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Assessing National Economic Effects of Nuclear Programmes

Final Report of a Coordinated Research Project

IAEA

International Atomic Energy Agency

ASSESSING NATIONAL ECONOMIC EFFECTS OF NUCLEAR PROGRAMMES

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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”.

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FINAL REPORT OF A COORDINATED RESEARCH PROJECT

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2021

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FOREWORD

Demand for clean, low carbon, sustainable energy continues to grow worldwide. Many countries consider nuclear power an important part of their response to the global energy and climate change challenge. An increasing number of IAEA Member States are considering adding nuclear power to their electricity generation portfolio or extending their current nuclear generation capacity to meet their electricity needs. The IAEA supports Member States with nuclear power programmes, as well as those that have decided or are planning to adopt nuclear power, in various ways. It also provides information for broader audiences engaged in energy, environmental and economic policy making.

Introducing or extending a national nuclear power programme raises a range of economic and financing issues. The decision to invest in a nuclear power plant has impacts that go beyond the project itself and even beyond the energy system boundaries. Energy investments in general, and nuclear energy investments in particular, tend to stimulate other economic sectors, such as construction, manufacturing and services, thus generating economic growth and creating new employment throughout the economy. It is therefore advisable to conduct a macroeconomic impact assessment to better understand how different technologies might affect a country's economy.

The IAEA encourages Member States to consider the compatibility of the potential impacts of a nuclear power programme with the country's overall goals for socioeconomic development. In addition to studies on energy demand and supply options, this requires macroeconomic assessment of the impacts of nuclear power on the national economy, measured by changes in gross domestic product, employment and other macroeconomic indicators.

In response to the growing number of Member State requests for assistance in this area, the IAEA developed the Extended Input–Output Model for Sustainable Power Generation (EMPOWER) to support macroeconomic impact analysis. It also initiated the coordinated research project entitled Assessing the National and Regional Economic Effects of Nuclear Programmes to support research teams in interested Member States in applying EMPOWER in their national studies of the economic impacts of nuclear power programmes.

This publication presents the outcomes of the coordinated research project. It provides a short description of the new IAEA model, presents concise summaries of its applications and the results produced by participating research teams, and summarizes the general insights drawn from the national studies. The publication illustrates the state of the art of assessing macroeconomic impacts of nuclear energy programmes using an innovative input–output model and other analytical tools adopted by the national teams. It is expected to support further the application of advanced models in more countries to improve the understanding of the macroeconomic and sectoral impacts of building and operating nuclear power plants.

The IAEA wishes to thank the experts involved in the research teams in participating Member States for their contributions. The IAEA officer responsible for this publication was V. Alexeeva of the Division of Planning, Information and Knowledge Management.

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1. INTRODUCTION

1.1. BACKGROUND

Due to the fast growing demand for energy, in particular electricity, in emerging economies and developing countries, an increasing number of countries are considering to adding nuclear power to their power generation portfolio. For over a decade, the IAEA has been providing integrated support for nuclear power infrastructure development to Member States that have decided or are planning to adopt nuclear energy to meet their electricity needs. Towards this end, the Agency has developed the Milestones Approach [1], a comprehensive guide for nuclear power programme development, and the related Integrated Nuclear Infrastructure Review service that help Member States assess the progress in developing their nuclear infrastructure and chart future activities.

The Milestones Approach supports countries in establishing an enabling environment for a successful nuclear energy programme as well as to consider and make the associated commitments and obligations. The approach consists of three consecutive phases: (i) considerations before a decision to launch a nuclear power programme is taken; (ii) preparatory work for the contracting and construction of a nuclear power plant (NPP) after a policy decision has been taken; and (iii) activities to implement the first NPP. Each phase leads to a specific milestone: (i) ready to make a knowledgeable commitment to a nuclear power programme; (ii) ready to invite bids/negotiate a contract for the first NPP; and (iii) ready to commission and operate the first NPP. Nineteen infrastructure issues need to be addressed in each phase, including nuclear safety, nuclear security, safeguards, legal and regulatory frameworks, radioactive waste management, human resource development and stakeholder involvement [1].

A range of economic and financing issues are also important to consider. Decisions to initiate a nuclear energy programme and to invest in an NPP have impacts that go beyond the project itself and are not captured by private corporate approaches. Energy investments in general and nuclear energy investments in particular tend to stimulate other sectors in the economy such as construction, manufacturing and services, thus generating economic growth and creating new employment through the entire economy. A short summary of recent studies on macroeconomic impacts of nuclear energy activities is presented by the IAEA [2]. A joint report by the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) and the IAEA explores the effects of nuclear energy programmes on employment [3].

Labour market effects of nuclear energy programmes are known to be at the core of the impetus for local and regional economic growth. Thereby, they include not only the initial direct effects of economic activities related to nuclear power but also the secondary or ‘ripple’ effects that flow from the initial activities. For example, recent experience in IAEA Member States with existing nuclear power programmes shows that secondary labour market effects (job multipliers) during the operational phase of an NPP are 4 to 12 times higher than the number of direct employment [4].

The IAEA Milestones Approach encourages Member States to consider to what extent the potential impacts from a nuclear power programme on the country’s overall goals for macroeconomic development — including but not limited to employment generation — may support or discourage its adoption. In particular, the milestones document recommends conducting “an evaluation of the impacts of nuclear power on the national economy, for example gross domestic product and employment” during Phase 1, and including it as an item into the comprehensive report ([1], p. 12). The Milestones Approach thereby recommends conducting a macroeconomic analysis in addition to studies on energy demand and energy supply options.

This recommendation has triggered considerable interest in IAEA Member States. An evaluation of the impacts of nuclear power on the national economy requires the development and/or adoption of appropriate macroeconomic models to the country's conditions in order to objectively gauge costs and benefits of nuclear power projects at the regional and the economy-wide level. In response to an increasing number of requests from Member States for assistance in this area, the IAEA has launched the development of a new quantitative tool to support national efforts for macroeconomic impact analysis, the **E**xtended Input–Output **M**odel for Sustainable **Power** Generation (EMPOWER) [5]. In addition, the IAEA initiated the Coordinated Research Project (CRP) 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 [6]. This publication presents the outcomes of the CRP.

1.2. OBJECTIVES

As part of the Agency's ongoing work on sustainable energy development, this CRP was part of the Project on Techno-economic Analysis, under the Sub-Programme Energy Economy Environment (3E) Analysis. The objectives of this Sub-Programme include improving decision making among Member States and international organizations about technology choices and sustainable development strategies.

The CRP was designed with the overall objective to provide insights into the compatibility of nuclear energy with the national sustainable development objectives.

Since many of the Member States that consider embarking on a nuclear power programme ('newcomers') lack experience in macroeconomic impact assessments, the specific objectives of this CRP were formulated as follows:

— To achieve a better understanding of the contribution of nuclear energy to socioeconomic development in individual Member States where this knowledge is missing or incomplete;
— To enhance capabilities of Member States to conduct macroeconomic impact analyses of nuclear projects at the national and regional levels through the introduction and/or further development of state of the art economic modelling techniques and databases;
— To review, test and apply prototype methodologies, in particular the IAEA's EMPOWER model.

To achieve the above objectives, the following implementation process was followed:

— Developing the database at the country and/or regional level is an important prerequisite for the subsequent macroeconomic impact assessment. The database needs to encompass all the relevant parameters required by the economic modelling tool applied in the second stage of the project.

— Developing and adopting one or more economic modelling tool(s) as one of the main activities of this CRP. Participants shared their experiences in applying the Agency's tools for quantitative macroeconomic analysis and in using their own existing models (tools).
— Apply the developed and adopted modelling tool(s) to quantify economic and social indicators to assess the relative contribution of nuclear energy production to the development of the national economy.

The focus of the CRP was primarily on the specific challenges arising in macroeconomic impact assessments of nuclear energy projects but it also included some assessments of macroeconomic impacts resulting from the deployment of other energy technologies. In general, the impacts of nuclear power programmes on the economy can differ across countries, depending on the size of the economy, its dependence on fuel imports and many other factors. While taking national circumstances into account, it is expected that the national case studies will contribute to a better understanding of the role of nuclear energy in socioeconomic development and to making more informed decisions on national energy strategies. It is also expected that the results of this CRP will help Member States embarking on new nuclear programmes to objectively gauge whether those programmes would be realistic and desirable in the overall context of their national economies.

The CRP provided a good platform to share new and important information and methodological tools across Member States, thus contributing to international research and hence to achieve the objectives of the 3E Analysis Sub-Programme.

Research teams from 12 Member States participated in this CRP. Researchers from Croatia, Indonesia, the Republic of Korea, Malaysia, Poland, the Russian Federation, South Africa, Tunisia, Uruguay and Viet Nam prepared final reports with case studies on macroeconomic impact assessments of their respective national nuclear energy programmes. Research teams from the United States of America and Germany were sharing their experiences in technical issues under so-called research agreements, an arrangement that does not require submission of a final report.

A note about dates and time periods in this publication is important. Various kinds of statistical data, including projected future values, may refer to years and times that were in the future at the time of writing but may be in the past by the time of publication. They are often not possible to update because no new data are available due to delays in compiling and publishing statistical data. Such updates would not be practical either because these data provide the basis for modelling and analysing the economic impacts of assumed nuclear energy projects. Newly available data could be used to rerun models for new impact assessments. Similarly, the nuclear new build project analysed in some of the national studies are assumed to start in calendar years that have passed by the time this publication is released. This may lead to very minor differences in the numerical results compared to the case if the timing of the projects was shifted by a few years. Considering the magnitude of even large nuclear energy projects relative to the size of the national economies, this would certainly not change the basic insights emerging from these assessments.

1.3. SCOPE

The overall purpose of this publication is to present the results of the CRP on Assessing the National and Regional Economic Effects of Nuclear Programmes. The report is intended for a variety of analysts, stakeholders and decision makers. It is hoped it will contribute to developing national energy strategies and policies at the governmental level and at pertinent ministries involved in energy planning, in particular development of the power sector and the electric grid.

1.4. STRUCTURE

Following this introduction about the background, objectives and scope of the publication, Section 2 presents a short introduction to the concepts and frameworks of macroeconomic impact analyses of nuclear energy programmes. It also includes a concise presentation of the Agency's EMPOWER model that is the common methodological tool adopted by the participating national research teams.

Section 3 then presents the tools, analyses and results of the national studies. It contains descriptions of methods and models which can be used for macroeconomic impact assessments and are applied by participating teams in this CRP, including but not limited to the IAEA's EMPOWER. It is of special interest that several Member State teams test the plausibility of the results obtained with EMPOWER by applying supplementary country specific quantitative tools. Results of the model simulations are summarized in the way to capture impacts of nuclear energy activities on major macroeconomic variables both at the aggregated and disaggregated levels. The former includes impacts on gross domestic product (GDP), disposable income, total production, public net savings, total employment, private consumption, and export and import flows. The latter includes production and employment effects calculated at the level of individual economic sectors (industries).

Finally, Section 4 presents a comparative analysis of the national studies in order to provide general insights into the assessment of nuclear energy's contribution to socioeconomic development, to draw lessons learned from the research teams on how to use various methods and models, and to provide recommendations for further development of EMPOWER.

2. METHODOLOGY, DATA REQUIREMENTS AND IMPACT ASSESSMENTS

2.1. MODELLING TOOLS FOR ASSESSING MACROECONOMIC IMPACTS

In recent decades, three main types of models have been used to estimate the macroeconomic impacts of major investment projects and policies. They include traditional input–output models (IOMs), econometric input–output models (IO-E) and computable general equilibrium (CGE) models. A joint report by the OECD NEA and the IAEA summarizes different types of models, including their limitations, that can be applied in analysing the effects of nuclear energy programmes on employment [3].

IOMs involve a quantitative approach to exploring various characteristics of national or regional economies. They analyse the interrelationships between various sectors of the selected economy. They include a system of fixed and linear equations (e.g. Leontief production functions) which describe the relations between a sector's inputs and outputs. They characterize technologies with constant returns to scale and do not allow substitution among inputs. An important underlying assumption is the unlimited availability (supply) of productive resources (e.g. capital, labour, and land and other natural resources) which means that additional output can be produced in any economic sector without limiting the availability and without changing the prices of these resources in other economic sectors. The equation system in IOMs facilitates the assessment of impacts resulting from changes in the inputs or outputs of one or several economic sectors, and their successive impacts on the entire economy [7].

In conventional IOMs, final demand for the outputs (goods and services) of each sector is specified exogenously. A system of linear production functions is then used to estimate primary and intermediate inputs required by the producers to meet this demand. These type of models are usually open, which means that there are no feedback linkages between primary inputs and the final demand. Moreover, such models are static, i.e. they do not take into account the intertemporal distribution of impacts of the investments or policies they analyse.

In recent years, more advanced IOMs have been used to analyse the macroeconomic impacts of various investment activities. Some impact studies adopt closed IOMs that establish feedback relationships between primary inputs and household consumption by specifying households as an industry taking food, consumer goods, medical care and other services as inputs and providing labour as output. This method allows the assessment of the economy-wide impacts of increased household consumption resulting from higher demand for labour. Another improvement is marked by dynamic IOMs that include a more realistic representation of the evolution of an economy over time.

The second type of modelling approaches to macroeconomic impact assessment is IO-E models that combine IOMs with macroeconometric models. This combination is intended to provide a better synthesis of supply and demand relations in the overall economy. Typical IO-E models use econometric models for estimating various components of the final demand (e.g. household consumption, government expenditures, savings and investments) over time. The results then serve as input to IOMs. This approach results in a dynamic modelling framework in which the IOM is updated for each consecutive year according to changes in various macroeconomic drivers such as employment, wages and labour force.

CGE models represent the third type of modelling tools for assessing the economy-wide impacts of major intended or actual changes in a country. A CGE model is rooted in the general equilibrium theory. The theory maintains that the interactions of producers and consumers in an economy will lead to a status of overall general equilibrium in which all markets clear (there are no surpluses or shortages) and prices and quantities do not change. A CGE model comprises a system of equations that describe producer and consumer behaviours. Producers are assumed to choose quantities of inputs and outputs that minimize their production costs, given the costs of inputs (e.g. equipment, raw material, energy and labour), the prices of outputs and the technological characteristics of production processes. Consumers are assumed to maximize their utility by purchasing the array of consumer goods (e.g. food, clothing, personal and public services) according to their preferences and permitted by their budget constraints and prices. These equations can take the form of Cobb–Douglas or constant elasticity of substitution (CES) functions.

There are major differences between the three model types in how they formulate production and consumption functions, how they deal with supply constraints, price responses and changes in the economy over time. While most IOMs assume no constraints on the availability of productive resources, IO-E and CGE models include mechanisms to represent supply constraints. Producer and consumer behaviours are described by linear functions in IOMs while non-linear functions are used in IO-E and CGE models. Changes over time in an economy are depicted in IOMs by capital coefficients that reflect changes in capital goods required for future production while IO-E models trace how the relationships between various macroeconomic variables (e.g. employment, personal income, household consumption) change over time, whereas economic dynamics in CGE models are driven by assumptions about changing producer and consumer behaviours over time. Due to the assumption of unlimited supply of inputs, prices do not matter in production and consumption processes in IOMs while prices (e.g. commodity prices and wages) can be included in the macroeconometric equations describing producer and consumer behaviours in IO-E models whilst producers and consumers adjust their production and consumption levels in response to changes in relative prices in CGE models.

In countries using or considering the introduction of nuclear power, input–output based models (IOMs and IO-Es) have been most frequently used for assessing the macroeconomic impacts of nuclear energy programmes due to their flexibility in introducing investment options and policy alternatives, their ability to simultaneously consider market and non-market systems, and to explore factor substitution in response to price changes. These types of models are more transparent and easier to implement than CGE models. The IAEA's EMPOWER described in the remainder of this section also belongs to this model category. The description is based on [5].

2.2. EMPOWER

The methodological basis of EMPOWER is an extended input–output framework that takes an input–output table (IOT) as its primary database. Such tables represent the monetary relationships among predefined aggregated economic sectors. They encompass information about which input products are demanded by each sector to produce the sector specific output and also include the composition and volume of outputs demanded by public and private consumers, and for gross investments and exports. The structure of IOTs is defined in the Systems of National Accounts [8]. IOTs are typically prepared by national statistical offices.

EMPOWER can thereby be applied to study macroeconomic effects of any types of energy investments, including but not limited to nuclear power. Technically, the model will be applied exactly the same way for alternative energy technology options. EMPOWER is structured so as to allow the assessment of macroeconomic impacts in the construction as well as in the operational phase of NPPs separately and the application of four consecutive levels of economic feedback mechanisms in both periods, depending on the availability of data and the interests of the model's users. It is also possible to quantify macroeconomic effects of decommissioning, waste management and funds set aside for disposal of radioactive waste but these activities are not included in the present study. The simplest application of the model with minimum data requirements can estimate the macroeconomic impacts of the investment in constructing an NPP and requires only a recent IOT of the economy and country specific investment costs of the plant. The latter may or may not include specific infrastructure spending, for example.

EMPOWER is designed as a traditional impact assessment in input–output analysis in which a new industry is introduced (see Ref. [7]). The final demand approach is used to introduce new activities (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. [9] for details). EMPOWER can be applied to assess macroeconomic effects of an NPP programme in economies which introduce nuclear power for the first time and in those which already have nuclear power in their energy mix. EMPOWER is flexible enough to evaluate economy-wide effects associated with long term operation.

EMPOWER goes beyond the traditional static IOMs that ignore the implications of additional incomes resulting from introducing a new industry in the national economy and thus underestimate the short term impacts. It provides mechanisms to keep track of such income implications. It also accounts for changes in wages as a result of increased labour demand which is missing from static IOMs and leads to overestimating employment effects. Yet another improvement in EMPOWER over traditional IOMs is a more realistic representation of the price–quantity relationships by introducing 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 allows to take into consideration feedback effects from public–private partnerships if the government finances a certain part of the investment. In this sense, EMPOWER can be viewed as a reasonable compromise between a quasi-realistic depiction of national economies on the one hand and unmanageable technical challenges (involved in a dynamic CGE, for example) on the other.

The model is implemented in Microsoft Excel (Version 2013) and uses the integrated Visual Basic for Applications to perform data transfer and calculations by using Excel's built-in 'Control buttons'. The complete model set comprises six Excel files (four dedicated to preparing input data, one containing the model algorithms and one presenting the results visually).

Direct and indirect impacts

The core equation of EMPOWER (Eq. 1) is a basic input–output equation.

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

where $\mathbf{x}$ is the column vector of gross output, $\mathbf{A}^d$ is the matrix of input–output coefficients for domestic demand, $\mathbf{cp}$ is the column vector of private consumption, $\mathbf{f}^*$ is the column vector of other (exogenous) final demand and $\mathbf{f}^{new}$ is the column vector of demand from the new activity.

Matrix $\mathbf{A}^d$ 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 $\mathbf{A}^m$ 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). In the baseline case with the original

IOT, $\mathbf{f}^{new}$ contains only zero elements, i.e. the situation in the absence of nuclear power investment or operation.

Equation (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 $\mathbf{f}^{new}$. This will initiate the basic output loop of the model: the nuclear energy investments $\mathbf{f}^{new}$ results in a new output vector $\mathbf{x}$, which in turn is inserted into $\mathbf{A}^d\mathbf{x}$ 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 $[\mathbf{I} - \mathbf{A}^d]^{-1}$ (where $\mathbf{I}$ is the identity matrix) (see Ref. [7]. 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.

Induced impacts

The first extension of the core model in Eq. (1) estimates the induced impacts of NPP construction or operation that result from direct and indirect impacts of increasing personal incomes through employment creation, which in turn leads to higher household expenditures on goods and services purchased from different sectors. This requires that the information about the value added components in the IOT, which determine the income components of households, is matched with data about the households' disposable income from the national accounts. The minimum disaggregation in the value added part of the IOT comprises wages, operating surplus and taxes net of subsidies, which are linked to the output by technical coefficients. Equation (2) is used to calculate the disposable income of households.

$$YD = \mathbf{l}wf_{\mathrm{w,hh}}(1-t_{\mathrm{hh}})\mathbf{x} + \mathbf{s}f_{\mathrm{s,hh}}(1-t_{\mathrm{hh}})\mathbf{x} + YD_{oth} \tag{2}$$

where YD is the disposable income, $\mathbf{l}$ is a row vector of employment per output coefficients, w contains the industry wage rates, $f_{\mathrm{w,hh}}$ is an adjustment factor, t_{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 gross operating surplus accruing to households and YD_{oth} contains other components of disposable household income.

Possible differences between wages in the IOT and wages reported in the national accounts are corrected by the adjustment factor $f_{\mathrm{w,hh}}$. The share of operating surplus accruing to households as disposable income is captured by the adjustment factor $f_{\mathrm{s,hh}}$. Taxes and transfers paid by households are calculated by an average tax rate t_{hh} on the disposable income YD. Other components of disposable household income YD_{oth} (e.g. net income from abroad, profits, rents) are specified exogenously in this model. The basic linkage of household incomes to the IOM is via wages and operating surplus.

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). Equation (3) uses a combined (fixed and variable) marginal propensity to consume. The consumption vector $\mathbf{cp}$ is determined by multiplying total consumption by a column vector of domestic budget shares $\mathbf{b}^{\mathrm{d}}_{\mathrm{hh}}$.

$$\mathbf{cp} = [\exp(const_{\text{cp}} + mpc(\log(YD))]\mathbf{b}^{\text{d}}_{\text{hh}} \tag{3}$$

where **cp** is the vector of private consumption, $const_{\text{cp}}$ is the fixed part of the marginal propensity to consume, *mpc* is the variable part of the marginal propensity to consume, *YD* is the disposable income and $\mathbf{b}^{\text{d}}_{\text{hh}}$ 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 $\mathbf{f}^{\text{new}}$ in Eq. (1), the corresponding new output vector **x** determines the resulting new disposable income *YD* in Eq. (2), which in turn determines the adjusted consumption vector **cp** in Eq. (3). This is inserted into Eq. (1) that calculates a new output vector **x** according to the new intermediate demand. The iteration process continues until the model solution converges to a stable new output vector **x**.

Labour market impacts

Construction and operation of NPPs generate changes in the labour market. Total employment *L* in the economy can be calculated as the matrix product of the row vector of employment coefficients **l** and the new equilibrium vector of real output $\mathbf{x}^{\text{r}}$ (in volumes). Elements of $\mathbf{x}^{\text{r}}$ 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 below). This static employment effect is realistic only if labour force is available in the required number and qualifications in the region where the NPP is built and operated.

The representation of the labour market in EMPOWER imitates a wage bargaining (also known as a wage curve) model. A parameter value for the impact of the unemployment rate on wage formation (β_{ur}) is defined to establish an inverse relationship between the two variables. In the case of full employment (e.g. an unemployment rate of 3% or lower) in the baseline case, an employment shock can trigger great effects on wage formation. The opposite holds if unemployment is high in the baseline case. The industry wage rate is calculated according to Eq. (4).

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

where *w* is the industrial wage rate, $const_{\text{w}}$ is the constant wage rate, β_{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.

Higher industry wage rates in turn have repercussions on employment. In EMPOWER, it is assumed that the nominal wage coefficients $\mathbf{l}w$ rise half as much of what the wage increase would imply. The term *lw* 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 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 output, l_{base} is the wage per employee in the baseline case, w_{base} is the industrial wage rate in the baseline case and w is the new industrial wage rate.

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

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

where L is the total employment, $\mathbf{l}w$ is the nominal wage coefficients, w_{base} is the industrial wage rate in the baseline case, w is the new industrial wage rate and $\mathbf{x}^{\text{r}}$ is the new equilibrium vector of real output.

The new coefficients for employment per output ($\mathbf{l}$) also lead to changes in disposable household income. Therefore Eq. (2) needs to be replaced by Eq. (2a) that reflects these changes.

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

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

Equation (2a) includes the endogenous wage coefficients (lw). All these changes also affect private consumption calculated in Eq. (3).

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

$$\mathbf{p} = \mathbf{p}\mathbf{A}^{\text{d}} + \mathbf{p}^{\text{m}}\mathbf{A}^{\text{m}} + \mathbf{l}w + \mathbf{s} + \mathbf{t}^{\mathbf{q}} \quad (6)$$

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

The vector $\mathbf{t}^{\text{q}}$ in Eq. (6) represents taxes net of subsidies per unit of output. In the case of the electricity sector, this term also contains markups that are used for financing the investment costs of the NPP (see section 'impacts of ex post financing, p. 11). The new coefficients for employment per output (**l**) yield a new output price vector calculated in Eq. (6a) that leads to a new vector of output at constant prices $\mathbf{x}^r$ (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.

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

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

By combining the calculations of labour market effects with the price effects, EMPOWER comes very close to a model type in which demand and supply (represented here by prices) interact and are determined simultaneously. Similarly, to the quantity component, the labour market component in Eqs (4) and (5) and the price component in Eq. (6) are also solved iteratively until they converge to stable results in a new equilibrium solution for all endogenous variables in the model.

Components of EMPOWER presented so far assume that financing the investment in an NPP will rely on external sources either by using existing funds in the new industry or allowing for a higher public budget deficit. Two additional model components allow assessing impacts of revenue neutral public financing. The first one explores ex ante (during the construction phase) financing while the second one investigates ex post financing in the form of a markup on the electricity price. Shares of the construction costs financed from different sources (r_{pub}^{hhtx} household and r_{pub}^{trans} public ex ante as well as r_{pub}^{mkup} ex post) can be chosen in a flexible manner across the three options.

Impacts of ex ante financing of an investment

Ex ante financing can be implemented either by increasing the households' tax rate t_{hh} and/or by decrease public transfers to households in an ex ante 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. Once the share of ex ante public financing of the total construction costs (collected according to the households' tax rate r_{pub}^{hhtx}) is determined, the new tax rate t_{hh} and/or the new transfers YD_{oth} are calculated in each year for the value of disposable household income $\boldsymbol{i}$ of the original data, i.e. the baseline case, according to Eqs (7) and (8).

$$YD_{oth} = YD_{oth}^{orig} - r_{pub}^{trans}\boldsymbol{i'}\mathbf{f}^{new} \tag{7}$$

where YD_{oth} is the new transfers, YD_{oth}^{orig} is the original transfers, r_{pub}^{trans} is the share of construction costs financed from public sources, $\boldsymbol{i'}$ is the disposable household income and $\mathbf{f}^{new}$ is the column vector of demand from the new activity.

$$t_{hh} = t_{hh}^{orig} + \frac{r_{pub}^{hhtx}\,\boldsymbol{i'}\,\mathbf{f}^{\text{new}}}{YD} \tag{8}$$

where t_{hh} is the new household tax rate, t_{hh}^{orig} is the original household tax rate, r_{pub}^{hhtx} is the household tax rate for the public financing of the investment, $\boldsymbol{i'}$ is the disposable household income and $\mathbf{f}^{\mathbf{new}}$ is the column vector of demand from the new activity.

This approach to determining the new tax rate reflects the case of ex ante revenue neutral financing. Since the disposable income *YD* 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 *YD* will be different.

Impacts of the nuclear plant operation

EMPOWER includes a procedure to represent technology details in the electricity sector. It allows changes in the column elements of the matrixes $\mathbf{A}^{\mathrm{d}}$ and $\mathbf{A}^{\mathrm{m}}$ 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 input–output technology is then introduced by changing the technology shares: the new power plant would change the electricity generation mix.

Macroeconomic impacts of the new power plant are assessed by applying a partitioned IOM in which the output of the electricity sector is determined exogenously. The new plant provides additional electricity output which means that more demand for electricity can be satisfied.

A part of the newly generated electricity is already consumed through the input–output linkages in upstream activities of other sectors and higher consumption due to higher wages. The remaining excess electricity is allocated to the consumption of final demand agents (private households, public consumption, investments and exports). Since gross output is the main endogenous variable in the IOM, the introduction of exogenous output changes requires the application of a partitioned model in which set 1 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) can be calculated according to Eq. (9).

$$\mathbf{x}_2 = \mathbf{A}_{21}^{\mathrm{d}}\bar{\mathbf{x}}_1 + \mathbf{A}_{22}^{\mathrm{d}}\mathbf{x}_2 + \mathbf{cp}_2 + \mathbf{f}^*{}_2 \tag{9}$$

where $\mathbf{x}_2$ is the column vector of output in set 2 industries, $\mathbf{A}_{21}^{\mathrm{d}}$ is the technology matrix of set 2 industries, $\bar{\mathbf{x}}_1$ is the output of the electricity sector, $\mathbf{A}_{22}^{\mathrm{d}}$ is the technology matrix of set 2 industries, $\mathbf{cp}_2$ 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 $\mathbf{A}_{21}^{\mathrm{d}}$ 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 a 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. (10).

$$\mathbf{cp}_1 + \mathbf{f}^*_1 = \left[\mathbf{I} - \mathbf{A}^{\mathrm{d}}_{11}\right]\bar{\mathbf{x}}_1 - \mathbf{A}^{\mathrm{d}}_{12}\mathbf{x}_2 \tag{10}$$

where $\mathbf{cp}_1$ 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, $\bar{\mathbf{x}}_1$ is the output of the electricity sector, $\mathbf{A}^{\mathrm{d}}_{12}$ 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 (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.

Impacts of ex post financing of an investment

An alternative to the partial revenue neutral financing discussed above involves calculating a capital cost term of a selected share (r_{pub}^{mkup}) of the total nuclear investment calculated by Eq. (11).

$$\mathbf{t}_1^{\mathbf{q,markup}} = \frac{r_{pub}^{mkup} \sum_t \boldsymbol{i}' \mathbf{f}_{\mathbf{t}}^{\mathbf{new}} (r + \delta)}{\bar{\mathbf{x}}_1} \tag{11}$$

where $\mathbf{t}_1^{\mathbf{q,markup}}$ is the additional markup due to the capital cost of the selected share of ex post financing in the electricity sector, r_{pub}^{mkup} is the selected share of ex post financing in the electricity sector, $\boldsymbol{i}'$ is the disposable household income, $\mathbf{f}_{\mathrm{t}}^{\mathbf{new}}$ is the column vector of demand from the new activity, r is the rate of return, δ is the rate of depreciation and $\bar{\mathbf{x}}_1$ is the output of the electricity sector.

The new markup calculated in Eq. (11) 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 $\mathbf{t}^{\mathbf{q,new}}$ that will result in Eq. (6b).

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

where $\mathbf{p}$ is the vector of sectoral prices, $\mathbf{A}^{\mathrm{d}}$ 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 output coefficients, w is the 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 $\mathbf{t}^{\mathrm{q,new}}$ is a vector of the new taxes net of subsidies per unit of output.

Impacts on exports due to changes in domestic prices

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. (12).

$$\mathbf{ex}^{real} = (1 + ((\ln(\mathbf{p}) - \ln(1)) * el^{\exp}) * \mathbf{ex} \tag{12}$$

where $\mathbf{ex}^{real}$ is the new real exports, $\mathbf{p}$ is the vector of sectoral prices, $el^{\exp}$ is the export elasticity and $\mathbf{ex}$ is the original real exports. 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 $\mathbf{x}^{\mathbf{r}}$ and thus, via the labour market, impacts on the rest of the economy described by all elements of the model.

