $\mathbf{b}_{\mathrm{hh}}^{\mathrm{d}}$ is a column vector of domestic budget shares.

Induced impacts of NPP construction or operation are calculated by Eqs. (1)–(3). By inserting basic data of the nuclear plant's construction into $\mathbf{f}^{\mathrm{new}}$ in Eq. (1), the corresponding new output vector $\mathbf{x}$ determines the resulting new disposable income $YD$ in Eq. (2), which in turn determines the adjusted consumption vector $\mathbf{c}^{\mathbf{priv}}$ in Eq. (3). This is inserted into Eq. (1) that calculates a new output vector $\mathbf{x}$ according to the new intermediate demand. The iteration process continues until the model solution converges to a stable new output vector $\mathbf{x}$.

### 2.2.3. Mechanism III: Feedback from the labour market

During construction and operation, NPPs affect the labour market. The total employment $L$ in the economy can be calculated as the product of the vector of employment coefficients per unit of output $\mathbf{l}$ and the new equilibrium vector of real output $\mathbf{x}^{\mathrm{r}}$ (deflated nominal output), which is $L = \mathbf{l}\mathbf{x}^{\mathrm{r}}$. Elements of $\mathbf{x}^{\mathrm{r}}$ are derived by dividing elements of the output vector $x_i$ at nominal values by the corresponding output price $p_i$, determined in the input-output price model (see

[1] This factor adjusts the compensation provided by the IO to "income from wages" of the national accounts in order to calculate disposable income accordingly.

below). The calculation of static employment effect assumes that the labour force is available in the required number and qualifications in the region where the NPP is being built and operated.

The labour market in EMPOWER is represented according to a wage bargaining (also known as a wage curve) model. To establish an inverse relationship between the two variables, a parameter describing the impact of the unemployment rate on wage formation ( $\beta_{\mathrm{ur}}$) is defined. In the case of full employment (e.g., an unemployment rate below 3%) in the baseline case, an employment shock can trigger significant effects on wage formation. The opposite holds if unemployment is high in the baseline case. The industry wage rate $w$ (wage per employee) in a given year is calculated according to Eq. (4).

$$w = exp(const_w + \beta_{ur} log(1 - L/LF)) \tag{4}$$

where $w$ is the industry wage rate, $const_w$ is the constant to calibrate the equation to the base years wage rate and $\beta_{\mathrm{ur}}$ is a parameter representing the relation between the unemployment rate and wage formation, $L$ is the total employment and $LF$ is the labour force. The unemployment rate is given as $(1 - L/LF)$.

Higher industry wage rates in turn have repercussions on employment. In EMPOWER, it is assumed that the nominal wage coefficients (nominal wages per unit of output) $\mathbf{l}w$ rise half as much as what the wage increase would imply (Eq. (4a)). The term $\mathbf{l}w$ represents the product of the wage per employee ($w$, wage rate) and the coefficient for employment per output (**l**) which implies the wage coefficient, i.e., wage per unit of output. The new **l** is then calculated in Eq. (4a):

$$l = l_{base} w_{base} / (0.5\, w_{base} + 0.5\, w) \tag{4a}$$

where $l$ is the coefficient for employment per unit output that represents labour intensity of production. $l_{base}$ is the coefficient for employment per output in the baseline case, $w_{base}$ is the industrial wage rate in the baseline case and $w$ is the new industry wage rate, it implies that in the respective base year without scenario inputs $w_{base}$ and $w$ are identical, hence the right-hand side division is equal to one and $l$ is equal to $l_{base}$.

The new value for total employment is calculated according to Eq. (5).

$$L = [\mathbf{l}w/(0.5w_{\mathrm{base}} + 0.5w)]\mathbf{x}^r \tag{5}$$

where $L$ is the total employment, $\mathbf{l}w$ is the nominal wage coefficients, $w_{base}$ is the industry wage rate (wage per employee) in the baseline case, $w$ is the new altered industrial wage rate in the simulations and $\mathbf{x}^{\mathrm{r}}$ is the new equilibrium vector of real output.

The new row vector with coefficients for employment per unit of output (**l**) also leads to changes in disposable household income. Therefore Eq. (2) needs to be replaced by Eq. (2a) that reflects these changes.

$$YD = \left[\left(\mathbf{l}w/(0.5w_{base} + 0.5w)\right) w f_{w,hh}(1 - t_{hh})\right]\mathbf{x} + \mathbf{s}f_{s,hh}(1 - t_{hh})\mathbf{x} + YD_{oth} \tag{2a}$$

where $YD$ is the disposable income, $\mathbf{l}$ is a row vector of employment per unit of output coefficients, $w$ is the industry wage rates, $w_{\mathrm{base}}$ represents industrial wage rate in the baseline case, $f_{\mathrm{w,hh}}$ is an adjustment factor, $t_{\mathrm{hh}}$ is the average tax rate on disposable income of households, $\mathbf{x}$ is the column vector of gross output, $\mathbf{s}$ is a row vector of operating surplus per unit of output, $f_{\mathrm{s,hh}}$ represents gross operating surplus accruing to households and $YD_{\mathrm{oth}}$ is other components of disposable household income.

Equation (2a) includes the endogenous wage coefficients ($\mathbf{l}w$). All these changes also affect private consumption calculated in Eq. (3).

Labour market effects and the resulting wage impacts can trigger changes in output prices. The basic equation of the input-output price model is:

$$\mathbf{p} = \mathbf{p}\mathbf{A}^{\mathrm{d}} + \mathbf{p}^{\mathrm{m}}\mathbf{A}^{\mathrm{m}} + \mathbf{l}w + \mathbf{s} + \mathbf{t}^{\mathrm{q}} \tag{6}$$

where $\mathbf{p}$ is the vector of sectoral prices per unit of output, $\mathbf{A}^{\mathrm{d}}$ is the matrix of input-output coefficients for domestic demand, $\mathbf{p}^{\mathrm{m}}$ is the vector of import prices, $\mathbf{A}^{\mathrm{m}}$ is the matrix of input-output coefficients for import demand, $\mathbf{l}$ is a row vector of employment per unit of output coefficients, $w$ is the industry wage rates, $\mathbf{s}$ is a row vector of operating surplus per unit of output and $\mathbf{t}^{\mathrm{q}}$ is a vector of taxes net of subsidies per unit of output.

The vector $\mathbf{t}^{\mathrm{q}}$ in Eq. (6) represents taxes net of subsidies per unit of output. In the case of the electricity sector, this term also contains mark-ups that are used for financing the investment costs of the NPP. The new coefficients for employment per unit of output (**l**) yield a new output price vector calculated in Eq. (6a) that leads to a new vector of output at constant prices $\mathbf{x}^{\mathrm{r}}$ (calculated by dividing the solution for output at nominal values in Eq. (1) by the new price vector provided by Eq. (6a)) and this leads to further changes in employment.

$$\mathbf{p} = \mathbf{p}\mathbf{A}^{\mathrm{d}} + \mathbf{p}^{\mathrm{m}}\mathbf{A}^{\mathrm{m}} + (\mathbf{l}w/(0.5w_{\mathrm{base}} + 0.5w))w + \mathbf{s} + \mathbf{t}^{\mathrm{q}} \tag{6a}$$

where $\mathbf{p}$ is the vector of sectoral prices per unit of output, $\mathbf{A}^{\mathrm{d}}$ is the matrix of input-output coefficients for domestic demand, $\mathbf{p}^{\mathrm{m}}$ is the vector of import prices, $\mathbf{A}^{\mathrm{m}}$ is the matrix of input-output coefficients for import demand, $\mathbf{l}$ is a row vector of employment per unit of output coefficients, $w$ represents industry wage rates, $w_{base}$ is the industrial wage rate in the baseline case, $\mathbf{s}$ is a row vector of operating surplus per unit of output and $\mathbf{t}^{\mathrm{q}}$ is a vector of taxes net of subsidies per unit of output.

By combining calculations of labour market effects with price effects, EMPOWER comes very close to a type of model in which demand and supply interact and are determined simultaneously. As with the quantity component, the labour market component in equations (4) and (5) and the price component in equation (6) are also solved iteratively until convergence to a new equilibrium solution for all endogenous variables in the model.

### 2.2.4. Mechanism IV: Feedback from financing of an investment during the construction phase (ex-ante)

The mechanisms presented so far assume external financing of the investment, i.e., the use of existing external funds. An additional model component allows assessing impacts of revenue neutral public financing. For this task, the financing of investment costs can be allocated over three sources by defining the respective parameters. The first parameter is $r_{\mathrm{pub}}^{\mathrm{hhtx}}$ which represents the share of investment costs financed by increased income taxes during the construction phase (ex-ante). The second parameter, $r_{\text{pub}}^{\text{trans}}$, is the share of the investment costs financed through a decrease of public transfers to households, also during the construction phase (ex-ante). The third option is given by the parameter $r_{\text{pub}}^{\text{mkup}}$ that defines the share of costs that is financed by the increase of electricity prices during operation (ex-post). The residual (1- $r_{\text{pub}}^{\text{hhtx}}$ - $r_{\text{pub}}^{\text{trans}}$ - $r_{\text{pub}}^{\text{mkup}}$) is the share that is financed by external to the economy sources.

*Ex-ante* financing can be implemented either by increasing the households' tax rate $t_{\text{hh}}$ and/or by decreasing public transfers to households in a revenue neutral manner during the construction phase. This means that taxes increase and/or transfers decrease according to a predefined share of the construction costs to be financed through these options. Once the shares of ex-ante public financing of the total construction costs ($r_{\text{pub}}^{\text{hhtx}}$ and $r_{\text{pub}}^{\text{trans}}$) are determined, the new tax rate $t_{\text{hh}}$ and/or the new transfers $Y_{\text{oth}}$ are calculated in each year for the value of disposable household income $Y$ of the original data, i.e., the baseline case, according to Eqs. (7) and (8).

$$Y_{\text{oth}} = Y_{\text{oth}}^{\text{orig}} - r_{\text{pub}}^{\text{trans}} \mathbf{f}^{\text{new}} \tag{7}$$

where $Y_{\text{oth}}$ are other components of disposable household income than received through labour or capital inputs, i.e., new transfers, $Y_{\text{oth}}^{\text{orig}}$ is original other income, i.e., original level of transfers, $r_{\text{pub}}^{\text{trans}}$ is the share of construction costs financed from public sources, and $\mathbf{f}^{\text{new}}$ is the column vector of demand from the new activity. Hence the last multiplication ($\boldsymbol{i}^T \mathbf{f}^{\text{new}}$) is the sum of the construction costs occurring in the respective year of construction.

$$\boldsymbol{t}_{\text{hh}} = \frac{t_{\text{hh}}^{\text{orig}} Y + r_{\text{pub}}^{\text{hhtx}} \boldsymbol{i}^{\text{T}} \mathbf{f}^{\text{new}}}{Y - r_{\text{pub}}^{\text{hhtx}} \boldsymbol{i}^{\text{T}} \mathbf{f}^{\text{new}}} \tag{8}$$

where $t_{\text{hh}}$ is the new household tax rate, $t_{\text{hh}}^{\text{orig}}$ is the original household tax rate, $r_{\text{pub}}^{\text{hhtx}}$ is a share for the public financing of the investment through increase of taxes, $\boldsymbol{i}^{\text{T}}$ is the transposed unitary column vector and $\mathbf{f}^{\text{new}}$ is the column vector of demand from the new activity.

These approaches to determine the new tax rate and altered transfer flows to households reflect the cases of ex-ante revenue neutral financing. Since the disposable income $Y$ changes according to the induced impacts of the construction of the nuclear plant (Eq. (2) or (2a)) and the final amount of the public budget is different, the equation structure of this component does not change, but the calculation of $Y$ will be different.

### 2.2.5. Mechanism V: Feedback from new electricity generation

EMPOWER includes a procedure describing the electricity sector's technology details. It allows changes in the column elements of the matrices $\mathbf{A}^{\text{d}}$ and $\mathbf{A}^{\text{m}}$ in response to impacts of the operation of the new NPP. The procedure involves aggregation of input coefficients of the electricity sector, recalculation of their values to reflect changes from the new generation source and combining data about operational costs. The impact of the new power plant on the IOT is then introduced by changing the technology shares in the generation mix.

Several studies quantify the impact of a new power plant operation by adding additional demand for electricity to the vector $\mathbf{f}^{\text{new}}$, in the same way as EMPOWER calculates the investment impact of the nuclear power plant during the construction phase. This approach, however, runs into problems of potential double counting or accounting inconsistency, at least. In EMPOWER, NPP operation impacts are assessed by applying a partitioned IOM in which the electricity sector's output is determined exogenously. The new plant provides additional electricity output, which means that more demand for electricity can be satisfied.

Some of the newly generated electricity is already consumed through input-output linkages in upstream activities of other sectors. The remaining electricity surplus is allocated to the consumption of final demand agents (private households, public consumption, investments and exports). Since the gross output is the primary endogenous variable in the IOM, the introduction of exogenous output changes requires the application of a partitioned model in which set 1 in Eq. (9) represents the electricity sector with its output set exogenously and the resulting changes in the output of sectors in set 2 (comprising all other industries). Then we can treat the output of set 1 as exogenous and quantify the impact of changes in this output on the other sectors (set 2) in Eq. (9).

$$\begin{bmatrix}\overline{\mathbf{x}}_1\\ \mathbf{x}_2\end{bmatrix} = \begin{bmatrix}\mathbf{A}^d_{11} & \mathbf{A}^d_{12}\\ \mathbf{A}^d_{21} & \mathbf{A}^d_{22}\end{bmatrix}\begin{bmatrix}\overline{\mathbf{x}}_1\\ \mathbf{x}_2\end{bmatrix} + \begin{bmatrix}\mathbf{c}^{\mathbf{priv}}_1\\ \mathbf{c}^{\mathbf{priv}}_2\end{bmatrix} + \begin{bmatrix}\mathbf{f}^*_1\\ \mathbf{f}^*_2\end{bmatrix} \tag{9}$$

where $\overline{\mathbf{x}}_1$ is the exogenously given output of the electricity sector, $\mathbf{x}_2$ is the column vector of output in set 2 industries, $\mathbf{A}^{\mathrm{d}}_{11}$ is a submatrix of $\mathbf{A}$ comprising only set 1, i.e. in this case the input from the electricity sector into the electricity sector — the own demand,$\mathbf{A}^{\mathrm{d}}_{21}$ is the input vector of sector 1 composing all other inputs (i.e. set 2), $\mathbf{A}^{\mathrm{d}}_{12}$and $\mathbf{A}^{\mathrm{d}}_{22}$ are analogous for set 2, $\mathbf{c}^{\mathbf{priv}}_1$ is the column vector of private consumption of goods from electricity sector, $\mathbf{c}^{\mathbf{priv}}_2$ is the column vector of private consumption of goods from set 2 industries, $\mathbf{f}^*_1$ is the column vector of other (exogenous) final demand for electricity sector and $\mathbf{f}^*_2$ is the column vector of other (exogenous) final demand for goods from set 2 industries.

The system can be resolved to yield the overall impact on $\mathbf{x}_2$.

$$\mathbf{x}_2 = \mathbf{A}^d_{21}\overline{\mathbf{x}}_1 + A^d_{22}\mathbf{x}_2 + \mathbf{c}^{\mathbf{priv}}_2 + \mathbf{f}^*_2 \tag{10}$$

where $\mathbf{x}_2$ is the column vector of output in set 2 industries, $\mathbf{A}^{\mathrm{d}}_{21}$ is the technology matrix of set 2 industries, $\overline{\mathbf{x}}_1$ is the output of the electricity sector, $\mathbf{A}^{\mathrm{d}}_{22}$ is the technology matrix of set 2 industries, $\mathbf{c}^{\mathbf{priv}}_2$ is the column vector of private consumption of goods from set 2 industries and $\mathbf{f}^*_2$ is the column vector of other (exogenous) final demand for goods from set 2 industries.

The matrix $\mathbf{A}^{\mathrm{d}}_{21}$ contains all technology changes so that both types of impacts (technology change and change in the electricity output) are considered. The new output values have feedback on the demand side. The additional electricity output needs to be produced. Part of that is consumed in sectors that are affected by the operation of the plant. The other part is assumed to be consumed in final demand that needs to be adjusted according to Eq. (11).

$$\mathbf{c}^{\mathbf{priv}}_1 + \mathbf{f}^*_1 = [\mathbf{I} - \mathbf{A}^d_{11}]\overline{\mathbf{x}}_1 - \mathbf{A}^d_{12}\mathbf{x}_2 \tag{11}$$

where $\mathbf{c}^{\mathbf{priv}}_2$ is the column vector of private consumption of the electricity sector, $\mathbf{f}^*_1$ is the column vector of other (exogenous) final demand for electricity, $\mathbf{I}$ is the identity matrix, $\mathbf{A}^{\mathrm{d}}_{11}$ is the technology matrix of set 1 industries, $\overline{\mathbf{x}}_1$ is the output of the electricity sector, $\mathbf{A}_{12}^{\mathrm{d}}$ is the technology matrix of set 2 industries and $\mathbf{x}_2$ is the output of set 2 industries.

If the impact assessment process involves the calculation of consumption endogenously, only the other component of the final electricity demand ($\mathbf{f}_1^*$) needs to be specified. However, due to changes in the technology matrices $\mathbf{A}^{\mathrm{d}}$, Eq. (6) or (6a) is affected as well. This leads to a change in the output price of the electricity producing sector, i.e., of set 1. As a result, all prices of the downstream production change through the price system and the economic interlinkages. Therefore, results in real terms differ from the nominal values in this case.

### 2.2.6. Mechanism VI: Feedback from ex-post financing of the investment

An alternative to the partial revenue neutral financing discussed above involves calculating a markup on electricity prices for a selected share ($r_{\mathrm{pub}}^{\mathrm{mkup}}$) of the total nuclear investment costs in Eq. (12).

$$t_1^{q,markup} = \frac{r_{\mathrm{pub}}^{\mathrm{mkup}} \sum_t \boldsymbol{i}^T \mathbf{f}_t^{new}(1+r+\delta)}{\overline{\mathbf{x}}_1} \tag{12}$$

where $\mathbf{t}_1^{\mathrm{q,markup}}$ is a markup for an ex-post financing of investments through increase in electricity prices, $r_{\mathrm{pub}}^{\mathrm{mkup}}$ is the share of ex-post financing in the electricity sector which can vary between 0 and 1 (1 implies that the entire investment is financed through an increase in electricity prices), $\boldsymbol{i}^{\mathrm{T}}$ is the transposed unitary vector, $\mathbf{f}_t^{\mathrm{new}}$ is the column vector of demand from the construction activities summed over the construction years $t$ , $r$ is the rate of return, $\delta$ is the rate of depreciation and $\overline{\mathbf{x}}_1$ is the output of the electricity sector in the base situation.

The new markup calculated in Eq. (12) is introduced in the price model in order to calculate impacts of the power plant operation. This is implemented by replacing the vector $\mathbf{t}^{\mathrm{q}}$ in Eq. (6a) with $\mathbf{t}^{\mathrm{q,new}}$that will result in Eq. (6b).

$$\mathbf{p} = \mathbf{p}\mathbf{A}^{\mathrm{d}} + \mathbf{p}^{\mathrm{m}}\mathbf{A}^{\mathrm{m}} + (\mathbf{l}w/(0.5w_{\mathrm{base}} + 0.5w))w + \mathbf{s} + (\mathbf{t}^{\mathrm{q}} + \mathbf{t}^{\mathrm{q,markup}}) \tag{6b}$$

where $\mathbf{p}$ is the vector of sectoral prices per unit of output, $\mathbf{A}^{\mathrm{d}}$ is the matrix of input-output coefficients for domestic demand, $\mathbf{p}^{\mathrm{m}}$ is the vector of import prices, $\mathbf{A}^{\mathrm{m}}$ is the matrix of input-output coefficients for import demand, $\mathbf{l}$ is a row vector of employment per unit of output coefficients, $w$ is the industry wage rates, $w_{\mathrm{base}}$ is the industrial wage rate in the baseline case, $\mathbf{s}$ is a row vector of operating surplus per unit of output and $\mathbf{t}^{\mathrm{q}}$ is a vector of the new taxes net of subsidies per unit of output in the base situation, $\mathbf{t}^{\mathrm{q,markup}}$ is a vector of the additional tax (mark-up).

### 2.2.7. Mechanism VII: Feedback on exports due to domestic prices changes

The construction and/or operation of a new power plant triggers changes in the entire national economy, including changes in domestic commodity prices. The latter will affect real export demand and the resulting changes are calculated as presented in Eq. (13).

$$\mathbf{f}^{\mathrm{ex,real}} = (1 + ((ln(\mathbf{p}) - ln(1))\gamma^{\mathrm{ex}})\mathbf{f}^{\mathrm{ex}} \tag{13}$$

where $\mathbf{f}^{\mathrm{ex,real}}$ is the new real exports, $\mathbf{p}$ is the vector of sectoral prices, $\gamma^{\mathrm{ex}}$ is the export elasticity with respect to own prices and $\mathbf{f}^{\mathrm{ex}}$ are original real exports in the final demand.

Consequently, the real export changed based on the difference between the actual sectoral prices and the reference sectoral prices which are 1.

Changes in real exports have direct impacts on real production $\mathbf{x}^{r}$ and thus, via the labour market, impacts on the rest of the economy described by all elements of the model.

### 2.2.8. Summary of equations and mechanisms

To sum up, the EMPOWER framework includes representations of the following mechanisms:

I) Direct and indirect effects.
II) Induced effects (endogenous private consumption).
III) Feedback from the labour market.
IV) Feedback from ex-ante financing of investment.
V) Feedback from new electricity generation.
VI) Feedback from ex-post financing of the investment.
VII) Feedback on exports due to domestic price changes.

EMPOWER consists of two modules — one dedicated to the construction phase, the other to the operation phase — each comprising four sub-modules implementing the mechanisms mentioned above. The four sub-modules are labelled A, AB, ABC and ABCD. Each sub-module builds on the previous one. For example, sub-module AB includes, in addition to the mechanism described by sub-module A, an additional mechanism (B). Sub-module ABC consists of the mechanism AB and an additional mechanism (C) and so on. The fifth mechanism represents the electricity sector in the operational module by the type of technology. As mentioned above, while several studies quantify the impact of a new power plant operation by adding additional demand for electricity to final demand ($\mathbf{f}^{*}$), EMPOWER treats electricity sector as exogenous to avoid a potential double counting problem. Adding new capacity will change the energy mix of a country and therefore the composition of the electricity sector by type of technology.

For the construction module, individual submodules capture the following effects:

**A:** Direct and indirect effects.
**AB**: Direct, indirect and induced effects.
**ABC:** Direct, indirect and induced effects; labour-market feedback; feedback on exports.
**ABCD:** Direct, indirect and induced effects; labour-market feedback; feedback on exports; effects from *ex-ante* financing via increase in taxation or decrease of transfers.

For the operational module, individual submodules capture the following effects:

**A:** Representation of the electricity sector by type of technology; feedback on exports.
**AB**: Representation of the electricity sector by type of technology; induced effects; feedback on exports.
**ABC:** Representation of the electricity sector by type of technology; induced effects; labour-market feedback; feedback on exports.

**ABCD:** Representation of the electricity sector by type of technology; induced effects; labour-market feedback; effects from *ex-post* financing via mark-up on electricity price; feedback on exports.

The ABCD submodules in the construction and operational module are interconnected consecutively: This is guaranteed because overall investment can be financed externally, internally (ex-ante and ex-post) or through a combination of both ways. The sum of the shares $r_{\text{pub}}^{\text{hhtx}}$, $r_{\text{pub}}^{\text{trans}}$ and $r_{\text{pub}}^{\text{mkup}}$ represents the share of investment costs that will be financed internality and thus needs to be generated in country. The difference of this sum to 1 is the share that is financed exogenously.

Table 2 describes how individual mechanisms and equations are allocated across submodules (A, AB, ABC and ABCD) in the construction and the operational module. Each submodule applies a distinct set of equations that corresponds with the seven mechanisms as outlined in the previous Sections. For instance, submodule AB in the construction phase applies equation (1), (2a) and (3), (4), (5), (6a) and (13), thereby covering the economic effects of mechanisms I-III and VII. Whereas submodule A in operation phase applies equations (10), (11), (6) and (13) to simulate mechanism V and VII. This representation in Table 2 demonstrates the consecutive structure of EMPOWER.

TABLE 2. DEFAULT COMPOSITION OF MECHANISMS IN SUBMODULES FOR CONSTRUCTION AND OPERATION PHASE WITH ACCOMPANYING EQUATIONS AS NUMBERED IN THIS DOCUMENT.

| Mechanism | Construction phase *submodules* | | | | Operation phase *submodules* | | | |
|---|---|---|---|---|---|---|---|---|
| | A | AB | ABC | ABCD | A | AB | ABC | ABCD |
| I | 1 | 1 | 1 | 1 | | | | |
| II | | 2, 3 | 2a, 3 | 2a, 3 | | 2, 3 | 2a, 3 | 2a, 3 |
| III | | | 4, 5, 6a | 4, 5, 6a | | | 4, 5 | 4, 5 |
| IV | | | | 7, 8 | | | | |
| V | | | | | 10, 11, 6 | 10, 11, 6 | 10, 11, 6a | 10, 11 |
| VI | | | | | | | | 12, 6b |
| VII | | | 13 | 13 | 13 | 13 | 13 | 13 |

To this end, submodule A in the construction module is equivalent to a standard “static” input-output modelling framework covering only direct and indirect effects associated with NPP. All other submodules represent an extension of the traditional model as illustrated in Figure 1.

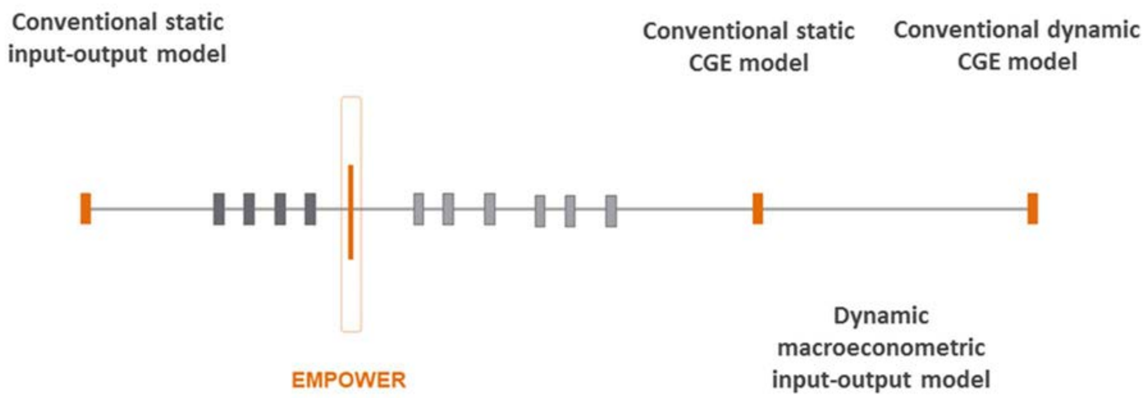



*FIG. 1. Spectrum of established macroeconomic model types. EMPOWER extends the conventional static IOM approach (adapted from Ref. [9]).*

Figure 1 represents a stylized spectrum of traditional macroeconomic model types. On the left side of the spectrum, conventional input-output-models are located. In this model type, an economic structure is static, and all effects are demand-driven, this implies that everything what is introduced as a new demand will be constructed (supplied). Consequently, any (positive) demand shocks will result in positive impacts. This kind of models is typically applied for a short-term impact analysis. On the right-hand side, dynamic Computable General Equilibrium models are displayed. This model type allows a structural change to occur due to changes in relative prices; those models implement supply constraints and optimize predefined equations (e.g., welfare) over various time periods. On such a spectrum, EMPOWER, as an IOM, is located to the right of a standard IOM due to model extensions such as labour supply restrictions, structural change of electricity generation and investment financing.

The full set of model specification (ABCD) in the construction phase can be written in the following form:

***Production loop:***

$$\mathbf{x} = \mathbf{A}^{\mathrm{d}}\mathbf{x} + \mathbf{c}^{\mathbf{priv}} + \mathbf{f}^{*} + \mathbf{f}^{\mathrm{new}} \tag{1}$$

$$Y = \left[\left(\mathbf{l}w/(0.5w_{base} + 0.5w)\right)wf_{w,hh}(1 - t_{hh})\right]\mathbf{x} + \mathbf{s}f_{s,hh}(1 - t_{hh})\mathbf{x} + Y_{oth} \tag{2a}$$

$$\mathbf{c}^{\mathbf{priv}} = [exp(const_{\mathrm{cp}} + m^{pc}(\log(Y))]\mathbf{b}_{\mathrm{hh}}^{\mathrm{d}} \tag{3}$$

$$Y_{\mathrm{oth}} = Y_{\mathrm{oth}}^{\mathrm{orig}} - r_{\mathrm{pub}}^{\mathrm{trans}}\boldsymbol{i}^{\boldsymbol{T}}\mathbf{f}^{\mathrm{new}} \tag{7}$$

$$\boldsymbol{t}_{\mathrm{hh}} = \frac{\boldsymbol{t}_{\mathrm{hh}}^{\mathrm{orig}}Y + r_{\mathrm{pub}}^{\mathrm{hhtx}}\boldsymbol{i}^{\mathrm{T}}\mathbf{f}^{\mathrm{new}}}{Y - r_{\mathrm{pub}}^{\mathrm{hhtx}}\boldsymbol{i}^{\mathrm{T}}\mathbf{f}^{\mathrm{new}}} \tag{8}$$

$$\mathbf{f}^{\mathrm{ex,real}} = (1 + ((ln(\mathbf{p}) - ln(1))el^{\mathrm{exp}}))\mathbf{f}^{\mathrm{ex}} \quad (13$$

***Labour market loop:***

$$w = exp(const_{\mathrm{w}} + \beta_{ur} log(1 - L/L^F)) \tag{4}$$

$$L = [\mathbf{l}w/(0.5w_{\mathrm{base}} + 0.5w)]\mathbf{x}^r \tag{5}$$

***Price loop:***

$$\mathbf{p} = \mathbf{p}\mathbf{A}^{\mathrm{d}} + \mathbf{p}^{\mathrm{m}}\mathbf{A}^{\mathrm{m}} + (\mathbf{l}w/(0.5w_{\mathrm{base}} + 0.5w))w + \mathbf{s} + \mathbf{t}^{\mathrm{q}} \tag{6a}$$

The fullest model specification (ABCD) in the operation phase can be written in the following form:

***Production loop:***

$$\mathbf{c}_1^{\mathbf{priv}} + \mathbf{f}_\mathbf{1}^* = [\mathbf{I} - \mathbf{A}_{11}^d]\overline{\mathbf{x}}_1 - \mathbf{A}_{12}^d\mathbf{x}_2 \tag{11}$$

$$\mathbf{x}_2 = \mathbf{A}_{21}^d\overline{\mathbf{x}}_1 + A_{22}^d\mathbf{x}_2 + \mathbf{p}_2^{\mathbf{priv}} + \mathbf{f}_\mathbf{2}^* \tag{10}$$

$$Y = \left[\left(\mathbf{l}w/(0.5w_{base} + 0.5w)\right)wf_{w,hh}(1 - t_{hh})\right]\mathbf{x} + \mathbf{s}f_{s,hh}(1 - t_{hh})\mathbf{x} + Y_{oth} \tag{2a}$$

$$\mathbf{c}^{\mathbf{priv}} = [exp(const_{\mathrm{cp}} + m^{pc}(\log(Y))]\mathbf{b}_{\mathrm{hh}}^{\mathrm{d}} \tag{3}$$

$$\mathbf{f}^{\mathrm{ex,real}} = (1 + ((ln(\,\mathbf{p}) - ln(\,1))\gamma^{\mathrm{ex}}))\mathbf{f}^{\mathrm{ex}} \tag{13}$$

***Labour market loop:***

$$w = exp(const_{\mathrm{w}} + \beta_{ur} log(1 - L/L^F)) \tag{4}$$

$$L = [\mathbf{l}w/(0.5w_{\mathrm{base}} + 0.5w)]\mathbf{x}^r \tag{5}$$

***Price loop:***

$$\mathbf{p} = \mathbf{p}\mathbf{A}^{\mathrm{d}} + \mathbf{p}^{\mathrm{m}}\mathbf{A}^{\mathrm{m}} + (\mathbf{l}w/(0.5w_{\mathrm{base}} + 0.5w))w + \mathbf{s} + \mathbf{t}^{\mathrm{q,new}} \tag{6b}$$

# 3. EMPOWER: MODEL IMPLEMENTATION

Based on the mathematical representation described in Section 2, EMPOWER (Rev. 7) is implemented in Excel and Visual Basic for Applications (VBA) and tested using the Office 365 Suite in Windows 10 as they stand in January 2022. This Section explains in a greater detail individual steps related to data compilation and transfer, scenario definition and result calculation by using Excel's built-in tools. Figure 2 shows a cover sheet of EMPOWER (Rev. 7). For simplicity purposes, this report further refers to EMPOWER (Rev.7) as EMPOWER.

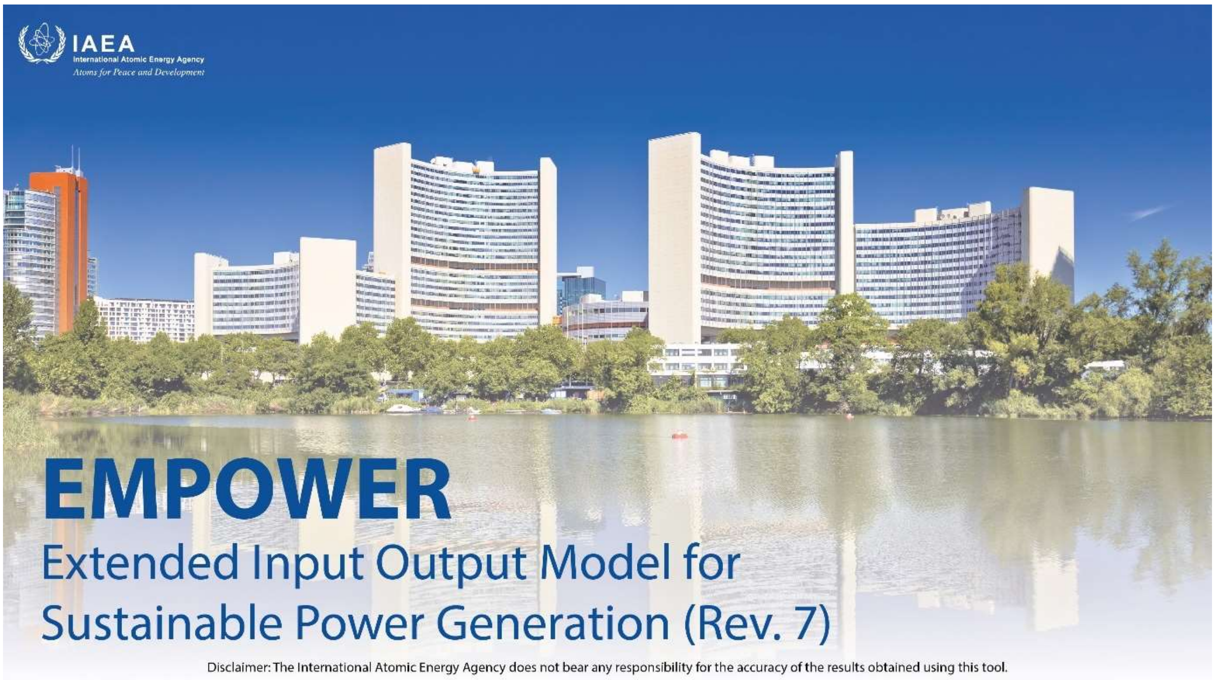



*FIG. 2. Cover sheet of EMPOWER.*

## 3.1. GENERAL STRUCTURE

EMPOWER consists of the following six MS Excel files or steps:

— EMPOWER_STEP1_AGGREGATION.
— EMPOWER_STEP2_INPUT_OUTPUT_TABLE.
— EMPOWER_STEP3_DATA_COMPILATION.
— EMPOWER_STEP4_SCENARIO.
— EMPOWER_STEP5_MASTERFILE.
— EMPOWER_STEP6_RESULTS_VISUALIZATION.

The data collection and processing routine consists of four individual files or steps. The data compilation procedure comprises the use of two files (step 1 and step 2) for IOT data aggregation. As mentioned above, EMPOWER is an extended input-output model relying on an IOT as its main data source. IOT represents the monetary relationships among predefined sectors in an economy. Structured according to the Systems of National Accounts [7], IOTs are typically prepared by National Statistical Offices. One file (step 3) loads the IOT information from the second file (step2) and further is used to collect data associated with submodules AB, ABC and ABCD for both construction and operation phases (below). Hence this file (step3) comprises all necessary data for the basic setup of the model. In step 4, additional exogenous data for scenario definition are compiled.

The central model file is the so-called Masterfile (step 5) which contains the impact model itself. The Masterfile loads both a data file (step 3) and a scenario file (step 4) and performs model runs with a predefined set of submodules. In principle, different data files and/or scenario files can be constructed and subsequently used in the Masterfile. This procedure is highly advisable to perform a sensitivity analysis on the key parameters.

The model reports a range of aggregated economic (macroeconomic level) and sector-specific indicators. The aggregated indicators (in both nominal and real terms) are the following:

- Gross Domestic Product (GDP).
- Disposable income.
- Production output.
- Net taxes received by government.
- Exports (total).
- Imports (total).
- Private consumption.
- Employment (reported in real terms only).

The sector-specific results are the following:

- Production output (in nominal and real values).
- Value added (in nominal and real values).
- Employment (in real values only).

The generated results can be loaded into the visualization file (step 6). The generalized structure of EMPOWER is presented in the Figure 3. The remaining part of this manual contains a detailed description of the individual steps required to prepare the data, to run the model and to visualize the results. It is important to stress that each file and each sheet within a file are designed in a way to be filled in a consecutive manner (i.e., one step follows the next).

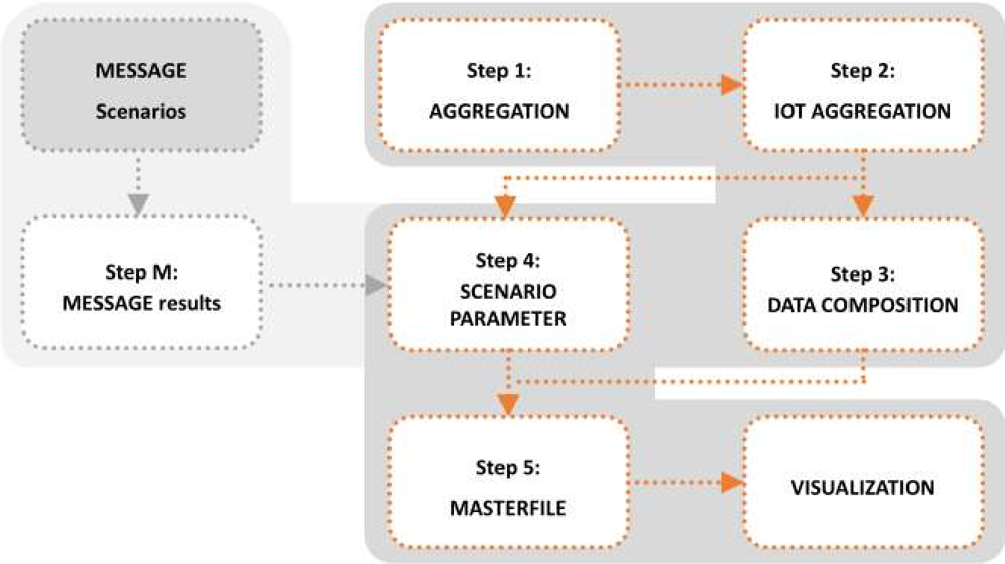



*FIG. 3. Generalized representation of EMPOWER structure.*

## 3.2. MODULAR AND SUBMODULAR STRUCTURE

EMPOWER was designed to support the macroeconomic assessment of power generation projects during each of the key phases of the project, from construction, to operation, to decommissioning. the complexity of the assessment, this manual focuses on quantification of macroeconomic effects associated with construction and operation only.

EMPOWER consists of two modules covering construction and operation and encompassing four submodules (A, AB, ABC and ABCD) implementing the economic feedback mechanisms described earlier in this report. Each submodule can be run only, if the necessary data are available and provided in the respective data files. Table 3 briefly summarises mechanisms to be activated in each submodule. Section 2.2.8 contains the exact specification.

TABLE 3. DEFAULT COMPOSITION OF THE SUBMODULES.

| Mechanism | Construction phase | | | | Operation Phase | | | |
|---|---|---|---|---|---|---|---|---|
| | A | AB | ABC | ABCD | A | AB | ABC | ABCD |
| I | ● | ● | ● | ● | | | | |
| II | | ● | ● | ● | | ● | ● | ● |
| III | | | ● | ● | | | ● | ● |
| IV | | | | ● | | | | |

| Mechanism | Construction phase | | | | Operation Phase | | | |
|---|---|---|---|---|---|---|---|---|
| | A | AB | ABC | ABCD | A | AB | ABC | ABCD |
| V | | | | | ● | ● | ● | ● |
| VI | | | | | | | | ● |
| VII | | | ● | ● | ● | ● | ● | ● |

**Note**: Adjustments in export flows, as represented by mechanism VII, are activated only in case of changes in domestic prices, i.e., if one of the mechanisms III or VI is active. Activating mechanisms I or II will not affect exports as domestic prices will not change.

The submodular structure implies that data for each 'lower-level submodule' needs to be included, when moving to a 'higher level submodule'. For example, to be able to run submodule ABCD, data-specific requirements for the ABC submodule need to be included and extended to cover the D component. To be able to run submodule ABC, data-specific requirements for submodule AB need to be included and extended to cover the C component. Finally, to be able to run submodule AB, data-specific requirements for submodule A need to be included and extended to cover the B component.

Both submodules A require a data set which enables the users to conduct a basic analysis. But the data specification is not the same, though there are some overlaps, because both submodules serve different purposes. The objective of submodule A in the construction module is to quantify direct and indirect effects of construction activities, whereas the objective of submodule A in the operation module is to quantify effects associated with operational activities (equivalent to changes in the prevailing energy mix). The logic behind the submodular structure is to enlarge and extend this basic structure with additional features ("additionally principle"). For both construction and operation modules, the complexity of relationships included into the model is highest in submodules ABCD, which is translated as being the submodules with the highest demand for data.

Figure 4 schematically summarizes the submodular structure of modules for both construction and operation phases together with their respective data requirements, when moving to a "higher level submodule".

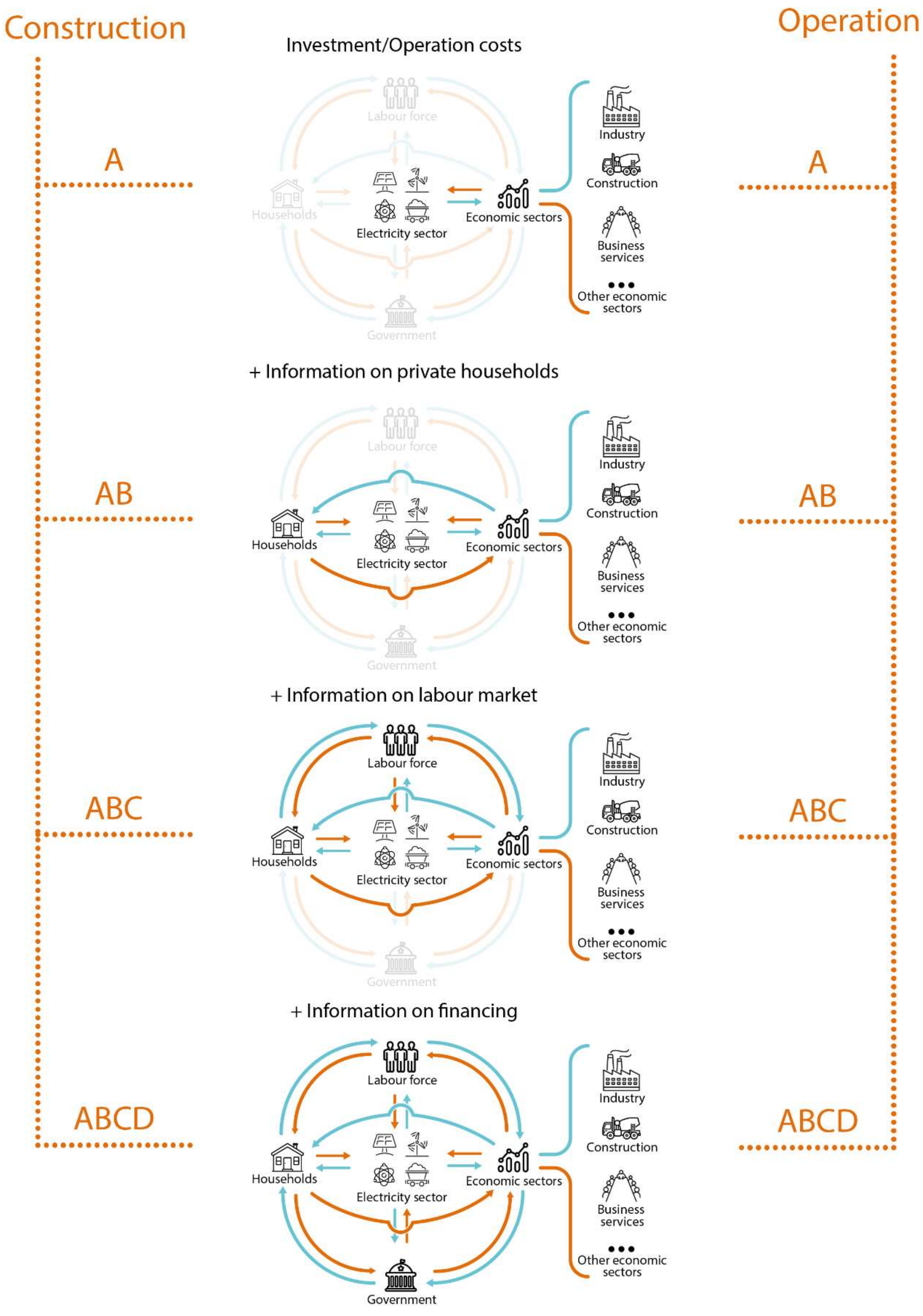



*FIG. 4. Schematic representation of EMPOWER submodules.*

## 3.3. DATA REQUIREMENTS

The EMPOWER extended input-output framework relies on an input-output table (IOT) as its primary input. It requires an IOT of the economy with a maximum of 35 sectors, though the definition of sectors is country specific. The IOT needs to have separate matrices for domestic and import flows and needs to follow a predefined structure for the final demand and the value-added components (Figure 5).

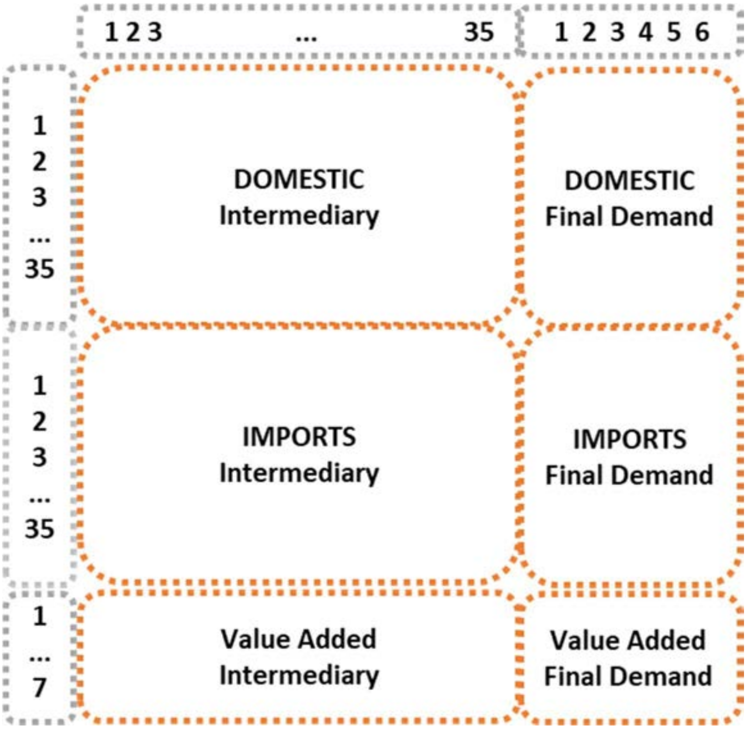



*FIG. 5. Scheme of the input-output data table for EMPOWER.*

The IOT structure in EMPOWER as shown in Figure 5 represents an input-output structure in basic prices and differentiates between imported and domestically produced goods for production (intermediary) and final demand following references [7] and [10]. Thereby, the import content of intermediary and final consumption is represented in a separate matrix, the "Imports intermediary" and "Imports final demand". OECD follows a similar structure[2].

National IOTs, including those comprising more than 35 sectors, need to be converted into an EMPOWER IOT, which could be done by leveraging EMPOWER's functionalities that assist users in aggregating data and defining categories of final demand and value-added. To keep consistency, all data specified for submodules and obtained from other sources than an IOT needs to apply to the same year, which is called hereafter a base year. This is the year for which the latest IOT is available and used for the analysis. Furthermore, EMPOWER provides a routine identifying the data needed to derive an IOT for a given year in the future (construction and operation starting dates, cf. Section 3.4).

The ability to run submodule AB in both construction and operation files requires two data sets in addition to an IOT. On the one hand, these are data on value-added component "compensation of labour". In case this component is not included in the national IOT, it needs to be provided from other sources that are consistent with the IOT. On the other hand, this is a specification of the disposable income of private households which can be obtained from the national accounts. Gross disposable income of households is estimated by adding up wages,

---

[2] https://www.oecd.org/sti/ind/input-outputtables.htm

operating surpluses accruing to households and profit and other sources of income, including government transfers to households, net of taxes and social security contributions paid to the government. As mentioned above, these data need to be collected for the base year of the IOT.

Data on the labour market at the base year are required to conduct an analysis with the ABC submodule. They include information on the total labour force, the unemployment rate, employment expressed in persons, jobs or full-time equivalent and the compensation of labour (wages) in each sector.

Finally, submodule ABCD requires data on the government budget in the base year, including:

- Public consumption: part of the government expenditures spent on buying goods and services from the sectors and constitutes a component of total final demand.
- "Other expenditures": government outlays spent as transfer payments to various kinds of recipients.
- Sources from which government outlays are paid, i.e., net taxes on incomes and products and other government revenues.

The difference between the government's total expenditures and total revenues gives the net public savings, which can be positive or negative.

## 3.4. SCENARIO SPECIFICATION

Based on the data described in the previous Section, EMPOWER can assess the macroeconomic impacts of NPP construction and operation activities under consistent sets of assumptions called scenarios. As part of a given scenario, the EMPOWER user can formulate a plausible development trajectory of population, economy, technologies, energy use and prices, and other relevant factors that influence the economic performance and broader impacts of a potential new nuclear power plant.

The scenario framework in EMPOWER is based on a comparison between the baseline scenario and the counterfactual scenario. The scenario formulation starts with the specification of the base year and the duration of the key phases of the project (construction and operation), with a maximum duration of 12 years for each of the two phases. A baseline scenario is defined for the entire time horizon to be analysed. It describes an assumed economic development, including the production per sector of the economy, and an assumed development of power generation technologies serving as a reference path. After characterising the deviation from the reference path, a different development path, called the counterfactual scenario, is calculated. This deviation comprises the change in the power generation system in form of increasing or decreasing construction and/or operation activities of specific technologies. Hence, the counterfactual scenario can comprise the addition of a single power plant as well as the change in the generation technology mix with different investment levels in different technologies. The latter can be provided by bottom-up models that simulate power supply. The macroeconomic impact associated with the construction phase - or the operation phase - is assessed by comparing the two scenarios (the base scenario and the counterfactual scenario) in absolute and relative terms.

For each of the two scenarios (baseline and counterfactual), a set of IOTs is calculated year by year throughout the analysed period. This calculation is based on assumptions about the growth rates of the economic sectors, which can be positive or negative depending on the economic prospects of the respective industries.

For each counterfactual case, input data needs to be provided about the change in power plant construction and operation. The investment costs, derived from the aggregated construction costs, need to be provided for each year of the construction period by disaggregation. If those costs are expressed in US $, then the exchange rate for each year needs to be reported, as IOTs use national currencies. Furthermore, an assumed depreciation rate of the NPP and a rate of return on investment need to be specified. These two parameters play a role if a part of new investments is financed during the operation phase via adjusted electricity prices. The depreciation rate reflects the economic life span in which the investment needs to be repaid and the rate of return represents the interest rates for the investment. Both define the necessary annual cash-flows and thereby the mark-up on the generation price needed to finance the investment.

In addition to the total cost associated with construction, the contributions of different economic sectors need to be indicated. If the goods and services required for construction are not provided domestically, they are assumed to be imported from abroad. EMPOWER requires the user to specify the share of domestic/imported inputs.

Additional information about the current electricity generation is required for assessing the impacts of the power output from the NPP for the two scenarios:

- The without-the-project scenario describes the evolution of the power sector in the absence of the NPP.
- The with-the-project scenario indicates the technology mix in electricity generation by considering the NPP.

Both scenarios are specified year by year over the time horizon of the analysed period. These scenarios assume that the electricity generated by an additional power plant will either substitute the power produced by other technologies or increase the total amount of electricity production. The excess power, i.e., the electricity from the new plant minus the increased electricity consumed as a result of economic feedback mechanisms, would be either used by households or exported. By defining the changes in net imports (i.e., imports minus exports) of electricity, the share of exported electricity is determined. Private households will entirely consume the remaining excess electricity.

To reflect the change in generation costs due to the change in generation technologies, the user needs to provide two types of information. First, the change in production costs for fuel consumption, fixed operation, variable operation, emission permit and capital. The second component specifies the price (as unit cost) to for supplied electricity and the price for traded electricity. This price excludes taxes and fees but includes costs for generation, investment and financing.

To trace the evolution of the power generation sector, fuel and operating costs need to be attributed to the respective sectors, which allows to calculate changes in usage patterns triggered by changes in the electricity generation mix.

Household income and consumption assumptions are also essential elements of a scenario. Accordingly, the growth rates of the various components of household income need to be assumed, including wages, operating surplus and profits accruing to households, taxes, social security contributions and other transfers - paid to the government or received from it by households - and other household income. The link between household income and consumption is described by a parameter called marginal propensity to consume, which designates the share of an additional unit of disposable income spent on consumption. This parameter varies across countries, and users need to specify it based on national data.

The labour market elements of a user-defined scenario are: labour force annual growth rate, productivity growth (determining the relationship between output growth and employment growth), productivity pass-through (defining the link between productivity and the growth of nominal wage rates and thus the operating surplus), the reaction of wages to the unemployment rate (indicating the competitive state of the labour market) and the price elasticity of the export demand for all commodities (describing the sensitivity of demand for exports to changes in prices).

EMPOWER can help explore impacts of NPP financing options. To this end, the user needs to specify the financing mechanism and sources. The investment can be financed by a combination of four possible sources: external (funds already available in the new industry or from public deficit), ex-ante revenue from income tax (increase in the tax rate of households in an ex-ante revenue neutral way), ex-ante revenue from transfer reduction (decrease in transfers to households) and ex-post markup on the electricity price (increase in electricity prices over the financing period). The length of the financing period is set by the user as part of the scenario.

### 3.5. MODEL RESULTS

EMPOWER assesses the macroeconomic and sectoral impacts during NPP construction and operation based on the data listed in Section 3.3 and the scenario specification described in Section 3.4. The assessment involves four consecutive economic feedback mechanisms in the Excel model for both phases, i.e., construction and operation. For both construction and operation modules, the complexity of relationships included into the model is least in submodule A and highest in submodules ABCD. It is highly recommended to conduct analysis for both construction and operation phases, while selecting the level of submodular complexity to use will depend on the data availability and the user’s interest.

As indicated in Section 3.2, EMPOWER can assess a variety of impacts associated with NPP construction and operation:

— Direct and indirect impacts of the NPP programme (construction period only).
— Induced impacts.
— Labour market impacts.
— Impacts of ex-ante financing of an investment (construction period only).
— Impacts of nuclear power operation (operational period only).
— Impacts of ex-post financing of an investment (operational period only).
— Impacts on exports due to changes in domestic prices.

For each mechanism, EMOPOWER determines a series of key macroeconomic indicators (aggregated and industry-level) describing the magnitude of impacts both in nominal and real terms. The aggregated indicators include:

— GDP.
— Disposable income.
— Total production.
— Output value.
— Net taxes for the government.

— Imports and exports.
— Private consumption and employment (in real terms only).

Industry-level indicators include production output values (in nominal and real terms) and employment (in real terms only).

### 3.6. TUTORIAL

In what follows, this manual will guide the user through all six files describing the procedure in Figure 3 in a step-by-step mode. In addition, in five files where user input is relevant, the data files and the master file a tutorial option. This tutorial will navigate the users through all important steps and provide supplementary information. It can be activated in all five files by clicking on the button “START TUTORIAL” which is located in the left upper corner in the “Description” sheet (Figure 6):


*FIG. 6. Tutorial start button in each sheet named “Description”.*

A user can move between different tutorial entries for a given sheet using a tutorial control button which is located in the left upper corner as shown in the Figure 7:

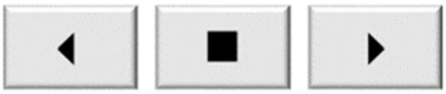
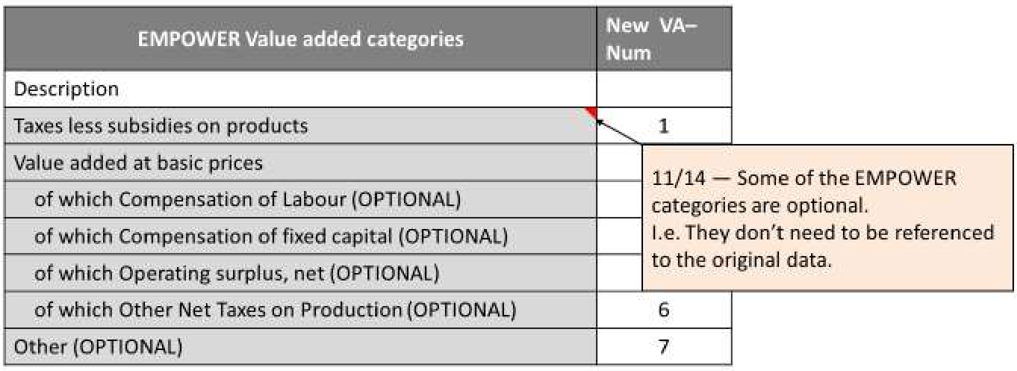


*FIG. 7. Tutorial control button.*

Tutorial consists of Excel comments, for example 1/15 means that this is the first out of 15 entries. These comments appear as in Figure 8 when the user proceeds by clicking the control button. The STOP-Control removes all comments.



| EMPOWER Value added categories | New VA–Num |
|---|---|
| Description | |
| Taxes less subsidies on products | 1 |
| Value added at basic prices | |
| of which Compensation of Labour (OPTIONAL) | |
| of which Compensation of fixed capital (OPTIONAL) | |
| of which Operating surplus, net (OPTIONAL) | |
| of which Other Net Taxes on Production (OPTIONAL) | 6 |
| Other (OPTIONAL) | 7 |

11/14 — Some of the EMPOWER categories are optional.
I.e. They don’t need to be referenced to the original data.

*FIG. 8. Example of a tutorial comment*

## 3.7. FILE ORGANISATION AND BUILT-IN CHECKS

Each Excel file in EMPOWER has a defined colouring of Sheets using the colour style “Office 2007-2010”.

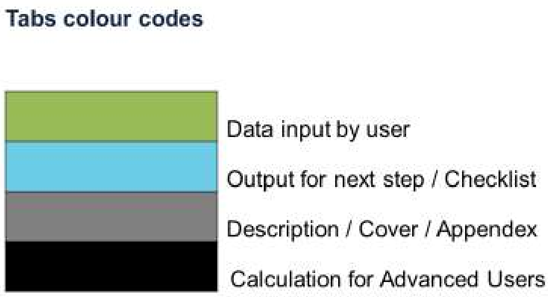



*FIG. 9. Sheet-Tab colouring in EMPOWER Excel files.*

Next to the first Sheet “Cover”, the grey Sheet “Description” provides a short overview of the content of the respective file. In Step 1, grey Sheets also provide aggregation examples. Sheets coloured in green are prepared for user’s inputs. Sheets that are coloured black need to only by used or changed by an experienced user. “AdminCalc” are background calculations for “Check” and in “AdminTut” the texts and position of the tutorial process can be set (Figure 9). The blue Sheet “Check” is the final step for a user in each file because it contains potential inconsistencies or missing data which are reported in form of OK, warnings or error messages:

**OK:** The check is fulfilled; no inconsistencies are detected.

**WARNING**: Inconsistencies are detected but they will not cause errors in the Masterfile.

**ERROR:** One or several inconsistencies are detected and they will cause errors either in the Masterfile or in the data construction files.

The “Error” case needs a special attention and needs to be resolved before moving to the subsequent step. The location of the error and a potential solution are provided next to the error message.

# 4. STEP BY STEP PROCEDURE IN EMPOWER APPLICATION

## 4.1. FILE 1: AGGREGATION SCHEMES

The initial step in data preparation involves adjusting the original IOT to the EMPOWER IOT format with 35 (or less) sectors and specific final demand and value-added categories.

The user is required to define the allocation of the original sectors and categories to EMPOWER's format in the file named "EMPOWER_STEP1_AGGREGATION.xlsm". This is done by including relevant information in the sheet "Select_Class"; the aggregation itself will be done automatically in the subsequent steps.

To facilitate the allocation process, the File 1 contains three examples of IOT structures from international sources: The European Statistical Institute (EUROSTAT), the World Input-Output Database (WIOD) and the OECD IOT. In File 1, EUROSTAT structure represents 64 sectors in the Statistical Classification of Economic Activities in the European Community, Rev. 2 (2008)[3] (in short NACE Rev.2). The 2016 version of WIOD[4] also uses an aggregated classification of NACE Rev.2 and provides 56 sectors. The OECD IOT's is represented in ISIC Rev.4 classification [11] in 36 sectors. However, ISIC Rev.4 and NACE Rev.2 are "are identical up to the two-digit level (divisions) of the classification" (page 37 in [11]). However, it is highly recommended to work with a statistician from a National Statistical Office, when completing the data allocation and aggregation routines. The plausibility of the results will crucially depend on the correct aggregation.

### 4.1.1. Step1.1: Define sectoral correspondence and aggregation codes (Sheet: Select_Class)

In the left-hand side of the green area in the Sheet "Select_Class" (Figure 10), the user provides an original sectoral structure from the IOT. The table allows to include codes and names of up to 120 original sectors and number them. The right-hand side of the green area in the Sheet "Select_Class" (Figure 10) contains the names of up to 35 sectors in the EMPOWER classification. The user is free to choose and allocate them with one important exception. In the EMPOWER classification, the electricity producing sector needs to always be the first sector. This is done to guarantee that all equations where the electricity sector is treated differently (than the remaining sectors) are linked to the respective cells.

If the original IOT consists of less than 35 sectors, EMPOWER will be able to make simulations. The way to proceed is to allocate the original sectors to the EMPOWER sectors by putting electricity producing sector in the first place and allocating the remaining original sectors to EMPOWER sectors. The name of the empty EMPOWER sectors can be filled with fictious words, for example as "Empty01", "Empty02" and so forth, or can be let empty. The empty EMPOWER sector numbers will have a red background and also indicate a "Warning" in the "Check" Sheet. This warning is essential to draw attention of the user to the correctness of the provided data, and that all source sectors are properly allocated to EMPOWER sectors. The model will automatically fill in empty sectors with zeros and conduct respective calculations. If the EMPOWER sector names stay empty, a default name will be automatically created for these sectors in the file Step 2

---

[3] For further details see RAMON - Reference And Management Of Nomenclatures (RAMON) URL: https://ec.europa.eu/eurostat/ramon/

[4] World Input-Output-Database (WIOD) release 2016, URL: www.wiod.org/ /release16

For the simulation of the operation phase, it is advisable that sectors that provide fuels for electricity generation (biomass, natural gas, etc.) are not aggregated with other sectors.

| Old SecNum | Industries / Products (Previous Classification) | | Corr SecNum | EMPOWER Industries | | New SecNum |
|---|---|---|---|---|---|---|
| | Code | Description | | Code | Description | |
| 1 | s01T03 | Agriculture, forestry and fishing | 2 | 1 | Electricity, gas, water supply, sewerage, waste and remediation services | 1 |
| 2 | s05T06 | Mining and extraction of energy producing products | 3 | 2 | Agriculture, forestry and fishing | 2 |
| 3 | s07T08 | Mining and quarrying of non-energy producing products | 4 | 3 | Mining and extraction of energy producing products | 3 |
| 4 | s09 | Mining support service activities | 5 | 4 | Mining and quarrying of non-energy producing products | 4 |
| 5 | s10T12 | Food products, beverages and tobacco | 6 | 5 | Mining support service activities | 5 |

*FIG. 10. Allocation of original IOT sectors to EMPOWER sectors.*

#### 4.1.2. Step1.2: Define correspondence and aggregation codes for value-added categories (Sheet: Select_Class)

The next step is to prepare an allocation for value-added categories and net taxes (taxes less subsidies) on products. Taxes less subsidies on products represent the net taxes for production inputs. Value-added is the difference between the monetary value of the produced commodities and services minus the necessary production inputs (including taxes). Value-added is then allocated between compensation of labour and compensation of capital (fixed capital consumption, net operational surplus) as well as taxes on production. Depending on the statistics, five categories are typically available. In the left-hand side of the table “Value added correspondences and aggregation codes”, up to 20 original categories for value-added can be included and allocated to seven EMPOWER categories (the right-hand side of the same table). EMPOWER value-added categories are based on the System of National Accounts ( [7]). The System of National Accounts 2008 (2008 SNA) is the latest version of the international statistical standard for the national accounts, adopted by the United Nations Statistical Commission (UNSC). Only two of them are mandatory: “Taxes less subsidies on products” and “Value added at basic prices”. The remaining five are optional and can be left empty (Figure 11). If those categories are left empty, the user can run submodule A. At a later stage (Step 2), the user has still an option to include additional data and thereby enable the usage of other submodules in EMPOWER.

| Old VA-Num | Value added categories | Corr VA-Num | | Info | EMPOWER Value added categories | New VA-Num |
|---|---|---|---|---|---|---|
| | Description | Add | Subtract | | Description | |
| 1 | Taxes less subsidies on intermediate and final products (paid in foreign countries) | 1 | | Add to 1 | Taxes less subsidies on products | 1 |
| 2 | Taxes less subsidies on intermediate and final products (paid in domestic agencies) | 1 | | Add to 1 | Value added at basic prices | 2 |
| 3 | Compensation of employees | 3 | | Add to 3 | of which Compensation of Labour (OPTIONAL) | 3 |
| 4 | Other taxes less subsidies on production | 6 | | Add to 6 | of which Consumption of fixed capital (OPTIONAL) | 4 |
| 5 | Gross operating surplus and mixed income | 5 | | Add to 5 | of which Operating surplus, net (OPTIONAL) | 5 |
| 6 | Value added at basic prices | 2 | | Add to 2 | of which Other Net Taxes on Production (OPTIONAL) | 6 |
| 7 | | | | | Other (OPTIONAL) | 7 |

*FIG. 11. Allocation of original value-added categories to EMPOWER categories.*

A dropdown menu helps to choose the corresponding EMPOWER category and allows to add or subtract original categories. For example, subtraction can be used for cases where a difference of two original categories needs to be allocated to an EMPOWER category. For instance, if an original value-added category is not provided but can be calculated from a difference between "Category A" and "Category B". By adding (Add to 2) the former and subtracting the latter (Subtract from 2) to EMPOWER category 2, the value-added can be allocated.

#### 4.1.3. Step1.3: Define correspondence and aggregation codes for final demand categories (Sheet: Select_Class)

The next step is to prepare an allocation routine for the final demand categories. Final demand resembles the excess production of an economy. It is composed of household consumption, government spending, investment, and exports. In the left-hand side of the table "Final demands correspondences and aggregation codes", a maximum of up to 20 original categories for final demand can be included and allocated to six EMPOWER categories which are placed in the left-hand side of the same table (Figure 12). The EMPOWER final demand categories are based on the System of National Accounts [7]. Four categories are mandatory: Final consumption expenditure by households; final consumption expenditure by households; gross fixed capital formation and exports. Two other final demand categories are optional and can be left empty.

The allocation of an original category is done by clicking into the cells of column "Add" and then by linking it to the respective EMPOWER category which can be selected in a dropdown menu. Analogously to the value-added categories (Section 4.1.2), the subtraction can be used for cases where a difference of two original categories needs to be allocated to an EMPOWER category.

| Old FD-Num | Final demands categories | Corr FD-Num | | Info | EMPOWER Final demands categories | New FD-Num |
|---|---|---|---|---|---|---|
| | Description | Add | Subtract | | Description | |
| 1 | Final consumption expenditure of households | 1 | | Add to 1 | Final consumption expenditure by households | 1 |
| 2 | Final consumption expenditure of non-profit institutions serving households | 2 | | Add to 2 | Final consumption expenditure, NPISH (OPTIONAL) | 2 |
| 3 | Final consumption expenditure of general government | 3 | | Add to 3 | Final consumption expenditure by government | 3 |
| 4 | Gross Fixed Capital Formation | 4 | | Add to 4 | Gross fixed capital formation | 4 |
| 5 | Changes in inventories | 5 | | Add to 5 | Changes in inventories and valuables (OPTIONAL) | 5 |
| 6 | Direct purchases abroad by residents (imports) | 1 | | Add to 1 | Exports | 6 |

*FIG. 12. Allocation of original final demand categories to EMPOWER categories.*

#### 4.1.4. Use allocation examples (Sheets: Appx_Eurostat, Appx_WIOD16, Appx_OECD)

These Sheets contain aggregation codes for three sources to the EMPOWER structure. They serve as a guideline on how to proceed in the construction of the aggregation codes. If the user relies on the IOT from those sources, the allocation code can be directly transferred to the Sheet “Select_Class”. As outlined at the beginning of this Section 4.1, all sources build on ISIC Rev.4 (which is identical to NACE Rev.2 at this classification level) but are available in different aggregations. EUROSTAT IOT’s comprise 64, WIOD’s IOT 56 and OECD’s IOT 36 sectors.

#### 4.1.5. Include additional information as an advanced user (Sheets: AdminTut and AdminCalc)

In the default version of EMPOWER, these Sheets cannot be changed (“frozen”). In an advanced version only, the user can add and modify the tutorial and the check reports. In “AdminTut” each step of the tutorial is defined. If an advanced user wants to add steps, then a Sheet name, a cell name and the text needs to be provided; the new tutorial note is generated. Furthermore, the colouring of the note can be set in the right column.

In AdminCalc the background calculations for the sheet “Check” are performed. If an advanced user seeks to add a check-algorithm it can be placed in this Sheet. Then one cell needs to comprise the results “OK”, “WARNING” or “ERROR”. In “Check” an empty cell needs to be linked to the results-cell manually. The message, location and a solution suggestion need to be added. The overall process can be easily seen when investigating the cells in “Check”.

### 4.2. FILE 2: AGGREGATION OF INPUT-OUTPUT-TABLE

The file “EMPOWER_STEP2_INPUT_OUTPUT_TABLE.xlsm” uses the information from File 1 and creates EMPOWER IOT. The initial step is an upload of information defined in Step1 in Sheet “Select_Class” which is then complemented by the data from the original IOT in following Sheets.

The original IOT provided needs to have separated matrices for domestic and imported flows and a certain structure in final demand and value-added categories, as discussed previously. The objective of the Step 2 is to construct an IO that corresponds to the structure in Figure 5. It needs to consist of the following of 6 sub-matrices (Sheets):

- **IM_Dom**: the use-matrix of domestically produced goods and services for intermediary use.
- **IM_Imp**: the use-matrix of imported goods and services for intermediary use.
- **IM_VA**: the matrix of primary inputs (as value-added) and the sum of taxes less subsidies of products.
- **FD_Dom**: the use-structure of domestically produced goods and services for final demand.
- **FD_Imp**: the use-structure of imported goods and services for final demand.
- **FD_VA**: the matrix of primary inputs and other in final demand.

Further Sheets “AdminCalc”, “AdminTut”, “BrdSEC”, “BrdVA” and “BrdFD” are for advanced users and are inactive in a default version of the model. In “AdminCalc” the reports in Sheet “Checks” can be modified or expanded. In “AdminTut” the tutorial steps can be altered and new notes can be added. The Sheets starting “Brd” contain bridge matrices for the automatic matrix aggregations. These need to not be altered.

### 4.2.1. Step 2.1: Load correspondence and aggregation codes (Sheet: Select_Class)

The “Select_Class” Sheet contains the same structure as in the Step1. The user is given the opportunity to load the information automatically from Step1 just by pressing the button in the top left corner “Load Aggregation Code from Step1” (Figure 13) and select the respective file. If this step is completed correctly, the blue area of the tables with sectoral, value-added and final demand aggregation codes is filled with the specified information. Clear the cells when the procedure needs to be repeated by using “Clear Data” button. It is highly recommended to make use of an automatic procedure to load the data rather than to transfer them manually. This avoids any inconstancies and/or errors when proceeding to the next level.