2.3. DATA REQUIREMENTS

EMPOWER requires an IOT of the economy with maximum 35 industries in which data for the electricity sector are placed in the first row and the first column. The definition of sectors is country specific. This implies that EMPOWER framework itself is flexible and national IOTs define the sectoral structure of its application. The IOT must have separate matrices for domestic and import flows and needs to follow a predefined structure for the final demand and the value added components, see Fig. 1.

National IOTs comprising more than 35 sectors need to be converted according to the scheme required by EMPOWER. The Excel implementation of the model includes tools that assist users in data aggregation and in defining categories of final demand and value added. If data on compensation of labour, net operating surplus and other value added categories are not included in the national IOT, they need to be provided from other sources that are consistent with the IOT so that their aggregated value is equal to the total value added in the IOT. In addition, EMPOWER provides a routine and identifies data needed to derive an IOT for a given year in the future at which construction and/or operation starts.

Determining disposable income of private households also requires data from the national accounts. Gross disposable income of households is calculated by adding up wages, the share of the operating surplus accruing to households, the profit and other incomes of households and the government transfers to households, and subtracting the taxes and social security contributions paid by households to the government.

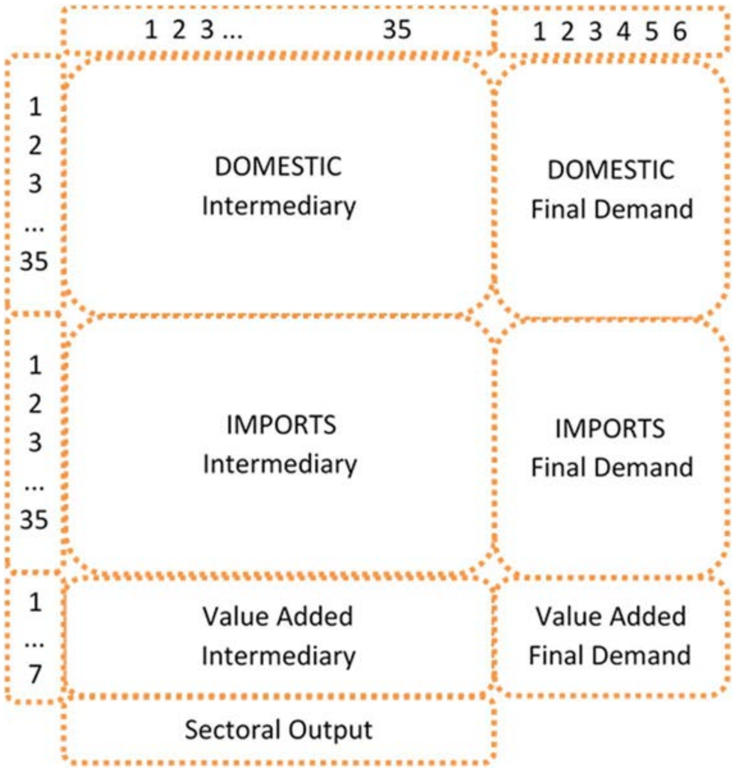

FIG. 1. Scheme of the input–output data table for EMPOWER. Source: Ref. [5].

Data on the labour market in the base year are also required. They include information about 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, data on the government budget in the base year need to be provided as well. They comprise the following components. Public consumption: a part of the government expenditures is spent on buying goods and services from the sectors and constitutes a component of total final demand. Other expenditures: another part of government outlays is spent as transfer payments to various kinds of recipients and for other purposes. Net taxes on incomes and products, and other government revenues are also sources from which government outlays are paid. The difference between the government's total expenditures and total revenues gives the net public savings.

To sum up, EMPOWER comprises two modules – one for the construction, the other for the operational phase – and four submodules for each module. In this way, EMPOWER is organized into eight submodules which is equal to the number of impact mechanisms included in the model. Submodules are labelled A, AB, ABC and ABCD. Each submodule has an additive structure, as it builds on the previous one. For example, submodule AB comprises the mechanism of submodule A and an additional mechanism (see below); submodule ABC comprises the mechanism of AB plus an additional mechanism and so on. The eighth mechanism is the representation of the electricity sector in the operational module which is different from the case in the construction one. In the operational module, electricity production is represented by the type of technology. This is not really a mechanism, only a representation. In the construction module, this representation is not needed because the production level is not changing. The production level is specified as the total of all technologies in monetary and physical units.

The model framework designed for impact analysis includes the following impact mechanisms:

I) Indirect effects of construction (including direct effects);
II) Induced effects (induced private consumption);
III) Labour market response;
IV) Feedback from ex ante financing of investment (in the construction phase);
V) Feedback from new electricity generation (in the operational phase);
VI) Feedback from ex post financing of the investment (in the operational phase);
VII) Feedback on exports due to domestic price changes.

Table 1 provides an overview of how individual mechanisms are allocated across the submodules in the construction and the operational module. Bullets indicates that the mechanism is active in the respective submodule. For example, submodule A in the construction module includes only mechanism I; submodule AB includes the mechanism of submodule A plus an additional mechanism II; submodule ABC includes the mechanism of the submodule AB plus an additional mechanism III and VII and so on.

TABLE 1. DEFAULT COMPOSITION OF MECHANISMS IN SUBMODULES OF EMPOWER

	Construction modules				Operational modules			
Mechanism	A	AB	ABC	ABCD	A	AB	ABC	ABCD
I	•	•	•	•				
II		•	•	•		•	•	•
III			•	•			•	•
IV				•				
V					•	•	•	•
VI								•
VII			•	•	•	•	•	•

Note: VII Feedback on exports due to domestic price changes: Exports are only impacted if domestic prices change, i.e. only if one of the mechanisms III–VI is active. If only mechanism I or II is active, exports are not influenced because prices do not change in mechanisms I and II.

Submodule A in the construction module is equivalent to the standard input–output modelling framework which includes only direct and indirect effects associated with the construction of a power plant. All other submodules represent an extension of the standard IOM as schematically illustrated in Fig. 2.

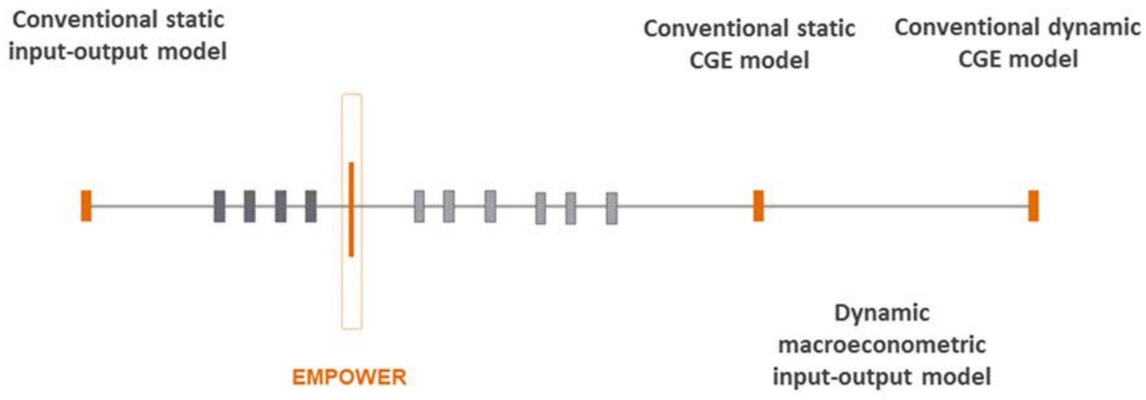

FIG. 2. EMPOWER extends the conventional static IOM approach. Source: based on Ref. [10].

2.4. SCENARIO SPECIFICATION

Based on the data characterizing the economy and listed in the previous section, EMPOWER can assess the macroeconomic impacts of nuclear energy activities under internally consistent sets of assumptions called scenarios. Users can formulate plausible development pathways of population, the economy, technologies, energy use and prices, and other pertinent factors that influence the economic performance and the broader impacts of a possible new NPP.

The scenario framework in EMPOWER is based on a baseline–counterfactual comparison. A baseline scenario is defined for the entire time horizon to be analysed. It depicts the assumed economic development of sectoral production in the absence of a newly constructed power plant and serves as a reference point. After introducing data characterizing the construction and/or operation of a new power plant, a different development pathway is calculated that is called the counterfactual scenario. Macroeconomic impact of the construction or operation is estimated by comparing the counterfactual scenarios to the baseline scenario in absolute and relative terms. Formulating a scenario starts with specifying the base year and the time span (starting year and final year) of the power plant construction and/or operation, with a maximum length of 12 years each.

The baseline or reference pathway in EMPOWER involves a series of IOTs, calculated sequentially for each year of the analysed period. The scenario information required for this calculation includes assumptions about the growth rates of all economic sectors. These values can be positive or negative depending on the economic outlook for the respective sector.

For each counterfactual case, a range of input data needs to be provided about the new power plant construction and/or operation. Starting with the aggregated construction costs, investment costs need to be provided for each year of the construction period in USD together with the exchange rate between USD and the national currency for each year. Moreover, an assumed depreciation rate of the power plant and a market conform rate of return for the investment have to be specified.

In addition to the total construction costs, shares of the contributions of economic sectors need to be indicated that represent the commodities produced by the sectors and used as input in the construction. Depending on the resource and technological attributes of a national economy, smaller or larger portions of the input required from different sectors can be provided by domestic suppliers, the rest has to be imported. As part of the scenario, shares of inputs from domestic sources need to be estimated and provided as input to EMPOWER.

To trace the development of the power generation industry (sector 1 in EMPOWER), fuels used in domestic power plants have to be allocated to the respective sectors. This is required for calculating changes in the use structure triggered by changes in the mix of electricity generation.

The electricity generated by the new power plant can be used to substitute power produced by other technologies or increase the total amount of electricity production. The excess electric power (the additional electricity from the new plant minus the increased electricity consumed as a result of economic feedback mechanisms) can be used by households and/or domestic industries or can be exported. The corresponding scenario parameter to be specified by the user is the share of new electricity to be exported and it can range from 0 to 100%.

Additional information about the current electricity generation is required for assessing impacts of the power output from the new plant and it needs to be provided in two scenarios. The first one describes the evolution of the power sector in the absence of the new power plant and the second one indicates the technology mix in electricity generation by considering the new plant. Both scenarios are specified year by year over the time horizon of the assessment. Unless the new generation facility will entirely crowd out existing generation capacities, the expansion of the total domestic power production needs to be provided as a scenario parameter.

Scenario information to be provided by the user about the cost of electricity generation includes two elements. The first one contains the cost structures of different power generation technologies in the base year and includes the following cost categories: capital, labour, various fuel inputs, other operating costs, taxes and subsidies. In addition, the unit price of electricity is also needed. The second component specifies the growth rates of various cost components over the scenario horizon.

Assumptions about household incomes and consumption are also important elements of a scenario. Accordingly, growth rates of various components of household incomes need to be postulated, including wages, operating surplus and profits accruing to households, taxes, social security contributions and other transfers paid to or received from the government by households, and other household incomes. The link between household incomes and household consumption is established by a parameter called marginal propensity to consume that denotes the portion of an additional unit of disposable income spent on consumption. This parameter varies across countries and users need to specify it according to national data.

The labour market elements of a scenario to be set by the user include the following: 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) and the price elasticity of the export demand for all commodities (showing the response of demand for exports to changes in prices).

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

2.5. MODEL RESULTS

Provided that all the required data listed in Section 2.3 are available and the specification of all scenario components itemized in Section 2.4 is complete, EMPOWER can assess the macroeconomic and sectoral impacts in the construction and the operational period of NPPs separately. The assessment involves the activation of four consecutive levels of economic feedback mechanisms in the Excel model in both periods.

As presented in Section 2.2, EMPOWER can assess the following kind of impacts associated with a nuclear energy programme: direct and indirect impacts of the NPP construction (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) and impacts on exports due to changes in domestic prices.

For each impact mechanism, a range of indicators is calculated to show 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, exports, imports, private consumption and employment (in real terms only). Industry level indicators comprise production output values (nominal and real) and employment (real only). A range of impact indicators of nuclear power programmes as assessed by the national study teams in this CRP is presented in Section 3.

3. MACROECONOMIC AND SECTORAL IMPACTS OF NUCLEAR ENERGY IN PARTICIPATING MEMBER STATES

Research teams from ten IAEA Member States submitted research proposals and participated in the CRP on Assessing the National and Regional Economic Effects of Nuclear Programmes. Each team adopted EMPOWER and calibrated the model by using country specific data. A few national teams also used additional models to estimate economic impacts of nuclear energy investment and use. This Section presents concise summaries of the model applications and their results based on the detailed final reports prepared by the national research teams. It is important to emphasize that all national studies (except the Republic of Korea – see Section 3.3) analyse hypothetical cases of building and operating new NPPs rather than actual or specific implementation plans.

This section contains case studies from ten research groups: Croatia, Indonesia, the Republic of Korea, Malaysia, Poland, the Russian Federation, South Africa, Tunisia, Uruguay and Viet Nam. Thereby, it is stressed that the relative impacts of building and operating new NPPs on the national economy will depend on many factors. On the one hand, those are socioeconomic characteristics of the country in which a nuclear power programme is initiated or a new NPP is built (population size, the size of the national economy, just to name the few). On the other hand, industrial structure, particularly with respect to national capabilities to contribute to construction and operation of an NPP, drives the outcome. A large heterogeneity in terms of these factors can be observed among the countries. Section 4 will discuss the overall results of national studies and draw conclusions against the background of this heterogeneity.

3.1. CROATIA

Croatia has been operating an NPP jointly with Slovenia since 1981. In response to the projected increase in the demand for electricity over the coming decades, the construction of a new nuclear plant might be considered (as of April 2020, it is not part of the official strategies). This section explores the macroeconomic impacts of building and operating a new power plant. It is based on Ref. [11].

3.1.1. National context

Croatia is a small country with a population of about 4.1 million and a GDP of about €50 billion which means about €12 000 per capita (converted at market exchange rate). Croatia is a major energy importer. The country imports 53% of its total energy needs and is highly dependent on foreign fossil fuel supply: 60% of natural gas, 80% of oil and 90% of solid fuels are imported. In 2019, Croatia imported 35% of the gross electricity consumption, another 35% is provided from hydropower, 22% from thermal power plants and 8% from renewable energy sources.

The Krško NPP provides 17% of the imported electricity. The plant operates in the Republic of Slovenia, about 40 kilometres from Zagreb, the capital of Croatia. The power plant's net electrical capacity is 696 MW(e). The Krško NPP was constructed during the 1974–1981 period. It was connected to the power grid on 2 October 1981 and went into commercial operation on 1 January 1983. The operating company Nuklearna elektrarna Krško (Krško Nuclear Energy) is co-owned by the Slovenian state-owned company Gen-Energija and the Croatian state-owned company Hrvatska elektroprivreda (shares of 50% each). The electricity generated by the Krško power plant is equally shared between the two countries. In 2012, the lifetime of the plant was extended for an additional period of 20 years, until 14 January 2043.

According to the energy strategy and the expected energy transition, electricity consumption in Croatia is expected to increase by about 40% by 2050, from 17.5 to 24.4 TW·h. The growth of electricity consumption indicates the need to build new generation capacities in the future.

3.1.2. Model and data

The EMPOWER framework is used for the macroeconomic impact analysis in Croatia. The application includes the following three impact mechanisms (also called submodules in the EMPOWER terminology) where each incorporates results of the preceding mechanism:

- A: Indirect effects (including direct effects);
- AB: Induced effects (including direct and indirect effects);
- ABC: Labour market responses (including direct, indirect and induced effects).

Submodule ABCD — assessing impacts by including feedback from financing the investment in a new generation capacity — is not applied in the construction module and does not produce meaningful results in the operational module due to the special characteristics of the Croatian economy. This is related to the assumption about labour force development (which is decreasing over time), whereas sectoral growth rates are positive. EMPOWER will not produce correct results (on purpose), if these assumptions do not fit together.

Results of the model simulations are presented in two ways:

- Aggregate results as impacts on GDP, disposable income, total production, public net savings, private consumption, exports and imports (all at current as well as at constant prices) and on employment;
- Disaggregated results by industry as sectoral production at current and constant prices, and employment.

The baseline IOT in EMPOWER for Croatia includes domestic and import flows published in 2016 for the year 2010. They contain tables of supply and use as well as symmetrical IOTs prepared at the level of 64 product divisions of activities according to the national classification of activities and at the level of 64 product divisions of product classification according to those activities as defined in 2002. The aggregation of the 64 sectors into 35 sectors required by EMPOWER is based on the homogeneity of sectors, i.e. their products. Future IOTs are created by adopting the RAS method (a technique to balance IOTs) both on the basis of average historical growth rates of sectors of the national economy (1997–2013) and growth rates estimated for certain sectors.

The investment in the NPP models (only as a modelled example) the construction of a Westinghouse Pressurized Water Reactor 12 (PWR-12) plant with a nominal capacity of 1147 MW(e). The estimated overnight construction costs amount to USD 5750 million. The assumed time for the power plant construction is seven years. Linear investment allocation per year is used and a 5% interest rate is assumed. The share of the domestic component in the total investment is estimated at 40% (labour and material costs are dominant) and the share of the import component at 60% (equipment cost is dominant) each year. The power plant construction in the model begins in 2023 and ends in 2029.

With regard to employment, Croatia is facing a significant population decrease that results in increasingly negative effects on labour force and employment. Accordingly, negative labour growth rates are used in the model.

Plausible assumptions are made about some macroeconomic parameters in the model because no data are available for Croatia. In accordance with the recommendations of the model developers, the marginal propensity to consume is set at 0.91 and the wage reaction to the employment rate is set at -0.05.

The model assumes that the NPP construction will be financed as follows: 50% from external sources and 50% from ex ante revenue raised from income tax. For the given output growth rates, employment growth rates are determined via an assumption about productivity growth specified at 0.6. The price elasticity of -1 is used for export demand. Data about the disposable income of households are not available for Croatia.

3.1.3. Results

Results from EMPOWER adopted for the Croatian economy according to the above model specifications describe aggregated (for each macroeconomic indicator) and sectoral (for all 35 sectors in the IOT) impacts of the construction and operation of the specified NPP in absolute and relative terms. The results are shown separately for each year, both for the construction and the operational phase. They include impacts on GDP, employment, production output, disposable income and net taxes for the government. Results for the construction phase are presented in Table 2.

Results calculated by the model for macroeconomic impacts in the construction phase confirm expectations. Direct and indirect impacts of the NPP construction on GDP (calculated in submodule A) slowly decline from 0.4% in the first year of the construction to 0.35% in the last year. Extending the analysis to include induced impacts (calculated in submodule AB), impacts on GDP are significantly higher but they follows a similar, slowly decreasing path over the years from 0.75% to 0.67%. The largest impacts on GDP are measured when adjustments in the labour market are also accounted for (and calculated in submodule ABC), ranging between 0.81% in the first year of the construction and 0.75% in the last year.

The model results show similar impacts on employment, production output and disposable income. Growth rates per year during the NPP construction decrease as GDP increases. The largest impacts on these other indicators are also quantified in the case when feedback from the labour market is also considered (and estimated by submodule ABC), Impacts in this case are more than twice as large as those of direct and indirect impacts (calculated by submodule A). The estimated multipliers, presented in the last block of Table 2, are consistent with the impact indicators measuring relative changes in percentages.

TABLE 2. MACROECONOMIC IMPACTS OF BUILDING AN NPP IN CROATIA, CHANGES RELATIVE TO THE BASELINE CASE (%)
(courtesy of T. Gelo, University of Zagreb)

Impact mechanism	2023	2024	2025	2026	2027	2028	2029
Impacts on GDP in constant prices (%)							
Submodule A	0.40	0.39	0.38	0.37	0.36	0.36	0.35
Submodule AB	0.75	0.74	0.72	0.71	0.69	0.68	0.67
Submodule ABC	0.81	0.80	0.79	0.78	0.77	0.76	0.75
Impacts on employment (%)							
Submodule A	0.51	0.50	0.49	0.48	0.48	0.47	0.46
Submodule AB	0.79	0.78	0.77	0.76	0.74	0.73	0.72
Submodule ABC	0.62	0.60	0.58	0.55	0.53	0.50	0.47
Impacts on production output in constant prices (%)							
Submodule A	0.46	0.45	0.44	0.44	0.43	0.42	0.41
Submodule AB	0.73	0.71	0.70	0.68	0.67	0.66	0.64
Submodule ABC	0.85	0.84	0.83	0.83	0.83	0.82	0.83
Impacts on disposable income in constant prices (%)							
Submodule A	0.45	0.44	0.43	0.43	0.42	0.41	0.40
Submodule AB	0.72	0.70	0.69	0.68	0.66	0.65	0.64
Submodule ABC	0.94	0.93	0.93	0.94	0.94	0.95	0.96
Multipliers in constant prices							
Submodule A	0.74	0.74	0.74	0.74	0.74	0.74	0.73
Submodule AB	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Submodule ABC	1.50	1.51	1.52	1.53	1.55	1.56	1.58

Table 3 shows results of EMPOWER concerning macroeconomic impacts of operating the new NPP. According to the model specification, it comprises only the first six years of operation (2030–2035). The results are shown annually for each impact mechanism (submodule) and macroeconomic indicator.

Macroeconomic impacts calculated by EMPOWER for the selected period of the power plant operation are higher and more significant than the impacts computed for the construction phase. This is attributable to the assumptions about the overall costs and the breakdown of energy technologies. For example, the direct and indirect impacts on GDP in the first six years of operation (calculated in submodule A) amount to 2.87% in 2030 and grow to 2.93% in 2035, the final year of the assessment period in EMPOWER. The power plant continues its operation far beyond this time horizon but the model is devised to calculate impacts for only a limited number of years, probably because uncertainties about the evolution of the national economy, energy use and other driving factors mount over the longer term.

All impact indicators in the operational phase turn out to be considerably higher than impacts calculated for the construction phase of the power plant which might be explained by the assumptions about cost development and technology breakdown.

TABLE 3. MACROECONOMIC IMPACTS OF OPERATING AN NPP IN CROATIA, CHANGES RELATIVE TO THE BASELINE CASE (%)
(courtesy of T. Gelo, University of Zagreb)

Impact mechanism	2030	2031	2032	2033	2034
Impacts on GDP in constant prices					
Submodule A	2.87	2.88	2.89	2.91	2.92
Submodule AB	3.27	3.29	3.30	3.32	3.33
Submodule ABC	3.54	3.60	3.67	3.75	3.69
Impacts on employment					
Submodule A	1.72	1.73	1.74	1.75	1.76
Submodule AB	2.06	2.07	2.08	2.09	2.10
Submodule ABC	1.17	1.06	0.92	0.73	0.39
Impacts on production output in constant prices					
Submodule A	2.23	2.25	2.26	2.27	2.28
Submodule AB	2.54	2.55	2.56	2.58	2.59
Submodule ABC	3.15	3.25	3.38	3.53	3.33
Impacts on disposable income in constant prices					
Submodule A	1.55	1.56	1.56	1.57	1.58
Submodule AB	1.85	1.86	1.87	1.88	1.88
Submodule ABC	2.97	3.14	3.35	3.61	3.42
Impacts on net taxes for the government in constant prices					
Submodule A	2.83	2.85	2.87	2.89	2.91
Submodule AB	3.37	3.39	3.41	3.43	3.45
Submodule ABC	4.15	4.28	4.45	4.65	4.46

3.1.4. Main conclusions

EMPOWER proves to be a very useful tool for assessing macroeconomic effects of investing in NPP construction and operation and also in other types of power plants. It is also valuable for comparing effects of various investment options in Croatia. As a result, decision makers in the government and governmental bodies such as energy agencies are provided with a quantitative basis about a series of macroeconomic indicators such as GDP, disposable income and employment for their decisions. The quality and/or availability of some of the data required for specifying model and scenario parameters raise problems even in Croatia with a reasonably good statistical system. However, the most important data items such as the IOTs for domestic and import flows as well as a series of other economic and energy input data required by the model are possible to obtain.

Croatia has multiple benefits from participating in this project. The most important benefit is the reintroduction of IOTs and input–output analysis as an important tool for analysing macroeconomic effects of investment options in the power generation sector. The input–output analysis was used in macroeconomic analyses and impact assessments until 1991. The economic transformation from the former socialist to a market based system and the independence war suspended the work on IOTs and the applications of input–output analysis for more than two decades. The first IOTs in the independent Croatia were prepared in 2013 for the year 2004 and comprised 60 sectors. The second set of tables were developed in 2016 for the year 2010. The latter are used in the analysis with EMPOWER in this study.

Another benefit from participating in the CRP is the reintroduction of input–output analysis in the curriculum of the Faculty of Economics and Business of the University of Zagreb. The acquired knowledge will be passed on to students and will educate them for applications of IOTs and input–output analysis.

Furthermore, EMPOWER and the CRP in general will serve as the foundation for developing more advanced analytical tools such as macroeconometric and CGE models.

An important outcome of the project is that the Government of the Republic of Croatia, its ministers and government agencies have started to understand the importance of macroeconomic analyses based on IOTs, i.e. input–output analysis, in preparing strategic documents in accordance with the prerequisites of the European Union which also require the calculation of macroeconomic effects of major investments in the energy sector.

Work on new IOTs is expected to continue in the future that will facilitate a more intensive application of input–output analysis in macroeconomic assessments not only in the energy–climate integrated plans but also in other sectors of the Croatian economy. With the spread of knowledge, the education of students at the University of Zagreb and their subsequent employment in economic sectors and at government institutions and agencies, the impacts of input–output analysis will grow exponentially. In this way, Croatia will join the current international trends in using models and other methods for macroeconomic analyses.

3.2. INDONESIA

This section presents the effects of the nuclear power programme on the national economy of Indonesia. The main objective is to estimate the nation-wide and sectoral impacts of the construction of an NPP on Bangka Island. The impacts can be divided into short term and long term ones with a view to their outcomes over time. The short term impacts are triggered by the construction of the nuclear plant that will increase the demand for output from various economic sectors used as input during the construction period. The long term impacts emerge as a result of the operation of the plant for which input from other sectors will be needed (these are the so-called backward linkages) while the electricity generated by the power plant will be used by other sectors (representing forward linkages). The underlying study estimates only the impacts of NPP construction and does not assess the impacts of its operation. This section is based on Ref [12].

3.2.1. National context

Propelled by economic development and population growth, the electricity demand is expected to increase fast in Indonesia. According to the National Energy Planning, the target installed capacity is 135 GW for 2025 and 443 GW for 2050 relative to the 30 GW in 2010 [13]. Achieving this goal requires large increases in electricity supply and the Indonesian power sector needs to develop accordingly.

In the 2010 fuel mix, coal was the most abundant fossil fuel source for electricity production in Indonesia. Coal is used for generating baseload electricity that accounted for up to 46% of total generation in 2010 and it is estimated to increase to 58% by 2019. Coal consumption for generating electricity was 38 million tonnes in 2010 and it is projected to increase significantly in the future. The use of natural gas, another fossil fuel source, is lower because its availability is limited and it is more suitable for mid-merit generation. Geothermal potentials are considerable in Indonesia and could be developed to meet some of the baseload demand in the future. Hydropower potentials in Java and Sumatra islands could also be developed and contribute significantly to the electricity mix. Yet to meet future electricity demand beyond 2020, Indonesia needs to consider other options for large scale baseload power generation. Nuclear power can provide considerable electricity without draining the nation's natural resources.

Although the Government of Indonesia has not yet made the final decision to add nuclear power to its energy mix, the country actively formulates the first NPP development programme by preparing feasibility studies and addressing other infrastructure issues. Indonesia considers implementing its nuclear plant project through an open bid mechanism. The contract type for the first NPP would be a turnkey arrangement and it would involve an open nuclear fuel cycle as the preferred option.

3.2.2. Model and data

Impacts of the NPP construction on the national economy is analysed according to the logical framework presented in Fig. 3. The analysis of the component and cost breakdown structures, and the cost components of the nuclear plant construction indicate the final demand for the required inputs. This value is used as a shock in an input–output analysis to calculate the macroeconomic impacts.

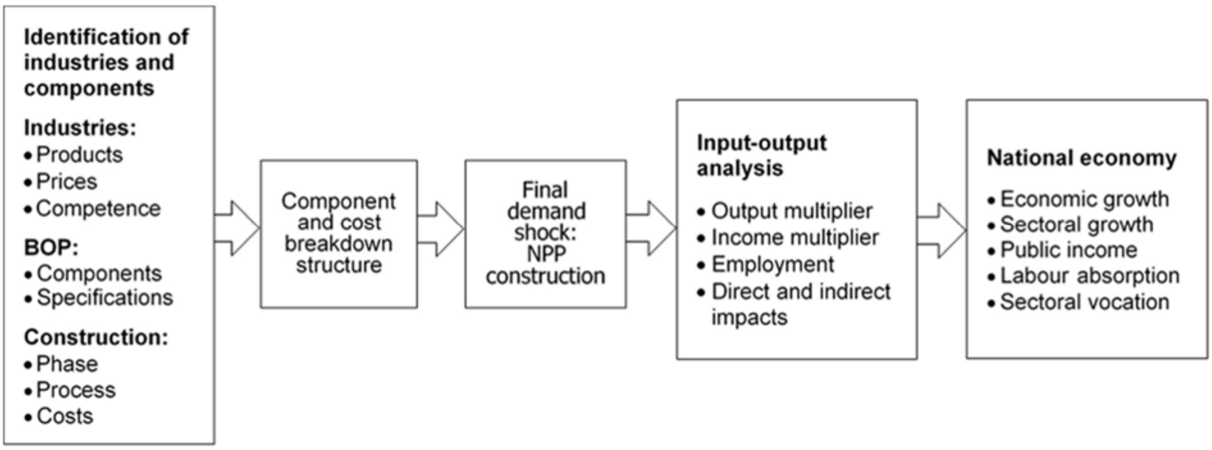

FIG. 3. Economic impact analysis for Indonesia. Note: BOP — balance of plant, NPP — nuclear power plant (courtesy of Suparman, National Nuclear Energy Agency).

The first step in the study is the analysis of the main components of the NPP and the preparation of the IOTs. The component analysis provides data on demand for products of several economic sectors that serve as inputs to the input–output analysis. Results of the input–output analysis include indicators that show impacts of the power plant construction on the economy. EMPOWER developed by the IAEA is used for the impact assessment (see Section 2).

The IOT used in this study is a 35 × 35 industry by industry table taken from the World Input–Output Database [14]. It is adjusted by using the Indonesian IOT for the year 2010. The reason for not using the Indonesian IOT is that it is not assembled industry by industry.

The top five industries with the largest sectoral value added (manufacturing, agriculture, forestry and fishing, wholesale and retail trade and repair of motor vehicles, mining and quarrying, and construction) produced about 70% of the total gross value added at basic prices in that year.

Labour force in 2010 amounted to 116.5 million people of which total employment was 108.21 million and unemployment was 8.3 million [15]. The distribution of employment across the main economic sectors in that year was as follows: 38.3% were active in the agricultural sector, 12.8% in industry, 20.8% in the trade and hotel sector and 14.7% in the service sector.

The cost structure of the NPP to be built is an important driver of the macroeconomic impacts. The main components of the construction costs comprise those that are directly related to the work on buildings and plant systems (equipment, building and civil engineering cost, contingencies and possibly the initial core fuel); and additional costs (owner's cost such as the costs of land acquisition, power and water supply, and consulting if needed as well as interest during construction). Table 4 presents the cost structure data for building a 2 × 1000 MW(e) NPP for which the economic impacts are assessed in this study [16]. It is assumed that 75% of the construction costs is financed from external sources.

TABLE 4. SUMMARY OF THE CONSTRUCTION COSTS
(courtesy of Suparman, National Nuclear Energy Agency)

Item	Cost (2010 USD million)
Mechanical and electrical systems costs	6107
Building costs	659
Civil costs	1060
Initial core fuel costs	553
Contingency	1676
Owner's costs	1398
Total	11 453

A number of studies were conducted to evaluate the future development and the possible participation of Indonesian industries in building NPPs (Refs [17], [18], [19], [20], [21]). Indonesian companies have already had some experiences in supplying nuclear components. Examples include condensers for the Olkiluoto 3 nuclear plant and outer and inner turbine casings.

This study focuses on the economy-wide effects of the NPP construction on Bangka Island. The size of the impacts depends on the capabilities of domestic industries to provide products and services for the construction. The two key determinants are the demand for outputs of relevant economic sectors and its distribution over the construction period.

For the purposes of this case study, the hypothetical construction of the nuclear plant with two reactor units is assumed to start in 2019 and end in 2028. The distribution of the construction costs over this period is presented in Fig. 4.

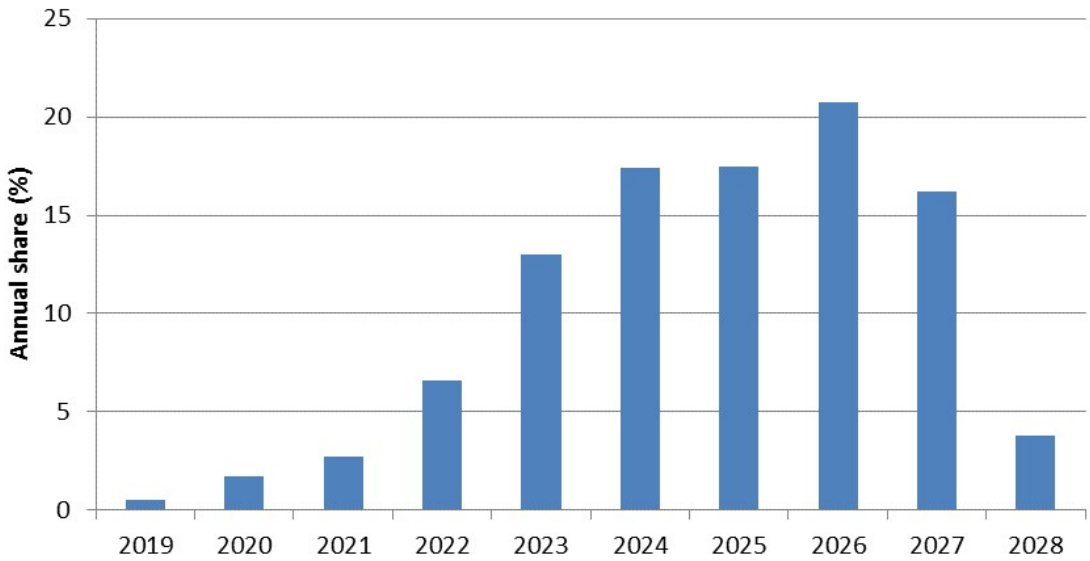

FIG. 4. Distribution of the investment outlays over the construction period (courtesy of Suparman, National Nuclear Energy Agency).

The level of national industry participation in the NPP construction is based on the results of previous studies and current national industry capability data. The share of components and services (hence components in this section) that can be provided locally is about 26% of the total investment cost for the first NPP. The contribution of domestic industries is then assigned to the appropriate industrial sectors in the IOT. The shares of domestic contribution by sector are presented in Table 5.

TABLE 5. SHARES OF DOMESTIC CONTRIBUTION BY SECTOR
(courtesy of Suparman, National Nuclear Energy Agency)

Sector	Domestic share
Construction	0.422
Mechanical equipment	0.284
Financial services	0.223
Electrical equipment	0.071

3.2.3. Results

Based on the features of the national economy and the assumptions presented in the previous section, the impact analysis shows how the domestic industries are affected by the NPP construction project. Charts in this section present the impacts in percentage terms relative to the baseline case in which no investment is made. As the scope of the impact calculations is broadened to include more impact and feedback mechanisms (i.e. moving from submodule A to ABCD in EMPOWER), results always integrate and update impacts of the previous steps.

According to the assessments provided by EMPOWER, building the assumed NPP has positive impacts on the national economy. The impacts are proportional to the amount of money spent for construction activities in a given year and the contribution of domestic industries in that year. Direct and indirect impacts measured in terms of seven macroeconomic indicators (calculated by submodule A) are presented in Fig. 5. The impact on public net saving is negative but this affects the national economy positively by reducing the budget deficit.

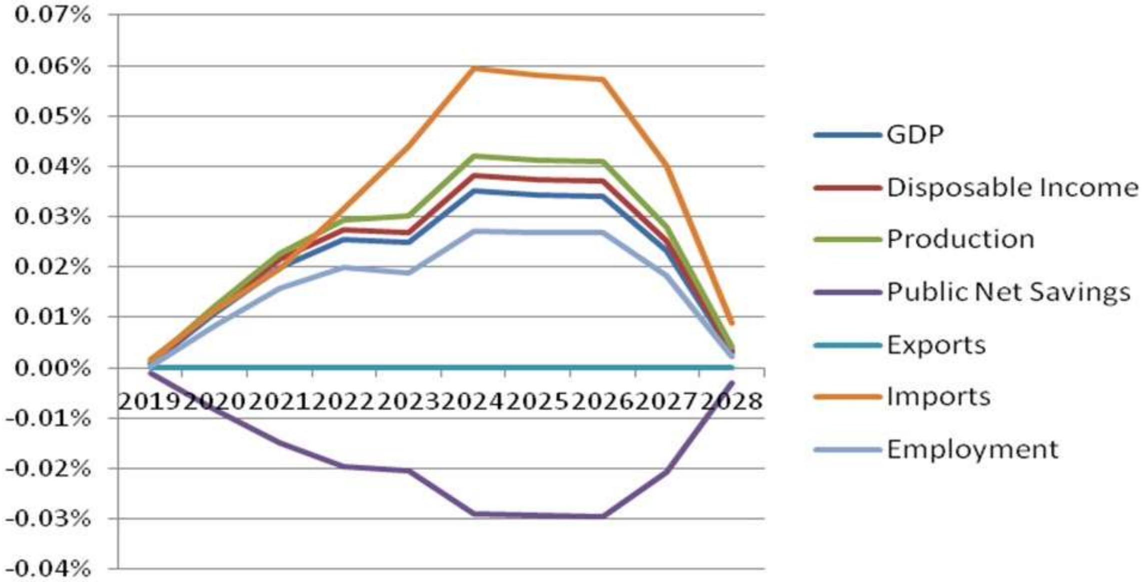

FIG. 5. Direct and indirect impacts of NPP construction in Indonesia (change relative to the base case) (courtesy of Suparman, National Nuclear Energy Agency).

Extending the scope of the macroeconomic impact assessment to include the repercussions of direct and indirect impacts of increasing personal incomes through employment creation by the construction work — which, in turn, leads to higher household expenditures (in comparison to submodule A) on goods and services purchased from different sectors including imported ones — provides the induced impacts of the nuclear plant construction. Results for the induced effects (calculated by submodule AB) are presented in Fig. 6.

The NPP construction generates changes in the Indonesian labour market with feedback on the rest of the economy. As described in Section 2, the representation of the labour market in EMPOWER imitates a wage bargaining or a wage curve model. Increasing industry wage rates affect employment. Labour market and the resulting wage effects can also bring about changes in output prices. Results of the combined calculations of the labour market and the price effects (calculated by submodule ABC) are presented in Fig. 7. Given the labour force situations in Indonesia, effects arising at the labour market are negligible (compared to results of submodule AB).

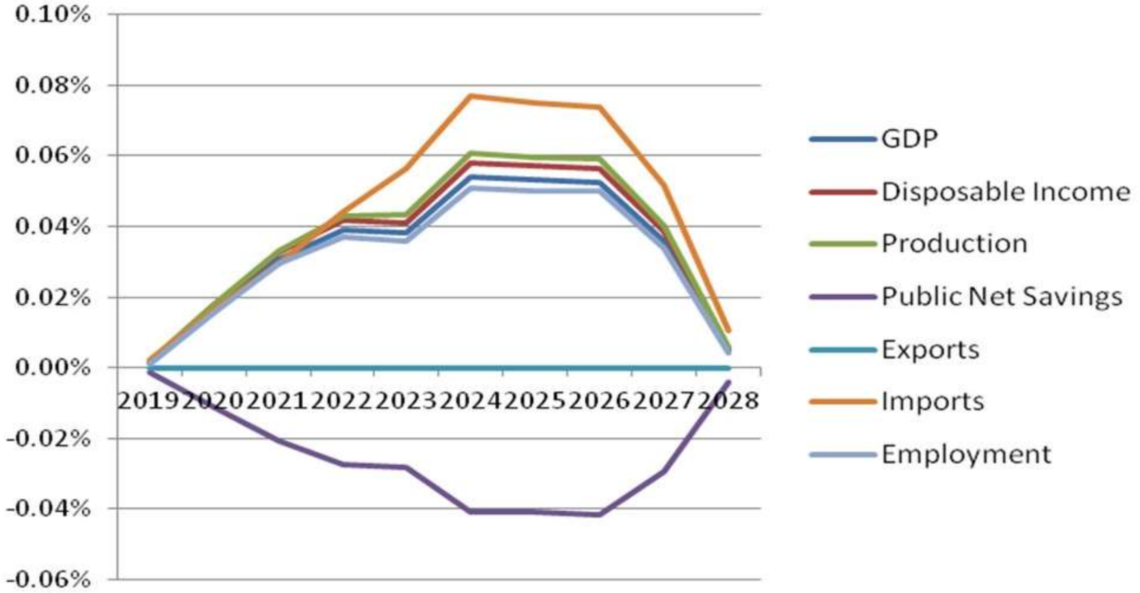

FIG. 6. Induced impacts of NPP construction in Indonesia (change relative to the base case) (courtesy of Suparman, National Nuclear Energy Agency).

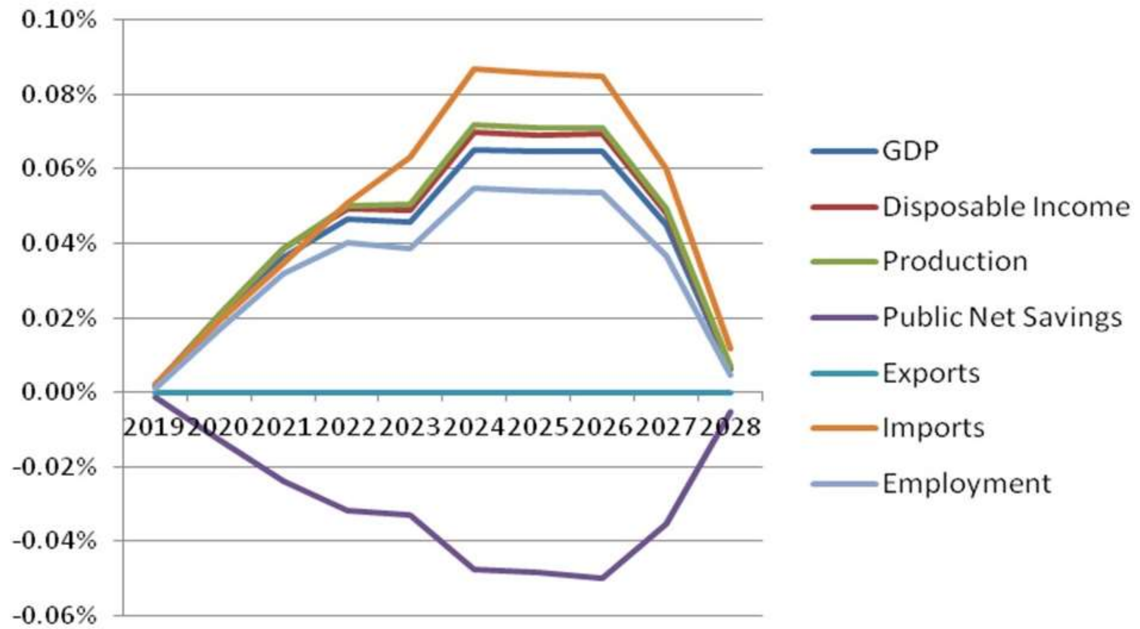

FIG. 7. Labour market impacts of NPP construction in Indonesia (change relative to the base case) (courtesy of Suparman, National Nuclear Energy Agency).

The ex ante financing of the nuclear plant construction can be raised by increasing the households' tax rate and/or by decreasing public transfers to households in a revenue neutral manner during the construction phase. Accordingly, taxes increase and/or transfers decrease to cover the 25% domestic share of the construction costs by the government. The new tax rates and/or the new transfers affect the disposable household income that triggers changes across the whole national economy. The resulting impacts (calculated by submodule ABCD) are presented in Fig. 8.

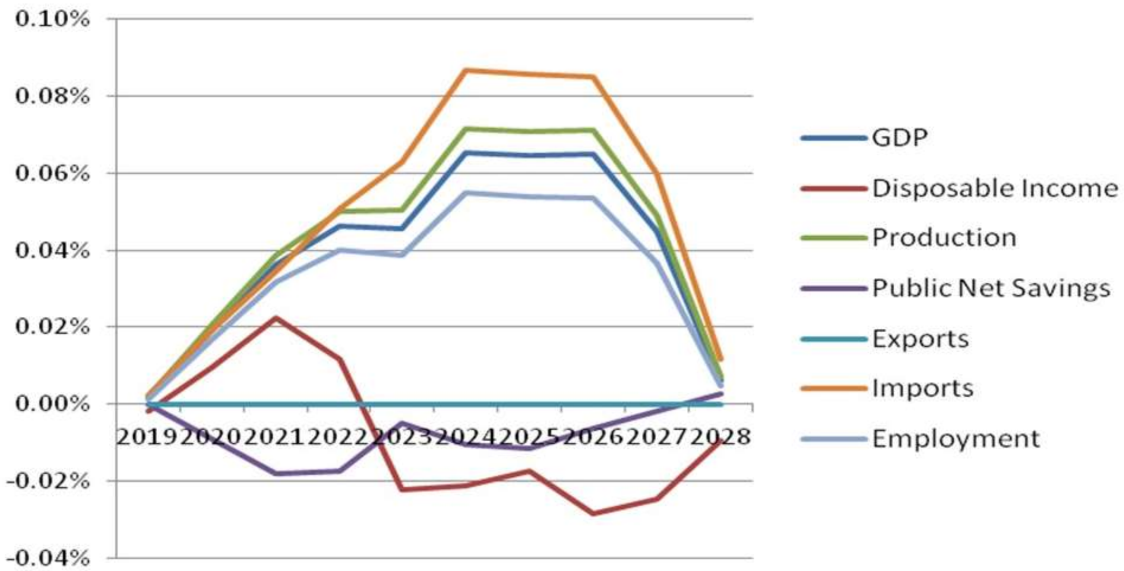

FIG. 8. Impacts of ex ante financing of NPP construction in Indonesia (change relative to the base case) (courtesy of Suparman, National Nuclear Energy Agency).

The construction of the Bangka NPP is projected to have positive impacts on the Indonesian economy. Results of EMPOWER show that the total domestic output in 2024 amounts to Rupiah (IDR) 9 144 900 531 million in the base case and it increases by 0.035% to IDR 9 148 109 310 million when the NPPs is built and its direct and indirect effects are considered (submodule A). The increase in GDP is 0.054% if induced effects are also considered (submodule AB), and 0.065% if labour market responses are also accounted for (submodule ABC). The impacts on GDP are very similar in the labour market results (submodule ABC) and in the financing feedback (submodule ABCD) cases.

Disposable income, i.e. the amount of money available to households for spending and saving from all income sources net of taxes and transfers is monitored in many countries as one of the key economic indicators measuring the overall state of the economy. The construction of the NPP is anticipated to have a positive effect on this indicator under the first three impact mechanisms (submodules A, AB and ABC). When effects of financing the nuclear plant investment are also included in the scope of the macroeconomic impact analysis (calculated by module ABCD), impacts on disposable income start decreasing in 2022 and become negative from 2023 until the end of construction period due to the funds diverted to cover the construction costs.

An important question for policy makers and planners is how the construction of the NPP will affect the total production output value. Only a few of the 35 sectors in the national IOT are directly affected by building NPPs: construction, basic metals, financial services, other business activities, chemicals and electric equipment. The sector most affected by the nuclear plant construction is machinery, i.e. the manufacturing sector. The reason is that the output of the manufacturing sector is used by various other sectors such as construction, mechanical and electrical equipment. The impacts on total output are very similar in the cases of labour market feedback (submodule ABC) and when effects of financing are also included (submodule ABCD).

Compared to others indicators, impacts on imports show the largest effects of the NPP construction. As noted above, the reason is that almost 74% of the investment costs are spent on importing equipment for the plant. Similarly to some other indicators, the impacts on imports are very similar in the case when the labour market feedback is considered (submodule ABC) to the case when consequences of financing are also included (submodule ABCD).

Impacts of the NPP construction on employment is another issue of key interest to politicians and decision makers. Over the ten years of plant construction, the investment is estimated to create jobs at the level of 416 855 person-years as direct and indirect impacts, 779 522 person-years when the repercussions of direct and indirect impacts of increasing personal incomes through employment creation by the construction (induced impacts) are also included, 840 197 person-years when labour market feedbacks on the rest of the economy are also counted, and 840 198 person-years when impacts of the ex ante financing of the plant construction from increasing the households' tax rate and/or from decreasing public transfers to households in a revenue neutral manner during the construction phase are also considered. The last two numbers show that the difference between the results of labour market impacts (calculated by submodule ABC) and the results of the financing impacts (submodule ABCD) is very small.

3.2.4. Main conclusions

EMPOWER made available by the IAEA for the present CRP is running well. It proves to be a useful tool for analysing the economy-wide and sectoral impacts of building an NPP in line with the considerations of the Indonesian government.

According to the assessments provided by EMPOWER, the construction of an NPP has positive impacts on the national economy if private financial sources are used. All aggregated indicators (GDP, disposable income, production output value, exports, imports, private consumption and employment) increase, except net taxes for the government that show some decline during the construction period. The impacts are proportional with the amount of money spent on construction activities and with the contribution of domestic industries in a given year.

As the scope of impact calculations is gradually broadened from assessing only the direct and indirect impacts of the NPP construction (in submodule A) to include more impact and feedback mechanisms such as induced impacts resulting from increasing personal incomes due to employment creation by the construction work and the ensuing higher household expenditures (in submodule AB) and further to consider additional adjustments in response to changes in the labour market (in submodule ABC), all the way to incorporate the impacts of ex ante financing of the related investment costs (in submodule ABCD), results always include impacts calculated in the previous steps. Accordingly, the assessed impacts are increasing as the scope is extended from direct and indirect to labour market impacts, i.e. moving from submodule A to ABC.

This pattern can also be observed when comparing results for particular impact indicators across the extending scope of impact mechanisms. For most indicators, the calculated impacts become higher as the scope of assessment widens to include labour market effects (i.e. up to submodule ABC). The only exception is disposable income that declines significantly when effects of financing the nuclear plant investment running through the national economy (due to the funds diverted to cover the government's share of the construction costs) are also included in the scope of the macroeconomic impact analysis.

Comparing the impacts of the NPP construction across the key macroeconomic indicators of interest for 2024, one of the peak years of investment outlays, provides plausible results. Since a large part (74%) of the plant components is imported, it is not surprising that imports have the largest relative impact. The second greatest impact is measured for total production output and the third for disposable income. The nuclear plant construction triggers smaller impacts on GDP than on disposable income but larger impacts on employment in that particular year.

3.3. REPUBLIC OF KOREA

The Republic of Korea has been using nuclear energy since 1978. There were 25 operational nuclear power reactors, which provided about 24% of the total electricity in 2018. The role of nuclear energy in the economic development of the country is presented in an earlier IAEA publication [9]. The national study in this CRP quantifies the net contribution of nuclear power to the country's economic development. In doing so, this case study explores what would have happened to the national economy of the Republic of Korea if nuclear power had been completely replaced with its substitute, coal power. The case study employs and compares the results of two approaches: the first is based on a specially modified IOT prepared by the Korea Atomic Energy Research Institute (KAERI) while the second adopts the newly developed IAEA tool EMPOWER. This section is based on Ref. [22].

3.3.1. National context

The contribution of nuclear power to a national economy includes an increase in total output, GDP, employment and a decrease in price level. This contribution is realized not only via backward linkage effects but also through forward linkage effects. Backward linkage effects of the nuclear energy sector are triggered by stimulating other economic sectors that provide intermediate inputs to the nuclear sector. For example, NPP construction needs input from the general machinery sector that, in turn, needs input from the primary metal sector that needs input from other economic sectors and so on. The chain reactions instigated by constructing an NPP continue this way. On the other hand, forward linkage effects of the nuclear power sector are elicited by stimulating other economic sectors that use its output (electricity) to produce their own outputs. As a result, the chain reactions triggered by nuclear power operation are spreading across economic sectors in the national economy.

In this study, the focus is on quantifying the net contribution of nuclear power in the operational phase to the national economy. Two scenarios are developed and compared: one represents the power sector in its present form without a structural change, the other depicts a hypothetical structural change in the power sector in which nuclear energy is replaced by coal based power generation. Total output, GDP, employment and price levels are calculated for both scenarios. The net contribution of nuclear power to the national economy is measured as the difference between the two scenarios in terms of these indicators.

So far almost all studies on the contribution of nuclear power estimate the economy-wide effects of an increase in investments arising from the construction and/or operation of NPPs. They assess these effects in terms of direct and indirect as well as induced impacts. However, they have no mechanism in place to capture the feedback between prices and output. Consequently, they have limitations in dealing with the economy-wide contribution of nuclear power when fossil energy prices sharply increase.

The present study explores what would have happened to the national economy of the Republic of Korea if nuclear power had been completely replaced with its substitute, coal power, in the past. The study provides a mechanism for addressing the possible feedback from prices and output on the national economy caused by the structural change in the power sector given the final demand across all economic sectors according to the IOT. In addition to adopting a modified IOT, the case study also verifies the IAEA’s Excel based model called EMPOWER. To this end, the study team of the Republic of Korea develops its own model that follows the logic of IAEA’s model.

3.3.2. Models and data

The KAERI model uses input–output analysis for this study. The IOT of the type non-competitive imports for the year 2009 published by the Bank of Korea [23] is used to make the analysis comparable with the IAEA’s model. The most detailed breakdown of the power sector is available in the basic classification IOT in which the number of sectors exceeds 400. From this basic classification, sectors closely related with nuclear energy are kept in the IOT and the rest of the sectors are aggregated. The result is a reorganized IOT with 38 industries in which four power sectors (hydro, thermal, nuclear and other power) are represented separately. In the integration process, the four power sectors are combined into one that yields 35 sectors as required by the IAEA’s model.

The estimation of the net contribution of nuclear power is based on the assumption that total final demand across economic sectors corresponds to that in the IOT of 2009 and, at the same time, the structural change in the power sector occurs by replacing nuclear power with coal generated electricity in the same year. For the purposes of the present analysis, coal power is defined as a separate sector. As a result, the modified power sector includes hydro, coal, other thermal and other power. The results show the effects of this structural change in the power sector on total output, GDP, employment and price level while meeting the given total final demand across all economic sectors.

The structural change in the power sector (shifting from nuclear to coal power) affects not only the output but also the input side of the economy. On the output side, it is assumed that the change does not alter demand (neither intermediate nor final demand) and output. The assumption is reasonable to the extent that there is no feedback from structural change in inputs to the electricity sector to output sectors in the national economy. The assumption is also realistic because demand for electricity is not affected by the structural change. However, the change in the power sector modifies imports for economic sectors and this needs to be incorporated into outputs in the IOT. The reason is that there are big differences in imported inputs between nuclear and coal power generation as input requirements for the latter are higher. Almost all the coal for electricity generation is imported to the Republic of Korea. On the contrary, intermediate inputs to nuclear power are relatively low and fuel for nuclear plants is fabricated in the country. This means that the value of imported inputs for coal power plants rise when fossil fuel prices increase. This leads to a rise in electricity prices that spreads across all economic sectors resulting in a higher price level in the national economy.

In order to assess the macroeconomic effects of the structural change in the power sector, the IAEA model augments the conventional IOM to include not only output markets but also labour market and price equations for analysing changes in both the output and input sides simultaneously.

The second approach to re-estimating the net contribution of the nuclear sector adopts the IAEA's EMPOWER (see Section 2). The model includes a technique for estimating input coefficients of the electricity sector when the power mix changes in the target year. In the first step, coefficients of input components to the electricity sector are estimated for the base year. They include labour costs, fuel costs, other operating costs, net taxes, direct purchases from abroad by residents and capital costs. The estimation is based on unit costs of generation of various power options, the total unit cost of generation and the share of various power options.

In the next step, residual terms are calculated as the difference between historical and the newly estimated input coefficients of components in the base year. The residual terms are understood as the unexplained parts of the historical input coefficients in the estimation. The same procedure is applied to estimate coefficients of input components to the electricity sector for the target year. In this case, the residual terms obtained in the previous step are added to the estimation. Finally, the estimation process is completed by converting the estimated coefficients of input components to the electricity sector into input coefficients of all sectors for the target year.

In addition, EMPOWER is revised to include inorganic chemical products and the gas supply sector as additional fuel sectors. Inorganic chemical products represent nuclear fuel pellet, which is the final form of the nuclear fuel loaded into the reactors. The gas supply sector represents liquefied natural gas (LNG) fuel for power generation.

3.3.3. Results

The first set of results shows impacts when the structural change in the power sector from nuclear to coal based electricity is incorporated in the modified IOT. The model examines the effects of this change on the total output, GDP, labour employment and price level in the national economy while leaving the final demand across all economic sectors unchanged as they are in the IOT of 2009.

The column vector of the thermal power sector without coal shows negative values for value added. The value added is estimated at Won (KRW) -2 709 043 million (about USD -2.5 billion). This means that the thermal power sector without coal includes generation from gas combined cycle and oil that requires more inputs than outputs in value terms. The value added coefficient for the power sector in the integrated hypothetical IOT when all nuclear power is replaced with coal, is estimated at 0.297, 13.2% lower than the historical value of 0.342. The input structure of the power sector greatly changes in the integrated IOT: the input coefficient for the mining and quarrying sector increases significantly from 0.167 to 0.292 and the input coefficient for the inorganic basic chemical products sector decreases considerably from 0.028 to 0.00017, reflecting that there is no need for nuclear fuel fabrication any longer. Drastic decreases in input coefficients are observed for chemical products, primary iron and crude steel, and precision instruments, which are classified as heavy industry.

Estimation of the rise in electricity price caused by replacing nuclear with coal power requires statistics of power generation and settled prices for each power option in the national wholesale electricity market in 2009, which are summarized in Table 6.

TABLE 6. PRICES AND QUANTITIES OF ELECTRICITY SOURCES IN THE REPUBLIC OF KOREA
(courtesy of M. Lee, Korea Atomic Energy Research Institute)

	Hydro	Coal, bituminous	Coal, anthracite	LNG[a]	Oil	Nuclear	Others	Average price
Price (KRW/kW·h[b])	110.53	60.23	109.1	129.54	147.24	35.56	103.68	67.39
Quantity (GW·h[c])	5 641	185 826	7 978	65 274	14 083	147 771	7 618	434 191

[a] LNG: Liquefied natural gas.
[b] KRW/kW·h: Won/kilowatt-hour.
[c] GW·h: Gigawatt-hour.

As the national wholesale electricity market is a cost based pool, the settled prices can be recognized as costs. The weighted average cost of electricity generation is 67.39 KRW/kW·h (see Table 6). The average electricity price in retail markets is 83.59 KRW/kW·h in the same year and the estimated transmission and distribution cost is 16.20 KRW/kW·h. Based on these electricity price data, replacing all nuclear energy with bituminous coal power would increase the wholesale electricity price from 67.39 KRW/kW·h to 75.79 KRW/kW·h. Consequently, retail electricity price would rise to 91.99 KRW/kW·h from 83.59 KRW/kW·h assuming that transmission and distribution costs remain unchanged at 16.20 KRW/kW·h. This means that the electricity price in the retail market would have increased by 10% if all nuclear energy had been replaced with bituminous coal power.

In order to estimate the net contribution of nuclear energy to the national economy, a modified IOT is adopted in which all nuclear energy is completely replaced by coal power. The economic structure would be changed from the historical IOT by increasing the electricity price by 10%. This price increase is expected to affect all macroeconomic indicators such as total production, GDP, employment and price level.

The impacts can be estimated by solving the simultaneous equations in EMPOWER (see Section 2). This requires the specification of two parameters: the marginal propensity to consume is set at 0.6 and the labour market coefficient β is -0.04.

The 10% rise in the electricity price directly caused by replacing nuclear energy with coal power has a spreading out effect and increases the price level in the entire national economy by 0.34%. Value added decreases by 0.57% in the hypothetical IOT relative to the historical IOT. The comparison also shows that total output value is 0.43% less in the hypothetical IOT without nuclear power than in the historical IOT with nuclear energy. These numbers show that the impact of replacing nuclear energy with coal power affects GDP more than total output. The impact on total employment is a decrease by 0.23%, amounting to 45 933 persons.

The estimated net contribution of the nuclear sector to the national economy is summarized for three cases of electricity price increase in Table 7. Due to structural changes in the power sector, electricity prices might increase by 5%, 10% or 19%, depending on the probable fuel mix replacing nuclear energy. The 19% increase in electricity price reflects the case when all nuclear energy is replaced with fuel sources by maintaining the historical shares of LNG, coal and oil power in the thermal sector. The electricity price increase depends not only on the power technology replacing nuclear energy but also on the increases in fuel prices.

TABLE 7. NET CONTRIBUTION OF THE NUCLEAR SECTOR TO THE NATIONAL ECONOMY IN CONSTANT TERMS
(courtesy of M. Lee, Korea Atomic Energy Research Institute)

	Electricity price increase due to structural changes in the power sector					
	Increase by 5%		Increase by 10%		Increase by 19%	
	Change (%)	Amount (KRW billion, person)	Change (%)	Amount (KRW billion, person)	Change (%)	Amount (KRW billion, person)
Total output	0.27	7 433	0.43	11 918	0.71	19 637
GDP	0.42	4 380	0.57	5 939	0.82	8 376
Employment	0.12	23 866	0.23	45 933	0.43	85 089
Fall in price level	0.17	n.a.[a]	0.34	n.a.[a]	0.64	n.a.[a]

[a] n.a.: not applicable

Table 7 shows that the national economy of the Republic of Korea would be weaker without nuclear power in terms of total production, value added, employment and price level. The negative effects on the national economy without nuclear power are recognized as a net contribution from nuclear power. Numbers in Table 7 indicate increases in total production, value added and employment, and the decrease in price level induced by nuclear power relative to the cases when the amount of electricity generated by NPPs is supplied by different combinations of other sources (LNG, coal and oil) characterized by the three cases of electricity price increase.