*FIG. 13. Button to load correspondence and aggregation codes from Step 1*

### 4.2.2. Step 2.2: Provide IOT data by component (Sheets: IM_Dom, IM_Imp, IM_VA, FD_Dom, FD_Imp and FD_VA)

This step involves copying of values (numbers only!) from the original sub-matrices of the IOT and transferring them into the green areas of the following Sheets: IM_Dom, IM_Imp, IM_VA, FD_Dom, FD_Imp and FD_VA. The areas are automatically coloured in green to facilitate the data transfer procedure. The size of the green area to be filled in depends on the original entries for all respective categories. For example, if the original IOT consists of 50 sectors, then the green area in the Sheet IM_Dom will be a 50x50 matrix. An error message will appear signalling that not all required fields (marked as green) are filled in, otherwise. The user needs to correct for this, before proceeding to the next level.

### 4.2.3. Step 2.3: Generate EMPOWER IOT (Sheet: Output_IOT)

If all green areas in are filled in correctly, the aggregation routine automatically generates an EMPOWER IOT which consists of two 35×35 matrices comprising the domestic and imported input structure of EMPOWER sectors and further four matrices representing EMPOWER value-added and final demand structures. It only remains to fill in the base year of the IOT, to provide the country name and to indicate the national currency together with a unit used in the top left corner of the matrix.

At the far right of the generated IOT a balancing check is performed. The sum of columns is compared to the sum of rows and an absolute and relative deviation is calculated. In a balanced IOT, the difference is zero. Due to statistical imbalances or rounding errors, some differences might be present in the original IOT. The average total imbalance is shown at the top of these calculations. As a rule of thumb, if imbalances are large (e.g., >5%), then this is can be interpreted in the way that some of the provided numbers are not correct. The sector with the largest deviation is the first to look at. If imbalances are small (e.g., <1%), then there might be a "Warning" in the "Check" Sheet, but this would typically cause no problem in EMPOWER. Furthermore, an automated balancing routine is provided in the Masterfile (Step 5) which erases small imbalances.

## 4.3. FILE 3: DATA COMPOSITION

Within a given phase (construction and operation), submodules — labelled as A, AB, ABC and ABCD — have an additive structure and build upon each other.

The file "EMPOWER_STEP3_DATA_COMPILATION.xlsm" compiles all the data needed to run submodules A, AB, ABC and ABCD. The file includes the Sheets "Data A", "Data B", "Data C" and "Data D" (other Sheets are discussed below). To run submodule A, the user will need to compile the data in the Sheet "Data A" only. To be able to run submodule AB, the user will need to compile the data in the Sheet "Data A" and "Data B". The complexity of relationships included into the model is highest in submodule ABCD. This is translated into the highest demand of required data which need to be compiled in "Data A", "Data B", "Data C" and "Data D".

The user is given an option to set the submodules active or inactive by using the dropdown menu as shown in Figure 14. Submodule A requires a data set which enables the users to conduct a basic analysis. It therefore remains always active. The switch button is located in the upper left corner of the Sheets "Data B", "Data C" and "Data D. The submodular structure implies that if the user sets the "B" component inactive, then consequently the "C' and "D" components become inactive.


*FIG. 14. ACTIVE/INACTIVE switch button*

### 4.3.1. Step 3.1: Load Step2 data (Sheet: Data A)

To compile the data for submodule A, the user is requested to click the button "Load IO-Table" which is located in the left upper corner of the Sheet "Data A" (Figure 15), select the Step2 file and to load the EMPOWER IOT. The matrix has the EMPOWER sectoral, value-added and final demand structures. The entire area is coloured blue because the data are loaded from the previous Step 2. If needed, the procedure can be repeated by clicking the button "Clear Input" which clears the blue highlighted area and pressing the button "Load IO-Table" again.


*FIG. 15. Button to load EMPOWER IOT in Step3 file.*

### 4.3.2. Step 3.2: Include information on labour and capital compensation in value-added block (Sheet: Data B)

Starting with "Data B" Sheet the user has the option to set subsequent submodules inactive. If a submodule is set inactive, then the respective areas for data inputs will automatically be marked grey and the submodule routine will become unavailable in the Masterfile. The information in this area is not deleted but will not be used in the following steps.

If the "Data B" is set active, then the features of submodule AB will become available in the Masterfile. The procedure starts by clicking the button "Copy Data from Sheet Data A" (Figure 16) which copies the lower rows (value-added rows) of the EMPOWER IOT into the respective area.


*FIG. 16. Button to copy data from EMPOWER IOT to the Sheet "Data B".*

If the original IOT contains sectoral data labelled "Compensation of Labour" and the "Operating surplus, net", then they are automatically transferred to the green marked fields, and the user does not need to undertake any other actions (Figure 17). Otherwise, the user is requested to use additional sources from the national statistical institutes and include the required information manually. It is essential that the collected data refer to the same base year as the EMPOWER IOT. This procedure can be seen as a disaggregation of "Value added at basic prices". Please note that the sum of all components of "Value added", i.e., compensation of labour, consumption of fixed capital, operating surplus and other net taxes, need to sum up exactly to the value of "Value Added" from the IOT. Otherwise, the value-added cell has a red background as a warning.

| Country | Sect 1 | Sect 2 |
|---|---|---|
| Value added at basic prices | 611 | 4,722 |
| of which Compensation of Labour | 291 | 915 |
| of which Consumption of fixed capital (OPTIONAL) | - | - |
| of which Operating surplus, net | 320 | 3,807 |
| of which Other Net Taxes on Production (OPTIONAL) | - | - |
| Other (OPTIONAL) | - | - |

*FIG. 17. Input mask for value-added components in the Sheet "Data B"*

The main purpose of the disaggregation of value-added in sheet "Data B" is to extract the part of value-added that relates to households' wages which is "compensation of labour". Other components such as "Net taxes on production" and the "Compensation of fixed capital" can be allocated to "Operating surplus" and are thereby optional for the functionality of EMPOWER. However, if this optional information is provided a more precise allocation of non-wage households' income can be made.

#### 4.3.3. Step 3.3: Include information on disposable income of private households (Sheet: Data B)

In the table labelled "Disposable income of private households" (Figure 18), aggregated data on disposable income from national accounts need to be included. It includes all sources of income for households, including net transfers as well as the sinks as income taxes and social contribution. Green highlighted cells need to be filled in manually by including the data for the base year. This data set provides the link between the labour compensation of the IOT and the actual disposable income that is available for consumption. It emphasizes that due to taxes and social contribution only a part of the labour compensation paid by producers remains and also that other sources that are not affected by an economic impact (e.g., from rents) play a role. All this information has impact on the reaction of disposable income due to changes in the economy what ultimately steers the induced consumption.

EMPOWER specification relies on the National Accounts which names and defines the following components of the gross disposable income:

- **Gross disposable income** (GrossYD) "*is the balancing item in the secondary distribution of income account. It is derived from the balance of primary incomes of an institutional unit or sector*" ( [7] §8.20). In EMPOWER it is derived in the following way:

  GrossYD = Wages + OperatingSurplusHH + Profit Income – TaxesGovHH – SocContGovHH + TransfersGovHH + OtherIncomeHH

— **Wage income** (wage): is a primary income source for households' income from labour supply. Wage income refers to the gross wage income including income taxes and social contribution but excludes taxes and social contribution already paid by the employer.

— **Operating Surplus** (OperatingSurplusHH) comprises the income of households from operating surplus. This includes income from self-employment.

— **Profit income** (ProfitIncome) comprises income from profits as rents and assets.

— **Income Taxes** (TaxesGovHH): "*Current taxes on income, wealth, etc. consist mainly of taxes on the incomes of households or profits of corporations and of taxes on wealth that are payable regularly every tax period*".

— **Social Contributions** (SocContGovHH) are the net contributions into social security system.

— **Net Transfers** (TransfersGovHH) are the net sum of transfers households receive; this includes transfers as pensions and unemployment benefits among others.

— **Income from other sources** (OtherIncomeHH) summarizes all other sources of income.

| | |
|---|---|
| **Wage (compensation of employees)** | 24,412 |
| **OperatingSurplusHH** | 18,952 |
| **ProfitIncome** | |
| **TaxesGovHH** | 3,283 |
| **SocContGovHH** | 1,068 |
| **TransfersGovHH** | 3,209 |
| **OtherIncomeHH** | |
| **Gross disposable income** | **42,222** |

| | |
|---|---|
| **s_hh(wage)** | 0.92 |
| **s_hh(surplus)** | 0.58 |
| **Tax rate** | 0.03 |
| **Wages, net** | 23,769 |
| **Other income** | 18,452 |
| **Gross disposable income** | **42,222** |

*FIG. 18. Disposable income of households for the Sheet "Data B"*

From the data provided in in Sheet "Data B" three parameters are derived (Figure 18). The values in the lower part of Figure 18 are coloured in white and are calculated automatically based on previous included data. Thereby, the sum of wages based on national accounts can be different from the sum of wages in the EMPOWER IOT. This discrepancy is calculated automatically and captured by the parameter "s_hh(wage)", the first of three derived parameters. "s_hh(wage)" is the share of National Accounts wages with respect to total labour compensation of the IOT. This resembles how much of the labour compensation flows to households. It is expected that this parameter will not be equal to 1. If the deviation is too large, an error needs to be excluded before moving to the next level. The second parameter "s_hh(surplus)" shows the share of the IOT's operational surplus which flows to households" income. This can comprise income from self-employment. The third parameter expresses the net tax rate, including the transfers, i.e., this fraction is the sum of income taxes and social contribution minus transfers divided by disposable income.

### 4.3.4. Step 3.4: Include labour market data (Sheet: Data C)

Data on the labour market need to be provided when the ABC submodule is of interest to the user as shown in Figure 19. The green marked data fields are mandatory and need to be filled in manually. The data include information for the base year about the total labour force, sectoral employment as expressed in persons, jobs or full-time equivalent. The model automatically loads the compensation of labour (wages), calculates wage rate (labour compensation per unit of employment) and total unemployment.

| | | |
|---|---|---|
| Labour force | 3,769,200 | Clear |
| Unemployment rate | 13.05% | |

| | Sect 1 | Sect 2 | Sect 3 |
|---|---|---|---|
| Compensation of Labour/Wages | 291 | 915 | 1,849 |
| Employment | 10,456 | 575,800 | 16,259 |
| Wage rate | 0 | 0 | 0 |

| | |
|---|---|
| Units of employment (hours, jobs, persons...) | Persons |

*FIG. 19. Additional information on the base year employment in the Sheet "Data C"*

#### 4.3.5. Step 3.5: Include information on public expenditures (Sheet: Data D)

While the file loads data on net taxes from the EMPOWER IOT such as "Net taxes on income", "Net taxes on products" and "Public consumption", others can be added in the Sheet "Data D", in particular "Other expenditures" and "Other revenues". Both additional values are optional. (Figure 20). They are optional in the sense that the EMPOWER simulation will not be affected by them. The main purpose of the provision of this data is the representation of the actual public net saving of the base year, i.e., these two values can be used to set the base years public net saving level. The changes in public net saving in the simulations can then be set in relation to the base case.

| Categories | Data at base year |
|---|---|
| Net taxes on income | 1,142.0 |
| Net taxes on products | 369.4 |
| Public consumption | 10,536.6 |
| Other expenditure | – |
| Other revenue | – |
| Public net saving | -9,025 |

*FIG. 20. Additional public expenditures and revenues in the Sheet "Data D"*

#### 4.3.6. Step 3.6: Further Sheets (Sheet: Check, AdminCalc, AdminTut)

The sheet "Check" is the last step for a user in each file where potential inconstancies or missing data is reported in form of OK, warnings or error messages. Data composition is finished with this step and the user can move to the specification of the scenarios.

In "AdminCalc", the reports in Sheet "Checks" can be modified or expanded. In "AdminTut" the tutorial steps can also be altered, and new notes can be added. However, those options are available for advanced users only — in the default version of the model those cells are frozen.

### 4.4. FILE 4: SCENARIO DATA

Based on the data characterizing the economy and listed in the previous Section, EMPOWER can assess macroeconomic impacts under a consistent set of assumptions called scenarios. This Section will guide the users (through the file "EMPOWER_STEP4_SCENARIO.xlsm") in formulating plausible development pathways for population, economy, technologies, energy use and prices, and other relevant factors driving the economic performance and the broader impacts of a possible new NPP. As indicated in Figure 3, scenario parameters (Step 4) and data (Step 3) are used by the Masterfile for the model runs.

#### 4.4.1. Step 4.1: Load MESSAGE information (Sheet: Description)

In the case where the bottom-up model MESSAGE is to be applied and the respective file "STEP_MESSAGE.xlsm" is prepared, the information can be loaded by clicking the "Load MESSAGE Data" button in the sheet "Description" and choose the respective file (Figure 21).

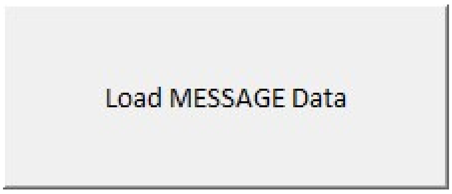



*FIG. 21. Button to load MESSEAGE information.*

This process automatically fills the time span of the construction period and operation periods in sheet "Growth (ABCD)", the Total construction costs in "ConstCosts (A)", and all information in "Operation energy (A)".

#### 4.4.2. Step 4.2: Load previous information (Sheet: Growth (ABCD))

This Sheet presents two coloured areas, blue and green. The blue coloured area will be filled by previously provided data. The green coloured area needs to be filled manually.

The first step here is to load information from the previous Step 3 to the tables labelled "Time span and growth assumptions". This is done — as usual — by clicking on the button "Load Information from Data3" (Figure 22) and choosing the respective file. The blue highlighted cells are filled with the uploaded information.


*FIG. 22. Button to load sectoral information from Step3 file*

This process filles the cells comprising sector names, base year, production values in base year, activity status of submodules, country name and currency. If required, the loaded information with the blue background can be removed by using the button "Clear blue area" button, whereas the information inserted in this Sheet with green background can be erased by the "Clear green area" button.

#### 4.4.3. Step 4.3: Define a time span (Sheet: Growth (ABCD))

The users are now asked to define a time span of construction and/or the operation phases in years (Figure 23). The base year (in blue) is automatically included when a button in Figure 20 is activated. It is recommended to conduct an analysis for both construction and operation phases to receive a comprehensive view of potential macroeconomic impacts. For the construction phase, the length is set at maximum 12 years. For the operation phase, the length is set at 12 years which implies that only a few years of the operation will be captured. Because EMPOWER assumes static relationships between inputs and outputs, it is recommended not to go beyond the time horizon of 25-30 years starting with the base year of IOT. If the users define a larger time span — as shown in Figure 23 — the respective cell turns red. The time span needs to be redefined before moving to the next step.

| Data base | | |
|---|---|---|
| Base | Base year of IOT | 2010 |

| Construction Period | | |
|---|---|---|
| Start | Start of Construction period | 2023 |
| End | End of Construction | 2040 |

| Operation Period | | |
|---|---|---|
| Start | First Year of Operation | 2030 |
| End | Year of Operation | 2035 |

*FIG. 23. Defining a time span for construction and operation phases.*

#### 4.4.4. Step 4.4: Sectoral growth assumptions (Sheet: Growth (ABCD))

An EMPOWER analysis is based on a comparison between the baseline and counterfactual scenarios. The baseline scenario, which serves as a reference point, is defined for the entire time horizon to be analysed. It describes the development of the sectoral production with growth rates assuming no new power plant. After introducing the data characterising the construction and/or operation of the new power plant, a different development path is calculated, called the counterfactual scenario. The macroeconomic impact of the construction or operation phase is derived from the comparison of the two scenarios (counterfactual and baseline) in absolute and relative terms.

The baseline in EMPOWER involves a series of IOTs, calculated sequentially for each year of the analysed period (construction and operation). The scenario information required for this calculation includes assumptions about the annual growth rates of all economic sectors defined in the IOTs (Figure 24). These values can be positive or negative depending on the economic outlook of the respective industry. The series of IOTs, calculated sequentially for each year of the analysed period, will be produced in the Masterfile (Step 5). The user is asked to fill in the average sectoral growth rates in nominal terms for the entire investigation period. “Nominal” refers here to current prices and not chain-linked volumes or in previous-year-prices. In general, it is advisable that the resulting total growth is in line with historical developments or official GDP projections and describes a plausible pathway.

| Annual growth rate | | |
|---|---|---|
| Sect 1 | Electricity | **8.07%** |
| Sect 2 | Agriculture, hunting, forestry and fishing | **8.05%** |
| Sect 3 | Mining and quarrying | **4.57%** |
| Sect 4 | Food products, beverages and tobacco | **10.57%** |
| Sect 5 | Textiles, textile products, leather and footwear | **2.18%** |
| Sect 6 | Wood and products of wood and cork | **8.80%** |
| Sect 7 | Pulp, paper, paper products, printing and publishing | **8.34%** |
| Sect 8 | Coke, refined pertolue products and nuclear | **6.03%** |

*FIG. 24. Including average sectoral output growth rates for the entire investigation period.*

In the Masterfile these growth rates determine the future output value (column sum) of each sector for the given time period in the IOT. Since in an IOT, the sum of each column is equal to the sum of the respective row, all row and column sums are pre-determined by these growth rates and the base year's production values. The well-known RAS (ranking and scaling data reconciliation method) procedure is then used to calculate a fully balanced IOT for a given year. This method - an iterative scaling method for data reconciliation - aims at achieving consistency between the entries of a non-negative matrix and pre-specified row and column totals (see for more details and information Box 11.3 in Ref. [10].)

The user can run a sensitivity analysis on alternative set of growth rates — for example for high, medium, or low growth — and identify the sensitivity of macroeconomic effects to an uncertainty regarding the future economic growth.

#### 4.4.5. Step 4.5: Include aggregated construction costs (Sheet: ConstCosts (A))

At the top of this Sheet the time periods as defined in Sheet "Growth (ABCD)" are presented. This defines the years listed in table "Total construction costs (US$)".

Investment costs need to be provided for each year of the defined construction period in the table labelled "Total construction costs" starting with the aggregated construction costs. Depending on the data availability, the users can select a uniform or non-uniform distribution. The non-uniform distribution implies that investment volume will vary across the investment period. To the right of this table, the "Approximated impact on economy's production" is calculated. This table uses the previously defined growth rates to estimate the economy's size during construction. This provides an insight as to whether the dimension (or currency) of the investment has the assumed magnitude.

If investment costs are reported in US $, then the exchange rate between US $ and the national currency for each year needs to be reported. The point of reference is the currency and units used for IOT. For example, if the IOT is reported in millions of national currency units, then annual construction costs will be in millions too. The model automatically calculates the annual investment volume and its relative distribution over the construction period (Figure 25).

| #Year | Year | Costs p.a. | Exchange rate (national currency/US$) | Costs p.a. in Millions Dollar | Distribution of costs ( %) |
|---|---|---|---|---|---|
| Y1 | 2023 | 1,161 | 3 | 3,482 | 14.3% |
| Y2 | 2024 | 1,161 | 3 | 3,482 | 14.3% |
| Y3 | 2025 | 1,161 | 3 | 3,482 | 14.3% |
| Y4 | 2026 | 1,161 | 3 | 3,482 | 14.3% |
| Y5 | 2027 | 1,161 | 3 | 3,482 | 14.3% |
| Y6 | 2028 | 1,161 | 3 | 3,482 | 14.3% |
| Y7 | 2029 | 1,161 | 3 | 3,482 | 14.3% |
| Y8 | 2030 | 0 | 3 | 0 | 0.0% |
| Y9 | 2031 | 0 | 3 | 0 | 0.0% |
| Y10 | 2032 | 0 | 3 | 0 | 0.0% |
| Y11 | 2033 | 0 | 3 | 0 | 0.0% |
| Y12 | 2034 | 0 | 3 | 0 | 0.0% |
| Totals | | 8,124.8 | | 24,374.5 | 100.0% |

| | |
|---|---|
| Depreciation rate | 1.67% |

| | |
|---|---|
| Rate of return | 5.00% |

*FIG. 25. Including annual investment costs over for the construction period.*

### 4.4.6. Step 4.6: Disaggregate construction costs by sector (Sheet: ConstCosts (A))

The contributions of economic sectors during the construction phase need to be defined, i.e., the monetary composition of commodities used as inputs during construction. Depending on the country context, smaller or larger portions of the input required from different sectors will be provided locally or imported. As part of the scenario definition, the shares of inputs supplied domestically need to be estimated and provided as input to EMPOWER.

The strength of an IOT model such as EMPOWER is that it accounts for interrelations between the used inputs of economic sectors and the produced goods and services (outputs). Because the demand for each output has a different impact on GDP, income or trade, it is of extreme importance that the sectoral distribution of annual investment costs is done correctly. Below the "Total construction costs" table (as indicated in Figure 25), four tables are included to collect and to proceed the required information.

- The table labelled "Shares for sectoral contribution" requires the users to distribute the annual investment costs for every given year of construction across the sectors in IOT by including a share in a green coloured field. For example, the share 0.10 implies that for a given year 10% of total annual costs are spent on buying goods or services from a particular sector. The shares for a given year need to sum up to 1 which implies that 100% of annual investments costs are distributed across sectors in the economy.
- Table "Split total construction costs by sector (in absolute numbers)" automatically calculates the sectoral contributions in absolute numbers by using the annual construction costs and defined shares. The blue bars visualize the relative allocation by sector.
- Table "Domestic shares in total construction costs by sector" requires the user to define a sectoral localization rate following the IOT structure in green marked cells. For example, a value of 0.4 implies that 40% of a particular sector's product originates from the domestic sources.

— Table “Domestic contribution by sector” automatically calculates domestic contribution (in absolute numbers) based on the annual sectoral distribution of construction costs and sectoral localization rates.
— Tables “Import shares in total construction cost by sector” and “Imports contribution by sector (in absolute numbers)” automatically calculates both an import share and a volume of investment originating from abroad. Based on the previous example, the import share will be 60%.
— Tables “Control check” reports red coloured “Error”, if investment costs are allocated to a year that is not part of the pre-defined construction phase.

The joint IAEA/OECD NEA report on “Measuring Employment Generated by the Nuclear Power Sector” [1] provides details on how to allocate input flows to the nuclear sector and draws on examples for different classification systems. It further provides a set of recommendations on how to proceed when allocating investment costs to various definitions of industrial sectors. This manual recommends including considerations laid out in this report into the allocation routine. For example, to avoid potential double-counting, the user is advised to stick to the concept of direct costs and seek additional advice from the National Statistical Office when completing all relevant steps.

In addition, and as part of the sensitivity analysis, the users can make alternative assumptions with respect to sectoral contributions and/or sectoral localization rates. This allows to define a lower and upper range of macroeconomic effects affects associate with an uncertainty regarding the domestic contribution.

#### 4.4.7. Step 4.7: Fuel mix of electricity generation (Sheet: Operation energy (A))

To consider the impacts of additional electric power generation and/or substitution effects in electricity generation further information on the actual electricity generation is needed. The user is asked to provide the data on development of an electricity generation system in form of energy units produced measured by Gigawatt hours (GW·h). The user further needs to define two scenarios: a “Reference Scenario” resembles the reference development of an assumed path (Figure 26) and an “Alternative Scenario” which considers a change in the power generation. EMPOWER includes 9 stylized technologies: wave/tidal, wind, solar, natural gas, coal, oil products, nuclear, hydropower and biomass.

**Reference Scenario**

| Powerplant Technology | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | -- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wave/tidal | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | - |
| Wind | 30,000 | 31,000 | 32,000 | 33,000 | 34,000 | 35,000 | 36,000 | 37,000 | 38,000 | 39,000 | 40,000 | - |
| Solar | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | - |
| Gas | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | - |
| Coal | 4,000 | 3,800 | 3,600 | 3,400 | 3,200 | 3,000 | 2,800 | 2,600 | 2,400 | 2,200 | 2,000 | - |
| Oil products | - | - | - | - | - | - | - | - | - | - | - | - |
| Nuclear | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | - |
| Hydropower | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 | - |
| Biomass | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | - |
| **Total** | **96,400** | **97,200** | **98,000** | **98,800** | **99,600** | **100,400** | **101,200** | **102,000** | **102,800** | **103,600** | **104,400** | **0** |
| Imports | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | - |
| **Supply** | **106,400** | **107,200** | **108,000** | **108,800** | **109,600** | **110,400** | **111,200** | **112,000** | **112,800** | **113,600** | **114,400** | **0** |

*FIG. 26. Input mask of energy mix development (in GW·h).*

A deviation from the reference development path for each technology is represented in the Table “Difference” (Figure 27).

**Difference**

| Powerplant Technology | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | -- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wave/tidal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wind | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Solar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gas | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Coal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Oil products | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nuclear | 8,772 | 8,772 | 8,772 | 8,772 | 8,772 | 8,772 | 8,772 | 8,772 | 8,772 | 8,772 | 8,772 | 0 |
| Hydropower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Biomass | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total, absolute** | **8,772** | **8,772** | **8,772** | **8,772** | **8,772** | **8,772** | **8,772** | **8,772** | **8,772** | **8,772** | **8,772** | **0** |
| Imports | -8,262 | -8,262 | -8,262 | -8,262 | -8,262 | -8,262 | -8,262 | -8,262 | -8,262 | -8,262 | -8,262 | 0 |
| **Supply** | **510** | **510** | **510** | **510** | **510** | **510** | **510** | **510** | **510** | **510** | **510** | **0** |

*FIG. 27. Calculated change in total electric power generation (in GW·h).*

A deviation from the reference scenario includes changes in both domestic output of electricity and net imports of electricity. All excess electricity that is not exported will automatically be allocated to the consumption of private households as presented in table “Usage of excess electricity” (Figure 28).

| | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | -- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Export | 94% | 94% | 94% | 94% | 94% | 94% | 94% | 94% | 94% | 94% | 94% | 100% |
| Households | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 0% |

*FIG. 28. Usage of excess electricity.*

### 4.4.8. Step 4.8: Costs of electricity generation (Sheet: Operation energy (A))

Next, the change in costs of electricity generation needs to be provided with respect to fuel costs, fixed operation costs, variable operation costs, emission permit costs and capital costs for each technology (Figure 29). This implies that changes in costs (in monetary units) need to be provided for each year of the operation phase, each technology and cost category.

Furthermore, affiliated cost changes that are relevant for the electricity supply need to be provided as shown in Figure 29 for interconnection lines, battery systems, electrical boilers and heat pumps.

| Powerplant Technology | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | -- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wave/tidal | - | - | - | - | - | - | - | - | - | - | - | - |
| Wind | - | - | - | - | - | - | - | - | - | - | - | - |
| Solar | - | - | - | - | - | - | - | - | - | - | - | - |
| Gas | - | - | - | - | - | - | - | - | - | - | - | - |
| Coal | - | - | - | - | - | - | - | - | - | - | - | - |
| Oil products | - | - | - | - | - | - | - | - | - | - | - | - |
| Nuclear | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 | - |
| Hydropower | - | - | - | - | - | - | - | - | - | - | - | - |
| Biomass | - | - | - | - | - | - | - | - | - | - | - | - |
| Interconnection lines | - | - | - | - | - | - | - | - | - | - | - | - |
| Batteries | - | - | - | - | - | - | - | - | - | - | - | - |
| Electrical Boilers | - | - | - | - | - | - | - | - | - | - | - | - |
| Heat pumps | - | - | - | - | - | - | - | - | - | - | - | - |
| **Total** | **44** | **44** | **44** | **44** | **44** | **44** | **44** | **44** | **44** | **44** | **44** | **0** |

*FIG. 29. Input mask for change in costs per electricity generation technology and auxiliary technologies.*

If country-specific estimates are not available, the user can rely on Ref. [12] which provides technology specific costs on fuel, capital (investment and financing) and operation per output unit (MW·h). Based on the change in output (GW·h) and the assumptions on generation costs (US $/MW·h), the changes in total costs (US $) can be derived and filled into the cost templates.

### 4.4.9. Step 4.10: Supply costs of electricity generation (Sheet: Operation energy (A))

Finally, the price for traded electricity can be set for the operation period. This defines the potential export revenues if excess electricity is exported. These data are relevant because the price of traded electricity can deviate from the domestic prices (Figure 30).

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reference** | 60 | 61 | 62 | 64 | 65 | 66 | 67 | 68 | 70 | 71 | 72 | - |
| **Counterfactual** | 60 | 61 | 62 | 64 | 65 | 66 | 67 | 68 | 70 | 71 | 72 | - |

*FIG. 30. Cost growth rates of electricity generation inputs and electricity price.*

### 4.4.10. Step 4.10: Allocation of physical fuels to economic sectors (Sheet: Operation costs_structure (A))

In order to calculate changes in the use structure due to changes in the electricity generation mix, the fuels used in domestic power generation need to be allocated to the respective sectors of IOT.

In the Sheet named Operation Costs_Structure(A), the overall focus is put on the disaggregation of Sector 1 which produces electrical power. The first table "Allocate fuels/energy carriers to respective sectors" requires the users to allocate the fuels used in domestic power production to the respective sectors of the EMPOWER structure by using the dropdown menu (Figure 31). For example, based on the structure in the original IOT, the users allocate natural gas to the sector "mining and quarrying". In other words, this sector produces natural gas which is used at a later stage in the power sector. These steps are repeated for all energy carriers — those used in the current and future energy mixes. It is highly advisable to conduct an allocation routine relying on the expertise from the National Statistical Office with respect to the country's sectoral classification. A potential misallocation can be viewed as a source for biased and/or implausible results. Based on this allocation, EMPOWER automatically fills the Table "Fuel costs structure" below.

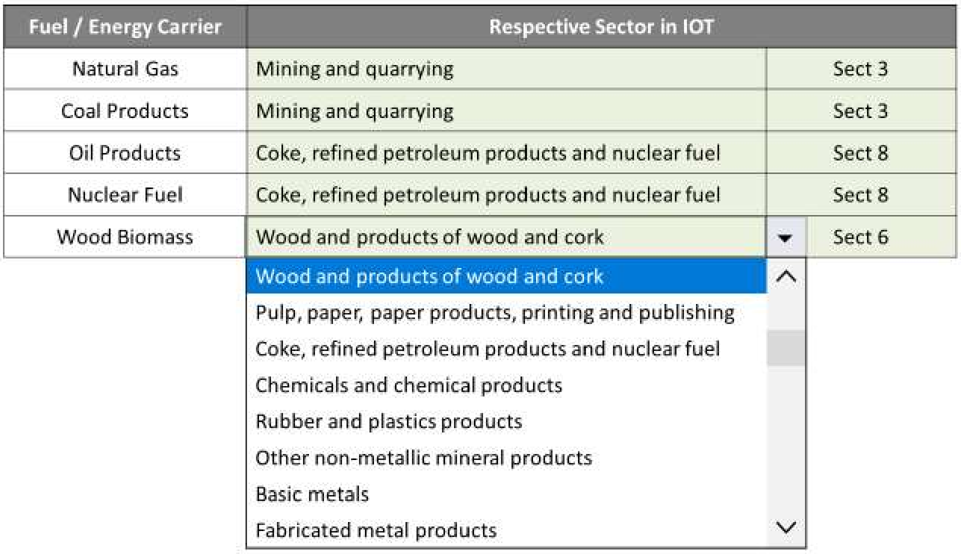



*FIG. 31. Input mask to allocate fuel commodities to sectors in an EMPOWER IOT.*

### 4.4.11. Step 4.6: Disaggregation of operation costs to economic sectors (Sheet: Operation Costs_Structure (A))

In this step, the allocation of operation cost categories, sub-divided as fixed and variable, needs to be provided. This step is analogous to the allocation of investment costs in the Section 4.4.6. The columns in the Table "Fix cost structure" and "Variable cost structure" represents electricity generation and auxiliary technologies. The structure in each column represents shares and needs to sum up to 1.

Given that the operation phase generates value-added, the value-added categories for labour and capital compensation need to be provided. The share of employment costs in fixed operation costs can be set at the row "Value Added — Compensation of Labour".

### 4.4.12. Step 4.12: Include household income parameters (Sheet: Income consumption (B))

Assumptions made as to household income and consumption are important elements of a scenario. Accordingly, growth rates of various components of household incomes need to be postulated, including (1) wages, operating surplus and profits accruing to households, (2) taxes, social security contributions and other transfers paid to or received from the government by households, and (3) other household incomes.

Similar to output growth rates, which are set in Section 4.4.3, the growth rates of household income categories (Figure 32) need to be specified in the Sheet "Income consumption (B)" in relative values (percentage growth). It is recommended to base assumptions in this category on national projections compiled by national ministries and/or authorities and assess for their overall consistency. As a rule of thumb, growth rates for various components of household income need to not deviate too much from an average production growth rate of the economy. The respective cells are marked green; the empty green fields set values to 0. This implies that — based on the example in Figure 32 — transfers received from the government by households will remain constant between the base year and any years for which analysis is conducted.

| Categories | Rates |
| --- | --- |
| Wage (compensation of employees) | 7.1% |
| OperatingSurplusHH | 0.5% |
| ProfitIncome | 7.0% |
| TaxesGovHH | 6.1% |
| SocContGovHH | 2.0% |
| TransfersGovHH | |
| OtherIncomeHH | |
| Gross disposable income | |

| | |
| --- | --- |
| Marginal propensity of consumption | 0.785 |

*FIG. 32. Input mask for disposable income categories growth rates in EMPOWER.*

The user needs to specify the household marginal propensity to consume, i.e., the portion of an additional unit of disposable income spent on consumption. This parameter ties household consumption to household income and is country dependent. For example, a value of 0.7 implies that 70% of additional income is spent on consumption of goods and services, while 30% is saved.

In general terms, it is recommended to set a marginal propensity between 0.6 and 0.9:

— 0.9 corresponds to a Keynesian model where income is important.
— 0.6 Life cycle model with liquidity constraints, where income is only important for poor consumers.

As part of the sensitivity analysis, the users can make alternative assumptions with respect to growth rates of household income and marginal propensity to spend.

### 4.4.13. Step 4.13: Labour market parameters (Sheet: Labour market (C))

As discussed in Section 2.2, EMPOWER provides a more realistic representation of labour market interactions compared to traditional IOMs. The labour market elements of a scenario to be set by the user include the following (Figure 33):

— Annual growth rate of the labour force.
— Productivity growth (determining the relationship between output growth and employment growth).
— Productivity pass-through (defining the link between productivity and the growth of nominal wage rates and thus the operating surplus).
— Wage reaction to the unemployment rate (indicating the competitive state of the labour market).
— Price elasticity of the real export demand for all commodities (showing the response of real demand for exports to changes in prices).

Nominal exports are exogenous and unchanged.

| | |
|---|---|
| Annual growth rate of labour force | 0.70% |
| Productivity / output growth | 0.70 |
| Productivity pass through | 0.75 |
| Wage reaction to employment rate | -0.09 |
| Export price elasticity | -1.0 |

*FIG. 33. Inputs for labour market parameters in EMPOWER.*

The purpose of these parameters is to establish consistency between various assumptions. On the one hand, the user sets a combination of the base years labour force - in file Step 3 - and its growth rate, a yearly pre-defined level for the baseline years is set. To set the respective employment demand, two parameters “Productivity/output” and “Productivity pass through” are used. In Table 4, an illustrative example is summarized. Let us assume that in a specific year the output of a sector “X” grows by 2.0%, then — when using the parameters of Figure 33 — the productivity growth is 70% of that, i.e., 1.4%. This gain in productivity reduces the necessary employment, hence only 0.6% employees are needed. A certain percentage (75%) of the productivity gain is transferred into increased wage rates (wage per output or +1.1%). The increase in wage rate (wage_per_employee) plus the increase in employment define the increase of the “wage sum” which relates to the labour compensation part of value-added in the IOT.

TABLE 4. ILLUSTRATIVE USE OF LABOUR MARKET PARAMETERS IN EMPOWER TO DERIVE GROWTH RATES IN EMPLOYMENT, WAGE RATE AND LABOUR COMPENSATION.

| Parameters | Illustrative calculation |
|---|---|
| Annual growth rate of sectoral output | 2.0% |
| Annual growth rate of sectoral productivity | 1.4% = (2.0 * 0.70) |
| Annual growth rate of sectoral employment | 0.6% = (2.0 – 1.4) |
| Annual growth rate of sectoral wage rate | 1.1% = (1.4 * 0.75) |
| Annual growth rate of sectoral wage sum | 1.7% = 1.1 + 0.6 |

**Labour force growth rate**

The annual growth rate of labour force — is a crucial parameter and needs to be chosen carefully. The user can rely on Ref. [13] for definition of labour supply. In fact, assumptions about future output growth (Section 4.4.3) and labour force growth needs to rely on plausible development pathways. If for a given level of output growth, the labour force growth rate is set too low, then this will result in a negative unemployment rate (labour supply shortage). Based on provided technical parameters on productivity and the pass-through of productivity gains to wages, EMPOWER calculates an approximation of the annual labour demand required to serve a given level of economic development, compares this value with the labour force for a given year and warns the users with an error message, if economy-wide labour demand tends to reach the level of labour supply. Generally speaking, the labour shortage is a growth-damping factor. Therefore, assumptions about future output and labour force growth needs to be aligned.