Looking at sectors of the national economy, inorganic basic chemical products and the business services sector have the greatest positive effects from nuclear power. It is not surprising that the power sector has by far the largest increase in value added when nuclear energy is part of the power generation mix. Concerning prices, manufacturing sectors have the greatest effects because their production is electricity intensive. In the case of labour employment, wholesale and retail trade and the business services sectors have the largest effects because both are labour intensive sectors.

The second assessment of the role of nuclear energy in the economic development of the Republic of Korea is based on EMPOWER. It involves estimations of input coefficients for all economic sectors and the seven power generation technologies (see Table 6) for the base year (when nuclear power is part of the generation mix) and for the target year (when nuclear energy is wiped out).

Two scenarios are assessed. Scenario A represents the case when nuclear energy is replaced entirely with coal power, while scenario B denotes the case when nuclear energy is evenly replaced with coal and LNG power. Differences between input coefficients in the base and the target years are shown in Table 8 for selected components.

The comparison shows that the capital coefficients decrease from the base to the target year. The reason is that coal and LNG power are less capital intensive than nuclear energy. The decrease is larger in scenario B than in scenario A.

TABLE 8. INPUT COEFFICIENTS IN THE BASE AND TARGET YEARS
(courtesy of M. Lee, Korea Atomic Energy Research Institute)

Cost item or sector	Base year	Target year		Target year / Base year	
		Scenario A	Scenario B	Scenario A	Scenario B
Capital	0.194 66	0.170 18	0.157 534	0.87	0.81
Labour cost	0.109 20	0.110 60	0.106 49	1.01	0.98
Mining and quarrying	0.168 37	0.229 06	0.174 309	1.36	1.04
Petroleum and coal	0.079 88	0.076 95	0.073 791	0.96	0.92
Inorganic chemicals	0.027 88	0.011 72	0.011 721	0.42	0.42
Gas and water supply	0.209 49	0.199 24	0.268 712	0.95	1.28
Other operational costs	0.172 72	0.166 72	0.171 857	0.97	1.00
Subsidies/taxes	0.037 80	0.035 522	0.035 586	0.94	0.94

The coefficient of the mining and quarrying sector increases from the base to the target year by 36% in scenario A but only modestly by 4% in scenario B. The coefficient of the inorganic chemicals sector decreases in the target year in both scenarios as expected because nuclear fuel is not needed in these scenarios.

The coefficient of the gas and water supply sector changes in different directions in the two scenarios: it decreases in scenario A when nuclear energy is replaced entirely with coal power, but it increases considerably in scenario B when a part of nuclear energy is replaced with LNG power.

Table 9 compares results of the two approaches to assessing the contribution of nuclear energy to the economic development of which the first approach is based on the appropriately modified IOT for the KAERI model while the second analysis applies EMPOWER.

The results presented in Table 9 show that the net contribution of the nuclear sector to the country's economy is positive according to estimates by both modelling approaches. Yet the degree of contribution in relative and absolute terms is assessed to be larger by the modified IOTs than by EMPOWER. When nuclear energy is replaced with other power options, EMPOWER allows the intermediate input from nuclear fuel (inorganic basic chemical products) to the electricity sector. In this process, EMPOWER is not flexible enough. This is one of the main reasons for the differences in the results produced by the two analytical approaches.

TABLE 9. CONTRIBUTION OF NUCLEAR ENERGY TO ECONOMIC DEVELOPMENT: COMPARISON OF RESULTS FROM TWO MODELLING APPROACHES
(courtesy of M. Lee, Korea Atomic Energy Research Institute)

Impact indicator	Modified input–output table (electricity price increase by 10%)		EMPOWER	
	Change (%)	Amount (KRW billion, person)	Change (%)	Amount (KRW billion, person)
Total output	0.43	11 918	0.40	10 992
Gross domestic product	0.57	5 939	0.45	4 716
Total employment	0.23	45 933	0.16	32 449
Fall in price level	0.34	n.a.[a]	0.34	n.a.[a]

[a] n.a.: not applicable.

3.3.4. Main conclusions

The incremental contribution of nuclear energy to the economic development of the Republic of Korea is assessed to be significant. The total increase in GDP is higher by 0.5–0.8% (around USD 6–8 billion), the price level is lower by 0.34–0.81% and the increase in employment is higher by 32–93 thousand persons depending on the assumed restructuring of the power sector in the absence of nuclear energy and the method of impact calculation. The incremental contribution of nuclear energy is even higher when fossil fuel prices increase further and nuclear energy is replaced with gas fuelled power. Input values to parameters (e.g. marginal propensity to consume and labour market coefficient) have only limited impacts on the net contribution because their effects are cancelled out in the process of replacing nuclear energy with coal power.

When the power mix is changed, the way of estimating input coefficients of the electricity sector is a good starting point for developing the methodology further. However, detailed information specified according to the requirements of a country need to be utilized to estimate these input coefficients in a more reasonable way.

The case study on the Republic of Korea is a good example to demonstrate how to use IOMs for analysing the incremental contribution of nuclear power to the national economy. These models are also useful for assessing changes in economic development caused by structural changes in the power sector.

The contribution of the study team of the Republic of Korea to this CRP includes model development as well as verifying and modifying the IAEA's EMPOWER model used by all other participating teams to do their own case studies on the macroeconomic impacts of nuclear power programmes.

It is suggested that electricity price changes due to power sector structural change be calculated outside the IOM, which is more reasonable than calculating them in the model itself. The verification of EMPOWER involves comparing results of the IAEA and the KAERI models built for this study by using the same analytical structure and common input data sets. Changes in EMPOWER include the calculation of net disposable income after paying taxes and incorporating price feedback between the electricity sector and other economic sectors.

When comparing the two models (IAEA's EMPOWER and KAERI's modified IOT), a relatively large difference is observed only in the calculated GDP impacts. The reason is the different methods of GDP calculation. In the KAERI model, GDP is calculated by summing value added of each sector in the national economy. In contrast, GDP is calculated on the basis of final demand in EMPOWER. This methodological difference needs to be further investigated because GDP is one of the major macroeconomic indicators of the status of a national economy. It might be worthwhile to incorporate both ways of calculating GDP in EMPOWER to better understand differences in the model's results.

It is also suggested that the operational submodule be considered differently than the construction submodule because double counting may arise. This idea is now incorporated in EMPOWER in such a way that the electricity sector is treated as an exogenous sector.

3.4. MALAYSIA

Under the economic transformation programmes, the Malaysian government is considering to initiate a nuclear energy programme. Three main impact assessments (environmental, social and radiological) are underway in preparation to make a knowledgeable commitment to a nuclear programme. This section presents the results of a fourth assessment that explored the impacts of the considered NPP on the Malaysian economy by paying special attention to the macroeconomic impacts during the construction and operational periods. This section is based on Ref. [24].

3.4.1. National context

Malaysia is an energy dependent country. The increase of electricity use is closely related to population growth. Electricity consumption per capita has a positive relationship with real income per capita. In the period 2000–2012, the correlation coefficient between the population and electricity consumption is 0.99. The Malaysian population is projected to reach 33.4 million by 2020 and 37.4 million in 2030. This will increase the demand for electricity to meet the requirements in direct consumption (i.e. housing and consumer utilities) and indirect consumption (i.e. consumption of goods and services).

Against this background, new sources of energy need to be explored. With a view to the uncertain future supply and volatile prices of coal, nuclear power is a promising option because it is cost effective and green. Under the economic transformation programme, the Malaysian government is considering to build and operate a twin unit NPP with a total capacity of 2 × 1000 MW(e) by 2030.

3.4.2. Model and data

This study endeavours to measure the impacts of the considered NPP on the Malaysian economy. Impacts during the construction and the operational periods are analysed. Impacts are calculated for the following macroeconomic indicators: GDP, disposable income, total output, net public savings, imports and employment. To achieve this objective, EMPOWER, developed by the IAEA, is adopted. Section 2 provides a detailed presentation of this model.

Data required to operate EMPOWER are grouped into three categories: (i) an updated IOT and exogenous parameters, (ii) investment costs during the construction period and (iii) operational costs.

The latest IOT of Malaysia includes 124 sectors for 2010 as the reference year. This IOT is updated by taking into account that the hypothetical construction period of the NPP starts in 2019. In this study, the IOT for 2020 is used as reference year. The final demand and primary input components for 2020 are taken from the Eleventh Malaysia Plan [25]. Data for final demand components, value added and imports for 2020 are available at aggregated levels [25]. Since the total output of the whole economy is not available from external data sources, a time series estimation technique is used to approximate it for 2020. Data for total final demand (for each final demand category), value added, imports and output are drivers of transactions at the detailed sectoral level.

The additional exogenous parameters required to run EMPOWER are listed in Table 10. Annual growth rates for employment and labour force are estimated by taking the average growth rates in the period 1982–2014. Estimating the annual growth rate of wages is constrained by the limited number of observations. Therefore, it is assumed to grow at a similar rate as GDP. This assumption is reasonable because the share of wages in the GDP is rather steady and changes only by one percentage point biennially. The marginal propensity to consume and the wage reaction to the unemployment rate are estimated econometrically. Regarding the government's budget allocation for the construction costs of the NPP, the government is expected to contribute only 10% of the total construction costs according to the Malaysia Nuclear Power Corporation. This contribution is covered by additional taxes to keep the budget constraint fixed.

TABLE 10. ESTIMATED PARAMETERS FOR EXOGENOUS VARIABLES
(*courtesy of M. Y. Saari, University Putra Malaysia*)

Parameter	Value	Source
Employment, annual growth rate	Sectoral*	CAGR[a], annual average 1982–2014
Labour force, annual growth rate	2.5	CAGR[a], annual average 1982–2014
Wages, annual growth rate	Sectoral*	CAGR[a], annual average 1982–2014
Marginal propensity to consume	0.48	Econometric estimation
Wage reaction to unemployment rate	-0.17	Econometric estimation
Export price elasticity	-1.03	Econometric estimation
Government financing share	0.1	Determined by MNPC[b]

Note: * indicates that employment and wage growth vary across sectors. For employment growth, it varies from the lowest value of -0.02% for the pulp and paper sector to the highest value of 0.1% for the financial intermediation sector. For wage growth, it varies from the lowest value of -0.01% for the pulp and paper sector to the highest value of 0.7% for the agricultural sector.
[a] CAGR: Compounded annual growth rate.
[b] MNPC: Malaysia Nuclear Power Corporation.

Data regarding investment costs and technology specifications are crucial input to EMPOWER to represent the nuclear plant construction as the counterfactual for the impact assessment. Since the availability of such data in Malaysia is very limited, the detailed construction material and input allocation is based on a former case study from the Republic of Korea [9]. These costs represent expenditures on final demand in the input–output analysis.

The annual investment costs of the NPP over the construction period comprise three main clusters. The first phase (2019–2025 in the hypothetical construction schedule) includes preparatory activities related to the infrastructure and the construction site with modest annual outlays on the order of Malaysian Ringgit (MYR) 6169 million in total. The highest construction costs arise in the second phase between 2026 and 2030 when civil and structural work, and reactor and electric plant equipment installations take place at annual expenses between MYR 5255.0 and 9096.4 million and with a total expenditure of about MYR 38 049.1 million. The third phase takes only one year (2031) to carry out inspection and testing at the cost of about MYR 1553 million before connecting the NPP to the electricity grid.

The investment costs by components need to be arranged according to the corresponding sectors in the IOT as presented in Table 11.

TABLE 11. ORDERING COST COMPONENTS TO INPUT–OUTPUT SECTORS (*courtesy of M. Y. Saari, University Putra Malaysia*)

Cost component	Sector in the input–output table
Machinery equipment and improvement	Machinery
Reactor plant equipment and electric plant equipment	Electrical equipment
Construction material and construction services	Construction
Owners costs	Other business activities
Financing and contingency costs	Financial intermediation

Three NPP models are considered in this impact assessment: PWR-12, Advanced Passive Pressurized Water Reactor (AP-1000) and Advanced Nuclear Power 1400 (ANP-1400). Their estimated costs serve as input for analysing economic impacts in the construction phase.

The estimated construction cost of a PWR-12 reactor (generation capacity 1000 MW(e)) is based on data from the late 1980s and updated to 2011 USD. Therefore, the indicated costs are likely to be conservative. The case assumed in this study is based on the PWR technology widely used in the Republic of Korea (for example, Ulchin-3 through Ulchin-6 and Yonggwang-5 and Yonggwang-6), see Ref. [9]. The AP-1000 is a two loop PWR with a nominal electrical output of 1110 MW(e). The design of AP-1000 is based on nearly 20 years of research and development that improves upon the established technology of major components used in current Westinghouse plants. The components include reactor vessel and internals, steam generator, fuel and pressurizer designs. The AP-1000 is a Generation III+ plant designed by Westinghouse and developed from the AP-600 design (Generation III). Data about the cost structure of the ANP-1400 are taken from Ref. [26]. It is based on an EPRI survey of capital cost estimates of a range of advanced reactors (Advanced Boiling Water Reactor, Evolutionary Power Reactor, Economic Simplified Boiling Water Reactor, AP1000, etc.) estimated for a generic 1400 MW(e) unit.

For all three models, electrical equipment represents the highest cost item (34% for both PWR-12 and AP-1000, 43% for ANP-1400). Construction costs is the second highest expenditure item (24% for PWR-12 and AP-1000, 23% for ANP-1400). The rest of the overnight costs includes machinery costs, financial intermediation and other business activities. The APR-1000 has the highest construction cost with MYR 42 183 million, followed by the ANP-1400 with MYR 30 420 million and the PWR-12 with MYR 12 472 million.

Based on these cost data, shares of domestic and international contributions are estimated. It is assumed that 50% of the machinery, electrical equipment and construction costs are imported. This is mainly due to the adoption of technologies from the Republic of Korea, including machinery and other transport systems during the construction period. Other activities such as financial costs and other business activities are fully supplied by the domestic economy and include insurance, local taxes, field office expenses, payroll insurance and taxes during the construction period.

Assessing the economy-wide impacts of an NPP in the operational phase requires data about two types of operation and maintenance costs: non-fuel and fuel costs, divided into fixed and variable elements. Fixed costs depend on the reactor's capacity rather than on the level of power generation. Variable costs depend on the amount of electricity produced and also include some non-fuel consumables. To estimate the electricity output for the target year of 2032, information about the electricity generation mix in the period 1992–2015 is used that comprises hydropower, gas, coal and diesel fuelled plants. EMPOWER also includes taxes, fees and miscellaneous costs.

The 2 × 1000 MW(e) dual unit NPP is assumed to operate at full capacity in the operational period and it is estimated to contribute 2.37% of the electricity output in Malaysia in 2032. The rest of the electricity will be generated by hydropower (5.43%), gas (33.5%), coal (58.38%) and diesel (0.3%) power plants.

The operational costs of all technologies are specified according to sectors in EMPOWER. They include expenditures on capital, labour costs, mining and quarrying, coke, refined petroleum, nuclear fuel and other operational costs, and subsidies and taxes. Data from the joint report of the International Energy Agency (IEA) and the OECD NEA [27] are used with a breakdown between investment costs, operation and maintenance costs, as well as carbon and fuel costs. The latter includes waste management costs for nuclear fuel. An overview of the estimated power generation costs used as input to EMPOWER is presented in Table 12.

TABLE 12. PROJECTED COSTS OF GENERATING ELECTRICITY IN MALAYSIA (MYR/MW·h)
(data source: estimated from Ref. [27] (courtesy of M. Y. Saari, University Putra Malaysia))

Technology	Labour costs	O&M[a] costs	Fuel costs
CCGT[b]	7.28	13.53	409.65
Coal	6.97	12.94	243.04
Nuclear	12.67	23.52	32.18
Solar	23.09	42.88	n.a.[c]
Hydro	13.87	25.76	n.a.[c]
Diesel	53.76	99.84	319.31

[a] O&M: operation and maintenance.
[b] CCGT: combined cycle gas turbine.
[c] n.a.: not applicable.

3.4.3. Results

This section presents the main economic impacts of the NPP in the construction and in the operational phase. The impacts are calculated by EMPOWER for three NPP technologies according to the parameter and scenario specifications discussed in Section 3.4.2 by using the technology cost structure of the PWR-12. Impacts of four increasingly broader economic effect mechanisms are assessed: (i) direct and indirect impacts (submodule A), (ii) induced impacts (submodule AB), (iii) impacts of labour market responses (submodule ABC) and impacts of feedback from the public–private financing scheme (submodule ABCD).

The assessed economic impacts increase as the scope of the effect mechanisms broadens, except when the impacts of financing are also included. Induced impacts (submodule AB) are larger than direct and indirect impacts (submodule A) because the former accounts for additional economic effects of the feedback from private consumption. Extending the span of impacts further to include the wage reaction that determines demand for and supply of labour in the market (submodule ABC) leads to even higher impacts. When implications of financing of the NPP are also considered by taking into account tax on household income (submodule ABCD), the aggregated impacts are somewhat lower than those in the induced and labour market cases but considerably higher than the direct and indirect effects. Figure 9 shows the impacts of the NPP construction on the Malaysian GDP in 2031 for the four impact mechanisms.

The macroeconomic impacts calculated for the broadest range of impact mechanisms (submodule ABCD) and measured by selected indicators assess impacts relative to the base case, i.e. no NPP construction. Results of this module are discussed below. The annual impacts vary considerably over the construction period because investment expenditures differ from year to year.

GDP in Malaysia is expected to increase by about MYR 21 893 million in total during the entire construction period from 2019 to 2031. GDP is above the base case value by MYR 310.80 million in 2019 and this impact increases significantly to MYR 742.85 million in 2031. On average, each MYR of investment is likely to increase the GDP by MYR 0.48.

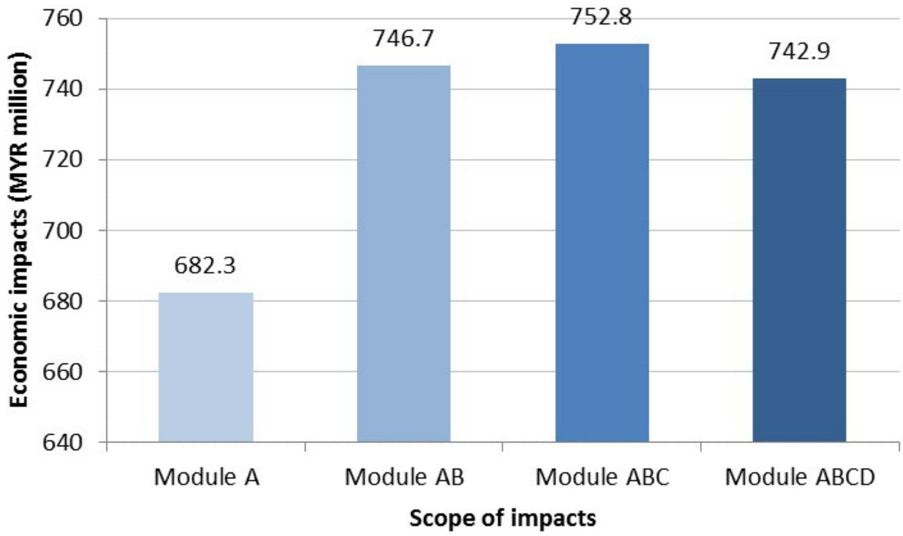

FIG. 9. Impacts of NPP construction on GDP in 2031. Note: MYR — Malaysian Ringgit.

The NPP construction is estimated to generate an increase of MYR 6798.34 million in disposable income during the whole construction period. The lowest impact on disposable income is recorded in 2031 at MYR 230.82 million when the construction work is almost completed. On average, each MYR of investment is likely to increase disposable income by MYR 0.15.

The amount of total output value produced during the NPP construction period is also higher than in the base case according to submodule ABCD. This indicator measures how direct output alters subsequent output across the industries and how these influence demand for goods and services in the economy. During the entire construction period, the total output is calculated to increase by MYR 56 592.27 million in total. On average, each MYR of investment is likely to generate MYR 1.24 of additional total output.

The construction of the NPP is expected to require imports on the order of MYR 9552 million as calculated by submodule ABCD. The highest import amount is estimated to occur in the second phase of the construction period, i.e. in 2028 at MYR 1892 million. This confirms that not the full amount of investment costs flows into the domestic economy because some plant equipment need to be imported. On average, each MYR invested in the plant is likely to require and additional MYR 0.21 worth of imports.

The NPP construction is expected to create employment at 172 594 person-years in total during the construction period as per submodule ABCD. When the NPP construction starts in 2019, employment is estimated to increase by 2450 jobs. The estimated number of additional jobs is significantly higher in the second phase of the construction period. EMPOWER estimates an increase in employment by 11.69% relative to the base case to 31 108 jobs in 2026 when the employment effect is greatest. The number of additional jobs is expected to decline in the final stage of the construction to 5857 in 2031. On average, every million MYR of investment is likely to create four additional jobs over the entire construction period.

Table 13 shows the annual impacts in 2023 (an average year of investment disbursements in the first phase of the construction period), in 2028 (the year with the highest annual impacts as investment outlays peak) and the cumulative impacts for the entire construction period 2019–

2031. For each effect mechanism, impacts are calculated for seven macroeconomic indicators: GDP, disposable income, production output value, public net savings, exports, imports and employment. Since exports are practically not affected by the construction, this indicator is omitted from the table. Impacts of the PWR-12 and the ANP-1400 reactors are virtually the same because their cost structures are almost identical, hence the corresponding results are listed in the same column.

Assessing the overall impacts, results indicate that the difference across economic indicators produced by the three reactor technologies are relatively small. This finding has two main implications. First, economic impacts of an NPP construction are invariant regardless the reactor model. Second, these results compare well with those of other countries that assessed macroeconomic impacts of nuclear plant constructions.

Concerning direct and indirect impacts (submodule A) over the whole construction period, the AP-1000 is expected to increase GDP by 0.18 percentage points more than the other two technologies. The estimated impact on GDP of building AP-1000 reactors is MYR 20 923 million while that of the PWR-12 and ANP-1400 reactors is MYR 21 893 million. The higher impact on GDP of the AP-1000 is explained by its lower import content in the production costs. Since imported goods are not produced by the domestic sectors, imports do not affect their output. Higher import content implies lower impact on GDP generation in the domestic economy and vice versa: lower import share in the construction costs triggers higher impact on GDP. Reactor cost data indicate that total imports in the case of the AP-1000 are lower at MYR 9480 million than import costs of MYR 9552 million for the other two reactor types.

Building PWR-12 or ANP-1400 reactors increases total output value by MYR 56 592 million which is more than the impact of the AP-1000 at MYR 56 345 million. Similarly, the impact of the AP-1000 on public net savings is lower at MYR 1859.33 million than those of the PWR-12 and ANP-1400 amounting to MYR 1863.46 million. Likewise, building PWR-12 or ANP-1400 reactors create more employment during the construction period with a total of 172 594 person-years than the AP-1000 with 172 215 person-years.

Two factors may particularly influence macroeconomic impacts in the construction period. First, the economic structure of the domestic economy, i.e. the magnitude and relative importance of sectors of relevance to building an NPP. Second, the volume and share of imports in the investment costs for components and material sourced from abroad because the domestic industries cannot provide them. About 50% of the total construction material and other inputs are imported for the NPP construction in Malaysia.

The macroeconomic impacts of operating the considered NPP in Malaysia are estimated to be significant. According to the hypothetical case for which economic impacts are assessed in this project, Malaysia is expected to commission the first NPP with two reactors and 2 × 1000 MW(e) capacity in 2032. To estimate the economic impacts in the operational period, new input–output coefficients related to the cost shares of different generation technologies are introduced in EMPOWER. The partitioned IOM with exogenous output of the electricity sector is then applied (see Section 2). Table 14 presents the economic impacts of the NPP in 2032, its first year of operation.

TABLE 13. ECONOMIC IMPACTS OF DIFFERENT TECHNOLOGIES DURING THE CONSTRUCTION PHASE (MYR MILLION, EXCEPT EMPLOYMENT)
(*courtesy of M. Y. Saari, University Putra Malaysia*)

Impact mechanisms and indicators	2023		2028		Total	
	PWR-12, ANP-1000	AP-1000	PWR-12, ANP-1000	AP-1000	PWR-12, ANP-1000	AP-1000
Direct and indirect impacts (submodule A)						
GDP	472	510	3 996	3 996	20 111	20 149
Disposable income	245	220	2 075	2 075	10 443	10 418
Total output	1 246	1 140	10 548	10 548	53 076	52 970
Net public savings	39	36	335	335	53 076	1 683
Imports	206	167	1 745	1 745	8 784	8 745
Employment (pyr[a])	4 030	3 661	34 133	34 133	171 652	171 284
Induced impacts (submodule AB)						
GDP	516	546	4 373	4 373	22 008	22 076
Disposable income	268	218	2 273	2 273	11 441	11 411
Output	1 333	1 085	11 291	11 291	56 817	56 627
Net public savings	44	39	372	372	1 874	1 873
Imports	224	182	1 901	1 901	9 569	9 531
Employment (pyr[a])	4 416	3 976	37 379	37 379	188 086	187 646
Impacts from labour market feedback (submodule ABC)						
GDP	520	550	4 409	4 409	22 186	22 215
Disposable income	270	220	2 292	2 292	11 535	11 484
Output	1 342	1 092	11 361	11 361	57 168	56 919
Net public savings	44	40	376	376	1 892	1 888
Imports	226	184	1 916	1 916	9 463	9 601
Employment (pyr[a])	4 108	3 725	34 721	34 721	174 930	174 547
Impacts from public–private financing feedback (submodule ABCD)						
GDP	514	543	4 351	4 351	21 893	21 923
Disposable income	159	110	1 350	1 350	6 798	6 748
Output	1 328	1 081	11 246	11 246	56 592	56 345
Net public savings	43	39	370	370	1 863	1 859
Imports	224	182	1 892	1 892	9 552	9 480
Employment (pyr[a])	4 107	3 724	34 297	34 297	172 594	172 215

[a] pyr: person-year.

TABLE 14. ECONOMIC IMPACTS OF NPP OPERATION IN 2032 (MYR MILLION, EXCEPT EMPLOYMENT)
(*courtesy of M. Y. Saari, University Putra Malaysia*)

	Submodule A	Submodule AB	Submodule ABC	Submodule ABCD
Gross domestic product	4020	4181	4181	4181
Disposable income	785	857	857	857
Total output value	2821	3143	3143	3143
Public net savings	242	272	272	272
Exports	132	132	132	132
Imports	193	262	262	262
Employment (person-year)	6086	7526	7526	6788

The macroeconomic impacts calculated for the broadest range of impact mechanisms that also includes feedback effects from the public–private financing scheme (submodule ABCD) and measured by the indicators in Table 14 assess the impacts relative to the base case, i.e. no NPP operation. It is estimated that the operating NPP increases GDP by MYR 4181 million. The plant's enhancement of the GDP is 33% more than its enlargement of the total output value (MYR 3143 million). Of the additional total output resulting from the operation of the NPP, 45% is attributed to GDP generation. This contribution to GDP during the operational period is higher than the contribution during the construction period at 38%. The explanation is that during its operational period the NPP generates additional output of electricity which in turn generates more GDP.

Results of EMPOWER also show that the operation of the NPP increases disposable income by MYR 857 million and net public savings by MYR 272 million. The operating NPP fosters exports because the additional electricity output supports the increased production of economic sectors. It is estimated that the operation of the NPP increases exports of Malaysian products by MYR 132 million.

3.4.4. Main conclusions

The analyses conducted with EMPOWER provide useful information for policy decisions regarding the economic impacts of NPPs. The overall conclusion is that economic impacts of building and operating an NPP on the Malaysian economy are considerable. In the assumed construction period between 2019 and 2031, total output value, GDP and disposable income are projected to increase significantly. The NPP construction is estimated to enhance employment by creating jobs at the level of 172 594 person-years in total. Given the total investment costs of MYR 45 711 million, the model shows that every MYR of investment increases total output by MYR 1.24, GDP by MYR 0.48 and disposable income by MYR 0.15 while each million MYR of investment creates employment at the level of four person-years.

The positive contribution of NPP operation to GDP is even higher than that of its construction. During the operational period, the NPP is expected to generate additional electricity which in turn generates additional GDP. This explains why the positive economic impacts of the NPP are higher in the operational period than in the construction period.

Altogether, it can be concluded that the results obtained in this study are plausible and comparable to those of other studies that measure economic impacts of NPPs during the construction and operational periods. Two factors may largely explain the divergences in outcomes: differences in the level of economic development across countries and differences in the capacity of various NPPs to supply electricity.

Although the macroeconomic impacts estimated by EMPOWER are credible and informative, several factors might influence results that are not possible to address because available data do not measure all characteristics of the economy perfectly. The main limitations of the present study are as follows:

- *Future economic structure:* this study updates the IOT for 2020 by taking into account that the hypothetical construction period of the NPP starts in 2019. The update is based on the averaged time series of IOTs for the period 2000–2013. This implies the assumption that all economic sectors grow uniformly and ignores all other factors that might change the production sectors. The validation and verification of the updated IOT is difficult because the actual economic structure in 2020 will not be known in the next few years;
- *Cost structures:* the total construction costs estimate provided by the Malaysia Nuclear Power Corporation does not include a breakdown of costs into specific construction materials and inputs. To run EMPOWER, total construction costs need to be divided according to specific sectors in the IOT for each year of the construction period. For the purposes of this study, construction materials and inputs are divided according to the cost distribution presented in a study from the Republic of Korea [9]. These construction cost components are considered as 'generic' and they can be changed once data about the actual cost components become available. Results may slightly change once more precise data about the reactor type and details of the investment costs become accessible;
- *Static analysis*: macroeconomic impacts of the NPP construction and operation are assessed without considering changes in other economic circumstances such as trade agreements, taxation and energy prices that might affect the results. Results are calculated by assuming all economic variables other than those discussed in Sections 2.3 and 2.4 remain unchanged. Inclusion of other economic variables in EMPOWER requires additional data sets and parameter estimations. However, unavailability of the necessary data might constrain these efforts.

These limitations can be overcome by extending data collection and improving data availability. For example, a detailed cost structure of the NPP construction becomes accessible once the reactor type and the vendor are selected. A unique feature of EMPOWER is that it allows users to input new data and rerun the model without affecting the model system itself.

3.5. POLAND

Adding nuclear energy to the electricity generation portfolio has been considered for some time in Poland. Assessing the macroeconomic impacts of building and operating NPPs is an important part of these considerations. The Polish study team participating in this CRP used two models to prepare such assessments. This section presents the results of their work. It is based on Ref. [28].

3.5.1. National context

The nuclear energy programme in Poland is currently under discussion both at the governmental level and among the general public. However, no final decision has been made on commitment, size and timing of the programme [29]. There is therefore a great demand for reliable analysis of the economic and social effects of possible implementation of the nuclear energy programme. Tools for carrying out multifaceted analyses, using modern techniques and computational methods might be very useful in the decision making process.

The aim of the work in this CRP is to quantify macroeconomic impacts of the NPP programme in the construction and operational phase. The work programme includes reviewing, testing and applying the prototype methodology by using EMPOWER to assess the economic impacts. In addition, PL-ATOM, a prototype CGE model is also developed and applied to assess the economic impacts of the Polish nuclear energy programme.