In the table labelled “User information: Approximation of potential labour demand”, EMPOWER calculates — for any given year over the entire time span covering construction and operation activities — sectoral and economy-wide labour demand based on parameters relating to sector productivity and the pass-through of productivity gains to wages. It further compares these values with economy-wide labour supply for any given year and calculates a respective unemployment rate. Based on this information, EMPOWER produces two types of messages which are located in the upper part of the Sheet: "This growth rate might lead to negative unemployment!” or "This growth rate seems to be sufficient to serve the labour demand!". If the model indicates and warns of a negative unemployment rate (red coloured cells at the bottom of the table), then it is essential to correct for this issue before moving to the next step. Otherwise, the model will stop the iteration process.

**Productivity per output growth**

In Section 4.4.3 the user had to decide on the growth potential of economy by selecting the appropriate sectoral growth rates. Now, the user is asked to decide on the impact on inputs by defining a productivity per output growth rate. This productivity defines the accompanying employment growth for any given production growth. For example, if the production increases by 1% and productivity also increases by 1% then no additional labour is needed. The user needs to determine a parameter that defines the relationship between productivity and output growth which is identical across all sectors. If this parameter takes the value of unity (i.e., 1), employment growth is zero. It therefore determines the relative employment growth. The user is advised to set the parameter based on the relations of historic economy wide growth rates of production ($g^{prod}$) and employment ($g^{emp}$)). The result is expected to be between 0 and 1 and lead to a plausible unemployment rate.

$$Productivity^{\text{output}} = \frac{g^{\text{prod}} g^{\text{emp}}}{g^{\text{prod}}}$$

**Productivity pass-through**

A related though a distinct parameter is the productivity pass-through rate which determines how productivity growth is translated into an increase of wages. The productivity pass-through is an economy-wide parameter and it can take the values between 0 and 1. If the parameter takes the value 1, this implies that 100% of the sectors productivity gain is translated into increasing wages. The user is advised to set the parameter based on the relations of historic economy-wide growth rates of production ($g^{prod}$), employment ($g^{emp}$), labour compensation ($g^{wages}$) and productivity per output.

$$Productivity^{\text{throughput}} = \frac{g^{\text{wages}} - g^{\text{emp}}}{g^{\text{prod}}\, Productivity^{\text{output}}}$$

It needs to be noted that value-added is a constant share in production, an increase in wages (which are a part of value-added) leads consequently to a lower share of capital compensation (e.g., operating surplus) in the baseline scenario. In this sense the parameter represents the bargaining power of the employees.

**Wage reaction to employment rate**

The wage reaction to employment rate is represented as $\beta_{ur}$ in Eq. (4) in **Error! Reference source not found.** and directly influences the industry wage rate **w**. The range for the wage reaction to the unemployment rate is between -0.05 and -0.09 for different groups of European countries. The more competitive the labour market is, the higher this parameter is. A high value (e.g., -0.09) implies that wages react strongly to changes in unemployment rate. Here, if unemployment increases, wages decrease due to the increasing oversupply and competitive wage bargaining. If $\beta_{ur}$ is low (e.g., -0.05) this implies that the labour market is less competitive, and wages are resilient. When the parameter is set to 0, this would resemble a non-competitive market with fixed wages — the wage will not decrease given changes in unemployment levels.

**Export price elasticity**

The price elasticity expresses the demand change for export commodities (in real terms), if domestic production prices increase. This parameter is used for each export commodity uniformly. A value of -0.6 for instance would imply that real exports of a specific sector product decrease by 0.4%, if the domestic prices of this product increase by 1%. It needs to be noted, that the nominal export is exogenously set in the baseline and is not affected by this parameter. Nevertheless, exports in real terms as well as the respective production in real terms is affected and can lead to changes in employment.

A value of -1 for export demand can be seen (in the light of the literature on Armington elasticities) as the lower value for analysis. This price elasticity applies to all commodity categories of export demand. Small, exposed countries might have values up to -2.

### 4.4.14. Step 4.14: Set financing parameters (Sheet: Financing (D))

As mentioned in section 3.4, EMPOWER allows the analysis of the impacts of different financing options for a new nuclear power plant. The user needs to specify the financing mechanism, its source and duration. Four options and (their combinations) are possible (in % as shown in the Figure 34):

- External financing describes a case where external financing is available without any repayment liabilities — in a standard input-output framework this is equivalent to a positive external demand shock. If 100% of the overall investment is financed by this option, the results of submodule ABCD will be identical to those of submodule ABC.
- Ex-ante revenue, income tax describes a partial revenue-neutral public financing mechanism implemented by adjusting the households' tax rate in an ex-ante revenue-neutral manner. In the EMPOWER framework, this financing option becomes available only during a construction phase and is restricted to a specific year's investment volume. For example, if in the first year of construction 100 million US $ need to be invested, then exactly this amount will be generated via an increase of the households' income taxes in this year.
- Ex-ante revenue, transfer cut is similar to the ex-ante revenue, income tax case, but the mechanism decreases transfers to households rather than increases taxes.
- Ex-post markup on electricity price describes a case where the investment is financed by an ex-post increase of the electricity price (via a mark-up) starting in the first year of the operation phase and lasting for a given time span (last parameter in the Figure 34). For example, if 100 million US $ are to be financed over 20 years, then a mark-up will

be calculated and added to the electricity price to generate 5 million US $ for each year over this time period.

| Source of financing | |
|---|---|
| External financing | 50% |
| Ex-ante revenue, income tax | 25% |
| Ex-ante revenue, transfer cut | 0% |
| Ex-post Markup on Electricity price | 25% |
| Years of financial Operation | 20 |

*FIG. 34. Deciding upon financing mechanisms.*

If sensitivity analysis is performed, the user can choose to start with 100% external financing which implies in the EMPOWER setting that no economic feedback due to an internal financing is considered (the results will replicate those of submodule ABC). Subsequently, the user can select various financing options to test the sensitivity of the macroeconomic results. If for example one of the ex-ante financing options is set to 100%, then it is likely to obtain more pronounced economic feedback in comparison to an ex-post option. This occurs because 100% of an annual investment volume will be financed by households during the construction phase. Given that overall investment volume, in case of a 100% reliance on ex-post financing, will be spread over a longer period (for example for over 20 years of operation as shown in the Figure 34), the economic impact is expected to be smaller than in the ex-ante financing case. As indicated above, EMPOWER allows combining various options to the extent that the financing of the overall investment can be spread over the entire construction and operation phases.

## 4.5. FILE 5: MASTERFILE

The Masterfile (Step 5) will assess macroeconomic and sectoral impacts associated with changes in the electricity generation system. Changes in construction and operation are simulated separately. This Section will guide the users through the file "EMPOWER_STEP5_MASTERFILE.xlsm" — the central piece of the EMPOWER model — which loads data and scenario specification, calculates and — as a final sub-step — exports the results to an output file which can be loaded by the visualization file.

### 4.5.1. Step 5.1: Load data and scenarios (Sheet: SetUp)

In the SetUp Sheet the prepared data and scenarios can be loaded by clicking the load buttons as indicated in Figure 35 and choosing the respective files. The user needs to click the button "Load country data" to load the country-specific data (Step 3) and "Load scenarios" to integrate the constructed scenarios (Step 4). To confirm, that the correct data is loaded, the key information such as country name, demand side[5] and supply side[6] GDP, time span for construction and operation phases, costs, activated sub- modules together with some other indicators are reported. If certain submodules are not activated, they will be marked grey.

[5] Demand side GDP is the calculation of GDP by demand categories as Consumption (C), Investments (I), Exports (X) and Imports (M), GDP = C+I+X-M

[6] Supply side GDP is the calculation of GDP on the production side comprising value-added (VA) and Taxes less Subsidies (TLS) GDP = VA + TLS

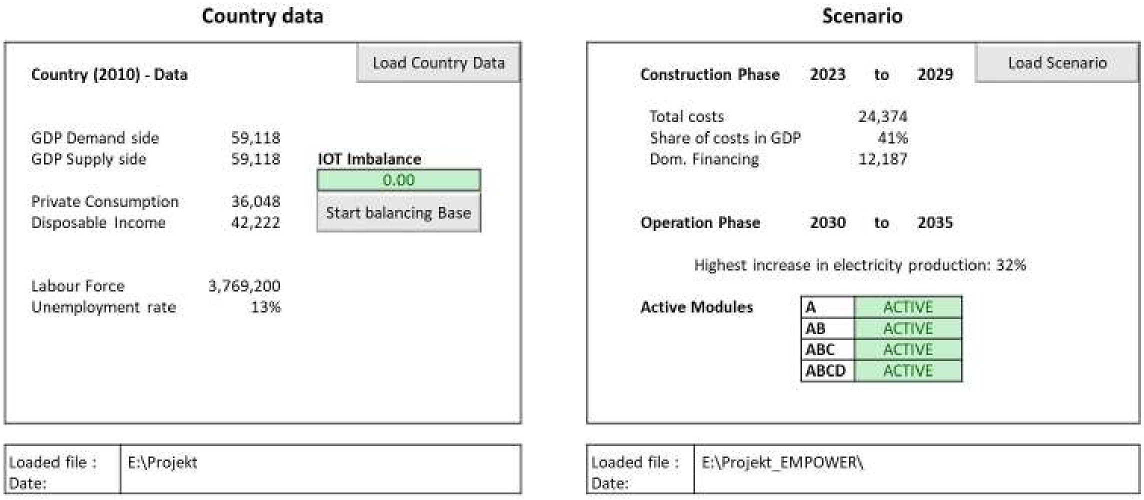



*FIG. 35. Data and scenario controls in the Masterfile.*

### 4.5.2. Step 5.2: Balance IOT (Sheet: SetUp)

The country data window (Figure 35) in the Sheet SetUp reports the calculated imbalances of the IOT. The Masterfile evaluates to what extent the total sum of each sector's row in the base year's IOT corresponds to the sum of the respective sector's column. If each row's sum is equal to the respective column, then the IOT is said to be balanced because all the goods produced are either used for intermediate production, consumed, exported, invested or put into the inventory. The value in the "IOT Imbalance" will be equal to 0.00 indicating that the user can continue with the analysis.

The IOT is said to be imbalanced, if inconsistencies are found, and the sum of rows does not correspond to the sum of columns. The value in the "IOT Imbalance" field will show an absolute sum of the imbalances in monetary units (Figure 36). An initial imbalance can indicate that not all produced outputs are consumed, and a discrepancy occur. It is also possible that due to rounding errors, statistical problems or missing data the IOT's row sums are not identical to the IOT's column sums. When an unbalanced IOT is projected into the future by growth rates (defined in file step 4), then this discrepancy will increase and potentially bias the simulation results.

As a rule of thumb, the user can apply the built-in balancing routine for relatively small deviations by clicking on the "Start balancing base" button. This routine relies on the RAS method, a ranking and scaling data reconciliation method. This procedure will adjust the base year's IOT in the Masterfile only. It is essential to seek advice from a National Statistical Office, if deviations are relatively large which can have different reasons and needs to be sorted out before moving to the next step.


*FIG. 36. IOT imbalance in the Country data window.*

### 4.5.3. Step 5.3: Handle control panels (Sheets: Ctrl CON and Ctrl OPR)

The control panel Sheets ("Ctrl CON" and "Ctrl OPR") activate scenarios A, AB, ABC and ABCD for construction and operation, respectively. Both control panels have an identical structure and layout. Country name, base and active years appear in the upper part of the control panel (Figure 37). The base year is the year for which IOT is available; the active year is the year for which the current simulation is conducted. In case of an incorrect behaviour (#NA values or oscillations), the model can be reset by clicking "Reset to base year". This button allows setting calculations back start and enables checking initial values for issues such as imbalances and/or empty (zero) values.

| | |
|---|---|
| Country name | Country |
| Base Year | 2010 |
| Active Year | 2029 |
| | Reset to Base year |

*FIG. 37. Country, base and active years' specification in the control panel.*

When the user starts model runs, dynamic updates on the convergence towards an equilibrium appear in the lower part of the control panel. During the simulation process, several cells provide information of the status (Figure 38). A simulation can take a few moments as the model runs a complex routine consisting of a RAS mechanism and individual loops for every single year of the specified period.

The "First selected result" is an indicator that represents the main results of simulations; they are located in the central part of the control panel. As a default, EMPOWER displays changes in nominal GDP, i.e., GDP in current prices, relative to the baseline values. The "Model status" and "RAS activity" are updated throughout a simulation run; they indicate what operation is being performed and what is achieved.

| | |
|---|---|
| First selected result: | **GDP, nominal** |
| Model Status | **Saved** |
| RAS Activity | **RAS Converged** |
| Production – Loop | 6.5096E-06 |
| Labour Market – Loop | 0 |
| Price Response – Loop | 0 |
| Unemployment rate | **13.004%** |
| Loop dampener | **20%** |

*FIG. 38. Information box on the model status, loops and "loop dampener".*

Table 5 gives an overview of messages shown in the "Model status" and "RAS activity" cells to describe different simulation stages. EMPOWER starts by generating an IOT of an active year; the model status is indicated as "RAS year" and the "RAS activity" is set to "RAS calculating" during this process. When a balanced IOT for a given year in the future is generated, the "RAS activity" is completed with the message "RAS Converged".

In cases, where EMPOWER is not successful in constructing a balanced IOT that matches the pre-defined sectors, the convergence based on a standard RAS method cannot be achieved. EMPOWER then automatically activates a ‘reduced’ logarithm — referred to as RAS Agg — which aggregates domestic and imported part of an IOT and runs the RAS method on those aggregates. If this procedure leads to a balanced IOT, then EMPOWER subsequently disaggregates the IOT by fixed import shares into two — domestic and imported — matrices, and the message “RASagg converged” appears. Otherwise, if convergence is not successful, the message “RAS failed” is displayed.

TABLE 5. MESSAGES OF “MODEL STATUS” AND “RAS ACTIVITY” TOGETHER WITH A SHORT INTERPRETATION.

| Model status messages | RAS activity messages |
|---|---|
| RAS year | RAS calculating |
| This message appears when EMPOWER calculates an IOT for a respective year using the RAS method. During this process, the “RAS activity” is set to “RAS calculating”; | This message appears when the RAS method starts generating a IOT for the active year based on the provided sectoral growth data; |
| Looping | RAS converged |
| This message appears shortly after the iteration process starts; | This message appears when the RAS method completes generating a IOT for the active year based on the provided sectoral growth data; |
| Loop 1, Loop 2, Loop 3 | RASAgg calculating |
| EMPOWER indicates what loop is being processed; in case of a non-convergence, a long appearance of a respective loop will indicate in which loop a problem occurred leading to non-solution; | This message appears when the standard RAS method is not successful in achieving a convergence. Then EMPOWER applies a reduced RAS method built on aggregates. |
| Saved | RASagg converged |
| The solutions are “Saved” when EMPOWER finds an equilibrium in all three loops reaching a global solution. Each last solution of each submodule is stored and ready to be exported into a separate file. | This message appears if a ‘reduced’ algorithm (RAS Agg) is successful in achieving a convergence; |
| | RAS failed |

| | |
|---|---|
| | The message appears, if EMPOWER cannot generate a balanced IOT; the process is failed. |

There are a number of reasons why a RAS process could fail. For example, a base year IOT can comprise too many empty sectors with zero values. In that case it might be helpful to aggregate some of those sectors, thereby reducing the number of sectors with zero values. Another reason can be linked to inconsistencies in parameter values as defined in the file Step 4. For example, sectoral growth rates might be too heterogenous and/or income growth rates drive apart from assumed production growth rates. Another reason could be that some labour market parameters are set in a way that causes divergences. An ad-hoc solution could be to apply more homogenous growth rates and/or average parameters as suggested in this manual. If this simplified procedure leads to a working simulation, then the previous settings (growth rates and parameters) could be re-introduced on a one-by-one basis to localize the problem. The user is advised to seek advice from the relevant National Statistical Office before moving ahead.

The next step of the procedure is initiated when the "Model status" automatically switches to the "Looping" message. Based on assumptions for construction and operation of a new energy technology, the scenario inputs are used to initiate a shift in commodity and/or labour markets and the price system. The "Model status" shows "Loop 1", "Loop 2" or "Loop 3" depending on which iteration process is active. In the production loop, EMPOWER searches for a solution at which the commodity market is cleared (all demanded commodities are produced). The labour market loop iterates until the demand of labour is equal to employment. The price loop adjusts prices until the output price is equal to the unit price of sector's inputs.

During the convergence process towards an equilibrium, i.e., finding local (in each loop) and global solutions, the respective looping cells alter in colours red, yellow and green, while remaining red coloured, if equilibrium is not found. The green-marked cells indicate that the solution is found. If this is the case, the loop values representing actual imbalances of the equations will be 0 or slightly larger than 0 (Figure 38). The tolerance ranges are set at 0.00001 to guarantee high precision and the existence of a unique solution[7].

The tolerance ranges of each loop can be changed by experienced users only in the Sheet "Calc". Thereby, 0.00001 refers to monetary units (production loop); 0,00001 to employment units (labour market loop) and 0.00001 units of price level (price response).

The "Unemployment rate" cell helps identifying potential oscillations at the labour market. These oscillations lead to ever increasing positive and negative changes in the unemployment rates until negative unemployment is calculated, and the model stops. If such a case is identified, then a decrease of the iteration step size[8] can be set with the "Loop dampener" in the cell below. By lowering the value, the step sizes decrease and oscillations might be erased. But a lowering

[7] Even though a unique solution cannot be guaranteed, there is no case known to the authors where different solutions are calculated using the same inputs.

[8] This "step size" refers to the magnitude of adaption that is processed in each iteration of the model. If step size is 100% then, 100% of an imbalance (in labour market) is corrected by one step. If the step size is set to 50%, only 50% of the imbalance is corrected. In both cases the imbalance will be below the convergence criteria but takes more steps in the second case.

also increases calculation times of simulations. If the dampener is increased this can decrease calculation time but can lead to oscillations in some cases.

If an equilibrium is not found, the cells remain red-coloured, and the user is required to localize the source of the problem. The user can test various hypothesizes by starting with a simplified scenario (the file Step 4) and setting inputs to some basic levels. For example, this might imply small homogenous sectoral growth rates; no or small construction costs; no or small changes in electricity generation; homogenous income growth rates (similar to sectoral growth rates); the default values for labour market parameters and export elasticities; and 100% external financing. This simplified scenario needs to be loaded in the Masterfile and the model run. If no equilibrium is found, then the source of problems is likely to lie in the IOT's structure and/or its auxiliary data in the data file (file Step 3). A thorough check or simplification of this data is recommended. If an equilibrium is found with a simplified scenario, then the user can re-introduce the previous setting on a one-by-one basis until the problem occurs and make an adjustment. For this final step no general rule can be defined, as an individual solution might be needed.

### 4.5.4. Step 5.4: Run scenarios (Sheet: Ctrl CON and Ctrl OPR)

Before starting the simulations, the user is advised to remove previous results by using the "Clear all" button at the centre of the control panel. This is not obligatory but helps to have an overview of which scenarios have been executed and which not. By using the "Clear" buttons above the submodules, the results can be cleared separately.

The scenario simulation of the reference scenario (BASE) and each submodule can be activated by clicking on the "Run" button — in Figure 39, those buttons are "Run BASE" and "Run A", respectively. It is not obligatory but advised to "Run BASE" first because the results of other submodules are represented in the panel as differences to this reference. Hence, without a reference (BASE) no result will be shown. Otherwise, the submodules work independently. The order in which the simulation runs of the submodules are executed is irrelevant and has no impact on the final results. As soon as "Run" button is activated for BASE and submodules A, AB, ABC and ABCD, EMPOWER performs a complex routine on an annual basis and informs the user on the convergence status:

- As indicated in Section 4.5.3, EMPOWER starts by generating an IOT of the single active year (via the RAS mechanism) and produces the message "RAS Converged" in the "RAS activity" when a balanced IOT has been generated. While it is calculating, it produces the message "RAS Calculating". The produced IOT is the reference IOT without a shock.
- Next, EMPOWER introduces a new activity into the existing equilibrium such as construction activities or operation of a newly added energy technology which changes the country's electricity mix.
- Then, EMPOWER runs three loops (production, labour market and price loops) consecutively in this order until a convergence towards an equilibrium is achieved. This is indicated in the cells of Figure 35 where the imbalances of the loops become 0 or small. The "Model Status" cell shows which loop is currently active by presenting "Loop 1" (Production), "Loop 2" (Labour Market) or "Loop 3" (Price response).
- Finally, EMPOWER writes a message "Saved" as the Model Status for a given year, stores results and starts the same routine for the following year.

Once the converge is done, the message “Simulation finished” appears. The user can move to the next submodule.

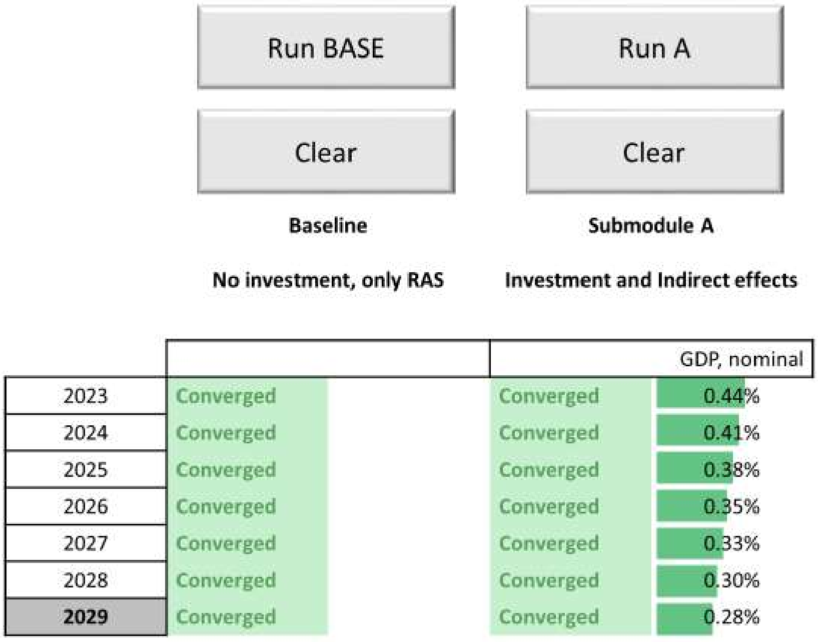



*FIG. 39. Buttons to start submodules and clear result, illustrative representation for baseline and submodule A only.*

Below the “Run” and “Clear” buttons additional information is provided. The messages “Converged” indicate that the RAS method for this year was successful. If convergence is not achieved the message of the respective year displays “Imbalance” instead. This does not stop the further procedure and the model proceeds to the next step with an unbalanced IOT. Below the “Run” button of the submodules the deviation of the simulation results from the baseline are presented. In Figure 39, differences are in nominal GDP (i.e., at current prices).

In cases where submodules are inactive (due to settings in the data file), the respective submodule areas in the control panel appears grey and the submodule cannot be run.

### 4.5.5. Step 5.5: Aggregated results (Sheet: Ctrl CON & Ctrl OPR)

The results in the panel and below are shown as differences to the reference scenario “BASE”, the “baseline”. These differences can be reported in absolute monetary terms and relative terms (percentages). The user can choose between these two options which are located on the left-hand side of the control panel as in Figure 40 before or after[9] starting the model runs. If the user selects “Absolute differences”, then results are immediately displayed in the monetary units of the IOT (e.g., in million Euro or 1000 US $). Otherwise, if the user selects “Relative differences”, then the results appear as percentage values on the bar to the right the “Converged” message (Figure 39). In the panel the results are represented as a deviation from the “BASE” scenario for a particular set variable. Figure 39 draws on the example in which GDP in nominal values increases in 2023 by 0.44% relative to the baseline of the same year.

[9] During EMPOWER simulation runs the Excel environment is working to full capacity and is not able to process further inputs

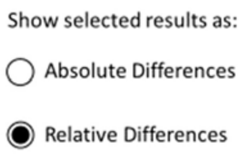



*FIG. 40. Options to report the results in the control sheet.*

While EMPOWER uses GDP in nominal values as a default setting in Figure 39, the user can alter this by choosing an alternative from the dropdown menu (Figure 41). Then, convergence message and results in Figure 39 will be reported for this alternative.

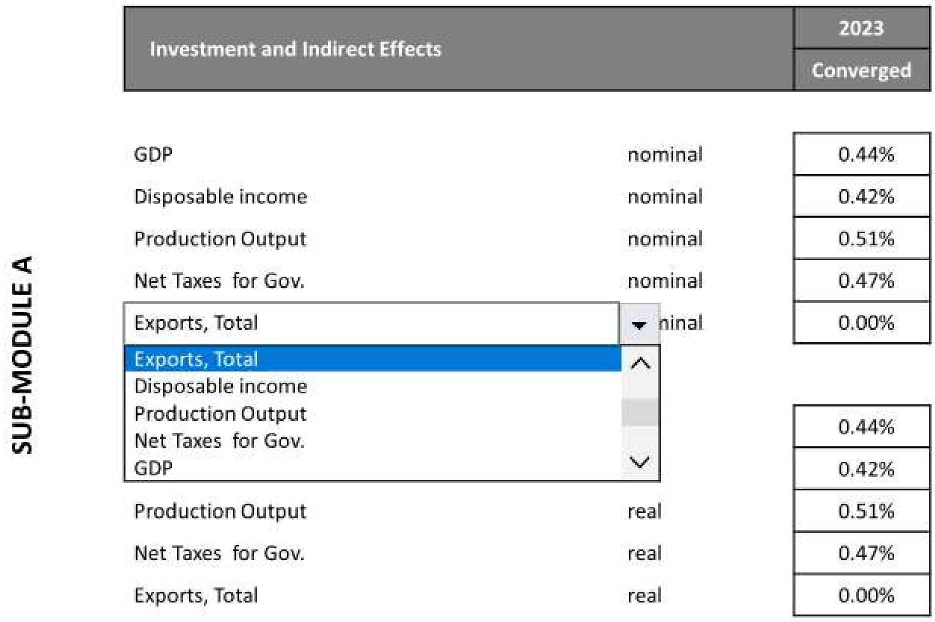



*FIG. 41. Choose displayed variable.*

Below the Controls, five selected indicators are displayed for each year in nominal and real values (Figure 42). However, only nominal values are displayed in the baseline scenario, while variables in nominal and/or real values can be chosen in the submodules. Further, in submodules A and AB of the construction phase, nominal and real values will be equivalent, as price effects are not captured there. In all other submodules, there will be a difference between nominal and real values due to price effects.

**BASELINE**

| No Investment, only RAS | 2023 |
|---|---|
| | Converged |
| | RAS Converge |
| GDP | 152,689 |
| Disposable income | 103,807 |
| Production Output | 298,866 |
| of which imported | 52,964 |
| Exports, Total | 80,558 |

Exports, Total
Production Output
of which domestic
of which imported
Value Added

**SUB-MODULE A**

| Investment and Indirect Effects | | 2023 |
|---|---|---|
| | | Converged |
| GDP | nominal | 0.44% |
| Disposable income | nominal | 0.42% |
| Production Output | nominal | 0.51% |
| Net Taxes for Gov. | nominal | 0.47% |
| Exports, Total | nominal | 0.00% |
| GDP | real | 0.44% |
| Disposable income | real | 0.42% |
| Production Output | real | 0.51% |
| Net Taxes for Gov. | real | -98.89% |
| Exports, Total | real | 0.00% |

*FIG. 42. Selected results.*

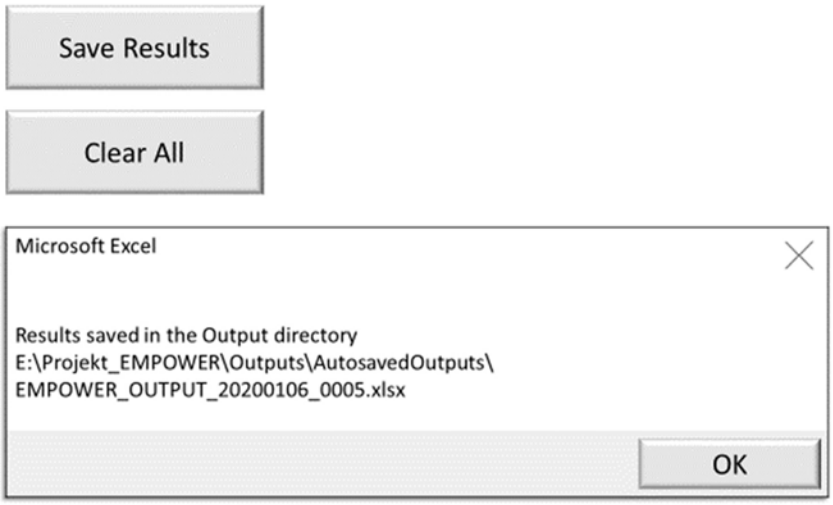


*FIG. 43. Saving and erasing results.*

When simulation runs of the operation and construction phase are finished the results of each submodule's last run are saved locally in EMPOWER Masterfile. These locally saved results comprise additional information as, for instance, the sectoral results. These results can be exported into a separate file. By clicking "Save results" (Figure 43) a folder (in the same directory as the Masterfile) will be automatically generated and will contain an output file with a time stamp. In this file all results from construction an operation phases are saved. This file can be loaded to the file Step 6 to visualize the results. "Clear All" on the other hand erases all local results.

## 4.6. FILE 6: VISUALIZATION

The file "**EMPOWER_RESULTS_VISUALIZATION.xlsm**" is designed to load and display simulation results in an easy and transparent way. Contrary to all preceding files, the use of visualization file is optional.

### 4.6.1. Step 6.1: Load results (Sheet: Description)

By clicking the Button "Load results" (Figure 44) in the Description Sheet a result file can be selected and loaded. These result files can be created when using "Export results" automatically generated by the EMPOWER Masterfile (Figure 43) can be loaded. "Clear Results" empties the respective cells.

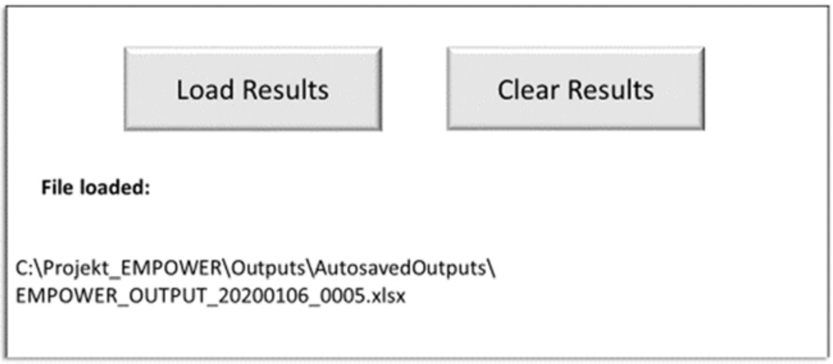



*FIG. 44. Button to load results into visualization file.*

### 4.6.2. Step 6.2: Visualize key macroeconomic variables (Sheet: Graphs CON1 / Graphs OPR1)

In this Sheet, five graphs are automatically generated to display the results of main variables. In total, 17 variables are available for visualization (relative to the reference scenario) but only five are shown in a default setting (see Table 6). The user needs to use a dropdown menu by clicking orange fields in the area below the graphs to change the default visualization options:

TABLE 6. SUMMARY OF DATA VISUALIZATION VARIABLES.

| # | Variable | Description |
|---|---|---|
| 1 | GDP (default) | Gross domestic product; |

| | | |
|---|---|---|
| 2 | Disposable income (default) | Disposable income of households; |
| 3 | Net taxes for gov. (default) | Net taxes for government; |
| 4 | Production output (default) | Economy-wide production value; |
| 5 | Employment (default) | Employment; |
| 6 | Public net saving | Public net saving (income less expenditures); |
| 7 | Imports, total | Economy-wide imports; |
| 8 | Intermediate inputs | Inputs in production; |
| 9 | Value added | Sectoral generated value-added; |
| 10 | Taxes less subsidies (intermediary) | Net taxes on products; |
| 11 | Final demand, total | Sum of consumption, investment and exports; |
| 12 | Private consumption, total | Consumption of private households; |
| 13 | Public consumption, total | Public consumption; |
| 14 | Gross fixed capital formation, total | Investments; |
| 15 | Exports, total | Total exports; |
| 16 | New investment, total | Scenarios construction costs for power plants; |
| 17 | Unemployment rate, total | Unemployment rate (percent points). |

In addition, the user has an option to make use of an additional graph to represent a multiplying effect of construction and operation activities. Broadly speaking, a multiplier in an input-output analysis compares initial demand shock with an overall impact on some redefined variables. EMPOWER calculates GDP multipliers only for both construction and operation phases. In principle, it allows comparing multipliers for different electricity generating technologies. During the construction phase, the overall impact on GDP is set in relation to total investments levels. During the operation phase, the overall impact on GDP is set relative to changes in produced electricity units. Thereby, the latter is only applicable for scenarios when electricity generation is extended. In other cases — when an electricity mix is changed but not the overall electricity production levels — this indicator cannot be used in a meaningful way. Two factors are likely to affect the magnitude of a multiplier the most: the sectoral cost structure of the investment and the localization rate.

Lastly, the user has an option to display the results as an absolute (in monetary units) and a relative (in %) deviation from the reference scenario as well as in nominal and real terms (Figure 46). The non-monetary variables (for example employment) are always represented as real values.

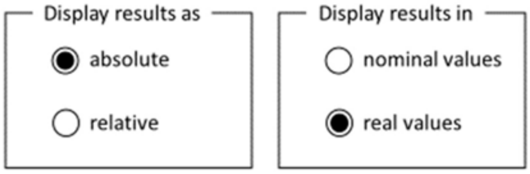



*FIG. 45. Options to visualize the results.*

#### 4.6.3. Step 6.3: Visualize sectoral results (Sheets: Sector CON / Sector OP)

Sectoral results are available for sectoral output and employment only. The user can select results to be shown in absolute and relative terms (Figure 46). It needs to be noted that both terms might give a different picture of the impact in each sector because the size of sectors and the total economy changes over time. An identical absolute impact can change over time in relative terms because the reference base has changed.

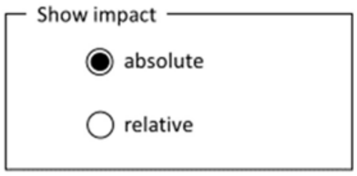



*FIG. 46. Options to visualise sectoral results.*

#### 4.6.4. Step 6.4: Identify sectors with strongest impacts (Sheet: Graphs CON2 / Graphs OP2)

To simplify the visualization of sectoral implications, both Sheets name 5 sectors each with highest positive and strongest negative impacts during the construction and operation phases. In Figure 47, the sectors are ranked based on the employment effects as measured in absolute values. In principle, adverse impacts at the sectoral level can occur due to the specification of financing options such as a tax increase, transfer cuts or markups because the consumption of private households will be affected.

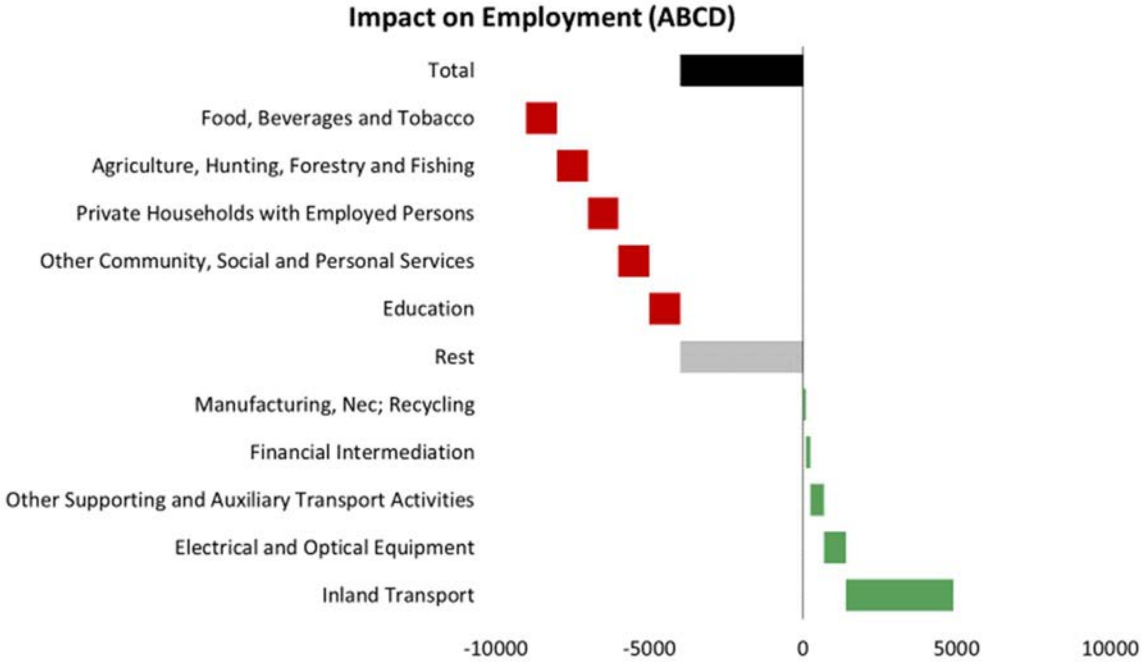



*FIG. 47. Illustrative representation of sectors with highest positive and negative impacts.*

The black bar in the Figure 47 displays an overall economy-wide impact on employment, consisting of both positive and negative implications. Red bars indicate the highest sectoral employment losses, while green bars indicate the strongest sectoral employment gains. The grey bar represents the sum (positive and negative) of impacts in all other sectors. As a default, an “average” over the whole 12 years period is displayed, but the user can change the setting to an annual sectoral impact via a dropdown menu located in cell B38.