3.5.2. Models and data

The first model used for the present study is EMPOWER, an extended IOM developed by the IAEA (see Section 2). Some changes are made in the original software such as providing better control over the process of solving the model to facilitate its operation by end users. The changes aspire to increase the flexibility of this tool so that the starting year of the model calculation can be adjusted to the schedule of launching the Polish nuclear power programme and to maintain control over the time period for which the model is solved. Moreover, the modified aggregation procedure makes it easier for users to work on data preparation for the model. The modified model is called Empower.pl [29].

Input–output data from the World Input–Output Database [14] are used for the modified version of EMPOWER. Data on supply and use of household incomes are taken from reports prepared by the Central Statistical Office of Poland for the year 2015. Data on the cost structure of the NPP are obtained from the document prepared by the Ministry of Economy [30].

EMPOWER is applied for assessing the economic impacts of the nuclear programme in Poland. According to the hypothetical construction scenario, it is assumed that an NPP with two 1500 MW(e) units and a total capacity of 3000 MW(e) will be built by 2030. The assumed rate of domestic participation is 50%. The first block is assumed to be launched in 2025. This investment triggers changes relative to the baseline scenario (no NPP construction) in the years 2018–2030 when the investment outlays in the economy are higher than in the base case. The distribution of investment costs over the construction period is presented in Table 15.

The scenario presented in Table 15 assumes that in the initial years expenditures will be relatively small but growing. In 2018, the costs will amount to 4% of the total amount envisaged for the construction and in 2021 the share will increase to 9%. In the following year, the expenditure will increase by 3 percentage points to 12%. From 2022 on, expenses for the construction of the first block, which will be launched in 2025, will no longer grow but investment in the construction of the second block begins. The highest amount of annual expenditure incurred in this scenario occurs in 2024 and amounts to Zloty (PLN) 9000 million (USD 2250 million), which is 15% of the total investment cost. Calculations with EMPOWER assume 100% private financing of the NPP construction.

TABLE 15. ASSUMED DISTRIBUTION OF INVESTMENT EXPENDITURES DURING THE CONSTRUCTION PERIOD
(courtesy of A. Miskiewicz, Institute of Nuclear Chemistry and Technology)

Construction year	Cost share (%)	Amount (million)		Calendar year
		PLN[a]	USD	
1	4	2400	600	2018
2	5	3000	750	2019
3	8	4800	1200	2020
4	9	5400	1350	2021
5	12	7200	1800	2022
6	13	7800	1950	2023
7	15	9000	2250	2024
8	8	4800	1200	2025
9	6	3600	900	2026
10	6	3600	900	2027
11	5	3000	750	2028
12	5	3000	750	2029
13	4	2400	600	2030
Total	100	60 000	15 000	n.a.[b]

[a] PLN: Zloty.
[b] n.a.: not applicable.

Impacts of the construction and operation of an NPP on Poland's economy is also studied by using a dynamic CGE model called PL-ATOM. It is a recursive dynamic CGE model solved in annual time steps. It captures the evolution of the economy over a time period starting in 2010 (base year) until 2030. Transition from one time period to the next takes place after solving the model (by using an optimization procedure) for the current period and modifying selected input parameters.

The initial simulations with the PL-ATOM model assess the external conditions under which electricity generation with nuclear technology in a given year is economically viable. Three cases are considered: (i) analysis of the impact of the expected climate and energy policy on the profitability of nuclear power, i.e. the price of CO_2 emissions and the requirements for producing energy from renewable sources; (ii) analysis of the impacts of changes in the capital costs on the price of electricity production and thus on the economic viability of the NPP; and (iii) analysis of the impact of a fixed price of electricity from the NPP on its profitability.

Subsequent simulations with the PL-ATOM model assess the economy-wide impacts of the power plant construction represented as an exogenous shock in private and/or public investment outlays in the model. (This is different from the EMPOWER assessment in which 100% private financing is assumed.) The PL-ATOM analysis includes four scenarios:

1) nuc_no: baseline scenario without NPP construction;
2) nuc_yes_prv: alternative scenario with NPP construction financed entirely by the private sector;
3) nuc_yes_half: alternative scenario with NPP construction financed equally by the private and the public sector;
4) nuc_yes_pub: alternative scenario with NPP construction financed entirely by the public sector.

All three alternative scenarios assume that the NPP is built according to the Polish nuclear power programme. They assume the same increase of investment expenditures and, consequently, the same level of capital expenditures in particular years. However, these scenarios differ with respect to the division of investment costs between the private and the public sector.

3.5.3. Results

Based on the input data of the Polish economy and the assumptions about the NPP construction presented in the previous section, the impact analysis with EMPOWER shows how the national economy is affected by the NPP investment.

Impacts of two increasingly broader economic effect mechanisms (see Section 2) are assessed: (i) direct and indirect impacts (submodule A) and (ii) induced impacts (submodule AB). Figures 10–12 below present the impacts in percentage terms relative to the baseline case in which no investment is made to build an NPP. These figures show the results for the alternative scenario nuc_yes_prv in which the construction of the NPP is entirely financed by the private sector.

Figure 10 shows impacts of the NPP construction on GDP under two impact mechanisms.

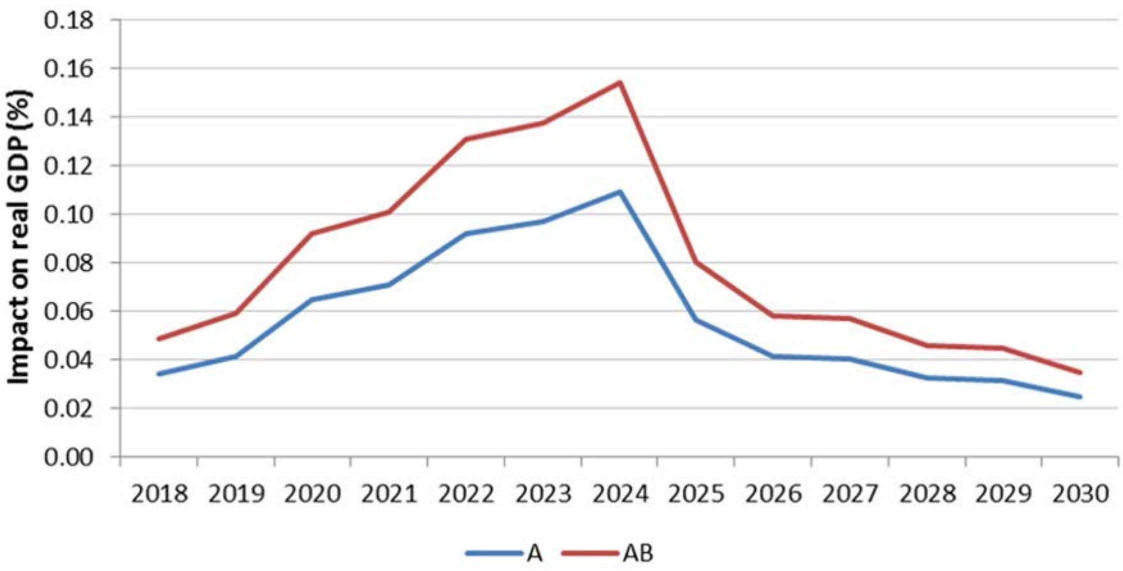

FIG. 10. Impacts of NPP construction on GDP (courtesy of A. Miskiewicz, Institute of Nuclear Chemistry and Technology).

Impacts of the NPP construction on GDP are positive through the entire investment period and they are proportional with the annual investment outlays (see Table 15). The largest induced impact (submodule AB) on GDP relative to the base case is reached in 2024 and it amounts to more than 0.15%.

Impacts of the NPP construction on employment under two impact mechanisms are shown in Fig. 11.

Impacts of the NPP construction on employment show a similar pattern to those on GDP. They are positive all over the investment phase and they are also proportional with the annual investment amounts. The largest induced impact (submodule AB) on employment relative to the base case is reached in 2024 at the level of 0.14%.

Impacts of the NPP construction on nominal public savings under two impact mechanisms are presented in Fig. 12.

The construction of the NPP is anticipated to have a negative impact on public savings over the entire investment period in the case when it is financed from private sources. Since public savings in Poland are negative (there is a public finance deficit), the negative deviation in public savings as a result of the nuclear plant construction means deficit reduction, i.e. a positive effect. Effects are about 0.17% (submodule AB) when induced impacts are calculated and are lower at 0.12% when only direct and indirect impacts are considered (submodule A). The negative increase of public savings, i.e. the reduction of public deficit is connected with the increase in economic activity resulting from building the NPP.

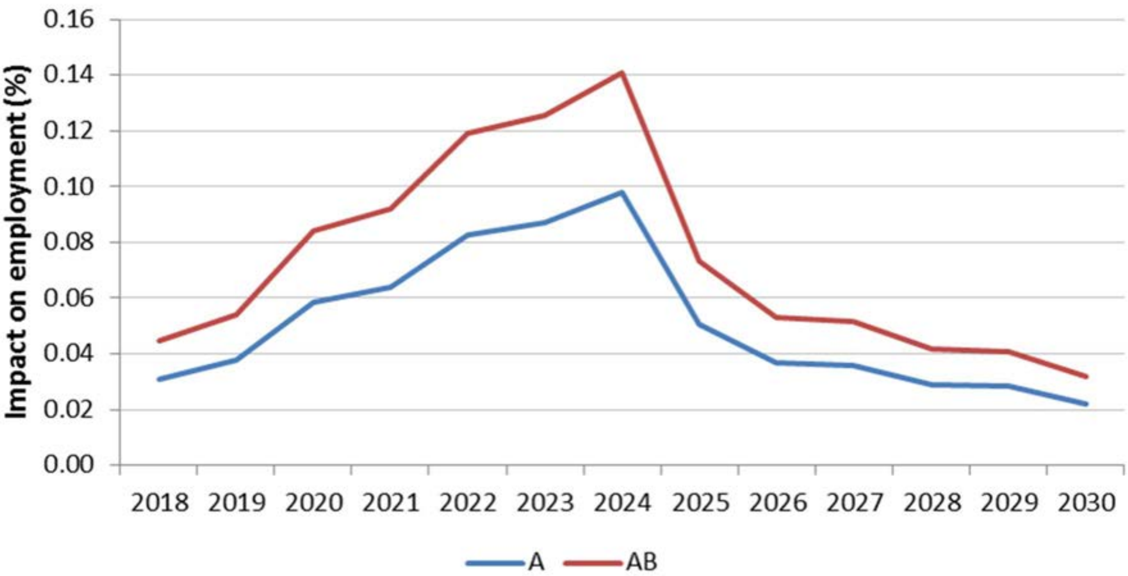

FIG. 11. Impacts of NPP construction on employment GDP (courtesy of A. Miskiewicz, Institute of Nuclear Chemistry and Technology).

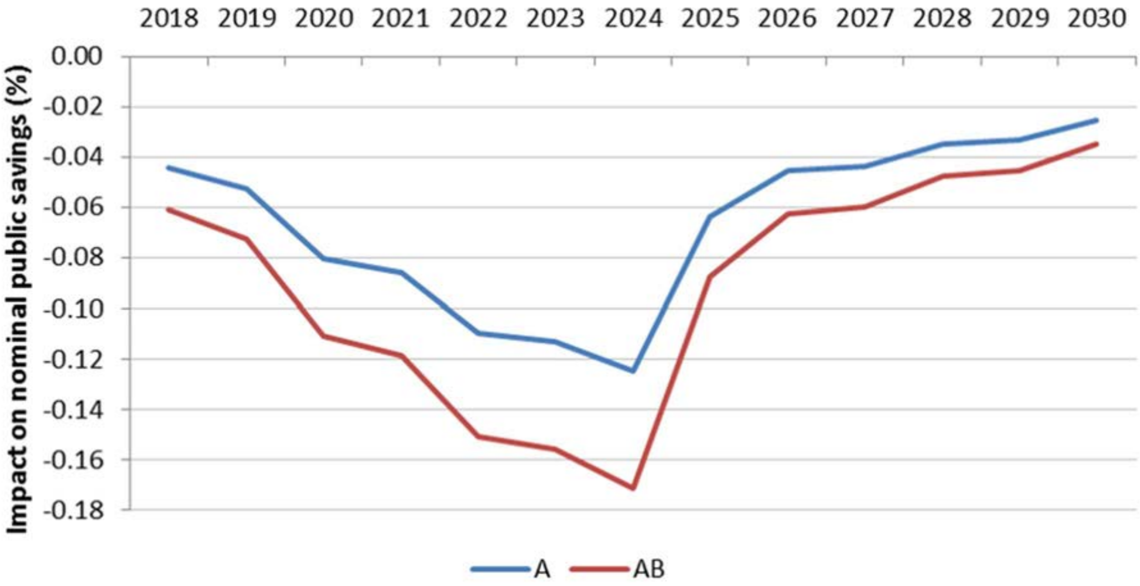

FIG. 12. Impacts of NPP construction on public savings GDP (courtesy of A. Miskiewicz, Institute of Nuclear Chemistry and Technology).

As a multisectoral model, EMPOWER provides insights not only into macroeconomic impacts but also into the effects of the NPP construction on economic sectors. Analysing the impacts on employment across the sectors, it is clear that the sectors benefiting most from the investment in building an NPP are those providing investment products: the machinery industry, the electrical and optical industry and the construction sector. The effects in other sectors are repercussions of these direct sectoral impacts traced via the economic impact mechanisms with increasing scope of submodules in EMPOWER.

A recent report [29] presents a new application of the Polish version of EMPOWER called Empower.pl. It is based on slightly modified but comparable assumptions relative to those presented in Section 3.5.2 above. In the new model runs, construction is assumed to start in 2020, the first block of the NPP will be launched in 2029 and the second one in 2033. In the first three years, annual expenditures are relatively small but growing, amounting to 6% of the total investment cost. Expenditures peak in the eighth year (2027) and amount to USD 2100 million, about 14% of the total cost, and then decline gradually.

The report presents employment impacts under the assumed NPP construction scenario on 35 sectors included in the IOT of the model for the case when feedback from financing the nuclear plant investments is considered (submodule ABCD) and funds are covered entirely by private sources (scenario nuc_yes_prv). Results confirm earlier estimates. In the year when investment disbursements peak (2027), economy-wide employment is about 12 000 jobs higher than in the base case. The largest increases occur in sectors providing investment products and services, i.e. construction (6500), machinery industry (1300) and electro-technical industry (800). They are followed by agriculture (400), and wholesale trade and retail trade (500 each). All other sectors lag far behind.

Turning to results of the PL-ATOM model, the construction of the considered NPP has positive impacts on Poland’s economy (measured by changes in GDP) under all three financing options (see Fig. 13). However, impacts emerge gradually after a slight initial decrease in GDP in the case of private and shared private–public financing. This downswing results from an enforced shift in private expenditure flows from consumption to investment in the case nuc_yes_prv or from a combination of this shift with an increase in fiscal burden (higher taxes) in the scenario nuc_yes_half. Yet any of these options accelerates capital accumulation, thereby contributing to GDP increase relative to the baseline scenario in the following years. This upswing turns out to be the strongest in the scenario in which the nuclear plant construction is financed entirely by the public sector (nuc_yes_pub). Nevertheless, the differences in impacts on GDP between the scenarios vanish almost entirely by 2030.

However, the collection of additional investment funds for the NPP construction leads to a reduction in household consumption expenditures at least in the short term. The strongest impact arises under the full public financing (nuc_yes_pub) scenario. Deviations of household consumption from the baseline scenario become positive after 2025 when electricity generated by the first reactor significantly increase the economic activity (see Fig. 13).

Figure 14 shows the deviations of public and private investments relative to the base case (no NPP construction) over the construction period 2018–2030. Trajectories of changes in investment outlays — both private and public — are almost entirely determined by the assumptions about the source of financing. Except private investment in the case of public financing, all deviations peak in 2024, i.e. one year before the launch of the first nuclear reactor. In the following years, deviations from the base case decrease in parallel with the gradual decay of the investment impulse. It is noteworthy that the initial level of public investment is significantly lower than the initial private investment. Therefore, the same absolute increase in the value of investment outlays (scenario nuc_yes_half) results in a higher percentage growth rate in the public sector.

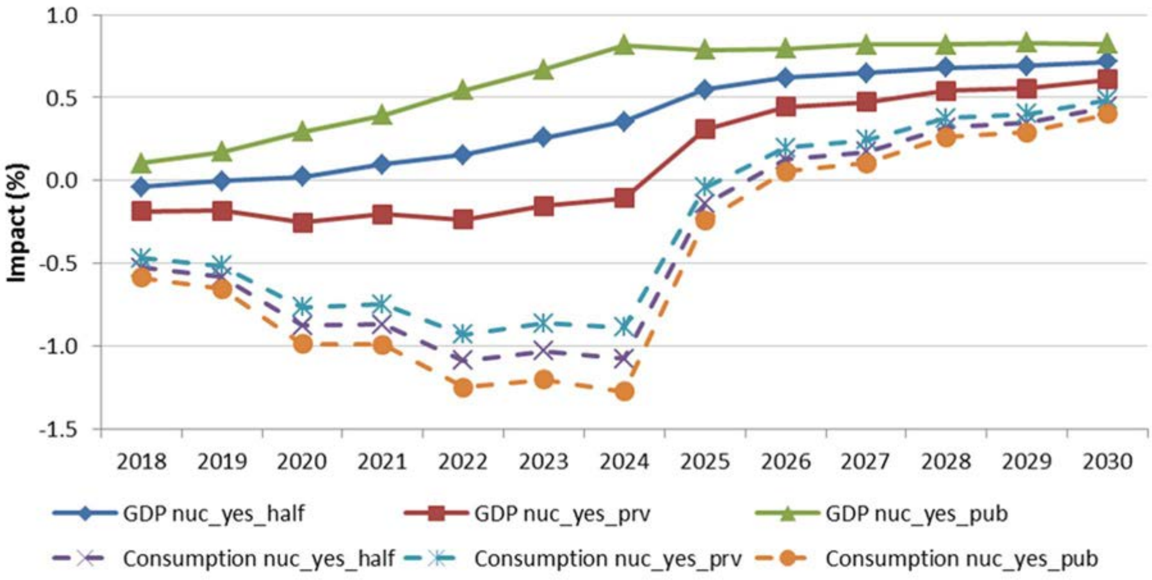

FIG. 13. Impacts of NPP construction on GDP and household consumption GDP (courtesy of A. Miskiewicz, Institute of Nuclear Chemistry and Technology).

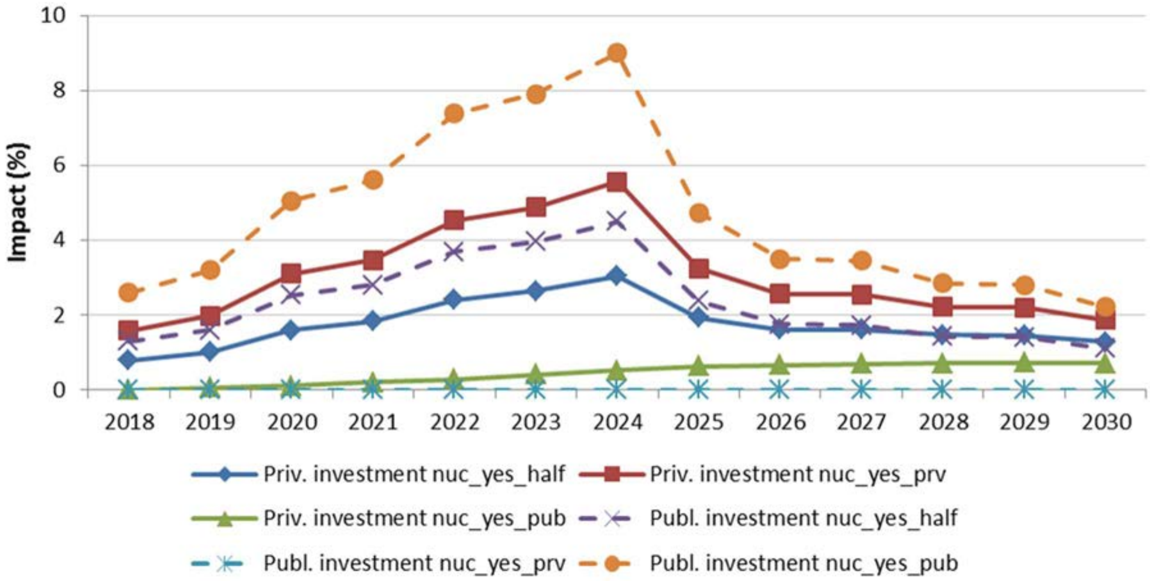

FIG. 14. Deviations of public and private investments relative to the base case under three financing scenarios GDP (courtesy of A. Miskiewicz, Institute of Nuclear Chemistry and Technology).

It is also interesting to note in Fig. 14 that private investment is slight increasing relative to the base case even when the nuclear plant construction is entirely financed by the public sector (scenario nuc_yes_pub). This results from the chosen model closure: private investment spending (endogenous by default) may freely grow also against the backdrop of changing public expenditure. The opposite outcome (i.e. increasing public investment under the nuc_yes_prv scenario) is not possible because government expenditures (including investment outlays) are specified exogenously, hence public investment remains unchanged (see Fig. 14).

In all three assessed financing scenarios, an improvement in trade balance is apparent: exports increase stronger than imports. This becomes especially visible after 2025 when the contribution of nuclear power to the energy mix improves the competitiveness of the Polish economy and reduces the need for imported fossil fuels as well. This effect, resulting in a higher openness of the economy, is largest when the nuclear plant construction is fully financed by the private sector (scenario nuc_yes_prv).

Concerning changes in relative wages at the aggregate economy level during the NPP construction under the scenario when it is fully financed by the private sector (scenario nuc_yes_prv) relative to the base case, the analysis with the PL-ATOM model reveals that in the initial period of the plant construction wages decrease somewhat relative to the base case due to the transitory downswing in economic activity. In the following years, this tendency gradually reverses and a particularly strong increase in wages occurs in 2025 in parallel with the increase of GDP relative to the base case in that year.

In contrast to wages, effects of the NPP construction on employment are transitory. They peak in 2024 triggered by the need to provide additional investment goods for the nuclear plant construction. This stems from the fact that the investment demand comprises to a large extent products supplied by relatively labour intensive industries. The positive employment effect gradually disappears in parallel with the vanishing investment impulse.

Changes in net tax revenues (i.e. adjusted for subsidies) of the state budget under the scenario in which the NPP construction is fully financed by the private sector (nuc_yes_prv) relative to the base case (no NPP construction) indicate that the impacts on the net budgetary revenues are positive over the entire construction period despite the transitory decline in economic activity in the early years. In this initial period (until the end of 2024), a part of the expenditure flows is diverted from consumption to investment. A vast part of the increased investment spending is disbursed on relatively highly taxed construction products, while lower consumption spending largely affects subsidized agricultural products. From 2025 onwards, net budgetary revenues increase further relative to the base case due to the elevated level of economic activity.

One of the main advantages of multisectoral CGE models like PL-ATOM is the possibility to assess the impacts of policy changes and/or external conditions on particular branches of the economy. The sectoral results for the scenario in which the NPP construction is assumed to be fully financed by the private sector indicate that the lignite industry is likely to become the main victim of the nuclear energy programme. The reason is that starting in 2025 demand for electricity from lignite fuelled plants declines strongly as it is crowded out by nuclear power. The hard coal sector is affected similarly as nuclear electricity replaces part of the coal based generation in the energy mix as well. Output volume changes in other industries are considerably lower.

In contrast, a significant production increase before 2025 is projected in industries whose products comprise important elements of the NPP investment demand: construction, other mining, manufacture of metal products, manufacture of computer, electronic and optical products, electrical equipment, machinery and equipment. This increase is, however, to a large extent transitory and diminishes as the investment impulse declines. Nonetheless, nuclear electricity entering the energy mix in 2025 results in increased competitiveness and output volumes in almost all other industries, particularly in the most energy intensive ones such as manufacture of basic metals, construction, manufacture of rubber and plastic products or manufacture of motor vehicles, trailers and semi-trailers and other transport equipment.

In addition to the macroeconomic and sectoral impacts of introducing nuclear energy in Poland, consequences for the energy sector are also important. Nuclear power plays a crucial role in areas such as electricity prices and CO_2 emissions from the energy sector. The PL-ATOM model can calculate the optimal (cost minimizing) energy mix for the scenarios without nuclear energy and with NPP construction financed solely by the private sector (nuc_yes_prv). Results do not show any noticeable differences in the level and structure of electricity production until 2024. Changes start in 2025 when electricity from the NPP becomes available. As a more cost efficient technology, it crowds out electricity from hard coal and lignite based power plants from the power supply mix. The competitiveness of nuclear power results from a combination of factors such as technology specific costs, fossil fuel prices and CO_2 emission allowance prices. Total electricity use in the scenario with NPP construction is higher by several terawatt-hours than in the baseline scenario as a result of increased level of economic activity.

Similarly, electricity prices are almost identical in the two scenarios until 2024. Starting in 2025, when electricity from the nuclear plant becomes available, electricity prices are somewhat lower relative to the baseline because the cost of nuclear power generation is lower than that of conventional sources. However, the price of electricity increases over time in all analysed scenarios. This is the result of ongoing economic growth, the related increase in energy demand, higher fuel prices and CO_2 emissions costs as well as changes in the availability of particular power generation technologies.

The amount of CO_2 emissions in the two scenarios is very similar until 2024. A significant change starts in 2025 when zero emission nuclear power becomes available. The partial replacement of electricity from hard coal and lignite power plants by nuclear power leads to a visible decrease in total CO_2 emissions in the energy sector.

3.5.4. Main conclusions

This study applies two different models to assess the macroeconomic and sectoral impacts of the Polish nuclear power programme: EMPOWER, an extended IOM developed by the IAEA and PL-ATOM, a dynamic CGE model. The comparison of the two models reveals that EMPOWER, the simpler model of the two, contains a narrower range of impact mechanisms than the PL-ATOM model.

These differences explain the observed dissimilarities in the magnitude of economic effects of the NPP construction calculated by the two models. Nevertheless, EMPOWER, a simpler model that is easier to control and verify, can be successfully used to validate results of the more complex PL-ATOM model. However, this will require additional research, involving the exclusion of some mechanisms from the PL-ATOM simulations in order to make it analogous with EMPOWER. Comparing the results of the two models in this way could help answer the question regarding which impact mechanisms in the PL-ATOM model work more forcefully than the equivalent mechanisms in EMPOWER. Such a comparison could also reveal whether the supplementary mechanisms in the PL-ATOM model — not included in EMPOWER — exert too much influence on results.

3.6. RUSSIAN FEDERATION

Nuclear energy is an important factor in the economic development of the Russian Federation. Various aspects of the national nuclear energy programme are subject to comprehensive scientific research. This section explores the macroeconomic impacts of building and operating new NPPs. It is based on the contribution of the Russian Federation research team to the CRP presented in Ref. [31].

3.6.1. National context

As of 2020, the Russian Federation operates 36 nuclear power reactors and there is a strong commitment to increase the contribution of nuclear energy to the national electricity supply. According to the latest federal target programme, the nuclear share in electricity supply is projected to reach 25–30% by 2030, 45–50% by 2050 and 70–80% by the end of this century. There are ten units under construction to be completed by 2030 [32].

This ambitious nuclear energy programme has significant impacts on the national economy. This study adopts two approaches to assess the economy-wide impacts of NPP construction and operation.

3.6.2. Models and data

The first approach to estimating the macroeconomic impacts of building and operating new nuclear plants in the Russian Federation applies EMPOWER developed by the IAEA (see Section 2). Most of the data required to run EMPOWER are available in official statistics. For this modelling study, the official IOT for 2014 published by the Russian Federal State Statistics Service is used. The original IOT is converted into a table with 35 sectors with the help of a simple aggregation algorithm. No RAS routine is used to create a future IOT, i.e. the IOT for the target year is the baseline IOT.

Construction and operational costs and production data for the new NPPs used in these calculations correspond to real NPP projects. They imply two units, a construction period of 17 years, the whole period considered covers 32 year and the total investment cost amounts to USD 6.77 billion at constant 2014 prices. Since the obtained construction costs data are aggregated at the level of expenses for machinery and equipment, construction and other goods and services, some special calculations are necessary to determine expenses for the investment products of various sectors. Two figures show the total amount and the structure of the construction costs (Fig. 15) and the operational costs (Fig. 16) of the considered NPP project.

In order to determine a new vector of technological coefficients for electricity generation, it is assumed that the NPP does not replace already existing generation capacities. It means that the operational costs of the new NPPs are added to the baseline operational costs in the electricity sector and the output of the new NPPs is added to the baseline output of the sector. As the calculations are carried out step by step, year to year, a new vector of technological coefficients is determined for every year of the operational phase by using annual output and operational costs.

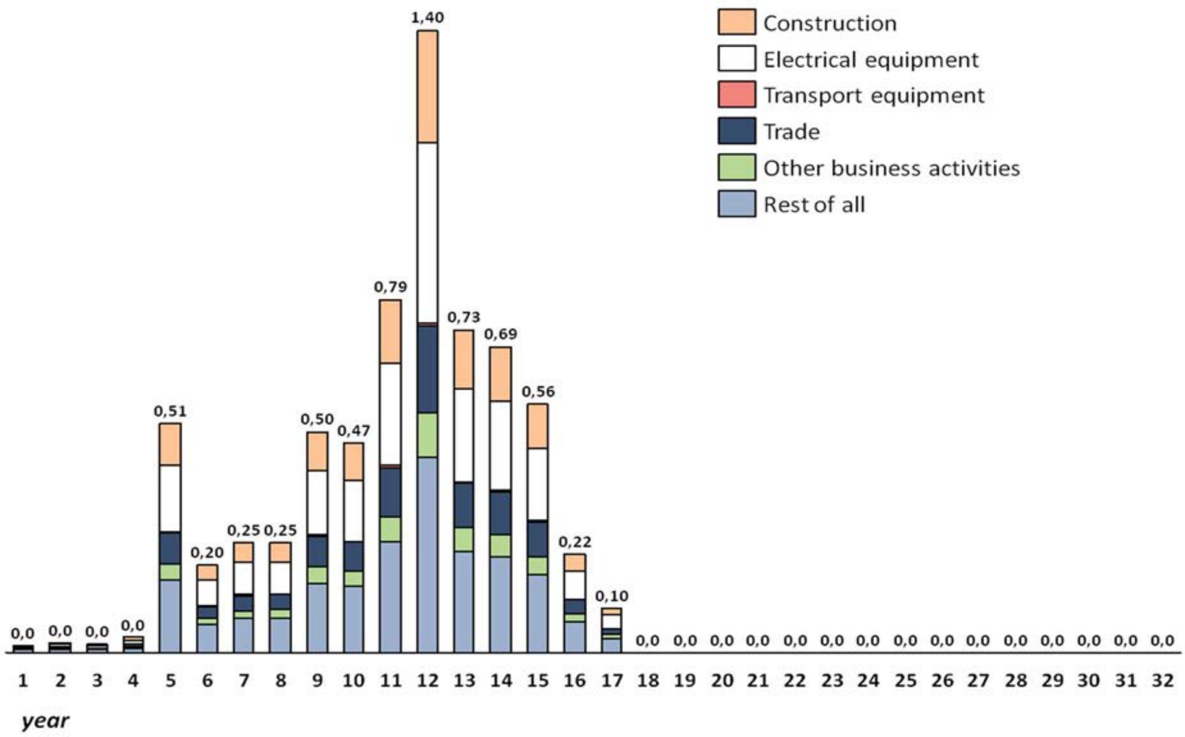

FIG. 15. Construction costs of the NPP project (billion constant 2014 USD) (courtesy of A. Shirov, Institute of Economic Forecasting).