Detailed sectoral impacts are presented in the Sheets “Sector OP” and “Sector CON”. The black-coloured Sheet named “AdminCalc” comprise a side-calculation for a case if less than 35 sectors are defined for a given list of selectable variables. “AdminTut” contains texts and defines a position of the tutorial steps. Two last Sheets need to be used by experienced modellers only and are frozen in a default setting.

## 4.7. ADDITIONAL FILE 7: STEP1B IMPORT MATRIX GENERATION

As outlined in Section 4.3, EMPOWER uses an IOT as primary input. The very basic variant of an IOT consist of three matrices [11] — as displayed in Figure 48 — which can be viewed as an aggregated version of the structures represented in Figure 5.

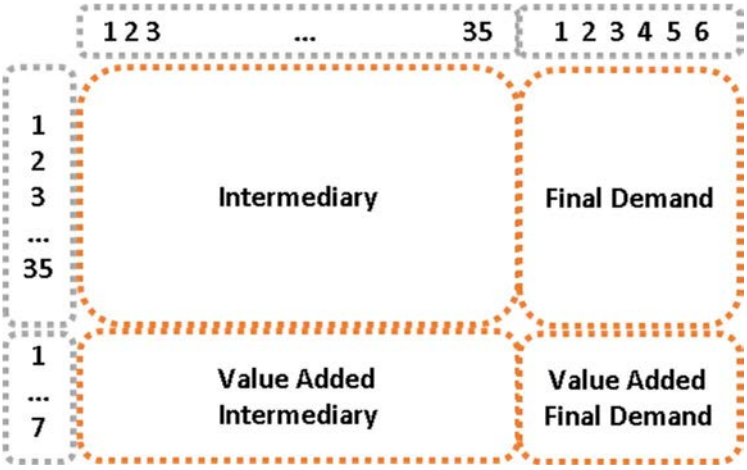


*FIG. 48. Structure of an IOT without details on imports.*

Similar to Figure 5, the central piece is the intermediary matrix, a symmetric matrix (dimension: sector × sector) which represents sectors' inputs (columns) and usage of sector's outputs (rows). Thereby, outputs can be used either as intermediary input by all sectors and/or consumed by final demand. The final demand matrix (dimension: sector × final demand category) depicts how parts of production which are not used as intermediary inputs are consumed by private households, government, investment activities, inventory changes and demand from abroad as exports (see UN, 2008). To produce a sector's output not only intermediary inputs are needed but also other inputs as wages, taxes and profits. These are part of the third matrix, the value-added matrix (dimension: value-added category × sector). A condition of a balanced IOT is that the sum of each sectors input (column of sector) needs to be equal to the sum of the sectors output (rows).

Thereby, the magnitude of economic impacts due to construction or operation activities crucially depends on the import structure of the economy. This can be considered as a relevant information for EMPOWER and needs to be included. In some cases, however, the IOT is not available in this exact necessary structure, with imports being singled out as in Figure 5. The user is then advised to seek further advice from the National Statistical Office. In addition, and as a potential remedy, the file labelled "EMPOWER_STEP1b_IMPORTMATRIX.xlsm" has been created to account for two possible deviations from the structure in Figure 5.

- First, when the intermediary and final demand structure captures domestically produced goods and services, while imports are integrated in an aggregated manner as an additional row (left hand side in Figure 49).

- Second, when the intermediary and final demand includes imports and imports are reported as an extra row or column (right in Figure 49).

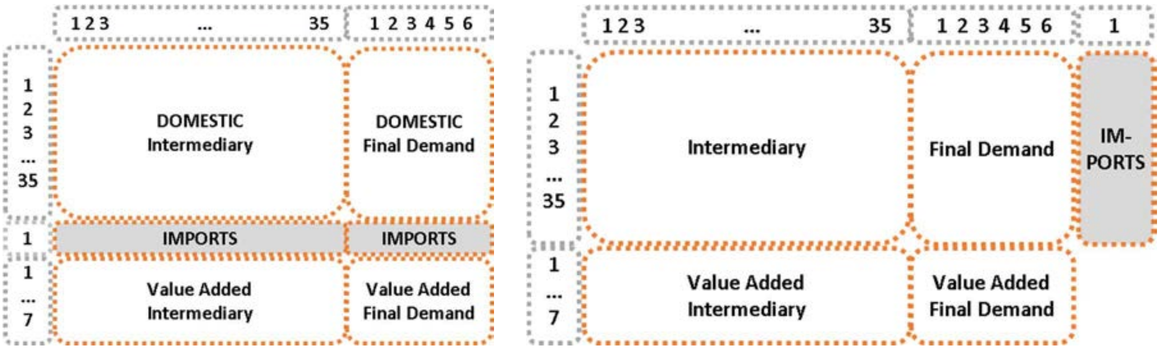



*FIG. 49. Possible deviations in national IOT in comparison to the EMPOWER structures.*

In the file “EMPOWER_STEP1b_IMPORTMATRIX.xlsm”, original matrices as represented in the Figure 49, are inserted, while the included formulas automatically construct the missing import matrices in the exact structure that is needed for File Step2. For simplicity, the formulas in this file apply an allocation of imports based on uniform import rates.

For the first case (left in Figure 49) — which is common in an IOT relying on an ‘activity by activity’ representation in which the inputs in production and final demand are domestically produced, while imports are captured as a separate row vector — the share of imports for each sector is known. The remedy is to apply the given import share to all inputs of a particular sector; this implies that imported inputs are distributed exactly the way as the domestic inputs.

For the second case (right in Figure 49) — which is common in an IOT relying on a ‘commodity by commodity’ representation — less information is available; in particular, the structure in Figure 49 (right) does not allow identifying the import structure at the sectoral level. The approach to generate the import matrix for EMPOWER is to apply a fixed import share (based on imports and total inputs) to both intermediary and final demand.

The procedure in the File Step1b starts by selecting the respective case as represented in Figure 47 with a radio button (Figure 50). The selection defines the allocation variant to be applied. Then, original matrices for intermediary, final demand, value-added and imports need to be inserted in the respective Sheets. The final step in the Sheet “Start” is to initiate the import allocation by clicking the “Start import allocation” button in the “Start” Sheet (Figure 51).


*FIG. 50. Selection of the data case for import matrix generation.*


*FIG. 51. Start button to generate import matrices.*

The results are analogous to the matrices in the file Step2 and can be used from the blue output Sheets (IM_Dom, IM_Imp, FD_Dom, FD_Imp).

# 5. ILLUSTRATIVE CASE STUDIES

This Section presents two illustrative case studies by applying a modelling routine described in the previous Sections. Both case studies investigate economy-wide and sectoral impacts associated with construction and operation of a new nuclear power plant. The first case study labelled as NUC assumes that an overall energy planning strategy consists of a decision to build a nuclear power plant. The second case study — labelled as ENE — takes a more compressive approach by assuming that upfront a policymaker considers investments in various energy options. The user first applies the IAEA energy planning model MESSAGE to assess to what extent a nuclear power investment will constitute an addition to the future energy mix and define alternatives. The user then applies EMPOWER to conduct an economic analysis on those options. To this end, both case studies are not comparable, they rather represent two ways in which EMPOWER can be used. The first case study is a mere demonstration of a standard approach in an input-output modelling framework — such as EMPOWER — based on the *ceteris paribus* principle [5]. The second case study can be viewed as an example of linking an energy model assessment with a macroeconomic tool in a coherent and consistent way.

Both case studies detail all necessary steps of the modelling routine as described above such as data compilation, execution of model runs and interpretation of results. Both case studies rely on fictious information. For demonstration purposes, the user will be guided through the assessment of construction and operation phases which can last for up to 12 years each (Section 3.3). As described in Section 3.2, each submodule in EMPOWER adds an economic feedback mechanism by building on an additional set of data. The submodule ABCD can be characterized by the highest degree of macroeconomic completeness in the EMPOWER framework and will require the largest amount of data. Given potential data constraints faced by the user, the application of submodules AB, ABC and ABCD is considered optional, though highly recommended. For completeness purposes, the user will be led through an assessment with submodules up to the level ABCD.

TABLE 7 . BRIEF OVERVIEW OF SUBMODULES AND DATA NEEDS IN EMPOWER.

| | Analysed Impacts | | | |
|---|---|---|---|---|
| | Submodule | | | |
| Phase | A | AB | ABC | ABCD |
| Construction | Construction activities and indirect effects along the supply chain | + Induced (additional) household consumption due to a new source of income | + Adjustments on a labour market; adjustments in sectoral production (prices and volumes | + Income tax increase and/or a governmental transfer cut to finance (parts of) investment costs |
| Operation | Operation activities and indirect effects along the supply chain, adjustments in sectoral production (prices and volumes) | + Induced (additional) household consumption due to a new source of income | + Adjustments on a labour market; further adjustments in sectoral production (prices and volumes) | + Electricity price markup to finance (parts of) investment costs |
| | **Data requirements** | | | |
| | Submodule | | | |
| Phase | A | AB | ABC | ABCD |
| Construction | IOT in EMPOWER resolution and investment cost structure | Data on disposable income of private households, including sectoral (aggreged) wages | + Labour market data, including sectoral employment | + Share of investment costs to be financed through one of the mechanisms |
| Operation | IOT in EMPOWER resolution and data on energy mix, including generation cost structure | Data on disposable income of private households, including sectoral (aggreged) wages | + Labour market data, including sectoral employment | + Share of investment costs to be financed through one of the mechanisms |

Before making the acquaintanceship with case studies, the user is urged to consult the Sections 3.2-3.4 for more details. As a brief reminder, Table 7 provides a short overview of the submodules' economic mechanisms and data requirements. The submodule A (construction phase) captures direct and indirect effects of a newly added demand during the construction phase and is equivalent to a standard input-output analysis. When a new power plant becomes operational in submodule A, electricity price can change and will lead to an economy-wide propagation via IO interlinkages and adjustments in production prices and levels. The adjustment process is kicked off because electricity constitutes an important factor to a variety of production processes, and a rational economic agent would react to increasing (decreasing) electricity prices.

In submodules AB, the user can investigate — in addition to the mechanisms captured in submodules A — how an overall consumption level will be adjusted to new sources of income acquired during construction and operation phases. These submodules add the household's consumption reaction to new income and increases overall consumption level in comparison to the A submodules. In EMPOWER, the households are assumed not to alter the composition of the consumption basket, which is reflected in the IOT, but rather purchase more goods and services in the same relations. The net effect of an increased aggregated income on consumption level is a difference in key parameters (for example GDP or sectoral production) between submodules A and AB for construction and operation phase, respectively.

In submodule ABC, the element C adds a complexity regarding potential interactions between increased commodity and labour demand. If the economy experiences constraints in labour supply — for example because it cannot easily mobilize the required labour resources to satisfy the increased demand for specific goods or services —, then the labour market adjusts via wages. Increased wages will have an impact on production unit costs and ultimately product prices; the latter can lead to reduced demand in real terms across the entire economy and lower export levels. This feedback effect might be of a particular importance for relatively small countries facing a large energy investment. On contrary, it is likely to be of secondary importance in countries with large labour markets and a free inter-regional and inter-sectoral movement of labour.

The submodule ABCD introduces the element D which reflects the requirement for capital costs of a new power plant (construction costs and interests) to be fully or partly domestically financed. The user decides upon four financing options: an exogenously given financing, an increase in income taxes, a cut in transfers to households and a mark-up on the electricity price over the lifetime of the power plant. Those options, though they are all meant to finance the same investment levels, will have different impacts on the economy.

The next Sections outline conceptual differences between case studies NUC and ENE by focusing on data preparation routine, simulation runs and interpretation of the results. For the case study ENE, Section 5.4 will make a reference to the IAEA model MESSAGE (Model of Energy Supply Strategy Alternatives and their General Environmental Impacts) and detail how its results will be integrated into the EMPOWER data preparation routine.

## 5.1. INTERPRETATION OF IMPACT ANALYSIS VS. SCENARIO ANALYSIS

Both case studies demonstrate the flexibility of EMPOWER to treat a nuclear power investment in two fundamentally different ways. The case study NUC isolates and analyses impacts associated with construction and operation phases of a nuclear power plant relying on the *ceteris paribus* principle. This principle is broadly used in an input-output assessment of energy technologies. It states that — apart from the changes in production levels due to construction and operation activities — everything else in the economy will remain unchanged.

## 5.2. DATA SOURCES FOR THE CASE STUDIES

The IOT used as primary input to EMPOWER represents the monetary interrelationships among predefined sectors in an economy capturing input structure in the domestic production and the use of imported goods and services. IOTs are typically prepared by National Statistical Offices.

For the illustrative purposes, however, both cases studies, make use of the OECD database of 'harmonized' national IOTs. The latest set of the OECD IOTs is available for 38 OECD Member countries and 28 non-Member economies, including all G20 countries. The OECD IOTs follow the 'industry * industry' approach which implies the preparation of matrices with inter-industrial flows of goods and services (produced domestically and imported) for 36 industries in current prices (US $ million) for the years 2005-2015 ( [14]). To avoid any ambiguity, the IOT developed for both case studies hereafter is not country-specific — it is artificially built following the OECD IOTs structure.

The second data set — related to wages and employment — is built upon the EUROSTAT database and used to derive plausible relations between sectoral production, wages and employment. The main source of information[10] for sectoral employment is "National accounts employment data by industry (up to NACE A*64)" (nama_10_a64_e). The EUROSTAT table "Employment and activity by sex and age - annual data" (lfsi_emp_a) is used to determine an illustrative relationship between total employment and available labour force. Also, the general trend of labour supply is used to define labour demand growth.

The third data set details the composition of disposable income of private households and builds upon the EUROSTAT database. The basis for plausible relations between the IOT's value-added and disposable income is the EUROSTAT table "Non-financial transactions" (nasa_10_nf_tr). Different items of the sector "Households" provide required information on the income composition. The item D.1 (compensation of employees) relates to wages in the IOT; B2A3G (operating surplus and mixed income, gross) represents the income from self-employment; the item D.4 (property income) is used to derive profit income. The income taxes are built upon the item D5 (current taxes on income, wealth, etc.) and social contribution payments the item D6 (net social contributions). Furthermore, the net received items D62 (social benefits other than social transfers in kind) and the item D7 (other current transfers) sum up to the transfers received by households. The income items less taxes and less social contribution payments plus transfers sum up to the disposable income.

The data sources mentioned above are *common* for both case studies. The fourth data set defines EMPOWER scenarios and includes changes in both physical electricity generation and costs (investment and operation). For the case study NUC, scenarios are constructed upon average values for capital and plant operating costs in newly built nuclear power plants as published in [12]. For the case study ENE, the MESSAGE simulation results will be integrated into EMPOWER and will include a more comprehensive energy investment strategy. MESSAGE is an optimization model which can be used for energy system planning, energy policy analysis and scenario development.

[10] Eurostat Tables can easily be found by inserting the table code (e.g., nama_10_a64_e) into the search bar at the EUROSTAT website https://ec.europa.eu/eurostat.

## 5.3. CASE STUDY NUC: POWER PLANT INVESTMENT — AN IMPACT ANALYSIS

As discussed in Section 4, the data compilation and scenario definition routine in EMPOWER is organized around four Excel-files which needs to be executed in a consecutive manner:

— In the file "EMPOWER_STEP1_AGGREGATION", original IOTs are aligned with the EMPOWER structure.
— In the file "EMPOWER_STEP2_INPUT_OUTPUT_TABLE", the IOT matrices are aggregated towards the EMPOWER structures for sectors, value-added and final demand components.
— In the file "EMPOWER_STEP3_DATA_COMPILATION", additional information on household income together with the sectoral distribution of wages and employment is compiled.
— The file "EMPOWER_STEP4_SCENARIO.xlsm" is specifically designed to define scenarios for analysis of nuclear power investment in a *ceteris paribus* manner.

The economic analysis of construction and operation activities is conducted with "EMPOWER_STEP5_MASTERFILE_CASE_NUC.xlsm" which is specifically designed for case study NUC.

To avoid duplication, the Sections below contains the description of major steps only. The user is advised to first consult the Section 4 which contains a step-by-step procedure in EMPOWER application.

### 5.3.1. STEP 1: Definition of the IOT aggregation scheme

As previously stated, IOTs describe the sale and purchase relationships between producers and consumers within a given economy. In both case studies NUC and ENE, we use an artificially created IOT that follows the structure of a harmonized national IOT provided by OECD[11] for the year 2015, in ISIC Rev.4 structure and in million US \$. The data set "DOMIMP" contains an IOT which is divided into a domestic and import matrix. The sectoral value-added components are provided in the "VAL" data set. These two data sets are the foundation of the IO analysis in both case study.

#### *5.3.1.1. Tab "Select_Class"*

The first step is determining the sectoral structure of the IOTs which comprises in an original setting 36 sectors. The code and descriptions of those sectors are copied into the left green area (Column C, D) in the Sheet "Select_Class" of File "Step1". As described above, these sectors are aggregated to 35 EMPOWER sectors and sector names are included in column G.

The next task is allocating each original sector to an aggregated sector. This is done by defining the allocation scheme in column E. In EMPOWER, it is essential that the first sector (cell G10) contains electricity production. In our case, this sector is labelled "s35T39 - Electricity, gas, water supply, sewerage, waste and remediation services" in cell E30. There is no need to further disaggregate this sector to extract electricity generation because only absolute cost changes — due to changes in the electricity generation comprising changes in fuel costs, operation costs

[11] At the date of construction of this manual the most recent IOT database from OECD is "Input-Output-Tables 2018 edition" at URL: https://stats.oecd.org/Index.aspx?DataSetCode=IOTSI4_2018 (accessed on 1st August 2021)

and electricity supply costs — will be analysed. The absolute changes of these costs will alter the structure of sector producing electricity accordingly.

The change of electricity supply prices alters the overall price for sector 1's products depending on the share of electricity in the aggregated sector products. For instance, if electricity supply prices increase by 10% and electricity comprises 20% of the output of sector 1, then the output price of sector 1 changes by 2% (10% *20%).

The second step in this Sheet is placing the value-added components of the IOT in the green areas of cell K10. Following the OECD structure, value-added components are captured in two sets "DOMIMP" and "VAL". In the "DOMIMP" data set, two rows of net taxes (TXS_IMP_FNL and TXS_IMP_FNL) together with the total value-added are provided. In the "VAL" data set, the value-added is further disaggregated into compensation of employees (LABR), other taxes less subsidies on production (OTXS) and gross operating surplus and mixed income (GOPS). Therefore, the value-added is represented in "DOMIMP" in an aggregated form, while "VAL" provides a further disaggregation of the value-added categories. These two matrices on Taxes less subsidies and three matrices on value-added together provide sufficient information for the value-added block in EMPOWER. These five categories are allocated to the EMPOWER structure via a dropdown menu in the column L.

The third step in this Sheet is the allocation of final demand categories in the green area at the cell K73. The final demand categories are located to the right hand-side of the IOT in the downloaded "DOMIMP" matrices; they comprise consumption, investment, exports as well as changes in inventory and direct purchases. This allows a straightforward allocation of the respective categories to the EMPOWER structure via a dropdown selection in column L.

##### *5.3.1.2. Tab "Check"*

No warnings or errors are indicated in this Sheet. Equipped with this information, the user can proceed to the next step.

### 5.3.2. STEP 2: IOT aggregation

In this file the actual IOT data sets are provided, and the automated aggregation is performed.

##### *5.3.2.1. Sheet "Select_Class"*

First, the file from Step 1 is loaded in the Sheet "Select_Class" by clicking on the button "Load aggregation code from Step1" at the very top.

##### *5.3.2.2. Sheet "IM_Dom" to "FD_VA"*

Next, the domestic part of the original IOT is copied into the green area of the Sheet "IM_Dom", while the import part is copied into the green area of the Sheet "IM_Imp", respectively. The two data rows on net taxes (row 81 and 82 in the OECD DOMIMP data set) and the three data rows of value-added (OECD VAR data set) can be placed in the green area of the "IM_VA" Sheet. The same approach is applied for the final demand columns in the Sheet "FD_Dom", "FD_Imp" and "FD_VA", respectively.

##### *5.3.2.3. Sheet "Output_IOT"*

The aggregated IOT appears in the Sheet "Output_IOT" where the user complements the uploaded information by including the IOT's base year, country name and currency (and units) at cells C8-C10. In column AW and in cell AW8 of the Sheet "Output_IOT", a balance of the IOT is reported at the sectoral and aggregated levels. These values show the difference between row and column sums. In a perfectly balanced IOT, these values would be zero; minor deviations of around 1,0% typically do not cause any problems in EMPOWER. With higher deviations, the user is urged to seek advice from the National Statistical Office before moving to the next level. Generally speaking, large deviations signal the existence of inconsistencies either in the original IOT or in the aggregation process which can occur when value-added and final demand categories are allocated.

##### *5.3.2.4. Tab "Check"*

Because of the imbalances reported above, a warning appears in the Sheet "Check". At a later stage (in the Masterfile), the user can proceed and apply an algorithm (the so-called RAS method) to fully balance IOT. This algorithm distributes imbalances — across columns and rows — and creates a fully balanced IOT. As mentioned above, this procedure needs to be applied for small deviations only.

### 5.3.3. STEP 3: Additional data

In Step 3, additional data on household's income, sectoral wages (sectoral labour compensation) and employment are collected to prepare for submodules AB, ABC and ABCD.

The Masterfile processes the information on data availability for each submodule. Therefore, it is important for the user to activate or disactivate in Step3 (cell C5 of each "Data" Sheet) a respective submodule. If "INACTIVE", EMPOWER will ignore the current and all following data sets. Only when "ACTIVE" is selected, will the model load and process them. For example, if "Data B" is set as "ACTIVE" and "Data C" is set as "INACTIVE", then submodules ABC and ABCD will not be available for execution. If "Data B" is set as "INACTIVE", then only submodule A remains active in the Masterfile. This feature has been built in to guarantee a modular structure of EMPOWER.

For illustrative purposes, all submodules are set "ACTIVE" in both case studies.

##### *5.3.3.1. Tab "Data_A"*

The first step in the Sheet "Data A" is to load the IOT data by clicking on "Load IOT from file Step2" at the very top. The user is advised to check the correctness of the transferred data. For example, negative cell values are highlighted in red to draw attention to potential irregularities. Negative values in column AR ("Changes in inventories and valuables") are not unusual in IOTs because it represents changes in inventories (positive or negative).

##### *5.3.3.2. Tab "Data_B"*

The upper part of the Sheet comprises sectoral labour compensation and sectoral operating surplus (highlighted in green). This data can be inserted manually or — if this information is already available in the IOT — can be loaded via the button "Copy data" at the top of "Data B". In our case, this information is available — therefore, this operation copies the rows 85 to 89 in "Data A" into rows 12 to 15 in "Data B". In some cases, cells in row 11 can be highlighted red which signals that the sum of value-added components (rows 12-16) is not equal to the aggregated value-added value in row 11. If a discrepancy is small, it can be ignored; otherwise, the user can add a difference to row 16 which offers an option to include other components of value-added than those named in rows 11-15.

In the green area in column D, components of household's disposable income need to be provided. The user is advised to collect this information with help of the National Statistical Offices. The disposable income represents the monetary value that is ultimately available to the households for consumption or saving. It comprises income components (before taxes), reduced by taxes and social contribution payments plus net transfers. Cell D20 collects wage data which needs to be in a range of the sum of row 12 labelled as "of which compensation of labour". A strong deviation from 1 can indicate an error in the composition of households' income and a recheck is advised. However, even if the ratio deviates significantly from 1 (e.g., 0.7) the model will still work properly. Cell D29 shows that in the underlying case the ratio between both values is 0.98; the user can proceed.

Cell D21 resembles income from self-employment. Income from self-employment in the IOT is part of sectoral "Operation surplus". Hence, a fraction (in our case over 30%) of the economy's surplus is part of the disposable income. Cell D22 comprises a non-wage income e.g., from renting. Although this income component can be of substantial size, it is rather related to the distribution of wealth rather than to changes in the economy's production. Therefore, it is kept constant according to the *ceteris paribus* assumption.

These first three income components (wage, operating surplus and profits) are values before taxes. The tax is deducted in the following way: The next two cells (D23 and D24) represent the net payments by households in income taxes and social contribution in net (i.e., paid less received). These values reduce the disposable income. The last value resembles net transfers that households receive back such as family subsidies, unemployment benefits, pensions, etc. The received values minus the paid elements sum up to the gross disposable income.

#### *5.3.3.3. Tab "Data_C"*

In an IOT only monetary values are represented. Information on actual sectoral employment needs to be added separately. In tab "Data C" data on employment, including labour force and sectoral employment, are provided in order to run submodule ABC. Given that employment can be measured in different units, cell E18 gives the user an option to define the unit of employment. Typically, employment is measured in persons, jobs or full-time equivalents (FTE) but worked hours can be used too. There is no distinction between self-employment and employed persons. However, given that wages in IOT would typically refer to employed persons only, the user is advised to seek advice from the National Statistical Office and possibly exclude self-employment from the data provided here.

In the underlying case study, we assume the employment of slightly over 2 million as measured in FTE, while the available labour force is 2.2 million which results in an unemployment rate of over 9,0%.

#### *5.3.3.4. Tab "Data_D"*

The information in the Sheet "Data D" is optional and has no impact on the economic analysis. This Sheet can be filled with other public expenditures and revenues in order to reproduce the actual public savings of the base year. In this way, relative deviations from the actual public saving values can be observed in the model results in the Masterfile.

#### *5.3.3.5. Tab "Check"*

All checkpoints show “OK”.

### 5.3.4. STEP 4: Scenario definition

In this file, scenarios are formed with respect to economic development, investment in electricity generation, costs of electricity generation, economic parameters and financing options. In the case study NUC, the construction and operation of a single NPP is analysed using EMPOWER. Table 8 summarizes the underlying parameters and the sources.

TABLE 8. CASE STUDY NUC — SCENARIO INPUTS.

| Category | Value | Unit | Source |
|---|---|---|---|
| Capacity | 1200 | MWe | |
| Capacity factor | 85 | % | IEA (2020) [15] chapter 2.2 |
| Lifetime | 60 | years | |
| Discount rate | 7 | % | |
| Generated electricity | 8772 | GW·h/yr | Multiplication (85% × 8600 hrs × 1200 MW) |
| Overnight costs | 4.262 | US $/kWe | IEA (2020) [15] - Table 3.13a[12] |
| Investment costs (7%) | 5.449 | US $/kWe | |
| Investment costs (7%) | 50.40 | US $/MW·h | |
| Fuel costs | 10.20 | US $/MW·h | |
| O&M costs | 16.00 | US $/MW·h | |
| of which fixed costs | 4,7 | US $/MW·h | Assumption: 5% of annual investment costs |
| of which variable costs | 11.2 | US $/MW·h | Assumption: Total O&M minus Fixed O&M costs. |
| Emission permit costs | - | US $/MW·h | |
| Construction phase | 2021–2028 | years | IEA (2020) [15] chapter 2.2 |
| Operation phase | 2028–2038 | years | |

[12]Levelized cost of electricity for nuclear plants at 85% capacity factor — New build; Average values of France, Japan, Korea, Republic of, Slovakia and United States of America

#### *5.3.4.1. Tab Growth (ABCD)*

The initial step in this Sheet is to load the information from the previous files by clicking on "Load Data from Step3". This places the previously provided data sets into the blue areas.

The next step is to define the time span of the analysis in cell D12. Up to 12 years for both construction and operation phases, can be defined. In this case study, the construction length is set at 7 years running from 2021 to 2027. The sectoral growth path of each sector in the green area is defined. While historical trends or projections can be used, in this case study we apply some random numbers. In principle, growth rates can take positive or negative values. The latter implies that the sector shrinks.

#### *5.3.4.2. Tab ConstCosts (A)*

In this Sheet, annual construction costs and localization rates are provided. In the case study NUC, the overall investment costs based on the values in Table 8 are approximately US $6.5 billion which are linearly distributed over 7 construction years, with an annual investment volume of US $934 million. These yearly investment costs are inserted into the green area of cell D25.

When a currency of the investment volume differs from the IOT currency, an exchange rate needs to be applied in cell E25 to transform the investment volume to the IOT currency. In this case study, IOT and capital costs are reported in the same currency and units.

Next, annual investments are distributed across sectors starting in the green area of cell C53. The user is urged to pay particular attention to this step, given that overall (economy-wide) and sectoral results largely depend on the distribution of investments. In this case study, we assume a *stylized* distribution of overall investment costs:

— Financial and insurance activities (20%).
— Construction (45%).
— Electrical equipment (15%).
— Computer, electronic and optical products (10%).
— Other manufacturing; repair and installation of machinery and equipment (10%).

The localization rate is defined in the matrix starting at the cell C135; for construction and financial services a domestic share of 99% is assumed (i.e., 1% of those services will be imported); for the remaining categories the localization rate is 50%.

#### *5.3.4.3. Tab Operation Energy (A)*

In this Sheet, the new electricity generation mix and generation costs are defined. The first part of this Sheet comprises the electricity generation mix. In the green area starting at cell D29 the reference development of the electricity generation mix in physical units (GW·h) needs to be provided. Nine technology groups are distinguished:

— Wave/tidal;
— Wind;
— Solar;
— Gas;
— Coal;
— Oil products;

— Nuclear;
— Hydropower;
— Biomass.

In this case study, we assume for illustration purposes that the increase in electricity demand will be met by an increase in wind power and a decrease in coal-based electricity. Imports are kept constant; the supplied electricity, hence, increases by 8.000 GW·h by 2038.

Starting at cell D45, assumptions concerning the future electricity mix are made for the counterfactual scenario. Hereafter, we limit the analysis to the construction and the operation of an additional nuclear power plant which will produce 8.772 GW·h per year starting in 2028. Therefore, the output of nuclear electricity in row 51 is increased by this amount.

Next, EMPOWER requires the user to determine how additional electricity is used. A part of the additional electricity is consumed by other industries due to the increase of production activities. For the use of the remaining excess electricity two options exist — it is either used by the households or exported. In order to define this allocation, net imports of electricity (row 55) need to be adjusted. In this case study, we assume that 500 GW·h of additional electricity is consumed by private households and the rest (approx. 8 300 GW·h) is exported. To implement that, net imports in the row 55will decrease by approx. 8 300 GW·h. At row 79 the use of the excess electricity is summarized. 94% of the additional electricity is exported and 6% is consumed by households.

In the lower part of this Sheet, changes in electricity generation costs can be defined. They need to be provided for each technology if the production output changes. In the case study NUC, the respective technology is nuclear. If for instance electricity production by natural gas decreases, the generation data for "Gas" needs to account for those changes. Based on the unit costs (per MW·h) in Table 8 (Scenario inputs), annual costs are displayed in Table 9. In the case study NUC, one type of power plant is added to the generation mix. Hence, production costs of the total system increase analogously to the production of electricity. The determining factor are the costs for electricity generation by nuclear power. The unit costs (US $/MW·h) combined with the generated electricity (GW·h) result in the additional annual costs due to an extended electricity production.

The user needs to note that the provision of generation costs as in Table 8 are optional. EMPOWER will run even if no costs are provided but consequently economic effects of the operation phase will not account for changes in costs. Furthermore, the differentiation between fixed and variable operation costs is also optional. They are differentiated here because they relate to different cost structures. Fixed costs typically comprise personnel costs, whereas variable costs relate to transport costs and disposal fees.

TABLE 9. ANNUAL COSTS OF NUCLEAR POWER PLANT OPERATION

| Category | Costs per unit | Costs per year |
|---|---|---|
| | US $/MW·h | In millions of US $ per year |
| Fuel costs | 10.20 | 90 |
| Fixed costs | 5 | 44 |

| | | |
|---|---|---|
| Variable costs | 11 | 96 |
| Capital costs | 50 | 442 |
| Electricity price (Trade) | 60 | – |
| Electricity Supply Costs (per Unit) | 100 | – |

Typically, the prices of exported or imported electricity deviates from the domestic price. Taking this into account is crucial in the economic analysis when the excess electricity is exported. Therefore, an estimation of the traded electricity is needed as input in row 178; we assume that the price for additional exported electricity is 60% of the domestic price. The supply price is set to be 100 US $/MW·h in 2028 and increases by 2 US $/MW·h per year. The lower price for exported electricity decreases the positive impact because the value of exported electricity directly contributes to GDP and increases domestic income. If the assumed price is higher or lower, this can strongly influence the overall impact on GDP.

In the case where changes in the domestic electricity generation have an impact on the price of traded electricity, the price adjustment can be set at row 182. In case study NUC, this is not applied, when, however, MESSAGE is used, then this information can be provided.

*5.3.4.4. Tab Operation Costs_Structure (A)*

Here for each of the cost categories (fuel, variable and fixed) the underlying sectoral cost structure needs to be provided.

Fuel costs can be allocated to the respective sector that produces this commodity via a dropdown menu at cell C27. According to the sectoral classification used in the OECD IOT (ISIC 4), we specify that natural gas and coal products are provided to the electricity producers by the sector “Mining and extraction of energy producing products”. Oil-based fuels are refined products of the sector “Coke and refined petroleum products”. Nuclear fuel is a product of the quite heterogenous sector “Chemicals and pharmaceutical products”. Finally, the production of biomass for electricity is allocated to the sector “Agriculture, forestry and fishing”.

The following cost categories relate to operation costs. In this case study we differentiate between fixed and variable costs. This differentiation is optional and can be applied if the respective data is available. If such data sets are not available, the user can just provide cost data in one of the two categories.

Fixed costs, comprising, costs that occur, even if no electricity is produced. This category encompasses permanent staff, necessary maintenance, rents and interest payments. For demonstration purposes in the case study NUC, it is assumed that 50% of the fixed costs are labour-specific, 20% are to cover expenditures on goods and services from the sector “Other manufacturing; repair and installation of machinery and equipment”; and 10% are spent on goods and services in each of the following sectors: “Telecommunications”, “Real estate activities”, and “Financial and insurance activities”.

Variable costs relate to produced energy units. Activities such as transport services (of fuel), training of personnel and information services are linked to production levels. In this case study, 50% of the variable costs are assumed to refer to "Other manufacturing; repair and installation of machinery and equipment", 30% to "Transportation and storage" and respectively 10% to "IT and other information services" and "Education".

#### *5.3.4.5. Income_Consumption (B)*

Annual growth rates of disposable income components which are linked to the sectoral development are defined in this Sheet. The first element — wages — is partly dictated by the sectoral development path in the Sheet "Growth (ABCD)". Other elements of disposable income can evolve at a different pace then the entire economy. In the NUC case study, random numbers are used.

The marginal propensity of consumption which represents the reaction of households' consumption to changes in disposable income is inserted in the cell F32. If this parameter is set to 1.0, then the total marginal (additional) disposable income is used for consumption; with the value equal to 0.0, households save total marginal income. Plausible values are likely to lie between 0.5 and 0.9; in this case study, the value 0.7 is applied.

#### *5.3.4.6. Labour Market (C)*

In this Sheet, parameters regarding the labour market and exports are set.