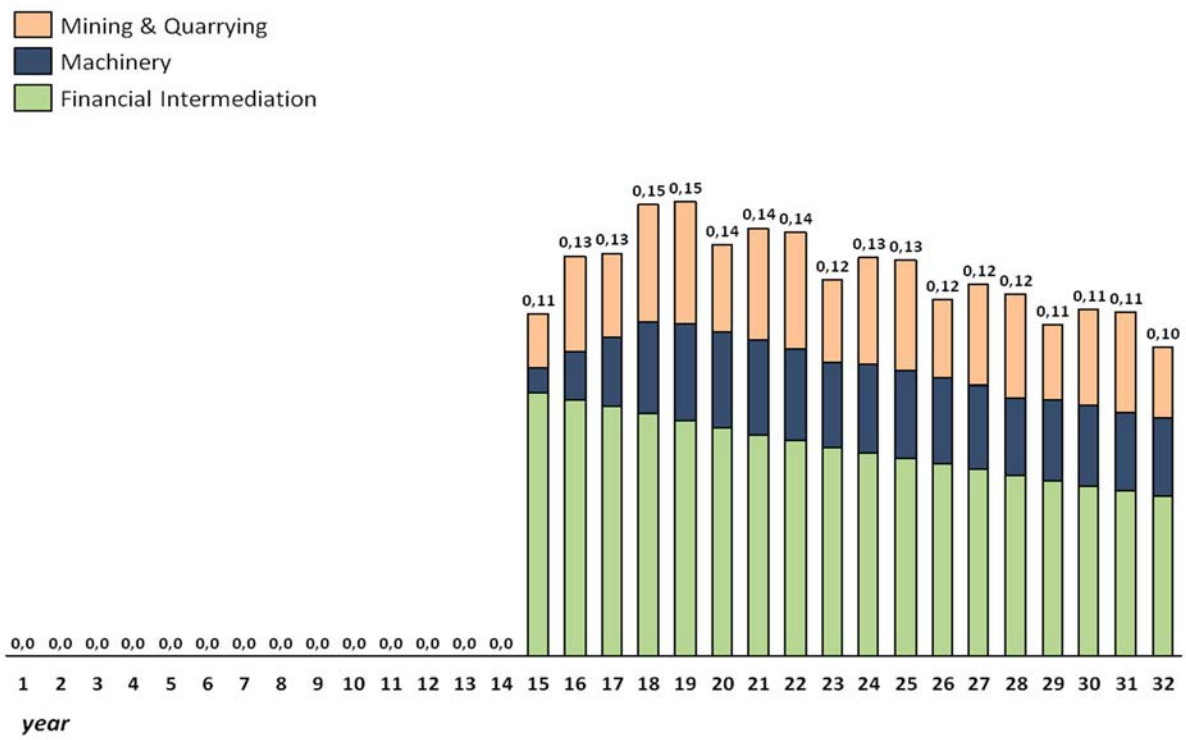

FIG. 16. Operational costs of the NPP project (billion constant 2014 USD) (courtesy of A. Shirov, Institute of Economic Forecasting).

The second approach for calculating macroeconomic impacts of the NPP project specified above involves the application of an alternative model. In order to verify EMPOWER results, similar calculations are carried out by using a model developed by the Institute of Economic Forecasting of the Russian Academy of Sciences (IEF RAS).

The principles of evaluating the multiplier effects in this model are almost the same as in EMPOWER. However, there are some differences. First, the IEF RAS model takes into account long term changes in the cost structure manifested in decreasing technological coefficients due to improving efficiency of the economy, i.e. increasing productivity of primary resource use. Second, the future IOTs used in the IEF RAS model are not balanced by any data reconciliation method. Third, the IEF RAS model also considers the macroeconomic effects of the distribution of additional taxes and profits in specifying final demand.

3.6.3. Results

In the first modelling approach, EMPOWER is used for calculating the evolution of the IOT year to year rather than only for the final target year. This involves a series of calculations in which the target year is continuously changed until the final target year is reached. In this assessment, submodules ABC and ABCD are not considered because they are not applicable to the Russian case. In fact, the implementation of an NPP project in the Russian Federation does not affect either the labour market or the prices in the electricity sector and the economy. The reason is that the electricity price is partly regulated by the government, and the nuclear power industry itself has been part of the country's economy for many decades.

Estimated annual indirect and induced effects of the NPP project on gross output are shown in Fig. 17. The cumulative effect are presented in Fig. 18. Results of EMPOWER calculations are quite plausible. Estimates of the multiplier effects are strongly correlated with the capital expenditures and operating expenses of the NPP. The cumulative increase in gross output is estimated at USD 15.8 billion (at constant 2014 prices) due to indirect effects and USD 10 billion arising from induced effects. The total cumulative increase in gross output due to indirect and induced effects is estimated at USD 25.9 billion or 0.7% relative to the baseline.

In the construction phase, the ratio of annual gross output increase (relative to the baseline) to the amount of annual investment is 1.7 for the direct and indirect impacts (calculated by submodule A of EMPOWER) and 2.34 for the induced impacts (assessed by submodule AB). In the operational phase, the ratio of annual gross output increase (relative to the baseline) to the total amount of investment is decreasing from 0.12 to 0.05 for the direct and indirect impacts (submodule A) and from 0.24 to 0.18 for the induced impacts (submodule AB). The ratio of the cumulative gross output increase to the total amount of investment in the project is 3.82 during the 32 year period.

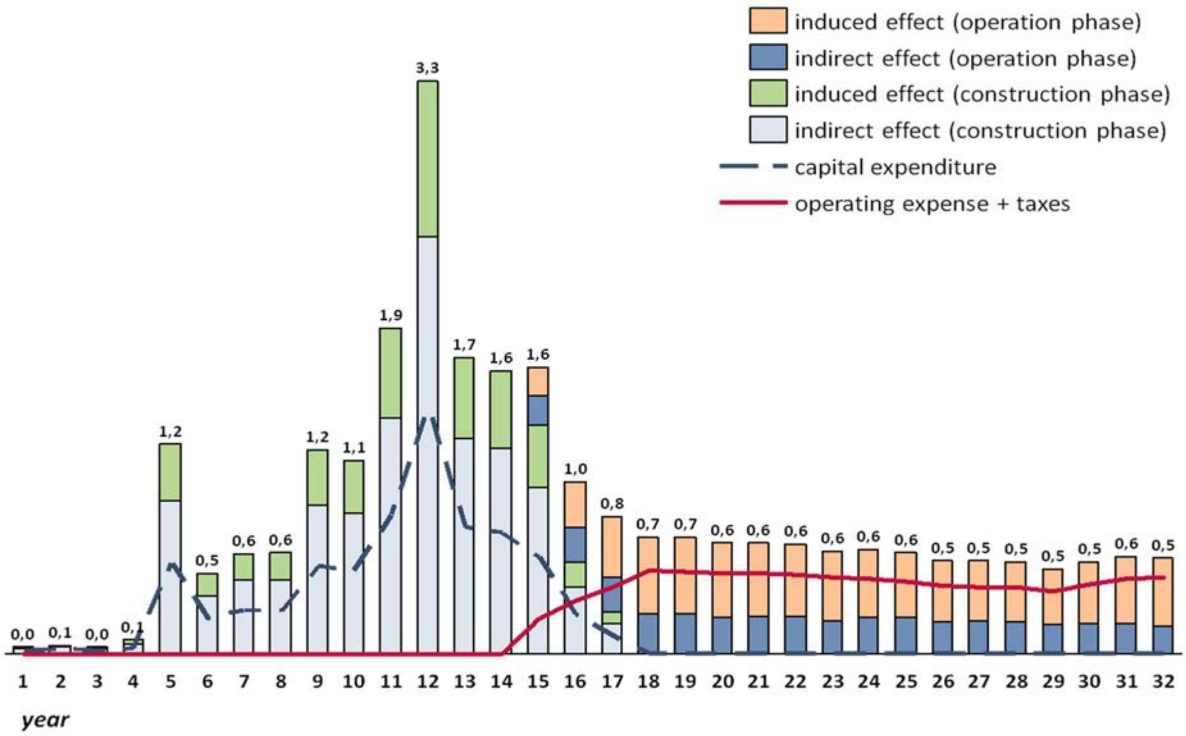

FIG. 17. Annual indirect and induced effects of the NPP project on gross output calculated by EMPOWER (billion constant 2014 USD) (courtesy of A. Shirov, Institute of Economic Forecasting).

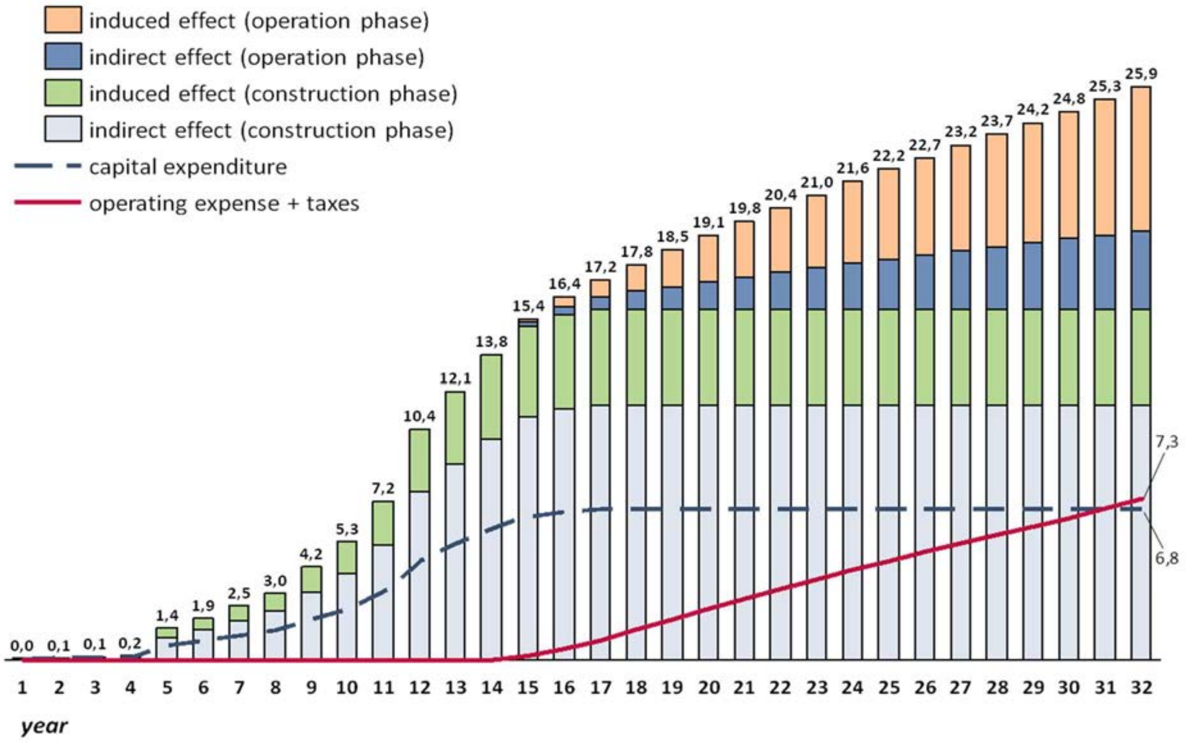

FIG. 18. Cumulative indirect and induced effects of the NPP project on gross output calculated by EMPOWER (billion constant 2014 USD) (courtesy of A. Shirov, Institute of Economic Forecasting).

Figure 19 presents the structure of the cumulative gross output increase in the construction and operational phases. In the construction phase, the largest cumulative output increase is projected in trade, electrical equipment, machinery and construction. In the operational phase, the largest cumulative output increase is expected in financial intermediation, trade, real estate activities and food production. The first rank of financial intermediation in the operational phase is due to the calculation procedure in the model assuming that interests arising in the investment phase are paid in the operational phase. These large loan related payments boost the financial intermediation sector.

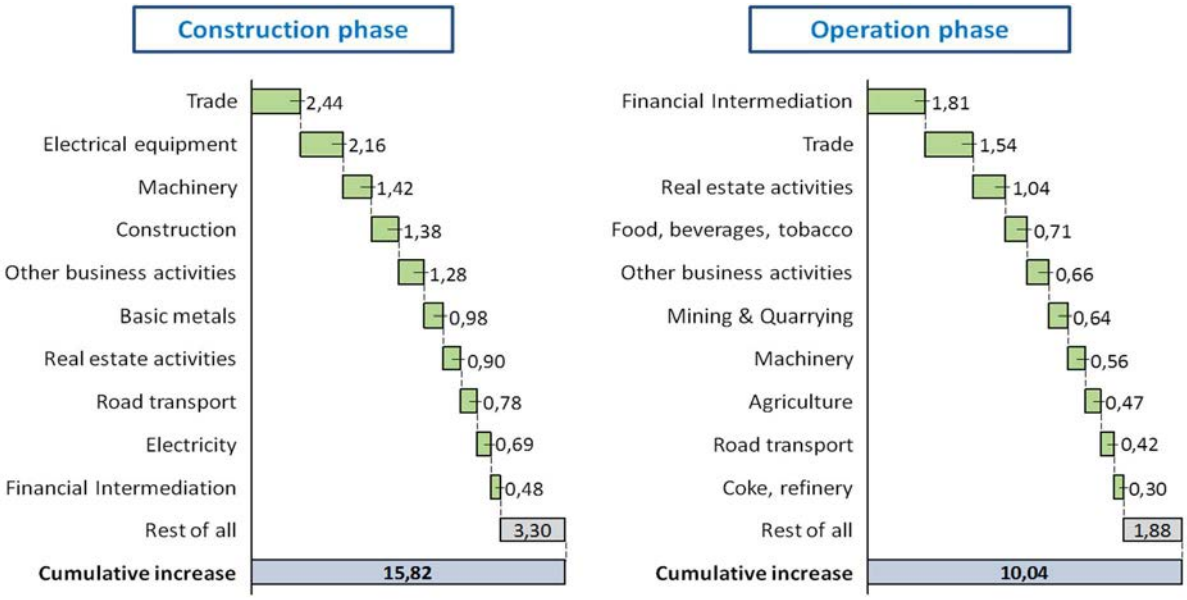

FIG. 19. Cumulative gross output increase in the construction and operational phases calculated by EMPOWER (billion constant 2014 USD) (courtesy of A. Shirov, Institute of Economic Forecasting).

Similar calculations are carried out by using the second modelling framework, the IEF RAS model. Estimates of cumulative increases in gross output triggered by indirect and induced effects of the NPP project obtained with EMPOWER and the IEF RAS model are presented in Fig. 20. The estimates are very close.

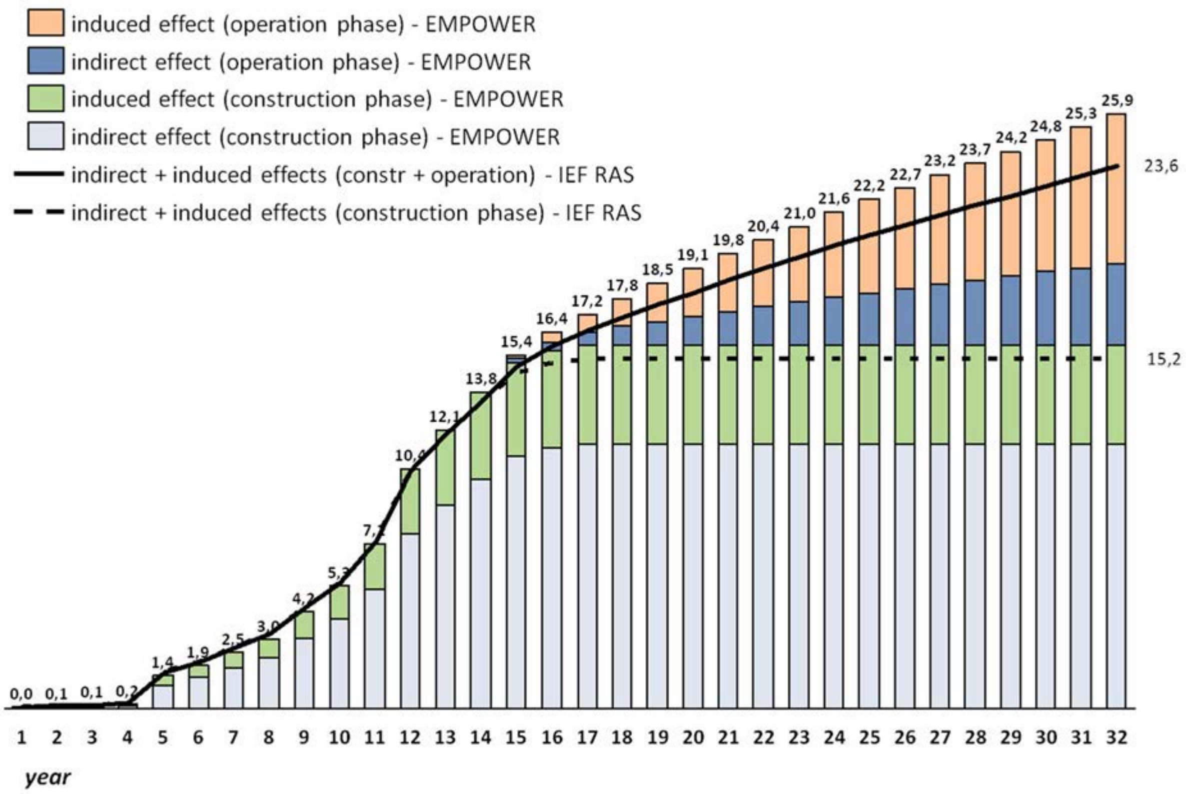

FIG. 20. Cumulative effects on gross output estimated by EMPOWER and the IEF RAS model (billion constant 2014 USD) (courtesy of A. Shirov, Institute of Economic Forecasting).

The structure of cumulative gross output increase in the construction phase estimated by EMPOWER is similar to that estimated by the IEF RAS model (see Fig. 21). The top five sectors with the largest output increase are trade, electrical equipment, machinery, construction and other business activities (including research and development).

For the operational phase, results of EMPOWER and the IEF RAS model are slightly different (see Fig. 22). The reason stems from the differences between the two models as explained in Section 3.6.2. For example, public administration, health and education are in the top ten sectors with the largest output increases in the IEF RAS model because it takes into account the effects of distribution of additional taxes on final demand and shares of these sectors in government consumption are high. The cumulative gross output increase calculated by the IEF RAS model is less than the one estimated by EMPOWER because the former takes into account that technological coefficients are decreasing over the long term.

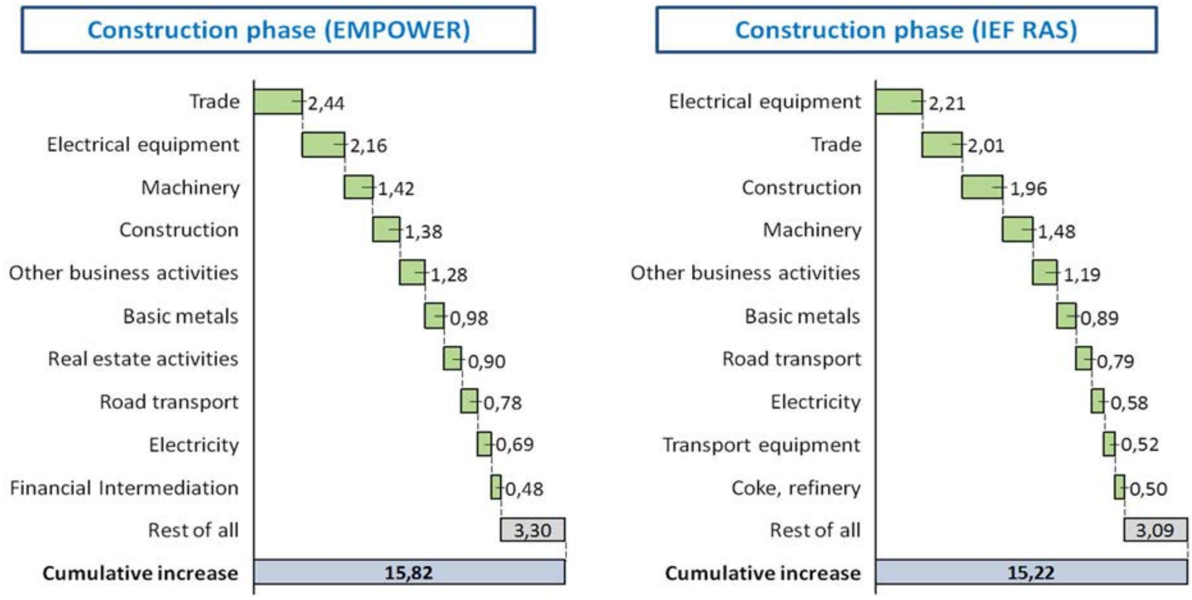

FIG. 21. Cumulative gross output increases in the construction phase estimated by EMPOWER and the IEF RAS model (billion constant 2014 USD) (courtesy of A. Shirov, Institute of Economic Forecasting).

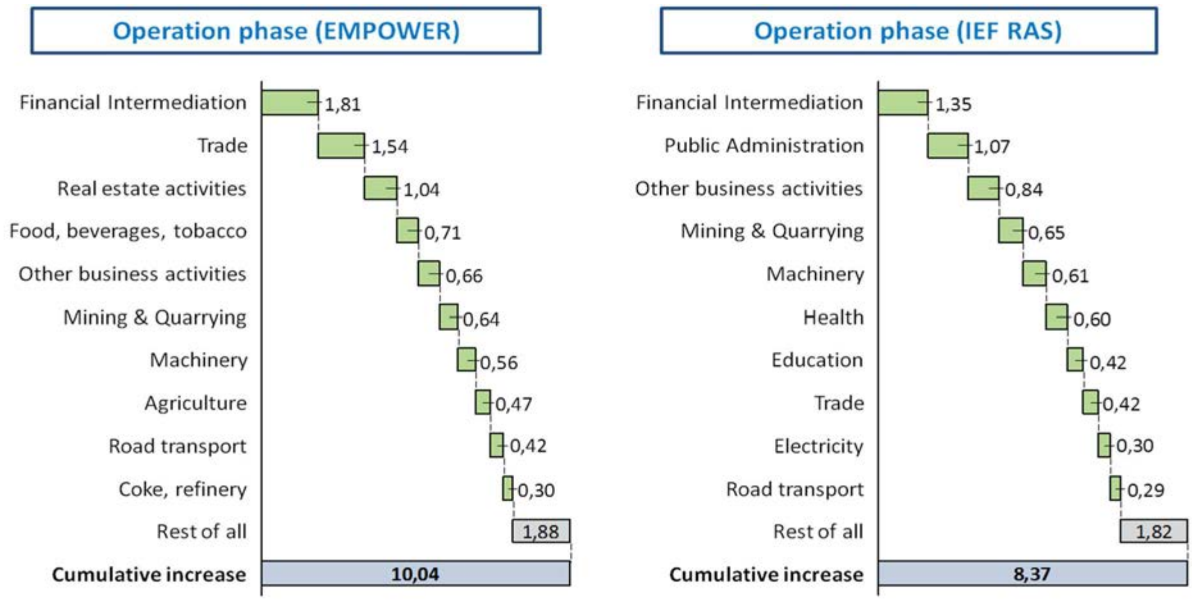

FIG. 22. Cumulative gross output increases in the operational phase estimated by EMPOWER and the IEF RAS model (billion constant 2014 USD) (courtesy of A. Shirov, Institute of Economic Forecasting).

The reason why financial intermediation has the largest sectoral impact according to both models is that the assumption concerning interest payments in the investment phase are related to the operational phase is implemented consistently in the calculation procedure of both models and the magnitude of interest payments exceeds the impacts on all other sectors.

3.6.4. Main conclusions

The overall conclusion is that EMPOWER provides plausible results and it can be used for assessing macroeconomic impacts of NPP projects on gross output. However, there seem to be possibilities for further improvements of EMPOWER.

The key points for improving EMPOWER include assessing the macroeconomic effects of the distribution of additional taxes and profits on the final demand and accounting for improving efficiency of the economy over the long term.

3.7. SOUTH AFRICA

The aim of the South African research team in this CRP is to quantify the economic effects of large nuclear energy programmes in developing countries, in particular in South Africa. The project also helps identify key actors for establishing macroeconomic modelling capabilities in South Africa and develop skills and data sets for the modelling activities. The lessons learned from the project can be rolled out to the rest of Africa and the Network for Education in Nuclear Science and Technology under the Africa Regional Cooperative Agreement for Research Development and Training Related to Science and Technology can be used for this purpose. This section is based on Ref. [33].

3.7.1. National context

Global energy demand will continue to grow as developing countries gain access to industrial technologies and improve the quality of life of their citizens. This requires the development of energy sources, including nuclear energy, and the transmission and distribution infrastructure so that end users can utilize electricity as efficiently as possible. The National Development Plan of South Africa includes plans with specific social and economic development targets. Nuclear energy programmes involve large capital costs and funding requirements that create challenges for developing countries. Information about quantified economic effects of a nuclear energy programme can help make decisions about financing such a large investment programme. These effects can also be measured against development plans to determine the effectiveness of such investments in realizing the targeted outcomes.

This study adopts input–output modelling methods and analyses the sensitivity of changes in input parameters cascading through the various systems. Benefits are measured against the capital investment in the project. As an external benchmark, results can be measured against expected development goals set for the country by its national development policy. Results provide a sound base for policy makers to arrive at investment and other strategic decisions.

The South African future electricity supply mix is prescribed by the Integrated Resource Plan 2010 that has been promoted by the Government. Based on this plan, the energy mix will include 9600 MW(e) nuclear generation capacity. In the meantime, however, the Integrated Resource Plan has been amended. A new draft plan was released in 2018 for comments. The draft plan does not include nuclear new build programmes.

3.7.2. Model and data

EMPOWER developed by the IAEA (see Section 2) is applied to assess the macroeconomic impacts of the nuclear energy programme in South Africa. The model requires the use of the latest national IOT. The table needs to be symmetric (i.e. row and column totals of each corresponding industry need to be equal) and in the format of separate domestic and import tables.

Since the IOT published by the Statistics South Africa is only available in aggregated format, other sources of IOTs are investigated. The OECD database of harmonized national IOTs [34] regularly publishes the latest IOTs based on the national accounts of South Africa. It uses the industry-by-industry approach and publishes the IOTs as two separate tables: domestic and import. The IOTs published by the OECD consist of 34 industries and fulfil all requirements of EMPOWER. The aggregation tool in EMPOWER is used to rearrange the IOT so that the electricity industry appears in the first row and the first column.

Data preparation for EMPOWER requires the approximation of future IOTs during the time of the NPP construction and operation. The RAS method (a widely used data reconciliation method) is used to approximate future IOTs and also to assist in balancing the IOT when the first approximated table is unbalanced. By using future average annual growth rates of output, projected future IOTs for the final target year and every year of the construction period can be computed.

Employment data for EMPOWER are obtained from the OECD and the Statistics South Africa. The labour force in South Africa is estimated at 18 501 000 in 2011. Employment data are not available for the 35 sectors included in EMPOWER but only in an aggregated form. The Quarterly Labour Force Survey published by the Statistics South Africa presents aggregated data at the level of the following industries: agriculture, mining, manufacturing, utilities, construction, trade, transport, finance, community and social services, and other. Employment data for EMPOWER sectors are calculated by disaggregating these industry level data. Growth rates of employment for the aggregated industries are calculated from historical annual average rates of growth or decline and they are used for projecting future annual growth rates.

Wages (compensation of employees) are obtained from the value added section of the OECD database for the year 2011. Annual growth rates of wages are required by industry for EMPOWER. However, these data are available only in aggregated form. The growth rate of aggregated nominal factor income was 8.8% in 2011 and 8.3% in 2012. The growth rate of wages decelerated from 12% in 2010 to 9.8% in 2011. The industries trade, transport and the general government sector have slower paces of wage increases. These sources are used for specifying wages in EMPOWER. The annual growth rate of labour force is determined from historical data obtained from the Statistics South Africa. It is calculated at 2.74%.

Data for the household section of EMPOWER are calculated from historical data to determine the average annual growth rate for each required variable. The sum of the wages for employees is obtained from the 2011 IOT of South Africa available in the OECD statistics. The share of operating surplus going to households is estimated at USD 49 955.6 million. The annual growth rate is estimated from historical data and calculated at 10.3%. Household incomes received from property in 2011 amount to USD 44 458.9 million. Their estimated annual growth rate is 7.09%. Income taxes paid by households to the government in 2011 total at USD 37 419 million. They are projected to grow at the rate of 12.3%/year. Social contributions paid by households to the government in 2011 equal USD 28 505.2 million. Their annual growth rate is calculated at 8.1%. Other transfers from the government to households in 2011 include social grants and reach USD 28 505 million. They are projected to grow at an annual rate of 11.38%.

The government datasheet requires data on government expenditures and revenues. They are obtained from the statistical tables published by the South African Reserve Bank. Financing the NPP construction is assumed to flow from external sources (85%) and ex ante revenues (15%). This assumption is based on current market conditions.

EMPOWER also requires the specification of a range of parameters. Data for some of these parameters are not available in the literature and it is difficult to make assumptions about them. In such cases, the guidance of the IAEA EMPOWER document [5] is followed.

Based on a paper by Bengtsson [35], the marginal propensity to consume is set at 0.7 for South Africa. The export price elasticity is estimated by Behar and Edwards [36]. The demand is highly price elastic ranging from -3 to -6. The price elasticity of supply is set at -1, but some estimates are as low as -0.35 [36].

The wage reaction to the unemployment rate is another parameter for which no data is available. Therefore, the value suggested by the EMPOWER document [5] is used and this parameter is set at 0.1.

The construction cost of the NPP is calculated from data acquired from the South African Department of Energy and from World Nuclear News publications. Based on data from the Department of Energy, the estimated investment cost is set at USD 5141.05/kW(e). Accordingly, the construction costs amount to USD 19 400 602 937, including interest during construction. The overnight cost (without interest) is calculated at USD 14 394 940 000. The total construction costs are based on a discount rate of 8.2% and a loan duration of 60 years. The load factor of 90% is used for a plant capacity of 2800 MW(e). The distribution of investment outlays during the six year construction period is as follows: 15% in each of the first two years, 25% each in the following two years and 10% each in the last two years. The distribution of construction costs across economic sectors is based on Ref. [37]. The sectors most affected by the NPP construction and mainly involved in the localization include construction, manufacturing and electrical machinery.

3.7.3. Results

EMPOWER specified according to the input data presented in the previous section is used to calculate macroeconomic impacts of the NPP construction. Impacts are assessed for two impact mechanisms (calculated by different modules in EMPOWER) where the second impact mechanism incorporates results of the first one: direct and indirect effects (submodule A) and induced effects, including direct and indirect effects (submodule AB). For each impact mechanism, macroeconomic impacts are estimated in terms of six indicators: GDP, disposable income, total output, public net savings, imports and employment. The results are presented in Table 16.