At cell F22, annual growth of the *labour force* is defined. This is a crucial parameter, given that, in some countries, the economy (and labour demand) can grow substantially stronger in some countries than labour supply which would result in a negative employment rate being calculated by EMPOWER and cause errors. To ensure that the user relies on plausible inputs, EMPOWER calculates sectoral labour demand for construction and operation phases. In row 74, an unemployment rate is calculated based on the exogenously given assumptions about economy's growth, productivity (F23) and labour force growth. If this rate is non-negative, then the respective inputs and assumptions are considered to be valid. If the unemployment rate is negative or implausibly low, then assumptions about a labour force growth or productivity gains (F23) can be changed. Alternatively, assumptions about an average economic growth in the Sheet "Growth (ABCD)" can be adjusted. In this case study, annual growth rate of labour force is set to 0.7% for illustrative purposes to achieve a sectoral unemployment rate between 9.2% and 9.4% (row 74).

The parameter *productivity/output growth* is equivalent to the total factor productivity (TFP) of the sectors[13]. The value of 0.4 implies that for a 1.0% growth in output, only 0.6% more inputs are used. While a plausible range is likely to lie between 0.3 and 0.7, the user is urged to carefully select the value relying on an experts' opinion. In this case study, we apply the value of 0.7 to balance employment demand, unemployment rate and annual growth in labour force.

*Productivity pass through* defines how much of the overall productivity gains (as defined by TFP) are transferred to labour compensation. For example, the value 1.0 implies that total productivity gains result in higher wages. In principle, plausible values could lie between 0.5 and 1.0; for illustrative purposes we set it at 0.75, whereas the user undertaking a real case modelling exercise is advised to search an expert's advice.

[13] Total factor productivity describes the relative decrease of inputs for the same amount of outputs.

*Wage reaction to employment* defines the reaction of wages to an unemployment rate in relative terms. The value 0.0 implies that there is no wage reaction to changes in an unemployment rate, and wages will remain fixed for any levels of unemployment. The value of -0.1 implies that an 1.0% increase in unemployment results in an economy-wide decrease of wages by 0.1%. Again, plausible values can lie between -0.02 and -0.1; we use the value of -0.09 for illustrative purposes, and the user is advised to carefully select it.

*Export price elasticity* defines the reaction of real exports to changes in domestic price levels in relative terms. A value of -0.7 implies that if domestic prices increase by 1.0%, then real exports decrease by 0.7%. While plausible values might range from -0.5 to -1.0, hereafter we apply a unity elasticity -1.0.

#### *5.3.4.7. Financing (D)*

In this Sheet, the sources of investment financing are defined. Four options are available. A generic term *external financing* is chosen to describe a case where project financing stems from some exogenously given sources. Because we further assume that no repayment will be done, this financing option will have no additional (real) impact on the economy in comparison to submodule ABC. While this case might appear abstract, it allows distinguishing various important effects at work. If financial means were available in an unconstrained way and for free — as it is typically assumed in a standard input-output analysis — then submodules A, AB and ABC would apply respectively. But in reality, the governments would need to generate at least a portion of total investment costs by increasing taxes, substituting other spending, putting a mark-up on electricity price or a combination of these options. Thereby, those options (singled-out or in combination) will have a real, though a distinguished impact on the economy. If on one hand the disposable income of private households decreases due to an income tax increase and/or a transfer cut, this leads to a lower private consumption and domestic production level. If on the other hand investment costs are financed via a mark-up on electricity prices, the impact takes a different form because price level increases and real exports decrease.

In this case study and for demonstration purposes, we assume that 40% of total investment costs are provided by exogenous sources, 30% are generated via income tax increase during the construction phase and 30% are put as mark-up on the electricity price.

### 5.3.5. STEP 5: Model run

The Masterfile file collects data and processes definitions from previous steps, in particular Step 3 and Step 4. Based on the basic data from Step 3 and assumptions about future development of an economy as defined in Step 4, the reference data set (including an IOT) is automatically generated for each year of construction and operation phases. The scenario data from Step 4 are further used to generate a demand shock (construction phase) or introduce a structural change (operation phase). The algorithm in EMPOWER calculates a new equilibrium and presents a deviation from the reference scenario.

#### *5.3.5.1. SetUp*

As above, the user needs to load the "Country data" from Step 3" and "Scenario data" from Step 4 via a button click in the Sheet "SetUp".

In our case, the IOT is not fully balanced to be seen at cell H13; therefore, we apply a RAS algorithm via the "Start balancing case" button. After balancing, the user can proceed to the next step.

*5.3.5.2. Ctrl_CON and Ctrl_OPR*

In the Sheet "Ctrl CON" and "Ctrl OPR", simulations for construction and operation phases are initiated. A simulation run for each submodule can take up to several minutes.

When the model run is completed, a message box appears, while deviations of nominal GDP with respect to the reference scenario "Baseline" are graphically presented to the right to cell L16. A green bar shows a positive deviation, a red bar a negative. At C25, the user can select between absolute and relative values. Below row 48, five options to display additional results can be chosen.

The results of each run can be saved by clicking on "Save results" at cell I8. This command saves all results, for both construction and operation phases, into a separate automatically generated output file which is located in the subfolder "\Outputs\AutosavedOutputs". This folder will also be automatically generated by clicking the button "Save results". The results can then be loaded into file "EMPOWER_STEP6_RESULTS_VISUALIZATION_" and visualized.

### 5.3.6. STEP 6: Results and interpretation

In the file "EMPOWER_STEP6_VISUALIZATION", the results which have been exported from the "EMPOWER_STEP5_MASTERFILE" can be loaded and visualized. Construction and operation phases are analysed and visualized independently.

The results of EMPOWER simulations are represented as deviations from the economic reference scenario triggered by construction and/or operation activities. The deviations can be represented in different ways; four options are available in the EMPOWER_STEP6_VISUALIZATION file:

— in *absolute* terms as a monetary deviation from the reference in predefined units;
— in *relative* terms as a percentage deviation from the reference;
— at *current* prices as nominal values; and
— at *constant* prices or in *real* terms as deflated values.

Given that price system adjustments are absent in submodules A and AB (construction phase only), the results in current and constant prices will be identical.

| Simulation results | | | |
|---|---|---|---|
| | Value | Price Index | Deflated Value |
| Reference | 100 | 1.0 | 100 |
| Scenario | 105 | 1.1 | 95 |

| Representation of differences | | | |
|---|---|---|---|
| | current prices | | constant prices |
| absolute | 5 | | -5 |
| relative | 5% | | -5% |

*FIG. 52. Simplified example on results' visualization.*

Figure 52 illustrates the importance of applying appropriate terms for results' visualization. Let us assume that the reference GDP in a given year is equivalent to 100 million US $. In EMPOWER, the price levels in the reference scenario are set to 1.0. Assume further that GDP has increased in *relative* terms by 5% or 5 million US $ in *absolute* terms as measured in nominal values at current prices due to construction activities. However, price levels have increased by 10% (as indicated by the price index 1.1) which leads to the GDP value of 95 million at the constant prices or a decrease of 5% relative to the refence scenario.

This example emphasizes the need to account for price changes when evaluating economic impacts. Therefore, the Sheets "Graphs CON1" and "Graphs OPR1" contain radio buttons at cell F47 to display the results in absolute and relative terms as well as at current and constant prices.

#### *5.3.6.1. Description*

The first step is to load the result of the case study by clicking the "Load Results" button in the Sheet "Description". The automatically generated output files (filename is a timestamp) are available in the subfolder "\Outputs\AutosavedOutputs" in the directory of the EMPOWER_MASTERFILE.

If the loading process is executed successfully, main results are displayed in the six green coloured Sheets. The economic impacts at the sectoral level for employment and production output are reported in the Sheets "Sector CON" and "Sector OP", respectively. Top 10 sectors — with largest gains and losses — are named in the Sheet "Graphs CON2" and "Graphs OP2". The main economic indicators are summarized in the Sheet "Graphs CON1" and "Graphs OPR1" for the construction and operation phase, respectively.

#### *5.3.6.2. Construction phase*

The effects on GDP in current prices for the entire construction phase are reported in the Figure 53 — it shows an equally distributed effect in absolute terms (right figure) based on construction costs profile which amounts to 934 million US $ annually. The direct and indirect effects calculated by submodule A is approximately 600 million US $ which is equal to about 0.22% relative to the baseline in 2021. This GDP impact is substantially smaller than the investment expenditures. This difference is caused by the outflow of expenditures into imports, either directly (import of machinery for the construction) or indirectly (as imports in up-stream production). The relative impact (left in Figure 53) decreases over time. This is due to the overall growth of the economy, whereas with growing GDP the same absolute impact (i.e., the investment expenditures of 934 million US $) become relatively smaller over time. The additional income and consumption associated with construction activities — as reported in submodule AB — increases the impact to around 800 million US $. Labour demand decreases unemployment and fuels wage negotiations on the labour market in submodule ABC. Higher wages are translated into higher consumption and let GDP impact raise to 900 million US $. In submodule ABCD, an income-tax increase to finance 30% of the investment costs reduces the purchasing power substantially and limits the positive impact on GDP to less than 700 million US $.

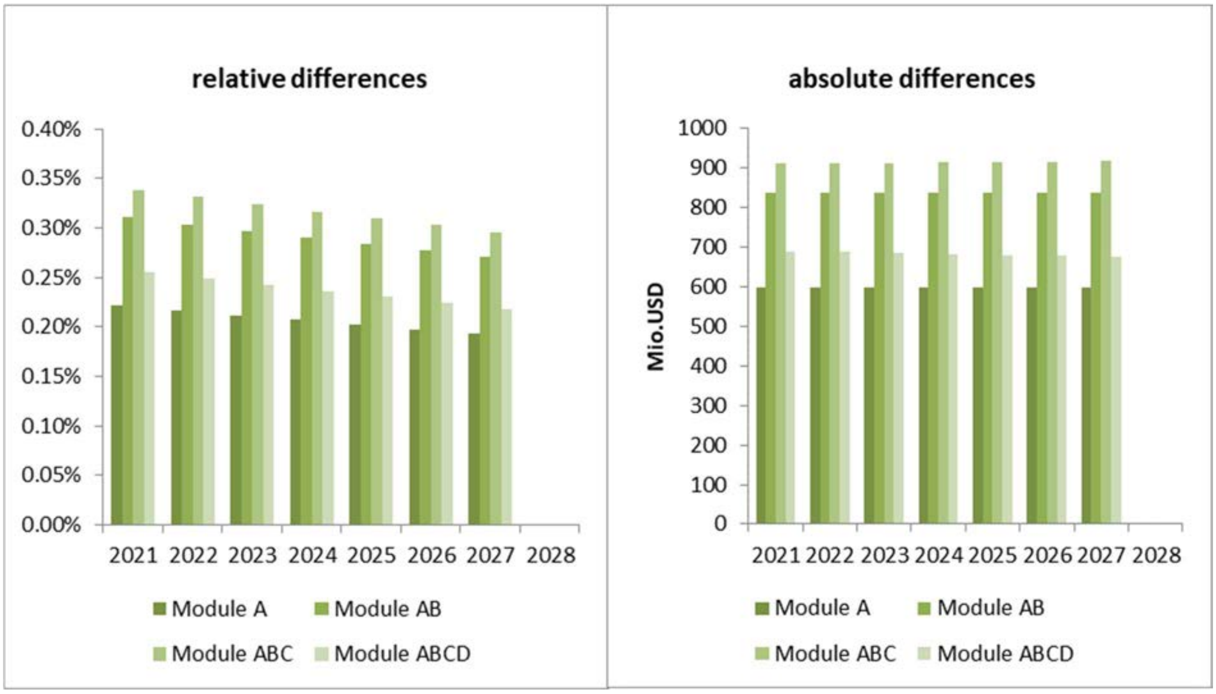



*FIG. 53. Impacts on GDP during construction phase (current prices) — Case study NUC.*

Figure 54 reports the same results but in constant prices which allows identifying an additional driving factor. Note that in submodule A and AB of the construction phase no price changes are simulated. Hence the price index is unchanged and the results in constant prices are identical to the results in current prices. When wages increase in submodule ABC due to a higher demand for labour during the construction phase, it has two effects which work in different directions. On the one hand, higher wages lead to higher consumption; but on the other hand, higher wages lead to higher production costs and overall higher price levels of domestic commodities. The latter makes consumption goods and services more expensive which leads to a reduction in consumption levels. When reported in constant prices, both effects are captured — therefore, impacts in submodule ABC are lower (around 780 million US $) in Figure 54 in comparison to Figure 53. This price effect has important implications for the export activity of the economy (Figure 55) and reduces the total exports up to 32 million US $ (0.04%) in real terms. It is also captured in submodule ABCD which falls below the GDP levels calculated in submodule A.

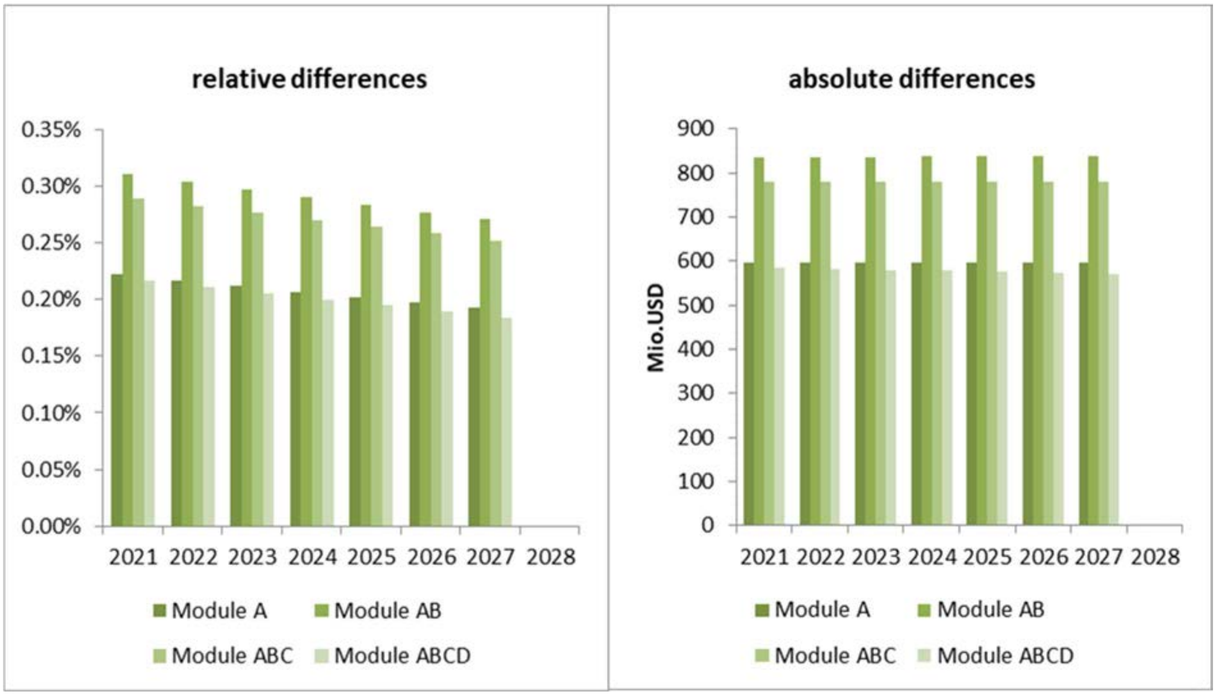



*FIG. 54. Impacts on GDP during construction phase (constant prices) — Case study NUC.*

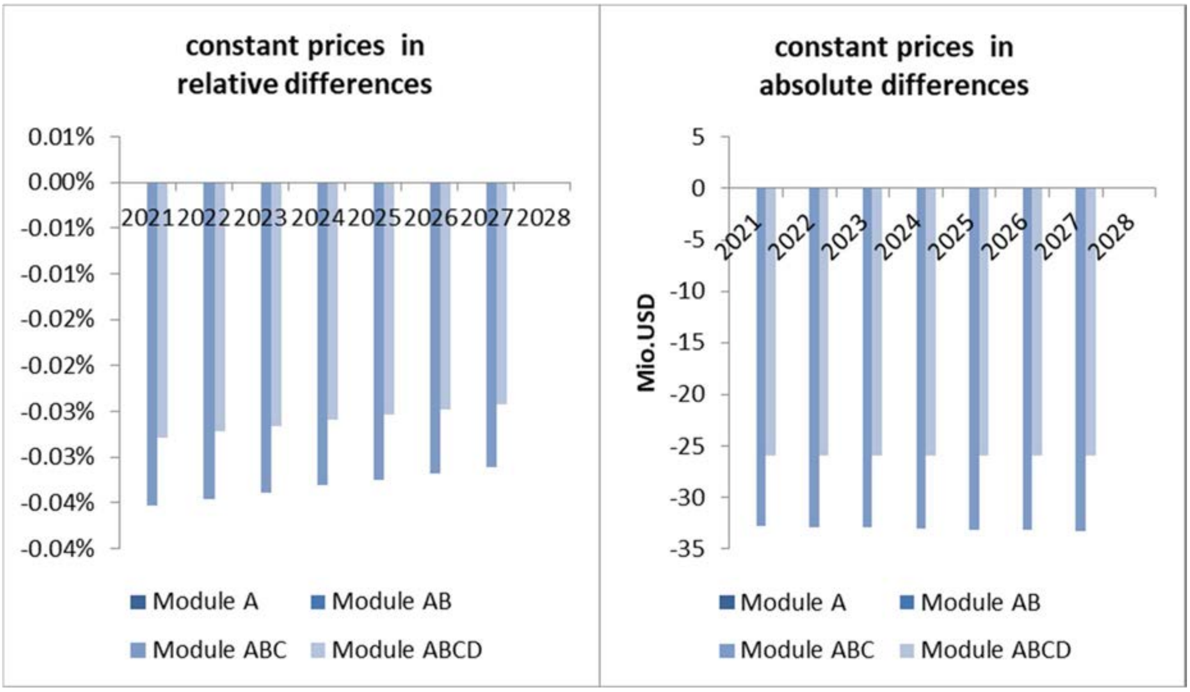



*FIG. 55. Impacts on exports during construction phase (constant prices) — Case study NUC.*

At the sectoral level the impacts are quite heterogenous. Figure 56 details impacts on employment in 5 sectors which gain most (green) and 5 sectors which lose most (red) based on the results of submodule ABCD as average during the construction phase. Not surprisingly, construction sector leads the ranking in terms of positive employment effects. The financing in this case study is defined in a way that 30% of the investment costs are raised by transfer cuts to households which ultimately reduces disposable income and private consumption. In submodule ABCD, transfer cuts decrease the demand for public administration, education as well as arts and recreation. The grey bar in the middle represents the average of the remaining 25 sectors; total effects are summarized in the black bar at the top of Figure 58.

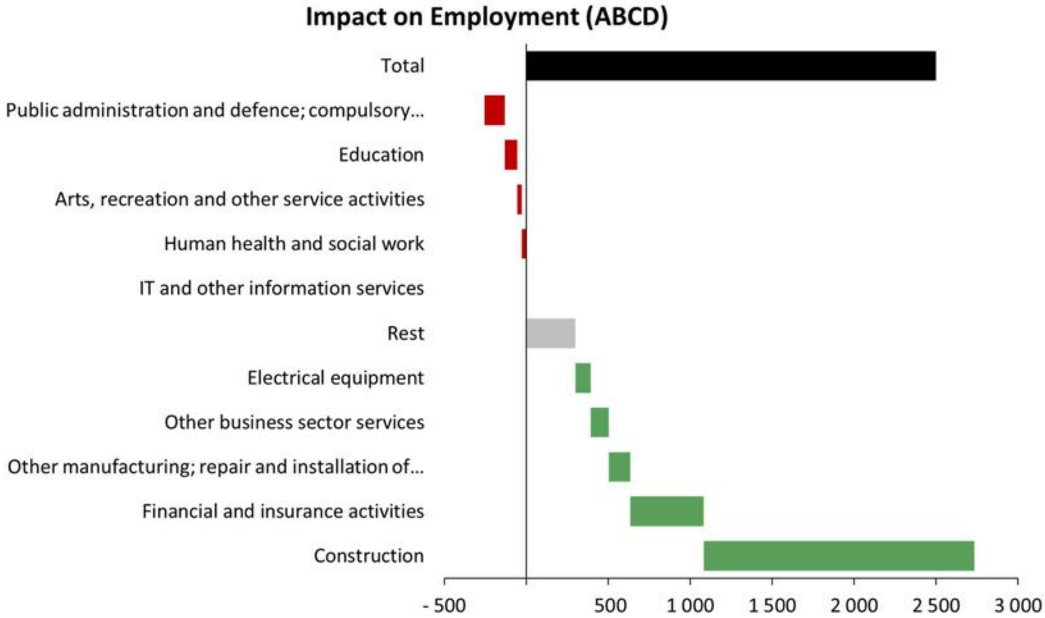



*FIG. 56. Impacts on sectoral employment during construction phase — Case study NUC.*

### 5.3.6.3. *Operation phase*

Macroeconomic impacts during the operation phase in Figures 57 and 58 are driven by the combination of three major factors: adjustments in costs structure of electricity generation, adjustments in electricity price levels and adjustments in export revenues for additional electricity.

The impacts on nominal GDP, as reported in absolute terms in Figure 57, shows a slightly increasing trend over the investigated period. The GDP impact occurs primarily because of increased export revenues (below); it is further amplified in submodules AB and ABC due to higher income and increased wages. In submodule ABCD, the impacts are slightly less because of an electricity price mark-up which decreases demand for electricity and reduces employment, income, consumption and ultimately production levels. The impacts on nominal GDP, as reported in relative terms in Figure 57, show similar trends, with one exception: the effects slightly decrease over time given that the GDP in the baseline grows stronger than the value of exported electricity.

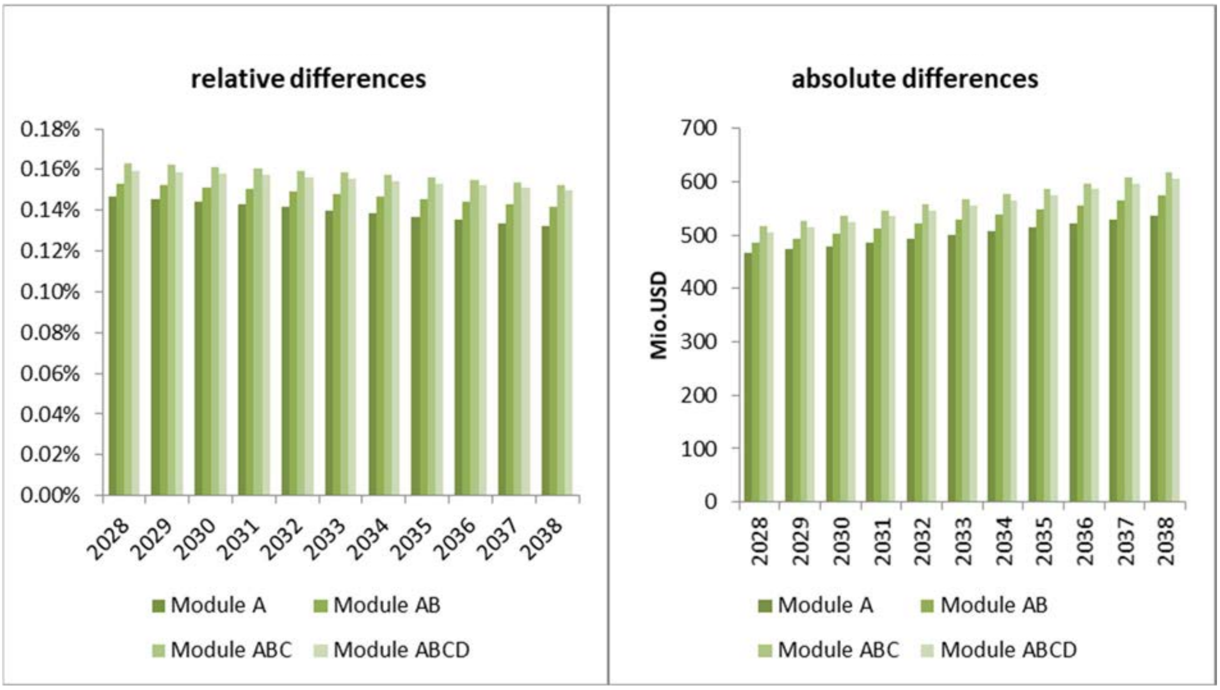



*FIG. 57. Impacts on GDP during operation (current prices) — Case study NUC.*

When looking at the GDP effects at constant prices (Figure 58), a slightly different picture evolves. The GDP impact, as measured at constant prices, is substantially higher than at current prices — in submodule A, it lies above 750 million US $ (Figure 58) in comparison to roughly 450 million US $ (Figure 59). The effect is driven by favourable economy-wide price level adjustments which originate from lower supply costs of electricity and lower electricity prices. The user needs to be reminded of the financing options applied in this case study: it is assumed that 30% of overall costs are financed during construction phase and 30% by external sources. With these assumptions, a substantial financing burden is shifted away from economic actors in 2028 and beyond. Therefore, the GDP effect in submodule A is higher at constant prices and further amplified in submodules AB and ABC; it is slightly smaller in submodule ABCD due to a mark-up on electricity prices which counteracts the initial impact.

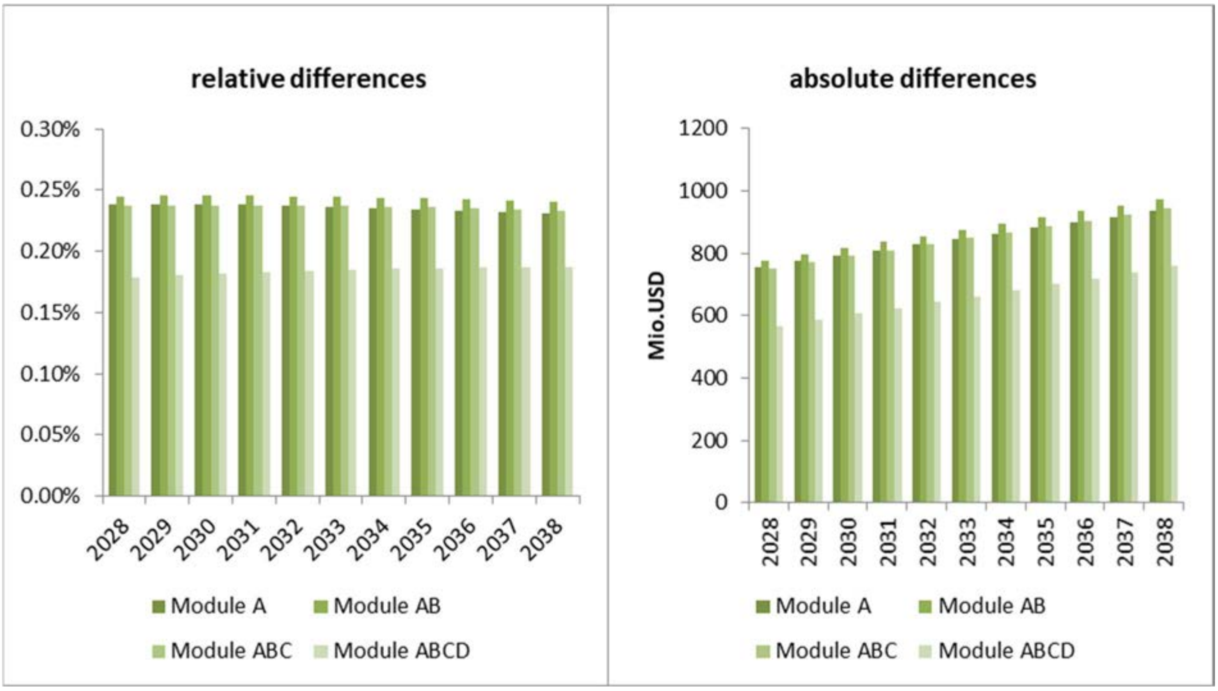


*FIG. 58. Impacts on GDP during operation (constant prices) — Case Study A.*

The additional electricity generated by the new power plant is largely exported at a favourable price. This has a strong impact at GDP level because net exports constitute its core element. As presented in Figure 59, total exports increase by 500 to 700 million US $ (or by 0.45%-0.55%) relative to the baseline. Given that overall exports grow faster than the value of the exported electricity, the relative increase in exports exhibits a slight decrease over time.

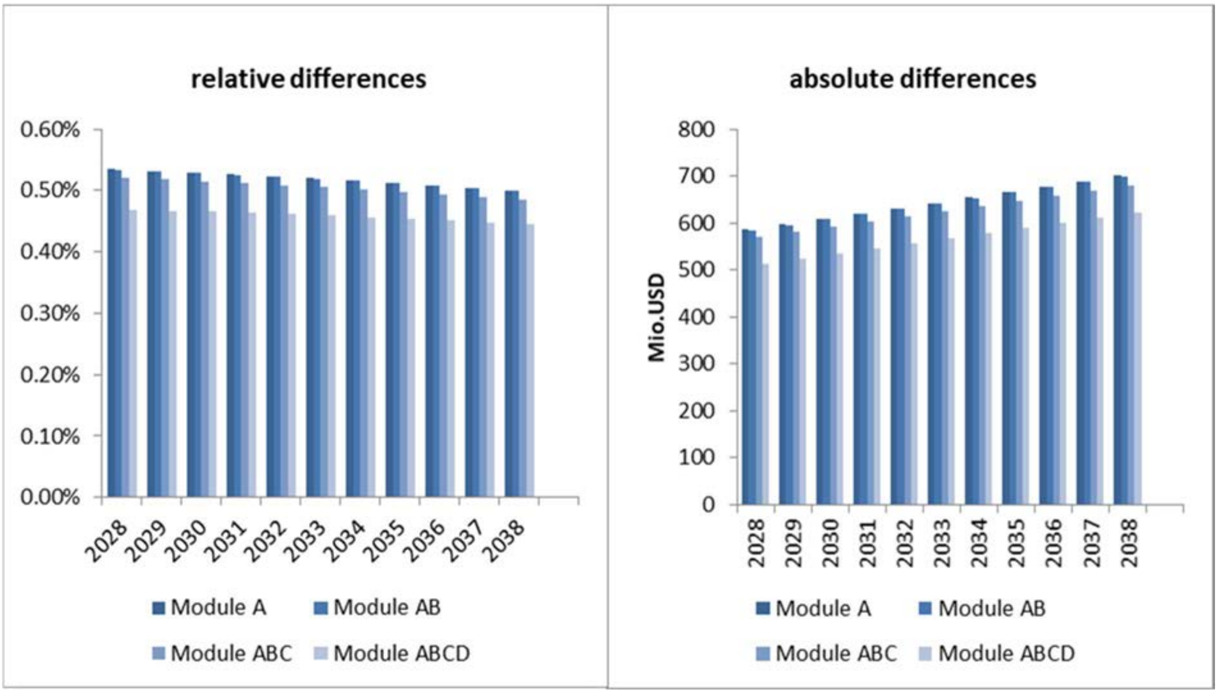



*FIG. 59. Impacts on exports during operation (constant prices) — Case study NUC.*

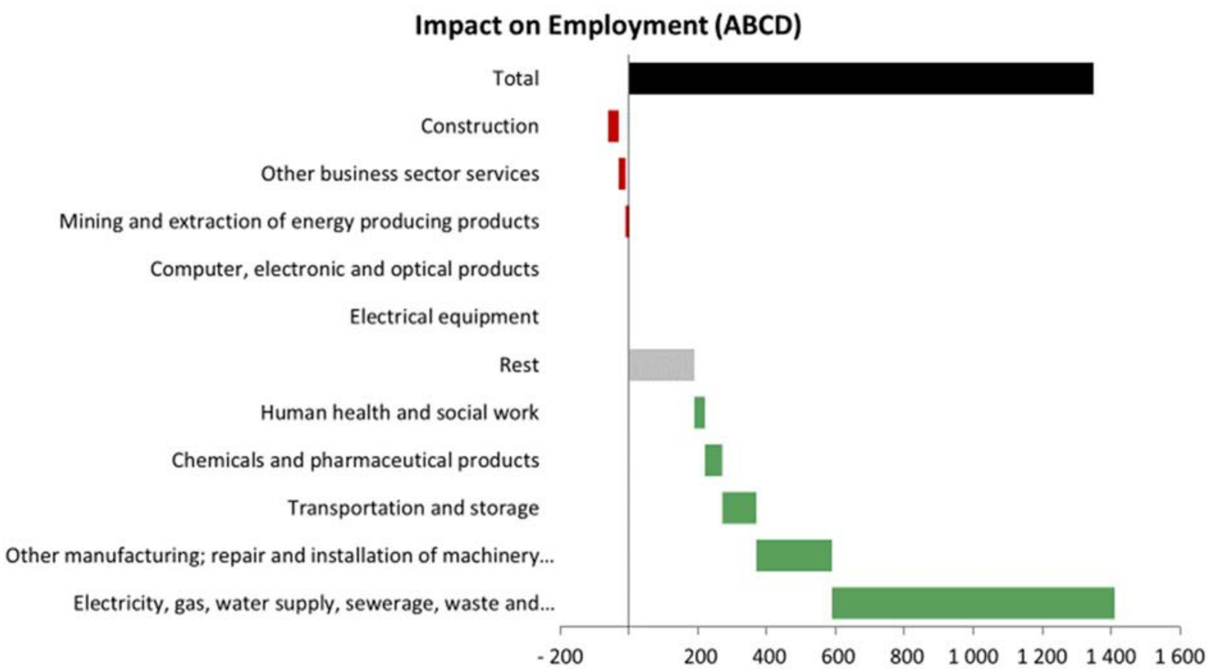



*FIG. 60. Impacts on sectoral employment during operation — Case study NUC.*

Figure 60 displays the employment effect at the sectoral level for submodule ABCD whereas major employment benefits occur in the “electricity, gas, water supply, sewerage, waste and remediation services’, followed by “other manufacturing; repair and installation of machinery and equipment”.

## 5.4. CASE STUDY ENE: COMPARING ENERGY SYSTEM DEVELOPMENT SCENARIOS

In this case study, labelled as ENE, the outputs of the optimization tool MESSAGE are integrated in the data routine of EMPOWER. The advantage of such a detailed bottom-up model is that it does not consider construction and operation of an additional power plant in an isolated manner, but rather as a part of an overall electricity supply strategy.

### 5.4.1. MESSAGE model description

MESSAGE (Model of Energy Supply Strategy Alternatives and their General Environmental Impacts) was first developed by the International Institute for Applied Systems Analysis in the 1970s to support energy system planning, energy policy analysis, and scenario development. The IAEA acquired MESSAGE in 2000 and further enriched it to support a detailed evaluation of alternative energy strategies, including nuclear technologies [16].

The model provides a framework for a detailed representation of an energy system and its interdependencies. MESSAGE optimises an objective (total system cost) function under constraints using numerical techniques such as linear and mixed-integer programming.

The degree of details in the description of the energy system is flexible and depends on the geographical and temporal scope of the problem being analysed. MESSAGE supports global, multi-regional, national, and municipal energy system representations. Moreover, MESSAGE allows accounting for environmental and other effects of satisfying the energy-service needs. It can further include environmental costs (or taxes) and help quantify sustainable energy scenarios under various constraints and specifications of energy policies.

As represented in Figure 61, the basis of MESSAGE is a technical description of energy system being modelled, including the categories of energy levels considered (e.g., primary energy, final energy, energy services, etc.), the energy products and other commodities used (e.g., electricity, coal, etc.) as well as energy services (heating, lighting, etc.) demanded by the system. Technologies are defined by energy forms’ inputs and outputs, efficiency of transformation and the degree of variability, if more than one input or output exists (e.g., cogeneration vs. multiple-fuel power plants).

Energy carriers, commodities and technologies are combined into energy/commodity chains where the energy/commodity flows from the supply side to the consumption and use side. The technical system provides a set of constraints to the model, together with the demand for energy/commodity, which needs to be met either by domestic sources and/or by imports through the modelled energy chains.

The model considers energy supply installations (e.g., power plants or refineries), sources of demand (e.g., cars or household appliances), and retirement of these facilitates at the end of their lifetimes. During the optimisation process, together with varying energy demands, the need to install a new capacity composed of various technologies is determined. The investment requirements are calculated for the new capacity needs. The overall cost of the system is minimised through an optimised choice of investments, fuels and production levels. The objective function includes the cost of fuel entering the system, and the costs associated with investing in and operating the chain of technologies required to meet the demand. The function also considers cost penalties, the salvage value of the technologies at the end of the modelling period, and export revenues.

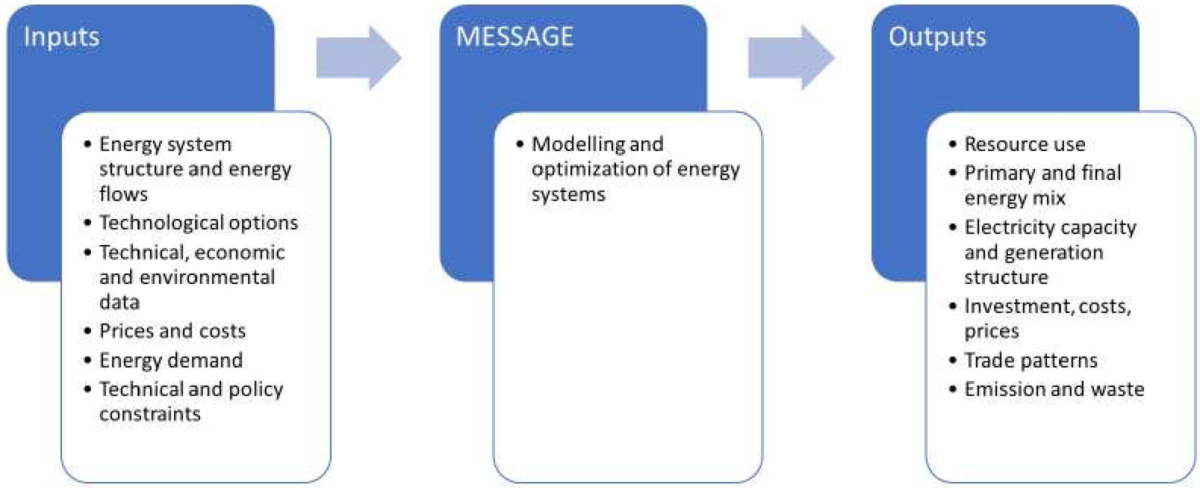



*FIG. 61.Schematic presentation of the MESSAGE modelling framework.*

For some energy carriers, ensuring timely availability involves considerable cost and management effort, and one of those is electricity. Electricity needs to be provided when it is consumed. MESSAGE simulates this situation by subdividing each year into a number of "load regions." The parts of the year can be grouped into one load region according to different criteria, for example when sorted according to power requirements or aggregated by typical demand patterns (summer or winter, day or night). This semi-ordered load representation makes it possible to model energy storage as a transfer of energy, for example from night-time to daytime, or from summer to winter. The inclusion of a load curve further improves the representation of power requirements and the use of different types of power plants.

The environmental impacts can be analysed by monitoring the amounts of pollutants emitted by various technologies at each step of the energy chains and introducing limits and penalties if necessary. This approach facilitates the evaluation of environmental regulations and their impacts on the energy system.

### 5.4.2. MESSAGE case study

In order to analyse and compare macroeconomic effects of alternative energy strategies, energy system development scenarios need to be defined. Typically, these scenarios rely on a set of detailed long-term energy demand and supply studies that are exploring future pathways and complex interdependencies between high-level objectives, technological options, operational requirements of energy sub-systems, environmental impacts, and other related components.

To demonstrate the application of EMPOWER for comparison of alternative energy scenarios, an illustrative case study in MESSAGE was developed with a focus on electricity (power) supply only. In this sense, the MESSAGE case study described hereafter can be viewed as an abstract from more complex (complete) analysis of the entire energy sector (e.g., set of full-scale energy demand-analysis scenarios and alternatives). This approach allows the user to better understand the main concepts, focusing on the electricity sector specifically, while keeping the analysis at a reasonable level of complexity. This case study exemplifies future development paths to the end as it explores low-carbon power supply options and electrification of end-use services which are expected to be one of the backbones of the energy transition.

*5.4.2.1. Description of the MESSAGE case study*

An illustrative power supply system is modelled in MESSAGE.

The energy (electricity) system — as modelled below — is comprised of a single node power supply system with various existing and potential generation options (including but not limited to nuclear power only). It is assumed that a certain number of cogeneration units are in operation to supply district heat. Such complexity opens a space for broader, inter-sectoral connections as it requires alternative heat supply technologies to be considered (for example electrical heat boilers, large scale heat pumps, etc.). The future energy systems are expected to be more integrated compared to an "isolated" operation (and planning) of sub-systems.

Final electricity and heat demand are introduced exogenously into the model. This implies that a specialized demand analysis has not been included into this case study. In reality, the user is strongly encouraged to conduct detailed demand studies to be able to identify a broad spectrum of low carbon options (scenarios), given that a number of policy objectives can be achieved through a demand side evolution.

The current portfolio of generating units consist of coal, natural gas, hydro, wind, peat and biomass (used mainly in cogeneration units) and nuclear power. Biomass is used in co-firing or as a fuel in power plants with the latest available technological solutions. Oil units are used as a backup (reserve) supply. The power system is well interconnected with neighbouring countries through several interconnection lines and the regional power market is well developed. In the energy system used for the MESSAGE case study, a relatively large share of electricity is imported — around 20% of the total needs.

The main energy and climate policy objective in this case study consists of reducing greenhouse gas emissions by 2050, an objective which is translated into an 85% emission reduction target for carbon dioxide from the power sector compared to the 2019 levels. Generating units are obliged to participate in a carbon emission allowances' trading scheme (i.e., they are obliged to buy allowances in the market). Coal and natural gas are imported; an excise duty (an additional tax) is applied to all fossil fuels to support a low-carbon transition.

Another important policy is a gradual reduction of reliance on electricity imports, from the current level of about 20% to a balanced domestic supply and demand by 2035. The latter assumption does not limit exchanges with neighbouring countries. Electricity imports and exports are still allowed within given technical limits of the tie-lines, but the net import-export balance is gradually reduced.

Future low-carbon power supply options include a continued use of biomass which replaces fossil fuels in cogeneration, large wind resources — on and off-shore —, solar with a rather low annual capacity factor due to geographical position and low irradiation levels, a remaining unused hydro component with a certain number of small-scale sites with run-of-river type facilities and nuclear power which has strong political and public support.

*5.4.2.2. Main assumptions*

*Planning horizon*

The planning horizon in this case study spans until 2050, whereas the starting year for simulations is set in 2019 — this is the so-called "historical" year which is used to calibrate the MESSAGE case study and represents a usual step in energy system modelling. An annual resolution is used until 2030, while the subsequent period is divided into 5-year steps. All costs are expressed in euros (EUR), with the reference year being 2019. The applied discount rate is set at 8%.

*Time Slices*

To capture temporal changes of certain parameters and variables — for example demand, prices, production patterns (capacity factors), storage operations (hydro and batteries) and others — each year in MESSAGE can be subdivided into seasons, day types and parts of a day.

Five seasons were defined based on the availability of hydro resources and seasonal variations in electricity and heat demand. Additionally, and to address variability and uncertainty of wind source, each season is sub-divided into three types of a day. They correspond to an expected occurrence of days with a very high wind generation, an average wind generation and a very low wind generation. Each day type is further subdivided into characteristic parts of a day based on electricity demand variations (e.g., morning and evening peaks, low demand during night) and availability of solar source.

*Commodities' prices*

Prices of various commodities used in the case study are assumed as presented in Table 10 below. Prices for hard coal, natural gas and crude oil were taken from the IEA World Energy Outlook 2020 (Sustainable scenario in Ref. [17]). Prices for $CO_2$ allowances are assumed to be in line with the assumptions used for EU NECPs (National Energy and Climate Plans). Other energy commodity prices (biomass, peat) are based on historical statistics.

TABLE 10. COMMODITY PRICES ASSUMED IN THE MESSAGE CASE STUDY

| | | Year | | | |
|---|---|---|---|---|---|
| Commodity | Unit | 2019 | 2030 | 2040 | 2050 |
| Nuclear | €/GJ | 0.34 | 0.34 | 0.34 | 0.34 |
| Coal | US $_{2019}$/tonne | 61.00 | 56.30 | 55.00 | 55.00 |
| Natural gas | US $_{2019}$/Mbtu | 6.70 | 4.80 | 4.90 | 4.90 |
| Crude oil | US $/barrel | 63.00 | 55.70 | 5.30 | 5.30 |
| Peat | €/MW·h | 13.30 | 16.30 | 16.30 | 16.30 |
| Biomass | €/MW·h | 58.80 | 58.80 | 58.80 | 58.80 |
| Electricity (import/export) | €/MW·h | 44.00 | 65.10 | 83.90 | 90.80 |
| $CO_2$ allowance | €/t$CO_2$ | 24.90 | 36.10 | 53.80 | 96.80 |

| Prices below are in €/MW·h at the fuel level (input of power unit or system), including excise duties (for coal, gas, oil and pear) | | | | | |
|---|---|---|---|---|---|
| Commodity | Unit | 2019 | 2030 | 2040 | 2050 |
| Nuclear | €/MW·h | 1.21 | 1.21 | 1.21 | 1.21 |
| Coal | €/MW·h | 39.64 | 35.17 | 34.34 | 34.34 |
| Natural gas | €/MW·h | 49.60 | 35.78 | 36.27 | 36.27 |
| Crude oil | €/MW·h | 53.00 | 46.40 | 44.20 | 44.20 |
| Peat | €/MW·h | 16.30 | 16.30 | 16.30 | 16.30 |
| Biomass | €/MW·h | 58.80 | 58.80 | 58.80 | 58.80 |
| Electricity (import/export) | €/MW·h | 44.00 | 65.10 | 83.90 | 90.80 |

In addition, to price changes over the planning period, electricity prices in the market change on a seasonal and intraday basis. Assumptions on variations were generated based on 2019 historical prices at NordPool day-ahead market.

*Technology data*

Each technology is characterized by technical, economic and environmental data. Technologies were grouped according to a fuel type (for primary forms of energy they include nuclear, coal, gas, oil, wind, peat, biomass, solar and wind), a status (existing and in operation, committed and candidates) and a technological process (for example, open and combined cycle gas units).

For all fuel types, appropriate IPCC (Intergovernmental Panel on Climate Change) emission factors are introduced[14].

Costs associated with a technology can be divided into the following categories:

— *Specific investment cost* are overnight costs of a technology (in EUR/kW) which include all costs required to construct and commission a power plant overnight. Overnight costs do not include project financing costs (IDC — interest during construction). IDC is calculated inside the model assuming a uniform distribution of overnight cost during the construction period. The user-defined discount rate is used to approximate the cost of capital.

— *Fixed operation and maintenance costs* are costs related to capacity of a technology, irrespective of its operation status (in EUR/kW per year), i.e., these costs exist even if the plant is not producing. Typical costs in this category are salaries of personnel, various fees for land (resource use), insurance, security and others.

[14] IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National, Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan

— *Variable operation and maintenance costs* are costs related to the production (operation) of a technology. Typical cost categories are water treatment and auxiliary systems, lubricants, royalties and others, excluding fuel costs which are accounted for separately.
— *Fuel costs* are costs related to fuel supply to the plant and can have various components (depending on the type of fuel and modelling approach — e.g., investments and other costs related to construction and operation of pipelines, mines, etc.). In the simplest form, fuel costs are expressed per unit of fuel supplied, assuming there is always enough quantity and capacity available to deliver it. In this analysis, total fuel costs are expressed in EUR per unit of fuel (simple representation).

#### *5.4.2.3. Scenario description*

The main approach in this analysis is to compare two energy system development scenarios:

— Reference Scenario (REF): Under this scenario, the nuclear option is excluded. Electricity demand is satisfied by other options, including electricity imports.
— Alternative Scenario (ALT): Under this scenario, the nuclear power plant is commissioned in 2028.

Other elements of the case study remain unchanged under the two scenarios: in particular, the same energy demand (provision of the same service level), assumptions on specific investment costs, fuel costs, emission reduction targets, maximum exploitable levels of some technologies (the same resource base), maximum penetration or expansion levels for all technologies, maximum electricity exchange levels and others. This approach guarantees that major differences between both scenarios will be reflected in capacity structure (changes in investment's volumes and dynamics) and generation structure (changes in fuel types and structure of generation costs).

#### *5.4.2.4. Scenario results*

Results for above defined scenarios REF and ALT are reported for the following variables:

— *Objective Function Value* is a discounted sum of all costs occurring during the planning horizon (construction cost, operational cost, penalties and taxes). During an optimization process, the objective function value is minimized so that the model will identify the least cost solution(s) which fulfils all user's defined constraints and parameters. This solution assumes ideal market conditions, i.e., in practice it is not possible to reach better solution (under given constraints).
— *Installed capacity* is a structure of existing and new capacities for each year (by fuel type).
— *Electricity generation* or structure of electricity supply (generation, imports and exports, transmission and distribution losses) for all years (by fuel type) and resulting fuel quantities used for generation.
— *Costs* encompass the following categories:
  - Investment costs and investment schedule for all years (by fuel type);
  - Fixed operation and maintenance costs for all years (by fuel type);
  - Variable operation and maintenance costs for all years (by fuel type);
  - Fuel cost for all years (by fuel type);
  - $CO_2$ related costs (cumulative payments for emission allowances);
  - Average generation/supply cost (calculated outside of the MESSAGE).

*Objective Function Value*

Objective function values for no-nuclear (REF) and nuclear (ALT) options are very close as presented in Table 11.

TABLE 11. COMPARISON OF OBJECTIVE FUNCTION VALUES IN REF AND ALT SCENARIOS.

| Scenario | Billion € | | Million EUR | % relative to REF |
|---|---|---|---|---|
| | REF | ALT | REF-ALT | REF-ALT |
| | No Nuclear | Nuclear | Difference | Difference |
| Objective function | 104.519 | 105.020 | 501.5 | 0.48 |
| Annualised value | 41.81 | 42.01 | 200.6 | 0.48 |

Over a 30 years' planning period, nuclear option is 0.5% more expensive than a no-nuclear option, equivalent to around 500 million EUR (discounted at 8% discount rate).

*Installed Capacity*

The total installed capacity (TIC) for the scenario REF is presented in the Figure 62. The exemplary energy system which is under consideration in this case study already operates nuclear power units; another unit is scheduled for commissioning in 2022 (committed project), while no additional nuclear power plants are planned before 2035.

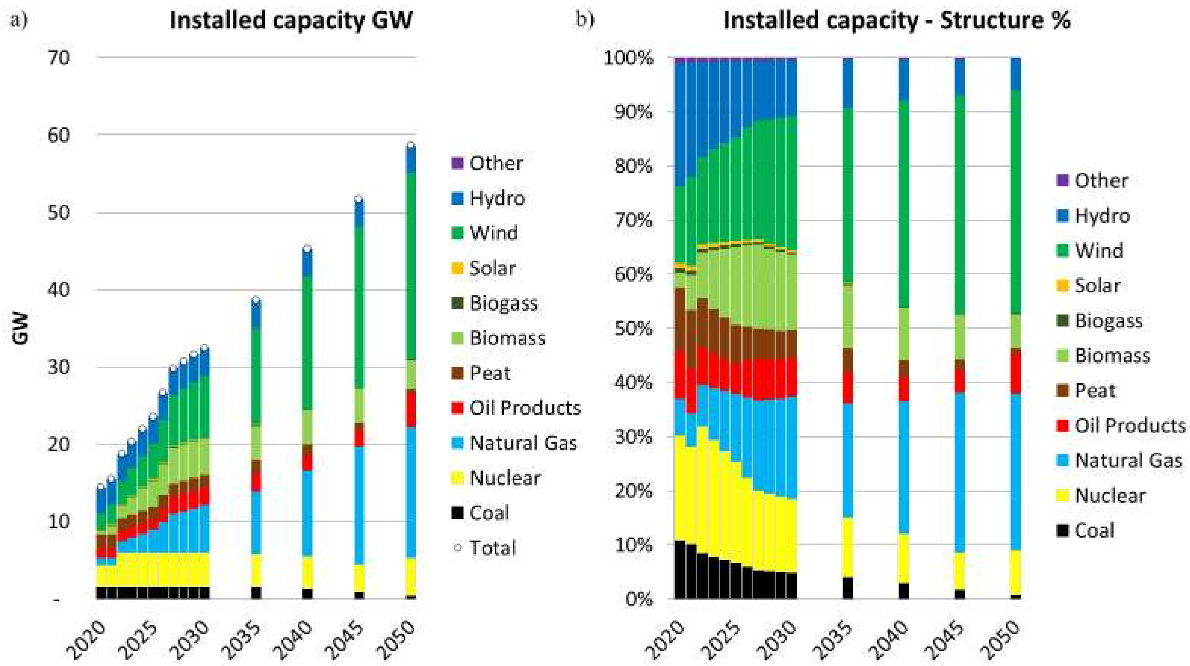



*FIG. 62. Installed capacity in GW (a) and share (b) — Scenario REF (a no-nuclear option).*

Due to the requirement of a reduced net dependency on imported electricity, new production units are constructed, mainly wind and gas power. As carbon emissions need to be reduced gradually, more wind power plants are constructed. Coal power plants are not further developed, and the current fleet is gradually decommissioned. Peat in cogeneration is gradually replaced by biomass, whereas more large-scale electrical boilers and heat pumps are installed towards the end of the planning horizon. An increase in gas and oil capacities is due to the need to have backup (reserve) capacity during days (hours) with low wind generation.

TIC increases from 14.3 GW in 2019 to 58.7 GW in 2050. At the same time, peak load increases from 14.9 GW to 27.6 GW, meaning total system reserve in 2050 reaches 112% (not taking into account capacity credit estimates). The share of renewables in TIC increases from 41.1% to 53.5%, while variable renewables (wind and solar) raise from 15.2% to 41.1% by 2050.

Total installed capacity for scenario ALT is comparable to the scenario REF (Figure 63). The main differences become visible when new nuclear units are commissioned in 2028. The REF scenario has in contrast more capacities installed in gas and wind power (Figure 64).

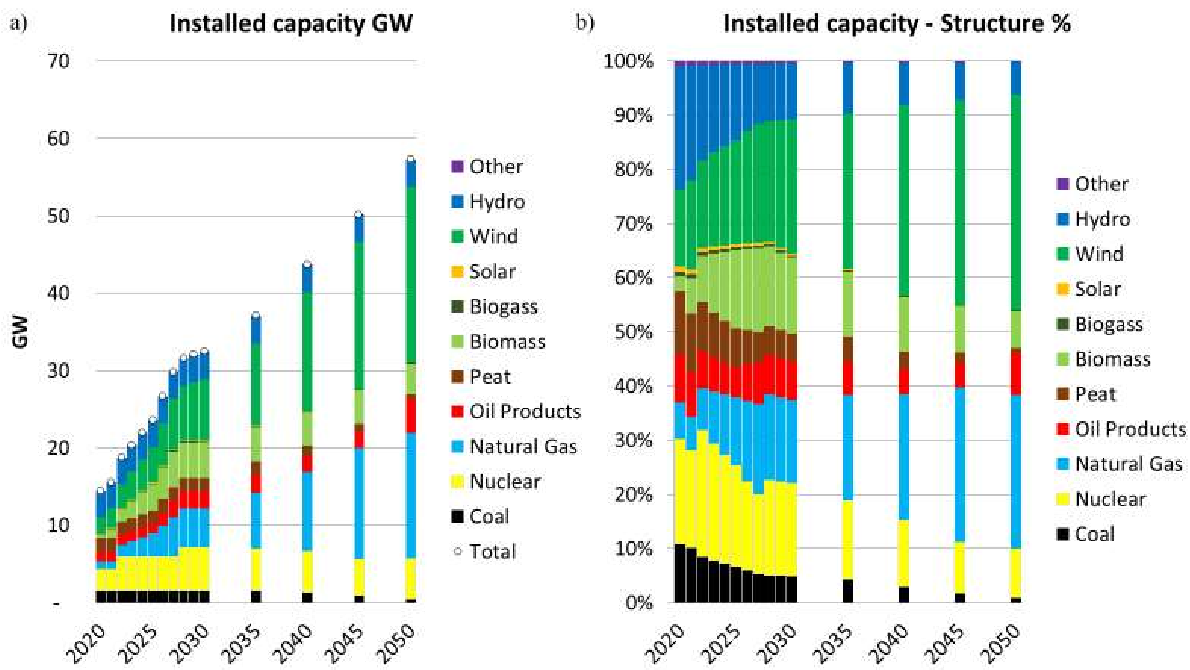



*FIG. 63. Installed capacity in GW (a) and share (b) — Scenario ALT (with nuclear power from 2028).*

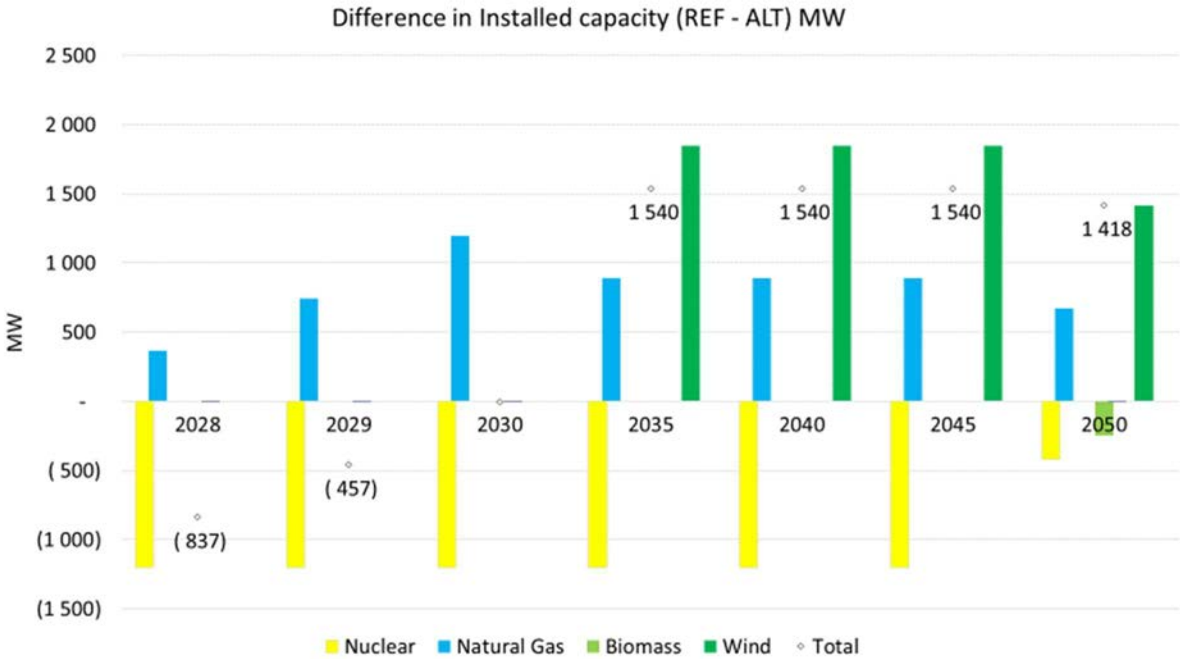



*FIG. 64. Differences in total installed capacity between REF and ALT scenarios.*

*Electricity Supply and Generation*

Electricity generation is projected to increase, due to an increase in demand and due to a reduced reliance on imports. As emission reduction targets are gradually introduced, future supply is dominated by low carbon options such as wind, hydro and biomass.

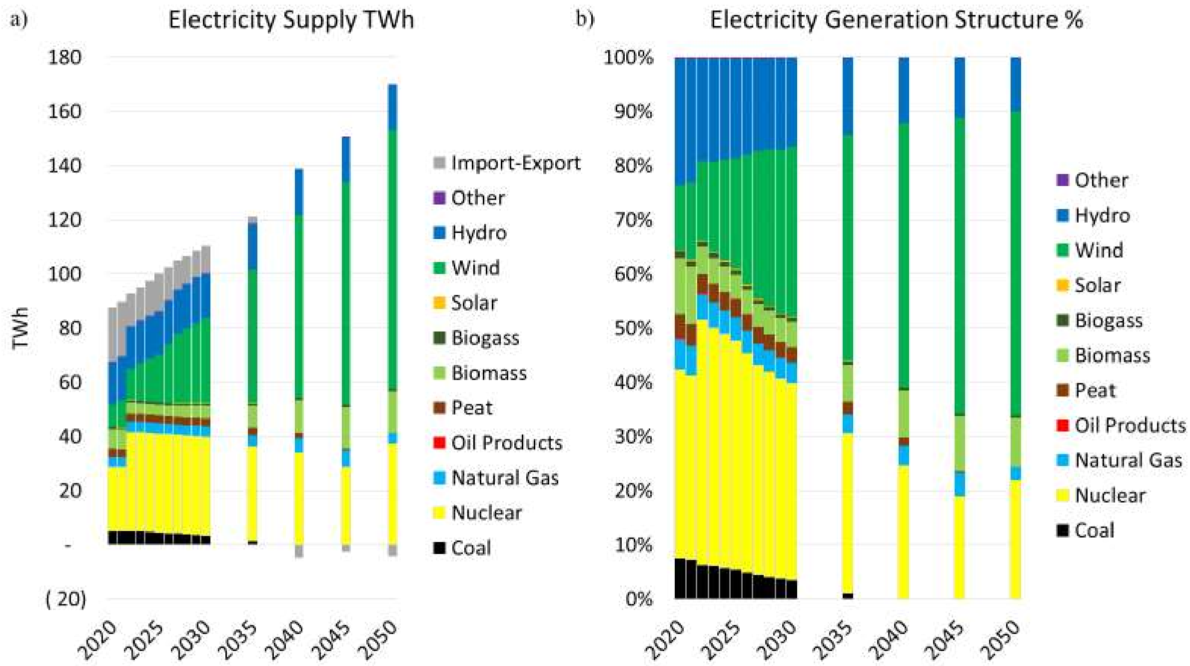



*FIG. 65. Electricity supply (a) and generation in TW·h (b) — Scenario REF.*

The share of nuclear generation is reduced as capacity is not extended beyond the current level (besides one unit which is committed for 2022) — from 27.4% in 2019 to 22.6% in 2050 in total electricity supply. The share of renewables in the total power supply increases from 35.0% in 2019 to 77.6% in 2050. Over the same time frame, the share of variable renewables increases from 7.1% to 57.7%. The capacity factor of the gas power plants is rather low because these units are mainly installed as a backup (reserve) capacity (Figure 65) and used to supply demand during low wind hours.

The main differences in generation patterns between nuclear and non-nuclear scenarios can be observed in Figure 66 with respect to imports, exports and wind generation. In the ALT scenario (with nuclear power), electricity imports are practically terminated when a nuclear unit becomes operational in 2028; there is also less of wind generation from 2035 onwards (no need to construct new units as nuclear provides supply). The share of renewables in total supply remains high, but slightly lower than in the REF scenario, whereas nuclear power makes one fourth of total supply in 2050.

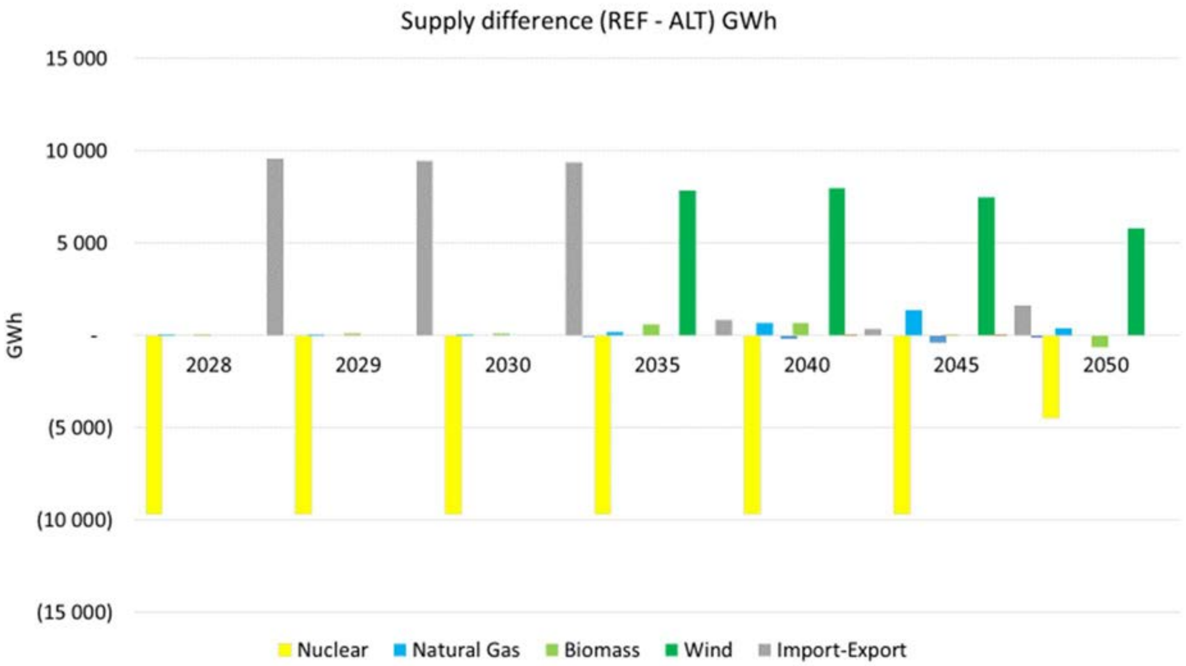



*FIG. 66. Difference in electricity supply patterns between REF and ALT scenarios.*

*Costs*

Total investment into energy system (by fuel type) for both scenarios are presented in Figure 67 which depicts investments into parts of district heating (heat pumps and boilers) and batteries. The level of investments in both scenarios is similar — 110.3 billion EUR in scenario REF (105.3 billion EUR for power supply only), and 111.3 billion EUR for ALT (107.0 billion EUR for power supply part).

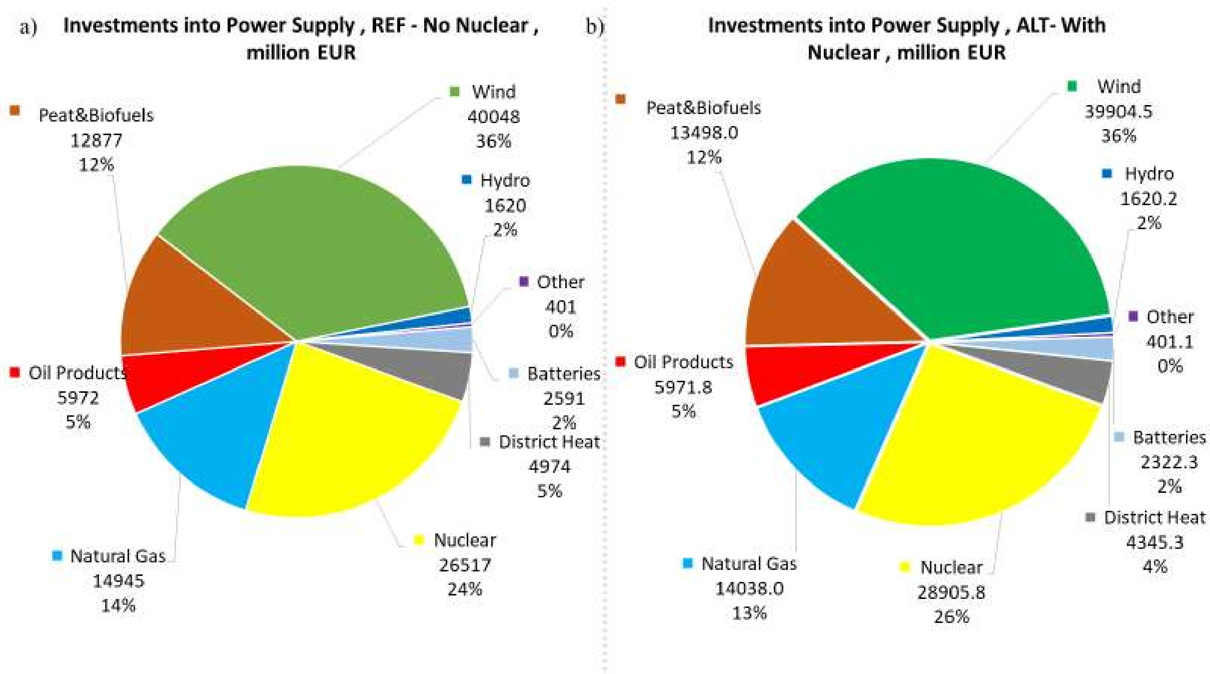



*FIG. 67. Investments into power supply technologies over the planning period — Scenarios REF (a) and ALT (b).*

Average supply costs are calculated based on annualized investments, operation and maintenance costs, fuel costs as well as emission allowances costs, assuming 8% discount rate (Figure 68).

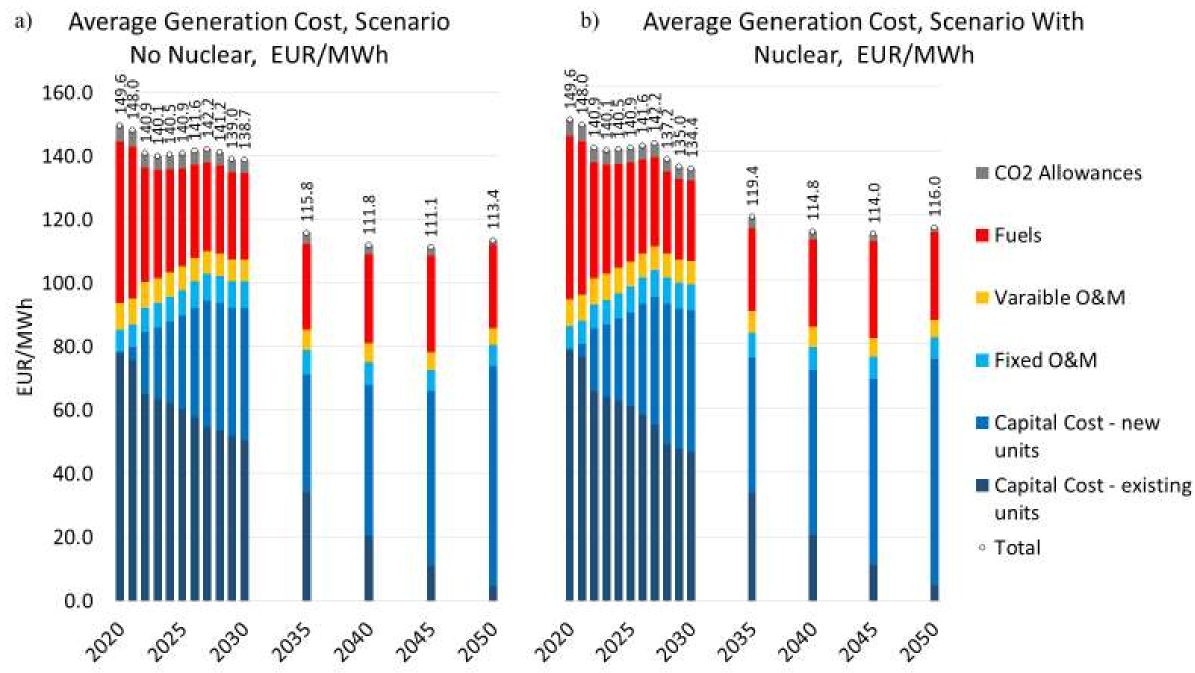



*FIG. 68. Average generation costs without nuclear — Scenarios REF (a) and ALT (b).*

The structure of overall generation cost in both scenarios changes towards a higher share of fixed costs (investment cost and fixed O&M costs) as presented in Figure 69. By the end of the period, roughly 70% of the generation costs are fixed in both scenarios.

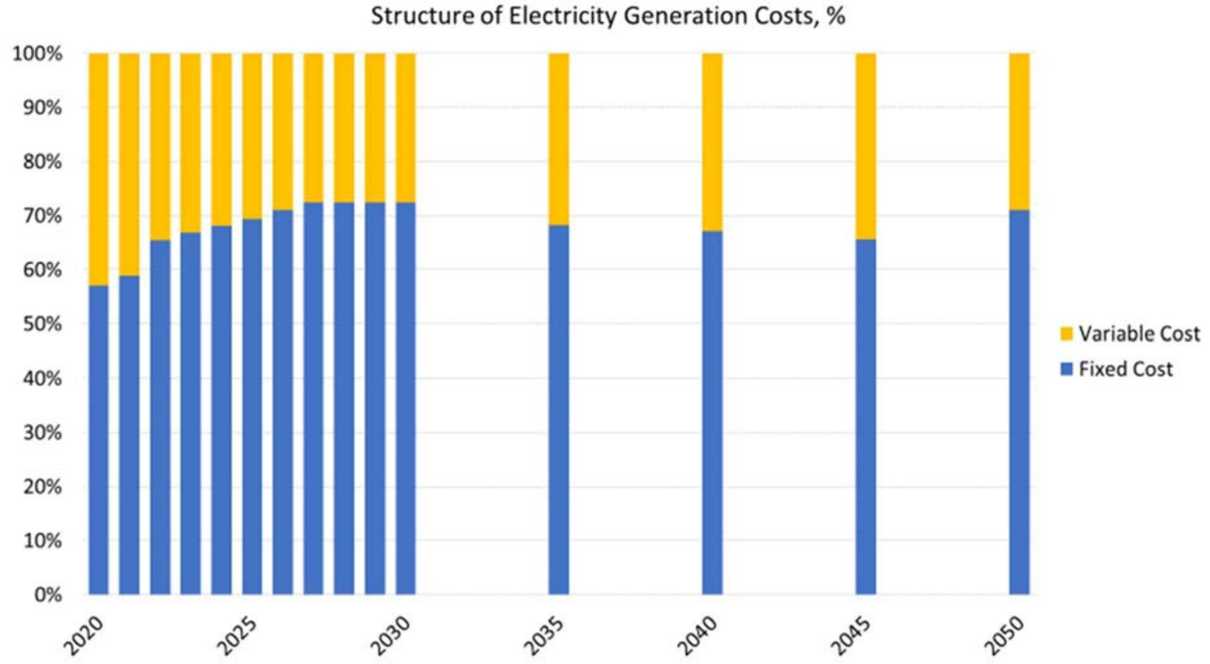



*FIG. 69. Structure of electricity generation costs — fixed and variable components.*

*Carbon Dioxide Emission*

In terms of $CO_2$ emissions, both scenarios achieve 83% of reduction by 2050 relative to the 2019 levels. Carbon intensity of electricity generation is reduced from 208 g/kW·h in 2019 to below 50 g/kW·h by 2040 and reaches 13 g/kW·h in 2050.