Table 16 shows that EMPOWER produces plausible results for both impact mechanisms. Direct and indirect impacts (submodule A) on GDP increase from 0.6% in the initial year to 2.2% in the penultimate year and decline to 1.3% in the final year of the NPP construction. Induced impacts (submodule AB) on GDP range between 0.8% and 2.8%.

Direct and indirect impacts (submodule A) of the NPP construction on employment increase gradually from 0.5% in the starting year to 4.9% in 2024 and drop to 1.3% in the last year of the construction period. Employment effects follow a similar pattern over the years under the other impact mechanism as well.

Reference material on economic impacts of operating the Koeberg NPP (1800 MW(e)) on the South African economy shows a 0.2% impact on the GDP. The estimation produced by EMPOWER for operating the assumed 2800 MW(e) nuclear plant comes to an impact of 0.7% on the GDP. However, this and all other results for the operational phase need to be verified, therefore they are not presented here in detail.

3.7.4. Main conclusions

A number of economic models are used to undertake techno–economic analyses on various subsystems of a nuclear new build programme. Results of these models are combined to form a set of input data to the input–output modelling work in this project. One particular difficulty is that data on total capital investment costs required for the macroeconomic modelling is not readily available for developing countries such as South Africa. A new methodology is required to determine investment costs in which labour costs are 'localized'.

EMPOWER delivers plausible results for the construction phase under the two impact mechanisms analysed for South Africa. However, various assumptions are required to produce meaningful results. These assumptions might affect the accuracy of the results and might be a hindrance for many countries in which comprehensive and reliable statistical data are not available.

TABLE 16. IMPACTS OF NPP CONSTRUCTION IN SOUTH AFRICA
(changes relative to the baseline case)

Impact mechanism	2020	2021	2022	2023	2024	2025
Impacts on GDP in current prices (%)						
Submodule A	0.6	1.2	1.2	1.5	2.2	1.3
Submodule AB	0.8	1.5	1.6	1.9	2.8	1.6
Impacts on disposable income in current prices (%)						
Submodule A	0.4	0.9	1.0	1.3	1.9	1.1
Submodule AB	0.5	1.2	1.3	1.6	2.4	1.4
Impacts on production output in current prices (%)						
Submodule A	0.7	1.4	1.6	2.0	2.9	1.7
Submodule AB	0.8	1.7	1.9	2.4	3.5	2.0
Impacts on public net savings in current prices (%)						
Submodule A	-0.7	-1.9	-2.3	-3.3	-5.2	-3.7
Submodule AB	-0.8	-2.3	-2.8	-4.1	-6.6	-4.7
Impacts on imports in current prices (%)						
Submodule A	0.5	1.1	1.0	1.2	1.8	1.3
Submodule AB	0.7	1.5	1.4	1.7	2.5	1.7
Impacts on employment (%)						
Submodule A	0.5	1.1	2.6	3.2	4.9	1.3
Submodule AB	0.6	1.4	2.9	3.6	5.4	1.7

Moreover, EMPOWER takes many steps to obtain results for the construction phase. The first step is to obtain the IOT in the required format. The baseline IOT for South Africa is taken from the OECD input–output database because the format of the IOT compiled by the Statistics South Africa is not compatible with the requirements of EMPOWER. The aggregation tool in the EMPOWER framework is helpful to organize the IOT in the correct order required by the model.

Data preparation and processing for the construction phase requires many hours of research, including examination of national accounts, publications of national reserve banks, the OECD and other economic institutions. In the case of South Africa, the main sources of data are the Statistics South Africa and the OECD databases. Projections are based on historical data because forecasts are not available from literature sources. Construction cost data are obtained from the South African Department of Energy and the Nuclear Industrial Association of South Africa. Data are not available for estimating parameters such as the marginal propensity to consume, the wage reaction to the unemployment rate and the export price elasticity, therefore values proposed by the EMPOWER document are used.

Results of EMPOWER show positive economic impacts on the GDP of South Africa for the assumed case of building a 2800 MW(e) NPP over six years. The model produces plausible results for the two impact mechanisms. Direct and indirect impacts (submodule A) on GDP increase from 0.6% in the initial year to 2.2% in the penultimate year and decline to 1.3% in the final year of the NPP construction. Induced impacts on GDP (submodule AB) range between 0.8% and 2.8%.

Estimated impacts of the NPP construction on employment are also positive. Direct and indirect impacts (submodule A) gradually increase from 0.5% in the starting year to 4.9% in 2024 and drop to 1.3% in the last year of the construction period. Employment effects follow a similar pattern over the years under the other impact mechanism.

3.8. TUNISIA

The research team from Tunisia participating in this CRP includes experts from the Tunisian Company of Electricity and Gas (Dr Chokri Zammali) and the Tunisia Polytechnic School (Mr Mehdi Gebs and Prof. Mahmoud Sami Nabi). This section is based on Ref. [38].

3.8.1. National context

Tunisia is among the 28 countries that are considering the introduction of nuclear power in their electricity generation mix. The country is participating in the IAEA's nuclear newcomers project that supports Member States in developing their infrastructure for a safe and sustainable nuclear power programme. This section present results of the assessment of macroeconomic impacts of building and operating an NPP in Tunisia.

3.8.2. Model and data

EMPOWER developed by the IAEA is applied to assess the economy-wide impacts of a hypothetical NPP in the construction and the operational phase. The model requires a large set of data about the Tunisian economy and the characteristics of the hypothetical NPP. Three major issues emerge in collecting the necessary data. First, differences between the two main data sources must be resolved; second, discrepancies between the data required by the model and those available from various sources must be sorted out in a coherent manner; and third, unavailable data such as annual growth rates need to be estimated by using historical data.

Two possible sources are considered for obtaining the IOT and other required data: the local databank of the National Institute of Statistics and the international databank of the OECD. Although national statistics provide more data, the IOT from the OECD database [34] is used because EMPOWER requires separate IOTs for domestic production and imports as principal inputs and this format is available only from the OECD. Data not available in the OECD database such as employment per sector is obtained from the National Institute of Statistics. This requires disaggregating data for the 24 economic sectors in the national database according to the 34 industries of the OECD IOT.

The OECD IOT aggregates the electricity sector with the gas and water supply sectors. However, EMPOWER requires that a separate electricity sector is placed in the first row and first column of the IOT. Therefore, national IOTs for the years 2001–2005 are used in which the electricity sector is separated. The process involves computing the share of the electricity sector in the aggregated electricity, gas and water supply sector and then extrapolating the result to the reference year 2010 by using average annual growth rates. The intermediate consumption of the electricity sector from other industries is calculated for each sector, then the resulting shares are extrapolated to 2010 by using average annual growth rates as well. In addition, data from the 2010 annual report of the Tunisian Company of Electricity and Gas [39] and other sources are used to calculate adjusted coefficients.

The reference year in the Tunisian model is 2010 and it contains economic data for that year. However, the NPP construction is assumed to start in 2024, therefore the production volume of all industries in the IOT are estimated by using the RAS method and annual production growth rates in order to assess the impacts over the construction period. Projections for the target year are calculated by averaging past annual growth rates for two phases: one calculated for the period of economic decline (2011–2017), the other calculated from data before 2011 to represent the economic recovery after 2017.

In order to estimate the growth rates of direct taxes, social contributions and other transfers from the base year (2010) to the target year (2024), the model also requires external input. Available data related to these items are used in a linear regression model between disposable income (which is estimated by the model for the target year) and other elements of the national accounts. For the year 2026, the extrapolation estimates the disposable income at Tunisian Dinar (TND) 140 679.5 million. The linear regression model estimates that direct taxes would be roughly equal to TND 9744.7 million, which represents an average annual growth rate of 7%. The same method is used to estimate the annual growth rates of social contributions and other transfers. Concerning other economic parameters, the marginal propensity to consume is estimated at 0.785 and the wage reaction to the unemployment rate at -0.07.

The total cost of building an NPP with one 1000 MW(e) PWR including interest during construction is estimated at USD 5 billion. According to the assumptions considered in a study of the Tunisian energy mix [40], the construction takes six years. It is assumed that construction starts in 2024 and ends in 2030. The distribution of annual construction outlays over the construction period is presented in Fig. 23.

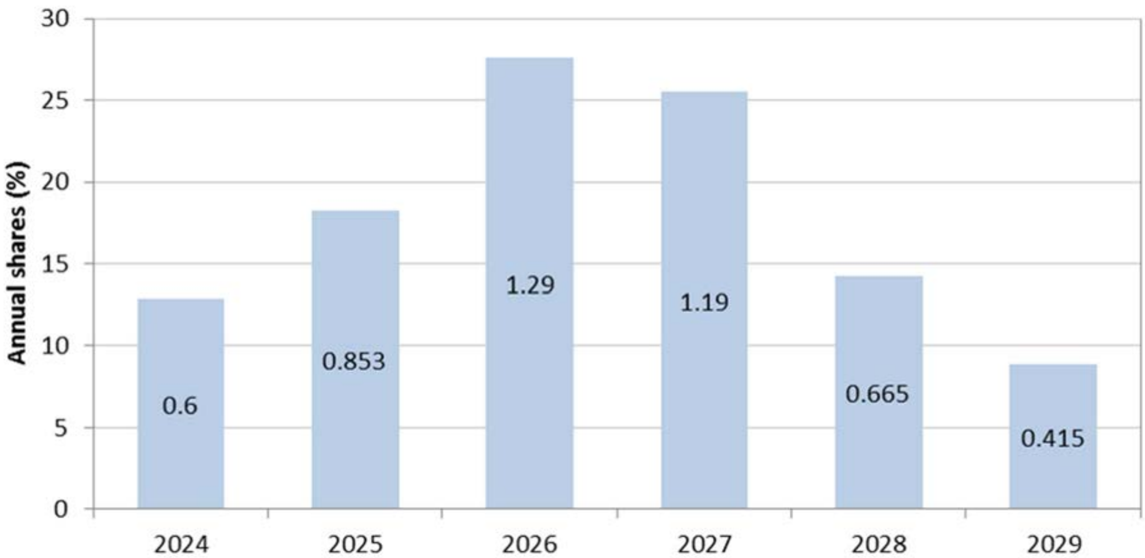

FIG. 23. Annual shares of construction expenditures. Note: Numbers in the columns indicate investment outlays in the given year in USD billion (courtesy of C. Zammali, Tunisian Company of Electricity and Gas).

The level of local industrial involvement is taken from the feasibility study of the first NPP project in Tunisia [41]. The contribution of the national industry to the construction is estimated at nearly 10% each year. The first approximation of the shares of annual sectoral contributions is presented in Fig. 24.

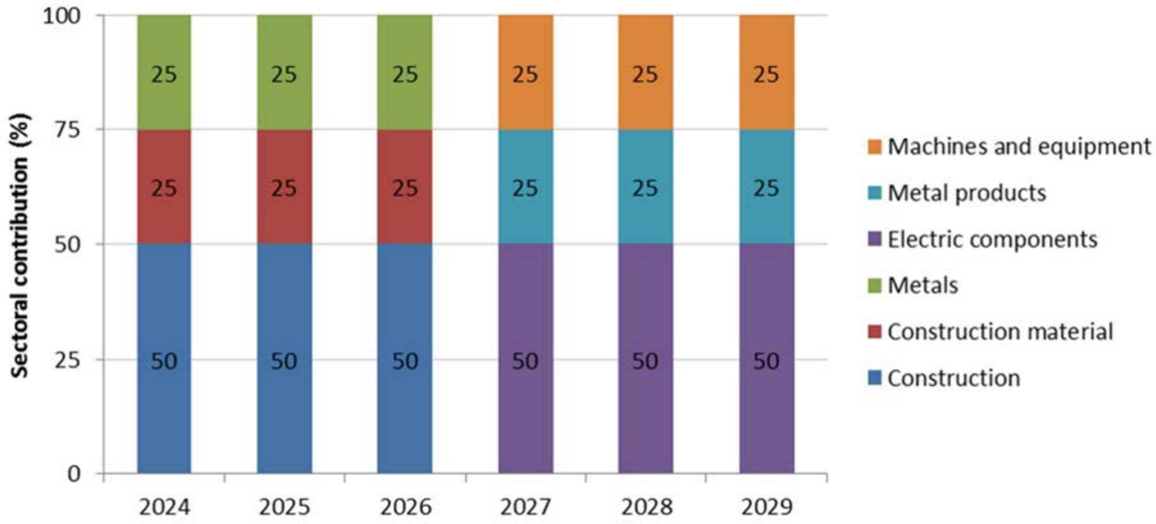

FIG. 24. Shares of annual sectoral contributions to the NPP construction. Note: Numbers in the columns indicate sectoral shares in the given year in per cent (courtesy of C. Zammali, Tunisian Company of Electricity and Gas).

Commissioning the NPP will change the Tunisian electricity mix. In order to analyse the macroeconomic impacts of the NPP operation, changes in the power generation portfolio need to be specified. Total electricity generation in 2010 amounts to 14 889 GW·h of which about 149 GW·h is from wind energy, 14 591 GW·h from gas fired generation and about 149 GW·h from hydropower. Total generation in 2030 will increase to about 32 730 GW·h, consisting of 24 581 GW·h gas fired generation, the same amount of hydropower as in 2010 and almost 8000 GW·h from the new NPP according to one selected scenario.

The characteristics of the NPP are as follows: 1000 MW(e) capacity, 90% availability factor, 8760 hours of annual operation and 7884 GW·h yearly electricity production. This power output represents about 24% of the total electricity generation in 2030. Data on the costs of power production are taken from the cost estimates for different power generation technologies published by the IEA and the OECD NEA [27].

3.8.3. Results

Macroeconomic impacts of the NPP construction are presented for 2026 because investment outlays peak at 26% of the total construction expenditures in that year. Considering the direct and indirect impacts of the construction (calculated by submodule A of EMPOWER), results show that the nuclear investment increases the GDP by approximately 0.13% relative to the business as usual scenario (baseline case) without nuclear energy. The corresponding increase in the total domestic production is 0.17% (which is equivalent to TND 636 million). The construction also generates about 9000 jobs as a direct and indirect effect**.**

Extending the scope of the impact assessment to include induced effects in addition to direct and indirect ones (calculated by submodule AB), results indicate that the NPP investment increases the GDP by 0.18% relative to the baseline case. Compared to the direct and indirect effects, the calculated increase in GDP is significantly higher when induced effects are also considered because the rise of disposable income as a result of the NPP investment generates additional demand. Total domestic production increases by around 0.22% (TND 824 million) and employment rises by almost 11 000 jobs. Table 17 presents the direct, indirect and induced impacts on employment in 2026.

TABLE 17. IMPACTS OF NPP CONSTRUCTION ON EMPLOYMENT IN 2026
(courtesy of C. Zammali, Tunisian Company of Electricity and Gas)

	Sector	Jobs	Increase (%)
Direct	Other non-metallic mineral products	1238	3.06
	Basic metals	1150	1.48
	Construction	5445	0.83
Indirect	Wholesale and retail trade, repairs	359	0.05
	Wood and products of wood and cork	154	0.44
Induced	Agriculture, hunting, forestry and fishing	510	0.11
	Food products, beverages and tobacco	124	0.10
	Textiles	120	0.06

As noted above, the NPP investment generates around 11 000 new jobs that decreases the unemployment rate by about 1.8%. In view of the 0.18% increase in GDP, the decrease in the unemployment rate seems to be overestimated. Yet the result may well be plausible because the sectors directly affected by the NPP construction are characterized by high rates of employment per unit of output.

By extending the scope of the impact assessment beyond direct, indirect and induced effects to include implications of labour market responses as well (submodule ABC), EMPOWER calculates even higher macroeconomic impacts. Results show that the NPP construction causes a slight increase in price levels of around 0.02% compared to the baseline scenario. This price effect is directly related to the labour market. The reason is that the nuclear investment generates additional demand for goods and services and this increases the demand for labour that, in turn, leads to an increase in wage rates in the labour market. In the marginal cost pricing context of EMPOWER, the rise of wage rates causes an increase in production costs and thus in prices as well, hence the slight increase in price levels.

Adding feedback effects running through the national economy from financing the NPP investment to all previous impact mechanisms provides the broadest range of macroeconomic impacts that can be assessed by EMPOWER. One option for public authorities to raise the necessary funds for financing an investment without increasing the national budget deficit is to increase the tax rate for households. In the assumed case, the additional tax rate is 0.2 percentage points, which represents an increase of 4.9% of the households' tax rate in order to finance the local contribution of the NPP construction amounting to 10% of the total costs.

However, this financing method (raising the households' tax rate) has some drawbacks. Increasing the tax rate reduces disposable income that leads to lower private consumption and thus to lower total domestic production, which in turn reduces GDP growth and job creation compared to the impacts calculated for the other three impact mechanisms for 2026. This means that the assumed way of financing reduces the positive impacts of the NPP construction on the national economy, yet most impacts remain positive relative to the base case (no NPP construction) except disposable income and public net savings at constant prices.

Table 18 presents impacts of the NPP construction over the years of the entire construction period.

TABLE 18. ECONOMIC IMPACTS OF NPP CONSTRUCTION IN TUNISIA
(courtesy of C. Zammali, Tunisian Company of Electricity and Gas)

Indicator	2024	2025	2026	2027	2028	2029
Direct and indirect effects (%)						
Gross domestic product	0.07	0.09	0.13	0.08	0.04	0.03
Disposable income	0.07	0.08	0.12	0.08	0.04	0.02
Total production	0.09	0.12	0.17	0.14	0.07	0.04
Imports	0.07	0.09	0.13	0.15	0.08	0.05
Employment	0.12	0.15	0.13	0.07	0.04	0.02
Direct, indirect and induced effects (%)						
Gross domestic product	0.10	0.12	0.18	0.12	0.06	0.04
Disposable income	0.09	0.12	0.17	0.12	0.06	0.03
Total production	0.12	0.15	0.22	0.17	0.09	0.05
Imports	0.10	0.13	0.18	0.19	0.10	0.06
Employment	0.14	0.18	0.26	0.10	0.05	0.03
Direct, indirect, induced and labour market effects (%)						
Gross domestic product	0.09	0.12	0.17	0.12	0.06	0.03
Disposable income	0.09	0.11	0.16	0.11	0.06	0.03
Total production	0.12	0.15	0.21	0.17	0.09	0.05
Imports	0.11	0.14	0.19	0.19	0.10	0.06
Employment	0.14	0.18	0.26	0.10	0.05	0.03
Direct, indirect, induced, labour market and financing effects (%)						
Gross domestic product	0.07	0.08	0.12	0.08	0.04	0.02
Disposable income	-0.09	-0.11	-0.16	-0.17	-0.09	-0.05
Total production	0.09	0.12	0.17	0.13	0.07	0.04
Imports	0.08	0.10	0.14	0.15	0.08	0.04
Employment	0.11	0.15	0.22	0.07	0.03	0.02

Turning to the economy-wide impacts of operating the NPP, the starting point is that the plant is assumed to produce 7884 GW·h electricity annually. As presented in Section 3.8.2, this amounts to about 24% of the total electricity generation in 2030. The macroeconomic impacts of the NPP operation are induced by the intermediate consumption of the electricity sector that is reflected in its production costs.

In the Tunisian case, the introduction of nuclear energy in the power generation mix leads to decreases in gas consumption in the electricity sector. However, the philosophy behind EMPOWER is that these decreases in gas consumption affect proportionally both the domestic production and imports. This generates a negative impact on the economy. The direct impact of the change in the intermediate consumption structure of the electricity sector due to the introduction of nuclear energy is that the production decreases in some sectors. This fall is directly correlated with the drop in the demand for intermediate consumption goods of the electricity sector. This decline is amplified by the indirect and induced effects and leads to a decline in GDP.

In order to address this negative economic impact, the Tunisian team proposes a different approach to dealing with the decrease in intermediate consumption of the electricity sector. The alternative approach intends to reduce these additional earnings first from imports then from domestic production if necessary. The macroeconomic impacts calculated on the basis of this approach, which is more appropriate in the Tunisian context, are remarkably better than those produced by using the original EMPOWER concept.

The following example illustrates the difference between the two approaches. The initial assumption is that in the baseline scenario (without the NPP), the intermediate gas consumption of the electricity sector is TND 600 million in 2030 of which 40% (TND 240 million) is imported and the rest (TND 360 million) is domestically produced. Nuclear energy represents almost 25% of the total electricity generation, thus gains in terms of imported gas will roughly be equal to TND 150 million (25% of TND 600 million).

EMPOWER's approach stipulates that domestic production and imports are proportionally affected by this gain. Consequently, the new domestic gas production will be equal to TND 270 million (TND 360 million minus (150 million × 60%)) and the new import value is TND 180 million (TND 240 million minus (150 million × 40%)). Although the decline of gas import generates a positive impact, the decrease of domestic production creates a negative impact on the GDP, disposable income and employment.

The alternative approach specifies that the gains firstly affect imports and then domestic production if it is necessary. In this case, gas import and domestic gas production are equal to TND 90 million (TND 240 million minus 150 million) and TND 360 million, respectively rather than TND 180 million and TND 270 million according to the IAEA approach. Results of the modified model show an even larger positive impact on import than results of the first approach while domestic gas production is kept at the same level.

Assessing direct and indirect effects of the NPP operation according to the original EMPOWER approach, results show an annual increase in GDP by 0.1%. This increase is due to the decrease of imports by 0.1%. However, total domestic production decreases by 0.2% due to the new structure of the intermediate consumption of the electricity sector. The most affected sector is mining and quarrying with an output fall of 6.22%. The decline in total production leads to a reduction in employment by 0.1%, which represents a loss of more than 2600 jobs. This causes a reduction of disposable income by 0.3%.

The induced effects of operating the NPP calculated on the same basis include a decrease in disposable income by 0.4% in one year. In the economic context of EMPOWER, this reduction triggers a decrease in private consumption and a 0.3% decrease in total production. The labour market impact is a 0.2% decline in employment, equivalent to a loss of more than 7000 jobs.

Direct and indirect effects of the NPP operation calculated according to the alternative approach amount to an annual increase of GDP by 0.5% in contrast to the 0.1% growth calculated in line with the EMPOWER approach. This is due to the decrease of imports by 0.8%. Since the gains in intermediate consumption of the electricity sector are deducted from imports, total production remains constant, therefore other macroeconomic aggregates such as employment and disposable income do not change either. Since disposable income remains unchanged, no additional induced effects are produced.

Operating the NPP generates an estimated TND 1300 million (about USD 433 million) net gains in imports annually. Over the 60 year operational period, these import gains reach TND 77 940 million (about USD 25 980 million). These gains can be used to boost investments or to repay the credit contracted for the construction of the nuclear plant amounting to 90% of the construction cost.

The construction cost of the assumed 1000 MW(e) NPP is estimated at USD 5000 million of which 10% is financed locally and 90% (i.e. USD 4500 million) from external sources. Assuming an interest rate of 3% (an average rate for international credits) and a grace period of six years during the construction, Table 19 shows the credit repayment schedule for a fixed annuity of USD 433 million.

Table 19 shows that by allocating the entire import gains for credit repayment the assumed funds borrowed to finance the external share of the construction costs can be paid off in the 13th year of the NPP's operation.

TABLE 19. CREDIT REPAYMENT SCHEDULE FOR THE ASSUMED NPP (USD MILLION)
(courtesy of C. Zammali, Tunisian Company of Electricity and Gas)

Year	Remaining balance	Interest	Principal
2030	4500	135.00	298.00
2031	4202	126.06	306.94
2032	3895	116.85	316.15
2033	3579	107.37	325.63
2034	3253	97.60	335.40
2035	2918	87.54	345.46
2036	2572	77.17	355.83
2037	2217	66.50	366.50
2038	1850	55.50	377.50
2039	1473	44.18	388.82
2040	1084	32.51	400.49
2041	683	20.50	412.50
2042	271	8.12	271.00
Total		974.90	4500.22
Total reimbursement			5475.12

3.8.4. Main conclusions

EMPOWER developed by the IAEA is an appropriate tool to assess the macroeconomic impacts of building and operating an NPP. For the hypothetical construction period between 2024 and 2029, findings show an increase the principal macroeconomic aggregates such as in

GDP by 0.2% and the creation of more than 11 000 jobs in 2026, the year with the highest construction cost outlays.

Two versions of the model are used for analysing economic impacts in the operational period. Using the original EMPOWER approach to calculate direct, indirect and induced impacts produces a 0.1% increase in the GDP caused by the decrease of imports but a decline in production, disposable income and employment due to the drop of the intermediate consumption of the electricity sector. The alternative version of the model — in which gains primarily affect imports and only secondarily domestic gas production — the annual increase in the GDP reaches around 0.5% due to the decrease in imports by 0.8%. Others macroeconomic aggregates remain unchanged.

Gains in imports are estimated at TND 1300 million (USD 433 million) per year which corresponds to TND 77 940 million (USD 25 980 million) over the 60 years of operation. These gains allow repaying the credit contracted for the construction of the NPP in the 13th year of its operation.

Another benefit of nuclear energy is that it is cheaper than electricity produced from gas, so it decreases the average electricity price. This can give a boost to energy intensive sectors leading to new investments in the economy. The introduction of nuclear energy has also positive externalities such as reduced greenhouse gas emissions and negative externalities related to radioactive waste. The impact of such externalities could be addressed in future versions of EMPOWER.

Some improvements could be added to EMPOWER in order to expand the economic impact assessments. Examples include tools for calculating possible welfare improvements as a result of introducing nuclear energy and tools to estimate the effect of nuclear power programmes on the exchange rate of the national currency that is assumed to be negative during the construction period because many elements of the power plants are imported but positive in the operational phase because nuclear electricity may reduce the need for importing other fuels for the power sector.

3.9. URUGUAY

Introducing nuclear power in the energy mix of Uruguay is a remote possibility at this point. Yet there are efforts to improve the understanding of various aspects of a national nuclear energy programme. This section presents the work of the Uruguayan research team in this CRP to assess the economic impacts of building and operating a hypothetical NPP. The section is based on Ref. [42].

3.9.1. National context

Uruguay is exploring nuclear power as a long term option to satisfy electricity demand. In 2009, a working group was created by a presidential decree to study and develop proposals for developing Phase 1 of a possible nuclear energy programme and to start preparatory activities by taking into account recommendations of the IAEA. The government pledged a budget of around USD 1 million for this work. The main task was to prepare proposals and recommendations to enable national authorities to come to an informed and sustainable decision about nuclear power as a long term option. The topics selected for analysis also included economic and financial aspects of a nuclear energy programme.

This working group concluded its activity in 2014. The final report to the government concluded that nuclear power generation was not viable in the short or medium term due to its high costs relative to the size of the national electricity system. Nevertheless, the decision about introducing nuclear energy in the long term has not been taken yet and there is still need for studies about the economic impacts that such a decision would imply. The Secretary of Energy is also interested in the socioeconomic externalities and macroeconomic effects of projects that may contribute to expanding the electricity generation mix, especially the supply costs of different power sources.

3.9.2. Models and data

Two models are applied in this project. The first is EMPOWER, developed by the IAEA. It follows the traditional impact analysis with an IOT in which a new industry is introduced. The other is a local model developed by the company Klynveld Peat Marwick Goerdeler (KPMG) in a consultancy work for the Secretary of Energy in 2013. Its objective is to measure the macro- and socioeconomic impacts of four electricity generation sources: wind, solar, biomass and natural gas fuelled combined cycle power plants.

The use of these two models allows to compare their results, analyse their main differences and expand the assessments because they include different types of effects of energy related investments. Although both models are based on the same methodology, there are some differences in how they tackle certain issues, some of which lead to important differences in their results when economic impacts are analysed at the sectoral level.

The KPMG model measures direct and indirect effects, its IOT includes 43 sectors and does not use the RAS method, and employment effects are measured by a special approach. EMPOWER estimates direct and indirect, induced, labour market and financing feedback effects, its IOT consists of 35 sectors and uses the RAS method, and it calculates employment effects within the input–output modelling framework. While the traditional approach to input–output modelling uses the Leontief inverse to solve the model, EMPOWER includes several solution loops to calculate impacts of an investment or other changes (see Section 2). Nonetheless, it can be shown that both approaches lead to the same results.

EMPOWER comprises four modules that progressively increase the scope of the assessed impacts from direct and indirect (submodule A) to induced (submodule AB) and further to labour market (submodule ABC) and investment financing (submodule ABCD) effects. Each module involves a specific solution loop. Although some impacts have the same name in both EMPOWER and the KPMG model, there are conceptual differences in their exact meaning.

Direct effects have the same meaning in both models but indirect and induced effects are treated differently. In EMPOWER, indirect effects capture all non-direct effects working through the sectoral interlinkages in the IOT and calculated together with the direct impacts in submodule A, whereas induced effects result from changes in the household consumption column vector in the IOT and calculated in submodule AB. In contrast, induced effects in the KPMG model are included in what is called indirect effects in EMPOWER. The final demand vector of private consumption is omitted. Instead, disposable income generated by direct investments is allocated according to a consumption basket across sectors. This raises problems when analysing results at the sectoral level.

The aggregation levels of the IOTs also differ. Whereas KPMG uses a 43 sector matrix, EMPOWER enables 35 industries. Both are derived from the most recent IOT for Uruguay incorporating 58 sectors for the year 2005. Differences in the aggregation level by itself lead to different results for the same investment vector, so care is required in aggregating sectors.

EMPOWER includes a RAS module that enables to update the original IOT to a different year by introducing growth rates for each of the 35 sectors in order to reflect the expected or actual evolution of the economy. The RAS method is also used to balance IOTs when their specification (e.g. sector aggregation) yields an unbalanced matrix.

Employment effects are also addressed differently. The KPMG model calculates the impact on total output first and then, by keeping the employment per output ratio constant, employment growth rates are derived for the sectors. In contrast, the EMPOWER approach takes into account wages as well and allows all related variables to grow at different rates. Labour market effects are introduced in the submodule ABC that accounts for effects of changing wages.

EMPOWER is a sophisticated analytical tool that goes far beyond the basic input–output approach. Beside the labour and consumption effects, it also enables assessing impacts of the tax rate needed to finance the public share of large investments.

Lastly, differences between the two approaches in assessing economic impacts in the operational phase of the nuclear plant are even larger than in the construction phase. The new NPP is depicted by three characteristics in EMPOWER: technology, output and capital costs. The new power plant changes the technology of the electricity sector that leads to new technical coefficients in the electricity column of the IOT. The additional electricity generated by the NPP is assumed to be sold at market prices. The representation of capital costs allows the inclusion of actual capital costs plus profits as actual data rather than a residual term. The KPMG model requires a more detailed specification of inputs during the operational phase. For this study only EMPOWER is used to assess economic impacts in the operational phase.

Data for the construction phase are specified as follows. The investment structure is taken from an ongoing Argentinian project involving the Canada Deuterium Uranium (CANDU) technology. Data are provided by Nucleoelectrica Argentina S.A., a state owned nuclear utility operating the three existing NPPs in that country. Values are expressed in millions of 2015 USD and represent overnight costs. The cost structure is adapted to the Uruguayan situation in terms of local content where shares of local participation are more likely to differ.