*5.4.2.5. Recommendations on a MESSAGE case study and a results' preparation*

When developing energy system case study to be used as input for comparison of potential macroeconomic effects of energy strategies, the following recommendations might be helpful (assuming use of the MESSAGE tool):

*Planning periods — duration and resolution (annual vs. multi-annual approach)*

— The MESSAGE case study covers 30 years, whereas the recommended duration of analysis (construction and operation phases) in EMPOWER is limited to 25 years. The user needs to include the entire construction period in an energy case study. In the case study presented in this Section, an additional nuclear unit becomes operational in 2028, preceded by a 7-year construction period.

— EMPOWER requires input data to be in annual resolution, whereas it is common for long-term energy studies that a distant future to be represented in steps of several years (for example 5-year steps beyond the 2030 horizon). To be consistent, MESSAGE results need to be prepared for inclusion into EMPOWER by interpolating values for the years in between. Alternatively, the user can develop a MESSAGE case study with an annual resolution. Depending on the case study size (level of details), this might result in a longer execution time of MESSAGE runs.

*Investment schedule (uniform vs. non-uniform distribution)*

— Based on the investment schedule identified by the MESSAGE simulation, the user needs to provide inputs for EMPOWER and distribute investments across the

construction phase on an annual basis. The original MESSAGE output results show lump sum investment attached to the period/year immediately before facility enters operation. The user needs to convert those values into annual contributions.
— By default, MESSAGE assumes uniform distribution of investments during the construction phase. This assumption is incorporated at the level of an objective function definition. Therefore, the user needs to uniformly distribute lump-sum investments across the entire construction period. EMPOWER is flexible to process the investment distribution in both a uniform and non-uniform manner. In the case where the user seeks to use a construction schedule other than in a uniform manner, appropriate recalculations need to be done when preparing input data for MESSAGE, and in order to have harmonized data inputs for EMPOWER.

*Existing generation capacities*

— Existing (historical) capacities are considered in MESSAGE, including a vintage schedule during the planning period. However, as investment in those were in the past, that cost component is not available (this does not influence results of simulation as sunk cost cannot change the outcome of the optimization). To provide complete inputs to EMPOWER, the evaluation of an average generation (supply) cost is needed. The user needs to collect information on existing capacities, original investment costs and lifetime which is not always straightforward to obtain (due to partial or full refurbishments, life extensions, unknown or unavailable data, discount rates, etc.). Based on these data and experts' judgment, a past investments' profile and annualized values together with an average generation (supply) cost need to be assessed for the entire planning period and passed onto EMPOWER.
— The user needs to prepare the evaluation of an average generation (supply) costs with and without investment (capital) part of costs so that appropriate calculations can be done in EMPOWER (e.g., assumption on the source of finance — from electricity prices or from other sources like budget or taxes).

*Number of technological groups*

— The current version of EMPOWER offers a certain number of technological groups to be processed (e.g., power plants grouped by fuel, primary energy type or technology type). The MESSAGE tool allows various types of technologies (activities) to be (dis)aggregated. These can be done in a more detailed way than in EMPOWER framework and then re-grouped before MESSAGE results are passed on for macroeconomic analysis. While having more detailed data sets is always an interesting option, users will often face issues in identifying (collecting) suitable input data (e.g., data on distribution of investment into certain technological option across the economic sectors).

### 5.4.3. File "MESSAGE input for EMPOWER"

An additional file "EMPOWER_MESSAGE_INPUT" has been designed to process MESSAGE outputs for EMPOWER. As described above, two scenarios — labelled as REF and ALT — have been developed in MESSAGE. However, EMPOWER will run on a 'difference' in terms of construction and operation costs, as determined in ALT and REF scenarios, rather than on individual scenarios.

The first step in this file is to manually copy the results of two MESSAGE scenarios (REF and ALT) into the sheets “Input REF” and “Input ALT”. The user is asked to fill data on electricity generation, investment costs, fixed operation costs, variable operation costs, fuel costs, net imports (imports less exports), emission costs and average generation as well as supply costs per unit MW·h. These categories are specified for 9 electricity generation classes; related costs — investment and operation — of interconnection lines, battery capacities, electrical boilers and heat pumps can be added. The time horizon is set to up to 32 years.

Costs reported in MESSAGE and EMPOWER needs to refer to the same currency. To establish the consistency, the user defines an exchange rate in the Sheet “Set currency” between the currency used in MESSAGE and the currency used in the IOT. The user needs to search for some advice from national authorities on the appropriate exchange rate; the simplest way is to use the most recent available average annual exchange rate and apply it uniformly over the entire time horizon.

The next step is to define the years covering construction and operation phases in the Sheet “Set Years”. The time span is limited to 12 years for each phase as in EMPOWER. The graph illustrates differences between the REF and ALT scenarios for investment expenditures and electricity generation. The blue highlighted areas indicate covered years and serves as an additional piece of information.

All remaining Sheets with tabs in light blue visualize inputs provided in this file: the values used in the REF and ALT scenarios as well as their difference (ALT minus REF) for construction costs (Construction), operation costs (Operation, Operation_FixCosts, Operation_VarCosts), unit costs of electricity generation (Prices) and fuel costs (Operation_FuelCosts).

The Sheets “Out_Con” and “Out_Om” contain collected data to be transferred to EMPOWER. In the Sheet “Check”, potential problems are identified and flagged in form of “Warnings” and “Errors”. As before, “AdminTut” comprises the text and position of the tutorial; “AdminCalc” contains the background calculations for “Check”. Two last Sheets are “frozen” in the default version.

### 5.4.4. How to include MESSAGE results in EMPOWER

The prepared MESSAGE outputs can be now loaded into file “EMPOWER_MESSAGE_INPUT” by clicking the button “Load MESSAGE results” at the top of Sheet “Operation Energy (A)”. All inputs are automatically filled with MESSAGE results.

Further steps are identical to those which have been discussed in the case study *NUC*, in particular with respect to the files “EMPOWER_STEP4_SCENARIO”, “EMPOWER_STEP5_MASTERFILE” and “EMPOWER_STEP6_VISUALIZATION”. The latter exports and visualizes main results for construction and operation phases independently.

### 5.4.5. Results and interpretation

*5.4.5.1. Construction phase*

Unlike the results in the case study *NUC*, impacts on GDP in Figure 70 follows a more heterogenous pattern, positive but decreasing between 2021 and 2027 and negative for 2028-2029. The investment pattern — defined as a difference between the two investment paths (ALT minus REF) — for the entire period drives this outcome. Similar to the case study *NUC*, a uniform distribution of investment expenditures is applied for the period until 2027.

The absolute impact of the additional investment stays constant between 2021 and 2024 (Figure 70) but starts declining in 2025 due to the algorithms used in MESSAGE and the assumption of unchanged domestic electricity demand which leads to less investments in other energy technologies. The major driving factor behind this is reduced investment levels in natural gas power plants which counteracts a positive impact of nuclear construction activities until 2027 and even turns into a negative deviation from the reference path in 2028-2029 when construction activities stop. In relative terms, the declining pattern is more pronounced because the economy grows between 2021 and 2029 (Figure 70).

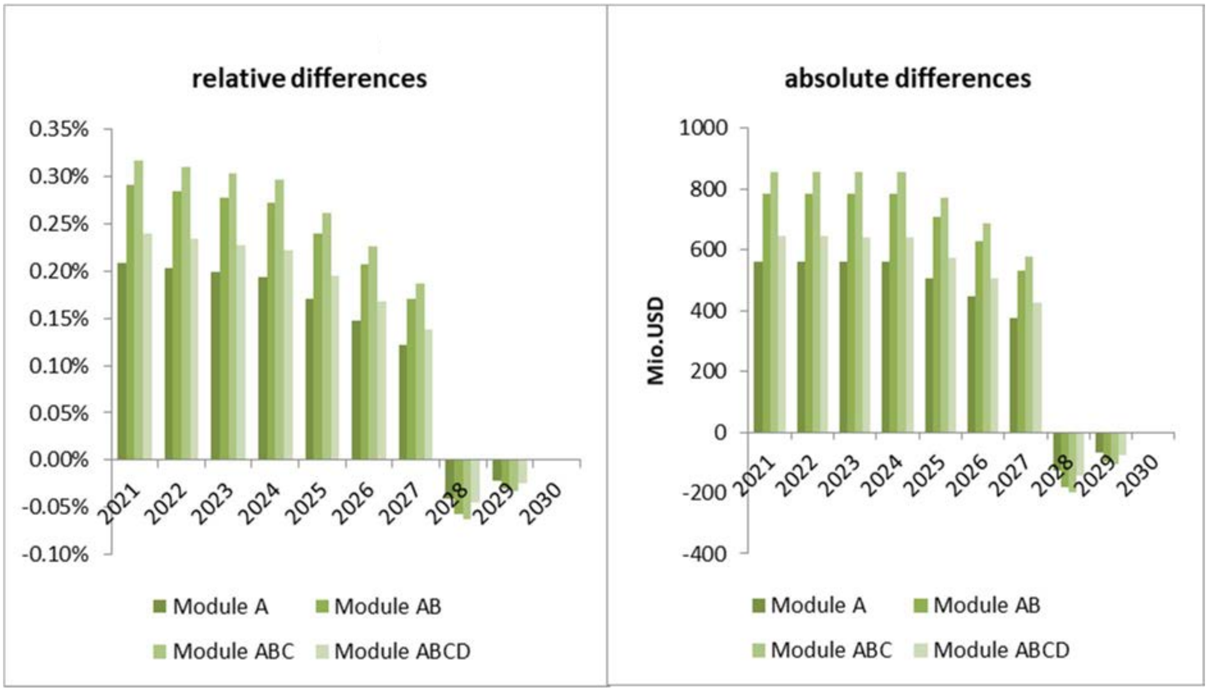



*FIG. 70. Impacts on GDP during construction phase (current prices) — Case study ENE.*

In submodules AB and ABC, nominal impacts are larger than in submodule A because of induced consumption and increasing wages. The results in submodules AB and ABC demonstrate an importance to account for induced effects and labour market interactions. The wage increases due to the labour market interactions which lead to higher production costs[15] and thereby a production price increase throughout the economy. Hence, in constant prices (Figure 71), those effects are smaller given that the overall price level increases reduce available income. In submodule ABCD, 30% of investment costs are to be financed by increased income taxes during the construction phase which significantly reduces GDP impacts.

[15] In EMPOWER is assumed that an increase in labour costs is to 100% transferred to production costs.

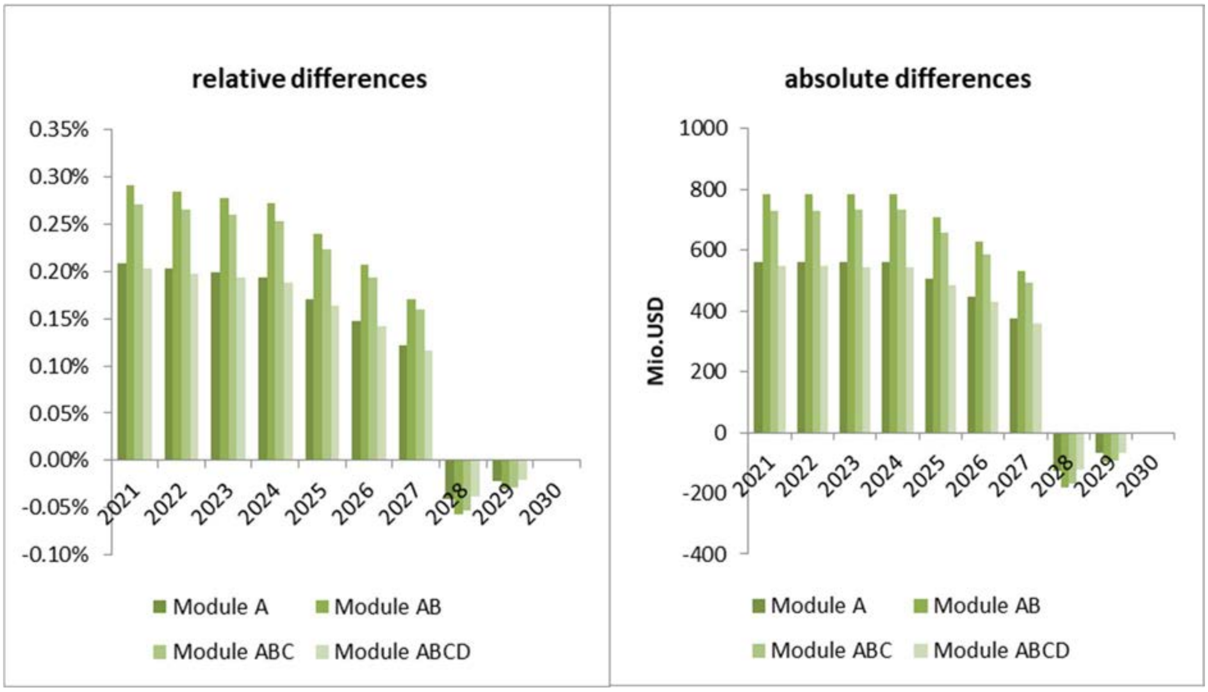



*FIG. 71. Impacts on GDP during construction phase (constant prices) — Case study ENE.*

The sectoral employment impacts are drawn on the example of submodule ABCD (Figure 72). As expected, amongst the five most positively affected sectors (marked in green) are the construction sector and financial and insurance activities. The production output and consequently employment in sectors of the public administration and education decrease due to declining private consumption which follows the power plant investment financing structure (via increased taxes).

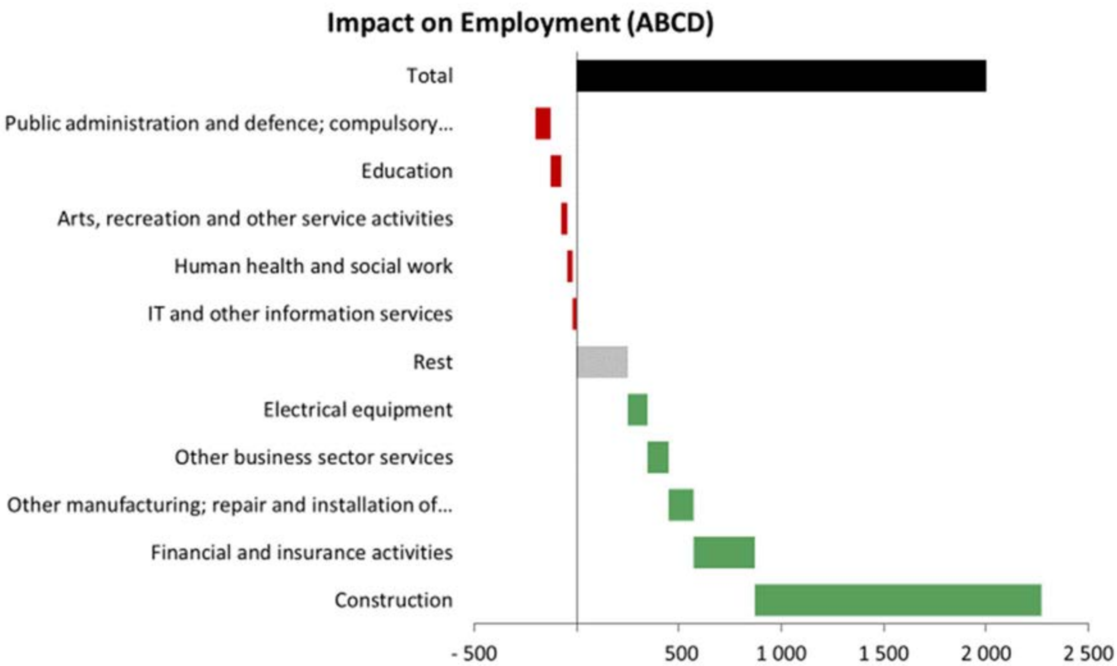



*FIG. 72. Impacts on sectoral employment during construction phase — Case study ENE.*

#### 5.4.5.2. Operation phase

With respect to the operation phase, positive but declining effects are reported in Figure 73 and 75, respectively. Similar to the NUC case study, the key impact on GDP stems from the contribution of export activities (below). The largest impact at both current and constant prices occurs during the first years of operation when the revenues from exported electricity are highest (Figure 73 and Figure 74). As explained above, the optimization algorithm in MESSAGE reduces investment levels in other technologies in comparison to the reference scenario which leads to lower electricity production and export revenues in the following years. The GDP impact decreases and stabilizes at relatively low levels beyond 2035.

Induced effects — as reported in submodule AB — are not likely to boost economic growth during the operation phase. The new electricity generation based on nuclear power forces the utilities using biomass and/or wind power to reduce the output. The latter reduces the overall employment in the electricity sector and along the supply chain, especially for biomass and its transport. Less employment means less disposable income and ultimately less consumption at the aggregated level. This effect is large enough to reduce the GDP impact slightly at the beginning and significantly at the end when the electricity production by biomass is 5% less than in the reference scenario.

In the NUC case study, the impact on GDP in submodule ABC is typically higher than in submodule AB. This is not the case after 2034 in Figure 73. The reason is that the employment effect is negative in this period, due to the decreasing demand for biomass. The negative employment effect reduces wages and consequently disposable income. Hence, the impact in ABC is less than that in submodules A and AB. The financing in submodule ABCD further reduces the GDP impact in current prices.

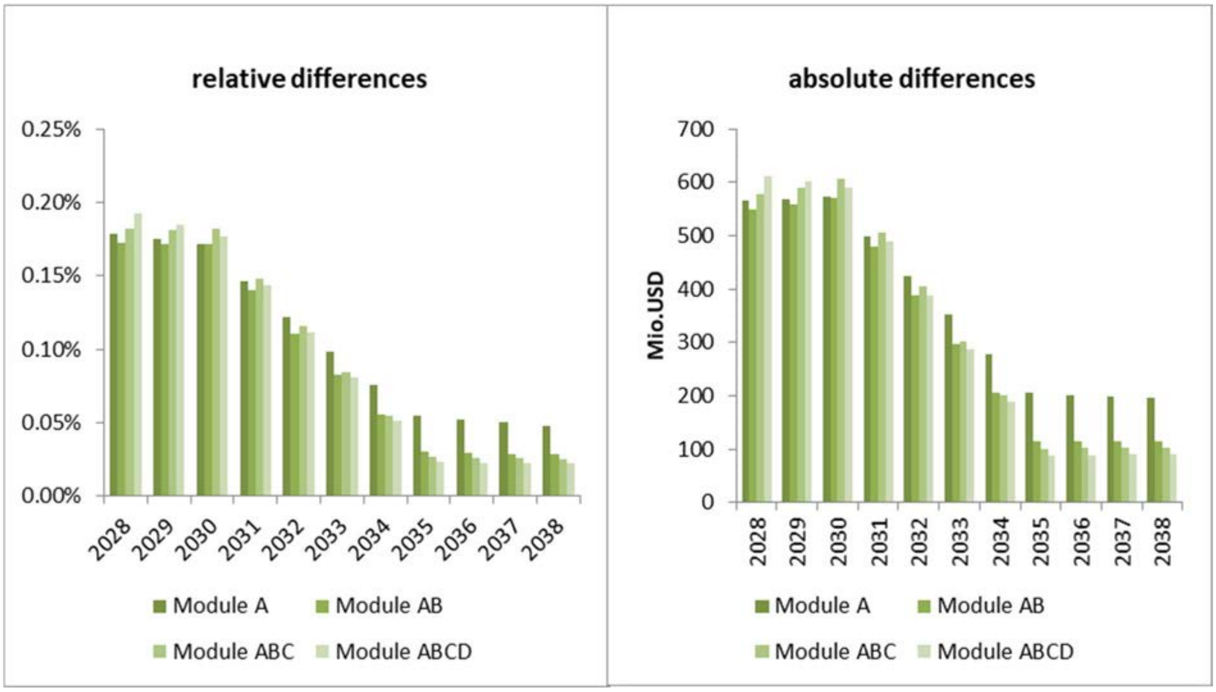



*FIG. 73. Impacts on GDP during operation (current prices) — Case study ENE.*

Because the supply price of electricity decreases in submodules A, AB and ABC, the GDP impact at constant prices is higher than at current prices. In submodule ABCD, the financing via an electricity supply price mark-up significantly reduces the GDP impact (Figure 74).

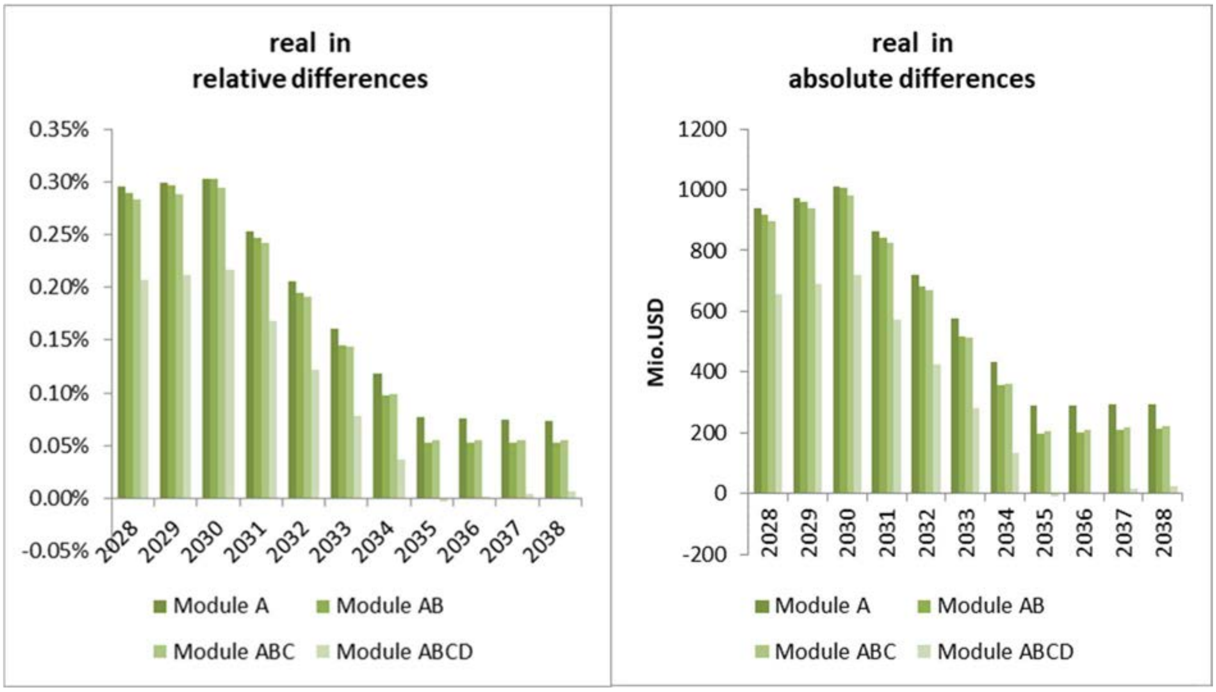



*FIG. 74. Impacts on GDP during operation (constant prices) — Case study ENE.*

Impacts on exports at constant prices are reported in Figure 75. Following a rise during the first years of operation due to lower prices, export levels begin to drop from over 700 million US $ to less than 100 million US $ beyond 2035. The latter effect is rooted in decreased levels in domestically produced natural gas-based electricity which reduces export levels to satisfy domestic demand. The mark-up on electricity to finance 40% of overall investments constrains the comparative advantage and reduces export revenues in comparison to submodules A, AB and ABC.

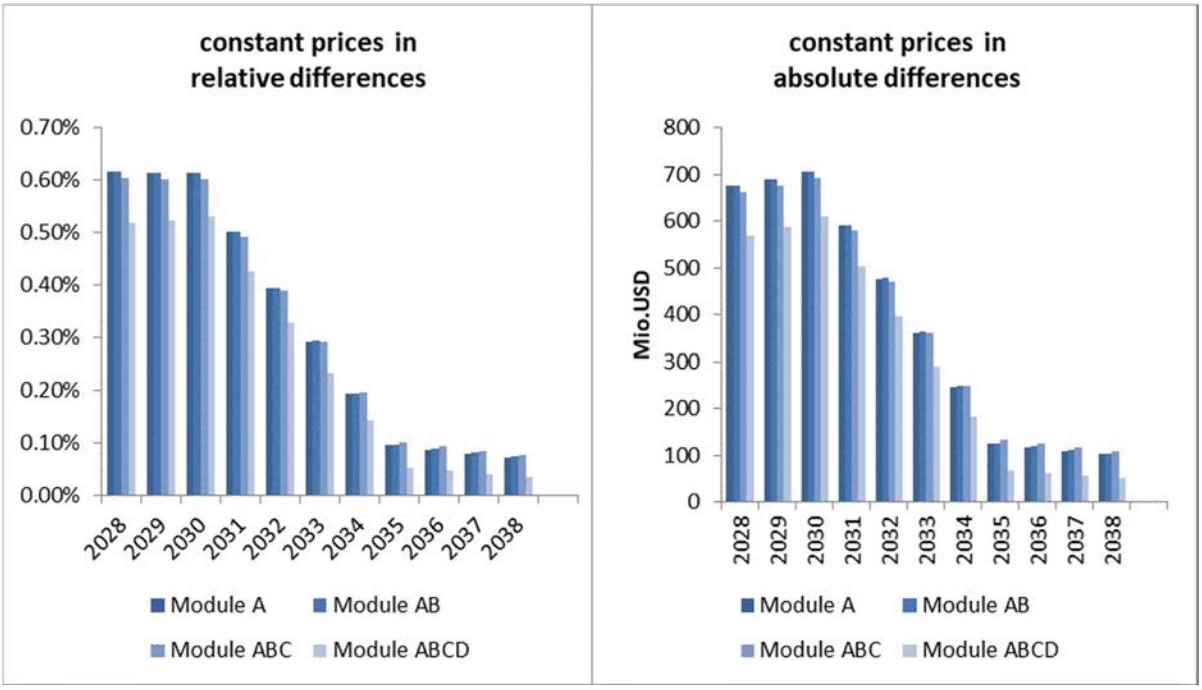



*FIG. 75. Impacts on exports during operation (constant prices) — Case study ENE.*

The sectoral employment impacts are reported in Figure 76. The overall impact on employment deviates significantly from the results in the case study NUC. The main reason is the reduction in electricity generation by technologies other than nuclear, particularly natural gas and biomass. In particular, the decline in biomass fuel demand causes a loss of employment in the sectors “Agriculture, Forestry and fishing” and “wood and products of wood” (marked red in Figure 76).

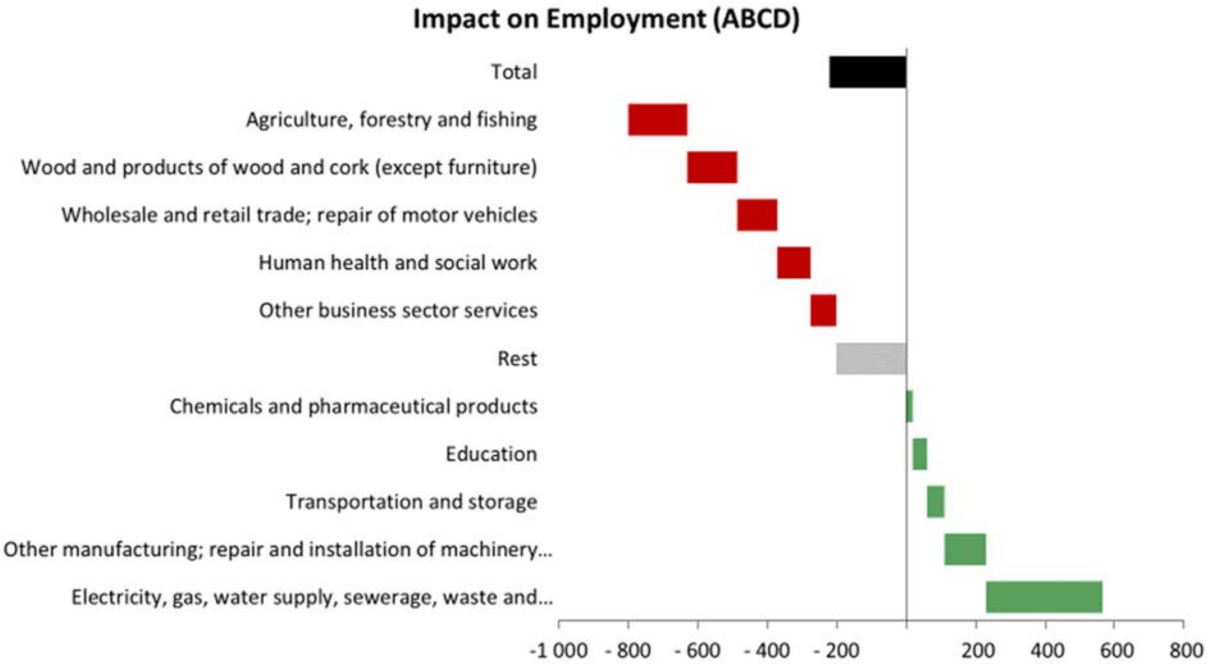



*FIG. 76. Impacts on sectoral employment during operation — Case study ENE.*

# SUMMARY

Investments in energy infrastructures tend to stimulate construction, manufacturing, engineering services, generating economic growth across a wide range of economic sectors beyond the project's boundaries. The labour market, for instance, is impacted by direct, indirect and induced (or "spillover") effects, which can be estimated and quantified, as illustrated in the joint report of the Nuclear Energy Agency and the International Atomic Energy Agency that studied the employment effects of nuclear energy programs [1]. This report provided a description of a macroeconomic assessment tool (EMPOWER) developed in the context of a Coordinated Research Project [5] covering the topic.

Following the introductory the background, objectives and scope of this publication, Section 2 presented an introduction to the quantitative frameworks of macroeconomic impact analyses of nuclear energy programmes. It included a concise presentation of the Agency's EMPOWER model in technical (mathematical) and non-technical terms (Rev. 7). Section 3 detailed the implementation of the model based on the integrated Visual Basic for Applications. Section 4 explained individual steps related to the data transfer, scenario definition and result calculation by using Excel's built-in tools. Section 5 presented an illustrative analysis of macroeconomic impacts at the national level and detailed how EMPOWER could be applied for two cases: investment into a single energy technology (nuclear energy) and investment into a comprehensive energy strategy. It provided recommendations for the application of EMPOWER, particularly related to the data requirements and results' interpretation. Based on a defined set of data and further assumptions, EMPOWER simulated the impact on GDP, domestic production activities, employment and several other economic indicators for each year of defined construction and the operation phases.

.

## REFERENCES


[1] INTERNATIONAL ATOMIC ENERGY AGENCY, OECD NUCLEAR ENERGY AGENCY, Measuring Employment Generated by the Nuclear Power Sector, NEA No. 7204, OECD Publishing, Paris (2018).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Milestones in the Development of a National Infrastructure for Nuclear Power, IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 1), IAEA, Vienna (2015).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Tools and Methodologies for Energy System Planning and Nuclear Energy System Assessments, IAEA, Vienna (2009).

[4] KRATENA, K., SOMMER, M., An Extended Input-Output Model for Impact Assessment of Nuclear Power Plants (EMPOWER II), unpublished report.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessing National Economic Effects of Nuclear Programmes: Final Report of a Coordinated Research Project, IAEA-TECDOC-1962, IAEA, Vienna (2021).

[6] MILLER, R., BLAIR, P.D., Input-Output Analysis, Foundations and Extensions, Cambridge University Press, New York, NY (2009).

[7] EUROPEAN COMMUNITIES, INTERNATIONAL MONETARY FUND, ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, UNITED NATIONS AND WORLD BANK, System of National Accounts 2008, ISBN 978-92-1-161522-7, New York (2009).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Technology and Economic Development in the Republic of Korea, Non-serial Publications, IAEA, Vienna (2009).

[9] KRATENA, K., et al., FIDELIO 1 – Fully Interregional Dynamic Econometric Long-term Input-Output Model for the EU27, JRC Scientific and Policy Reports, JRC81864, European Commission Joint Research Centre Institute for Prospective Technology Studies, Seville (2013), https://publications.jrc.ec.europa.eu/repository/bitstream/JRC81864/lfna25985enn.pdf.

[10] UNITED NATIONS, "Handbook on Supply and Use Tables and Input Output-Tables with Extensions and Applications, Department of Economic and Social Affairs, Statistics Division, Series F No.74, Rev.1," United Nations, New York, NY (2018).

[11] UNITED NATIONS, International Standard Industrial Classification of All Economic Activities (ISIC), Rev.4, Statistical Papers Series M No. 4, Rev.4, United Nations, New York, NY (2008).

[12] INTERNATIONAL ENERGY AGENCY, NUCLEAR ENERGY AGENCY, Projected Costs of Electricity Generation – 2020 Edition, Paris, 2020..

[13] OECD, Labour force (indicator) (2021), https://www.oecd-ilibrary.org/content/data/ef2e7159-en.

[14] OECD, Input-Output Tables (IOTs) (2021), https://www.oecd.org/sti/ind/input-outputtables.htm.

[15] INTERNATIONAL ENERGY AGENCY, OECD NUCLEAR ENERGY AGENCY, Projected Costs of Generating Electricity: 2020 Edition, OECD Publishing, Paris (2020).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, MESSAGE Model of Energy Supply Strategy Alternatives and their General Environmental Impacts, User Manual (DRAFT), Vienna 2007.

[17] INTERNATIONAL ENERGY AGENCY, World Energy Outlook 2020, OECD Publishing, Paris (2020).

## LIST OF ABBREVIATIONS

| | |
|---|---|
| CGE | computable general equilibrium |
| CRP | coordinated research project |
| EMPOWER | Extended Input-output Model for Sustainable Power Generation |
| FTE | full-time equivalents |
| GDP | gross domestic product |
| IDC | interest during construction |
| IEA | International Energy Agency |
| IO-E | econometric input-output model |
| IOM | input-output model |
| IOT | input-output table |
| NEA | Nuclear Energy Agency |
| NPP | nuclear power plant |
| OECD | Organisation for Economic Co-operation and Development |

## CONTRIBUTORS TO DRAFTING AND REVIEW

| | |
|---|---|
| Alexeeva, V. | International Atomic Energy Agency |
| Sommer, M. | Austrian Institute of Economic Research |
| Tot, M. | International Atomic Energy Agency |
| Dardour, S. | International Atomic Energy Agency |
| Kratena, K. | Centre of Economic Scenario Analysis and Research |
| Swainson, I. | International Atomic Energy Agency |
| Subbotnitskiy, D. | International Atomic Energy Agency |
| English, E. | International Atomic Energy Agency |
| Van Heek, A. | International Atomic Energy Agency |

IAEA
International Atomic Energy Agency

No. 27

# ORDERING LOCALLY

IAEA priced publications may be purchased from the sources listed below or from major local booksellers.

Orders for unpriced publications should be made directly to the IAEA. The contact details are given at the end of this list.

## NORTH AMERICA

***Bernan / Rowman & Littlefield***

15250 NBN Way, Blue Ridge Summit, PA 17214, USA
Telephone: +1 800 462 6420 • Fax: +1 800 338 4550
Email: orders@rowman.com • Web site: www.rowman.com/bernan

## REST OF WORLD

Please contact your preferred local supplier, or our lead distributor:

***Eurospan***

1 Bedford Row
London
WC1R 4BU
United Kingdom

***Trade Orders and Enquiries:***

Tel: +44 (0)1235 465576
Email: trade.orders@marston.co.uk

***Individual Customers:***

Tel: +44 (0)1235 465577
Email: direct.orders@marston.co.uk
www.eurospanbookstore.com/iaea

***For further information:***

Tel. +44 (0) 207 240 0856
Email: info@eurospan.co.uk
www.eurospan.co.uk

## Orders for both priced and unpriced publications may be addressed directly to:

Marketing and Sales Unit
International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22530 • Fax: +43 1 26007 22529
Email: sales.publications@iaea.org • Web site: www.iaea.org/publications

24-03837E

International Atomic Energy Agency
Vienna
www.iaea.org