According to the World Nuclear Association [43], engineering, procurement and construction costs represent about 80% of the overnight costs of which 70% are direct (physical plant equipment with labour and material to assemble them) and 30% indirect (supervisory engineering and supporting labour costs with some material). The remaining 20% of the overnight costs are contingencies and owners' costs. The NPP assumed in this study is a CANDU model with 740 MW(e) capacity, its capital cost is USD 5900 million (2015 USD) and the construction time is eight years. The share of external financing is 70%, the source of public funding for the remaining 30% might be a mixture of profits of the state-owned electricity company and possibly treasury bonds of the government.

Table 20 presents the cost structure of the assumed NPP.

Following the KPMG methodology, items are divided in three categories (equipment, on-site labour costs and on-site material costs), as shown in Table 20. Shares of various categories in each item are estimated according to the Energy Economic Database prepared by the US Department of Energy [44] in the 1970s and 1980s which comprises average actual costs incurred in the construction of several Westinghouse four loop PWRs in the USA. Local components are estimated according to the assumption that all on-site labour costs are domestic. This matches the assumption taken by KPMG in agreement with the Secretary of Energy. From this point of view, the key issue is where spillovers and externalities occur and not the provenance of the labour force. It is also assumed that the shares (set at 50%) of equipment and on-site material costs arising in site preparation and in the civil work stage reach portions similar to those in recent large projects implemented in the country. Based on these assumptions, the local component in the nuclear new build project reaches 23%.

Lacking information about the distribution of investment expenditures over the construction period and considering that EMPOWER assesses impacts consecutively year by year, total investment costs are uniformly distributed over the eight years of construction. Hence impacts are calculated for an average construction year with USD 737.5 million investment expenditure.

The NPP entering operation is characterized by three components: technology, output and capital costs. The new technical coefficient vector for the electricity sector is automatically calculated by the model based on the expansion plan and the decomposition of the technology components (labour, fuel and other costs).

The expansion plan uses results of the business as usual scenario of the Wien Automatic System Planning Package (WASP) model [45] that includes an expansion scheme based on wind power plants from 2025 on. Although this expansion plan is no longer optimal once a new power plant is introduced exogenously (ex post), it is still a good approximation. Operational costs of different technologies are taken from the report of the IEA and OECD NEA [27] because no domestic data are available. The target year 2030 is the same for both the construction and the operational stage.

Information sources for the model include the national account system published by the Central Bank of Uruguay, socioeconomic data such as income level and components based on annual household surveys of the Statistical Office, the Public University and other academic institutions.

The most recent IOT for Uruguay developed by the Institute of Economy at the University of the Republic comprises 56 sectors defined according to the International Standard Industrial Classification. KPMG uses a smaller, 43 sector version derived from the original IOT by merging mostly primary sectors. EMPOWER allows only 35 sectors, therefore some industries are further aggregated from the 43 sector version by merging primary sectors and also some textile branches. The only exemption is activities of private households as employers, which is included in the other services category because its row and column vectors are full of zeros. This may lead to convergence problems in the loops calculating some of the impact mechanisms. The same procedure is followed for the imports IOT.

TABLE 20. COST STRUCTURE OF THE ASSUMED NPP
(courtesy of G. Ferrer, Secretary of Energy)

Cost categories	Total costs ($ mill[a])	Equipment /vendor ($ mill[a])	On-site labour ($ mill[a])	On-site material ($ mill[a])	Local component ($ mill[a])	Share[b] (%)	Equipment /vendor ($ mill[a])	Share[b] (%)	On-site labour ($ mill[a])	Share[b] (%)	On-site material ($ mill[a])	Share[b] (%)
Engineering (external services)	855	855	0	0	0	0	0	0	0	0	0	0
Technical services	258	258	0	0	0	0	0	0	0	0	0	0
Supplies	2059	1253	579	227	579	28	0	0	0	0	0	0
Long lead equipment	1172	919	202	51	202	17	0	0	202	100	0	0
No long lead equipment	649	334	257	57	257	40	0	0	257	100	0	0
Bulk material, associated supply	238	n.a.[c]	119	119	119	50	0	0	119	100	0	0
Construction and startup	1328	333	654	341	793	60	0	0	0	0	0	0
Site preparation	79	1	46	32	63	79	0	50	46	100	16	50
Civil work	556	72	311	172	434	78	36	50	311	100	86	50
Mechanical and piping	346	2	233	111	233	67	0	0	233	100	0	0
Electricity and instrumentation	148	59	63	25	63	43	0	0	63	100	0	0
Commissioning and startup	199	199	0	0	0	0	0	0	0	0	0	0
Other costs	1400	1031	0	368	0	0	0	0	0	0	0	0
First core	39	39	0	0	0	0	0	0	0	0	0	0
Project management	338	338	0	0	0	0	0	0	0	0	0	0
Engineering, on-site indirect	844	540	0	304	0	0	0	0	0	0	0	0
Pre-project costs, facilities, land	178	114	0	64	0	0	0	0	0	0	0	0
Total project costs	5900	3731	1233	936	1372	23	37	0	1233	0	102	0

[a] $ mill: USD million.

[b] Shares indicate the proportion of the domestic component of the preceding column in the total of the corresponding cost item.

[c] n.a.: not applicable.

The IOT is updated to 2030 by using the simple RAS routine in EMPOWER. Sectoral growth rates are projected from historical data, which are taken from national statistics for the period 2005 to 2016. From 2017 on, projected sectoral growth rates of value added are used as drivers until the target year. There is at least one sector that ends up with a negative growth rate but this is perfectly consistent with the historical trends.

The method of projecting wage growth rates is the same as that of projecting sectoral growth rates. Sectoral employment data are measured by the number of employees in the IOT. This is replaced by the annual number of working hours taken from the 2005 household survey of the Statistical Office to measure labour input to each sector. The projection of the employment level is based on the expected population growth rate.

The total amount of labour force in the base year 2005 is derived from the unemployment rate of 12% in that year. This rate is projected to decline to 7% by 2030, which is considered close to its natural long run equilibrium value. The current rate (as of 2017) is around 8.5%. Wage levels are taken directly from the IOT. Projected growth rates of wages are estimated by using GDP as driver.

3.9.3. Results

Since a major objective of this research is to compare results of the two methods and the KPMG model does not use the RAS technique to update the original IOT for future years, two versions of EMPOWER are applied for the construction phase: one with the original 2005 IOT, the other with the IOT projected out to 2030.

Using both methodologies, overall and sectoral impacts on the economy are calculated over the lifespan of the project. These impacts include total production output, GDP, disposable income and current account flows. The assessment comprises the construction and the operational phase of a hypothetical nuclear power project, and national and sectoral impacts.

In EMPOWER, the average annual investment expenditure of USD 737.5 million affects only three of the 35 sectors directly, as shown in Table 21. The local component includes two out of the three directly involved sectors and accounts for 23% of the investment outlay. It involves the metal industries and the construction activities sectors. The business activities sector, which represents the largest share of the total investment, is assumed to be completely supplied from abroad.

TABLE 21. ANNUAL INVESTMENT EXPENDITURES
(courtesy of G. Ferrer, Secretary of Energy)

Sector	Total investment (USD million)	Annual investment (USD million)	Local component (USD million)	Share of local component (%)
Manufacture of basic metals, fabricated metal products, machinery and equipment	2246	281	80	29
Construction	982	123	91	74
Renting and business activities	2672	334	0	0
Total	5900	738	171	23

Direct and indirect (submodules A), induced (submodule AB) and labour market (submodule ABC) impacts are assessed with EMPOWER where subsequent submodules include impacts of all preceding ones. In all cases, the original IOT for 2005 and the projected table for the target year is used. The original IOT is useful to make a comparison with the results of the KPMG model for the direct, indirect and induced (AB) and the direct, indirect, induced and labour market response (ABC) impacts. Table 22 shows the impacts for one year of the construction period.

Impacts on GDP in an average year of the NPP construction range between 0.4% and 0.9%, depending on the range of impacts considered. Accordingly, total impacts on GDP over the entire construction amount to 3.2% to 7.2% that is perfectly reasonable given the magnitude of the investment. Total output and disposable income are also positively affected by the investment by varying degrees, depending again on the impact mechanisms considered. Public net savings likewise improve (negative growth rate) because taxes are collected from a broader basis given the increasing output. The current account deteriorates because the investment increases imports. This impact is high in a small and open economy like Uruguay where most capital goods are imported. Export flows are only affected in the constant price model because the assumed price elasticity of exports is 1. Effects on GDP are less important in the constant price model because volumes are deflated by higher prices.

Table 23 shows the impacts for 2005.

TABLE 22. ECONOMIC IMPACTS OF NPP CONSTRUCTION IN 2030 (EMPOWER)
(courtesy of G. Ferrer, Secretary of Energy)

Indicator	Impacts under different mechanisms in thousand Uruguayan peso (UYU), except employment								
	Baseline	Submodule A	Change (%)	Submodule AB	Change (%)	Submodule ABC current	Change (%)	Submodule ABC constant	Change (%)
GDP	895 999	900 510	0.5	903 155	0.8	903 897	0.9	899 989	0.4
Disposable income	319 482	321 272	0.6	322 052	0.8	322 270	0.9	322 022	0.8
Total output	1 619 619	1 629 197	0.6	1 633 651	0.9	1 634 900	0.9	1 633 398	0.9
Public net savings	-43 244	-42 799	-1.0	-42 621	-1.4	-42 571	-1.6	—[a]	—[a]
Exports	270 132	270 132	0.0	270 132	0.0	270 132	0.0	267 118	-1.1
Imports	265 966	267 113	0.4	267 742	0.7	267 918	0.7	267 918	0.7
Employm[b] (million h[c])	3 640	3 667	0.7	3 676	1.0	3 674	0.9	3 674	0.9

[a] —: data not available.
[b] Employm: Employment.
[c] h: hours.

TABLE 23. ECONOMIC IMPACTS OF NPP CONSTRUCTION IN 2005 (EMPOWER)
(courtesy of G. Ferrer, Secretary of Energy)

Indicator	Impacts under different mechanisms in thousand Uruguayan peso (UYU), except employment								
	Baseline	Submodule A	Change (%)	Submodule AB	Change (%)	Submodule ABC current	Change (%)	Submodule ABC constant	Change (%)
GDP	390 038	394 398	1.1	396 355	1.6	396 408	1.6	396 126	1.6
Disposable income	157 036	158 512	0.9	159 212	1.4	159 231	1.4	159 208	1.4
Total output	713 199	722 638	1.3	725 975	1.8	726 067	1.8	725 953	1.8
Public net savings	17 255	16 820	2.5	16 669	3.4	16 665	3.4	—[a]	—[a]
Exports	117 591	117 591	0.0	117 591	0.0	117 591	0.0	117 373	- 0.2
Imports	115 778	117 075	1.1	117 571	1.5	117 585	1.6	117 585	1.6
Employment (million h[b])	1 831	1 851	1.1	1 860	1.6	1 860	1.5	1 860	1.5

[a] —: data not available
[b] h: hours

As expected, using the original IOT for 2005 instead of the one updated by using the RAS method to 2030 leads to larger direct and indirect impacts (submodule A). In fact, impacts double when the IOT is not updated. The reason is that the size of the economy in 2005 is smaller than in 2030, therefore the relative differences in impacts are larger for the same level of investment. Induced impacts (in addition to direct and indirect effects, calculated by submodule AB) increase GDP by 1.6% in an average investment year. They exceed 10% over the eight years of construction time. Sectoral impacts on value added and employment are by far the highest in the construction sector. Induced effects are distributed more evenly than direct and indirect effects. Although the relative change in employment is larger in the original IOT (1.1%) than in the updated table (0.7%), the impact in absolute terms is smaller. This means that the NPP construction creates more jobs (working hours) in the entire economy in 2030 than in 2005. The explanation is that different growth rates of sectors modify their shares in the national economy over this period.

In order to make results of the two models comparable, the same annual average construction expenditures are used in the KPMG model as in the EMPOWER analysis. The distribution of direct investments across sectors differ between the two IOTs. The KPMG model uses the original IOT of 2005 and calculates impacts on total production (output) and employment only. Direct and indirect impacts on total production are presented in Table 24 in local currency and in USD. Direct impacts consider only the local component of the investment.

The KPMG model does not allow to calculate direct impacts on employment, therefore it is added exogenously. Based on estimates in other studies, 1600 workers are assumed to work directly in an average year of the nuclear plant construction.

TABLE 24. ECONOMIC IMPACTS OF NPP CONSTRUCTION IN 2005 (KPMG MODEL)
(courtesy of G. Ferrer, Secretary of Energy)

Indicator	Direct impacts	Indirect impacts	Total impacts
Total production eight years (USD million)	1 371	578	1 949
Total production annual (USD million)	171	72	244
Total production annual (UYU million)	5657	239	804
Employment (person)	1 600	9 482	11 082

Table 25 summarizes the results of the two models for three macroeconomic aggregates. Other impact indicators such as commercial flows and disposable income are absent from the KPMG model. Impacts on total production output in an average construction year are higher in EMPOWER than in the KPMG model but the difference is small.

TABLE 25. DIRECT AND INDIRECT IMPACTS OF NPP CONSTRUCTION IN TWO MODELS
(courtesy of G. Ferrer, Secretary of Energy)

Indicator	EMPOWER[a]	Change (%)	KPMG	Change (%)
GDP (UYU million)	4 360	1.1	n.a.[b]	n.a. [b]
Total production (UYU million)	9 439	1.3	8 043	1.1
Employment (person)	19 424	1.1	11 082	0.7

[a] IOT 2005, RAS updating not applied, results from submodule A
[b] n.a.: not applicable

Differences in the results are explained by the fact that models allocate the investment vector to different sectors. Only three industries are affected by the NPP investment in EMPOWER while many more sectors are affected in the KPMG model because it divides labour costs according to a consumption basket. Sectoral impacts calculated by the models vary considerably as a direct consequence of this difference. Assessing the employment effects requires special care because the KPMG model uses the number of workers and EMPOWER uses the number of working hours in the base year. This means that the models use different sources to calculate employment effects and the results are expressed in different units.

Only EMPOWER is used to assess economy-wide impacts of operating the hypothetical NPP because the KPMG model requires a lot more information that are not available. In the year of commissioning the NPP (2030), it is expected to account for almost 28% of the total power generation. EMPOWER assumes that all this additional electricity is purchased by consumers at market prices. The investment implies a major change in electricity production in the country. EMPOWER captures this change in technical coefficients in the electricity vector in the IOT. Shares of power generation technologies in 2030 are as follows: hydropower 34%, wind and solar generation 27%, oil products 11% and nuclear energy 28%.

The target year of the impact assessment is 2030 and the RAS technique is used to project the IOT out to this year. Direct and indirect (submodule A) and induced impacts (including direct and indirect impacts as well in submodule AB) are calculated. The main results are presented in Table 26.

TABLE 26. IMPACTS OF NPP OPERATION IN 2030
(courtesy of G. Ferrer, Secretary of Energy)

Indicator	Baseline	Direct and indirect		Direct, indirect and induced	
	(UYU million)	(UYU million)	(%)	(UYU million)	(%)
GDP	895 999	923 908	3.1	927 849	3.6
Disposable income	319 482	322 306	0.9	323 468	1.2
Total output	1 619 619	1 639 762	1.2	1 646 335	1.6
Public net savings	-43 244	-41 692	-3.6	-41 441	-4.2
Exports	270 132	270 585	0.2	270 585	0.2
Imports	265 966	268 659	1.0	269 590	1.4
Employment (Mh[a])	3 640	3 662	0.6	3 676	1.0

[a] Mh: million hours.

EMPOWER shows that externalities in an average year of construction of the NPP would be significant, accounting for up to 0.9% of GDP growth depending on the impact mechanism considered. Direct and indirect effects (submodule A) increase GDP by 0.5% while induced impacts in addition (submodule AB) increase GDP by 0.8%. The NPP construction affects all macroeconomic aggregates positively, except the current account. Import flows increase significantly by 0.7% in each year of the construction period. Exports are more difficult to model because they depend on global incomes and internal prices. EMPOWER accounts for changes in export flows only when internal prices (and wages) change.

Table 27 compares impacts of the assumed nuclear energy programme in the construction and the operational phases in 2030.

The employment impacts of the NPP construction at 1% of the total amount of working hours is rather significant. Most of the new jobs are created in the basic metal and the construction sectors, growing by 23% and 6%, respectively. The annual impacts are even higher in the operational phase as measured by the selected indicators. Operational impacts account for 3.6% of the projected GDP. Considering the size of the domestic economy, this seems to be perfectly reasonable for a large project like an NPP.

3.9.4. Main conclusions

This study assesses the impacts of building and operating a hypothetical NPP in Uruguay. The absence of a real project is the main restriction. Although it is possible to choose among many different technologies, locations, plant capacities and other features in the literature, real data for Uruguay are absent. Therefore, several assumptions are made to substitute real data.

Lack of information about the temporal distribution of investment expenditures during the construction period is another restriction. Investment outlays are distributed uniformly over the construction period and their impacts are assessed for an average year.

TABLE 27. IMPACTS OF NPP CONSTRUCTION AND OPERATION IN 2030
(Uruguayan Peso million, except employment) (courtesy of G. Ferrer, Secretary of Energy)

Indicator	Baseline	Construction (direct, indirect, and induced)				Operation	
		2030		Full period		2030	
		Amount	(%)	Amount	(%)	Amount	(%)
GDP	895 999	903 155	0.8	953 248	6.4	927 849	3.6
Disposable income	319 482	322 052	0.8	340 041	6.4	323 468	1.2
Total output	1 619 619	1 633 651	0.9	1 731 875	6.9	1 646 335	1.6
Public net savings	-43 244	-42 621	-1.4	(38 261)	-11.5	-41 441	-4.2
Exports	270 132	270 132	0.0	270 132	0.0	270 585	0.2
Imports	265 966	267 742	0.7	280 171	5.3	269 590	1.4
Employment (Mh[a])	3 640	3 676	1.0	3 929	7.9	3 676	1.0

[a] Mh: million hours.

Projecting economic growth is much more complicated in a small developing country like Uruguay than in large developed nations. The greater projection uncertainty may lead to erroneous results when applying them in analytical tools. The evolution of small economies is less predictable because their economic structure represented by the IOTs is vulnerable and prone to major changes. An example is provided by the structural change as a consequence of establishing two big wood pulp factories over the last decade in Uruguay where the paper sector was almost entirely absent before. Since the inauguration of these plants, the sector has been growing by more than 20% each year and accounts for a large share of the overall GDP growth. This means that a technological change has occurred and the corresponding new technical coefficients cannot be projected by the RAS method.

3.10. VIET NAM

Viet Nam was considering introducing nuclear power in its electricity generation mix for some time. The country was participating in the IAEA’s nuclear newcomers project that supports countries in developing the infrastructure for a safe and sustainable nuclear power programme. However, a resolution of the National Assembly cancelled the nuclear power development programme in 2016. It might be reconsidered for the time after 2030 later. The impact assessment presented here takes the hypothetical case of building the first NPP according to the energy plan before the nuclear energy programme was cancelled. It is important to keep in mind that the entire analysis and all statements and conclusions are related to the specified fictitious case rather than actual policy considerations or plans.

This section presents results of the assessment of macroeconomic impacts of building and operating a hypothetical NPP in Viet Nam. The research team participating in this CRP includes expert from the Institute of Energy and Ministry of Industry and Trade. This section is based on Ref. [46].

3.10.1. National context

Viet Nam has achieved a remarkable economic development due to the economic reforms introduced in 1986. The country’s economy was growing steadily at an average annual rate of 6% in the period 2005–2015. Growth was particularly strong in the industrial sectors, which recorded a growth rate of 9.6%/year in this period, followed by the services sector at 7.5%/year and agriculture with 4.5%/year. Viet Nam was in the 32nd place in the global GDP ranking with respect to purchasing power parity in 2014. Economic growth has slowed down in 2013 and 2014 partly due to global economic conditions that hinder exports, an important engine of growth, and also due to the weakening of growth dynamics brought about by the reforms.

The increasing population, a rising demand for goods and services, rapid urbanization and rapidly growing economic activities are putting increasing pressure on energy supplies in Viet Nam. The availability of adequate and reliable energy resources is an essential prerequisite for maintaining Viet Nam's enviable record of socially inclusive economic growth. Viet Nam's GDP is projected to grow at 6.9%/year in the 2016–2020 period and at 7.0%/year between 2021 and 2030.

The power subsector is critical to the energy sector not only because it is an essential service but also because it is the clearing house for natural gas, coal and oil, and it has a profound impact on their relative prices. The national Power Development Master Plan [47] is the primary planning document in the power sector. The current master plan was prepared in 2011 for the period up to 2020, with long term vision up to 2030. It was revised and the final version was approved by the prime minister in 2016. Based on the outlook for economic growth, electricity consumption is projected to increase at an average annual rate of 8.8% between 2015 and 2030. The system's peak capacity may reach 41.6 GW by 2020 and 88.8 GW by 2030.

In order to meet the projected demand in the revised master plan, the total installed capacity is expected to increase to 57 409 MW by 2020 and to 113 944 MW by 2030. This implies an annual growth rate of 8% in the 2015–2030 period. In this time span, coal fired capacities have the second highest growth rate at 11.2%/year and their share rises from 32% in 2015 to 49% in 2030, corresponding to an additional capacity of 44 935 MW or about an increase of 3000 MW/year on average. Figure 25 shows the scenario of expanding power generation capacities up to 2030 that still includes nuclear energy.

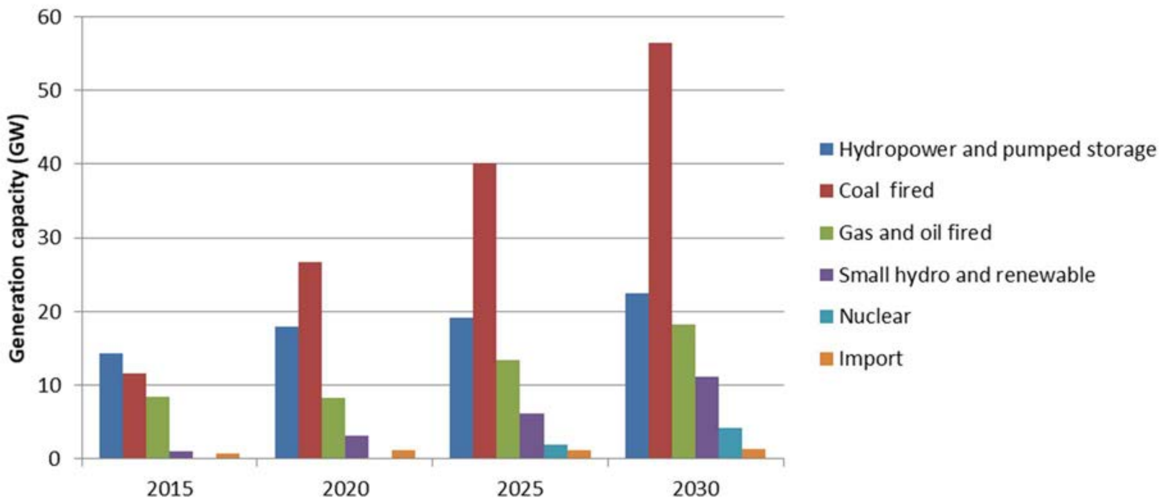

FIG. 25. Expansion of power generation capacities. Data source: Ref. [47] (courtesy of A. T. Nguyen, Ministry of Industry and Trade).

According to the revised master plan before the nuclear programme withdrawal, the first NPP was expected to generate electricity in 2028. Viet Nam has prepared feasibility and site selection studies for the Ninh Thuan 1 and 2 NPPs with a total capacity of 4200 MW(e). In this plan, nuclear power is projected to account for 3.9% of the total generation capacity by 2030. It shall contribute to the diversification of energy sources, reduce dependence on fossil fuels and mitigate greenhouse gas emissions.

The rapid expansion of the power sector will be very demanding on Vietnam Electricity and its holding companies. While the technical capability of these agencies has improved quite strongly over the past two decades, it is still not at the level needed to cope with the expected rate of expansion. Moreover, the financial requirements are huge and beyond these agencies' reach. Key objectives for the power sector include developing national gas resources, finding secure sources of coal and gas imports for power generation, meeting the huge financial requirements of the sector, balancing multiple objectives in setting tariffs, strengthening environmental protection, fostering technical innovation and enhancing human capacity.

Viet Nam started to consider nuclear power as an option for energy supply in the 1980s. In 2002, the prime minister established the Government Steering Committee for the Development of Nuclear Power in Viet Nam. The committee completed its report entitled Long Term Strategy for Peaceful Utilization of Atomic Energy in Viet Nam up to 2020 by 2006. In order to implement this long term strategy, a pre-feasibility study was prepared and then approved by the National Assembly on 25 November 2009. Nuclear technology was chosen to diversify the energy supply in response to the limited fossil fuel resources, fast growing demand and environmental constraints (pollutant emissions). A strong commitment by the government to develop a nuclear power programme received impetus from three main factors: lack of domestic energy resources, favourable world nuclear markets in the 2010s and an active and concerted government cooperating with developed countries possessing advanced nuclear power competences (Japan, the Republic of Korea and the Russian Federation).

Meaningful national participation in an NPP construction requires a capable construction industry as well as medium and heavy manufacturing, including cement, steel, machinery and equipment, and chemicals. It also requires proficiency in other services such as civil engineering, quality assurance, control and testing, and specialized manpower training, including managerial skills. Currently Viet Nam is building these capacities and skills.

The Ninh Thuan 1 NPP was planned as the first nuclear plant to be built in Vietnam. Its principal technical parameters include:

- Installed capacity: About 2 × 1000 MW(e) with further extension to 4 × 1000 MW(e);
- Technology: Light water reactors of water–water energetic reactor (WWER) type;
- Fuel: Imported fuel supplied by the technology provider Russian Federation;
- Power unit readiness to take up load: At least 0.90;
- Cooling water: Sea water;
- Fresh water: To be supplied from the Nha Trinh lake (about 30 km away).

The total investment capital is around USD 10 800 million of which about 2400 million is interest payment for loans during the construction time.

The second NPP, Ninh Thuan 2 was planned to be invested by a Japanese company and uses Japanese technology. Its principal technical parameters are:

— Installed capacity: 2 × 1100 MW(e);
— Technology: Light water reactors of boiling water or PWR type;
— Fuel: Imported fuel supplied by the technology provider Japan.

The total investment capital for Ninh Thuan 2 NPP is about USD 13 000 million.

The third NPP, Ninh Thuan 3 is invested by a Korean company and uses Korean technology.

3.10.2. Model and data

An IOT with 34 sectors is prepared with a focus on quantifying the contribution of nuclear power to GDP (industrial sectors) over time. This input–output analysis tracks the purchases of goods and services by the nuclear power sector from other industries and thus its contribution to the final output of those industries. The time horizon is 2030.

In order to use EMPOWER provided by IAEA for this study, a modified IOT is restructured from the 2007 IOT of the General Statistics Office. The original national IOT has 121 sectors and it is regrouped into 35 sectors according to the EMPOWER structure. Since all coefficients in a given sector are additive, the restructuring does not invalidate any input coefficient taken from the original table.

The General Statistics Office does not prepare and publish IOTs for imports at the sectoral level. Therefore, the sectoral IOT for imports is based on the original IOT by assuming the same proportionality of the share of each sector in the import matrix as in the domestic IOT.

Economic activities associated with the nuclear power sector are broken down and classified as construction, nuclear fuel fabrication, operation and maintenance. In the case of plant construction, the activities are divided into civil construction, architecture engineering and component manufacturing. Inputs to the IOT for components of the NPP such as construction, boiler equipment, operation and maintenance costs are taken from Russian and Japanese data if available.

The construction schedule and expense disbursement follow an S curve taken from the feasibility study. Construction is assumed to start in 2021 and finish in 2027 (see Fig. 26).

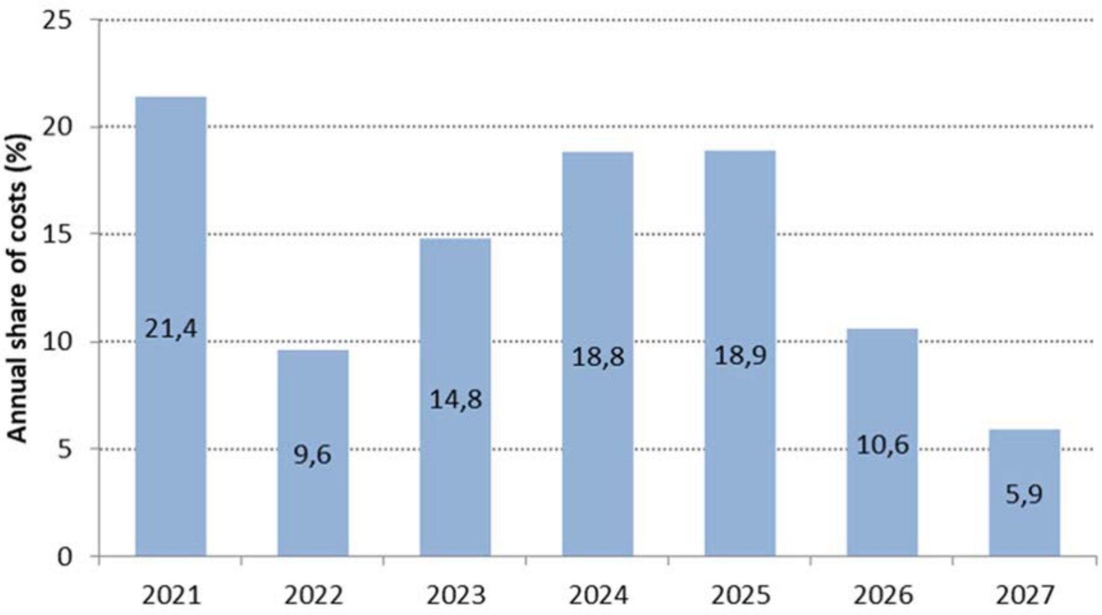

FIG. 26. Distribution of construction costs for the first NPP in Vietnam (courtesy of A. T. Nguyen, Ministry of Industry and Trade).

The NPP construction costs are allocated to affected sectors for each year between 2021 and 2027 according to the shares of domestic and import components. These costs can be viewed as expenditures. They are used in the input–output analysis as estimates of final demand generated by the construction investment. These cost items are then allocated to the corresponding sectors in the reorganized IOT. Domestic shares of the construction costs are very high (close to 100%) in the electricity, hotels and restaurants, and public administration sectors and in the various transport branches. Import shares are high in the electrical equipment and other manufacturing sectors.

Employment data about sectoral jobs, wages, labour force and their annual growth rates are obtained from the national economic accounts. Household sector data include disposable household income, households' share in operating surplus, other household incomes and incomes tax, all from the General Statistics Office. The government group in the IOT comprises data on the main aggregates of the public sector, which partly can be directly taken from the household accounts (net taxes on income) or the input–output data (e.g. public consumption, net taxes on products calculated as taxes less subsidies on products). Other expenditures and revenues are also based on official statistics. Values recommended by the model developers are taken for a few model parameters (e.g. marginal propensity to consume, wage reaction to the unemployment rate) because local data are not available.

3.10.3. Main results

EMPOWER is adopted to assess economy-wide and sectoral impacts of the assumed NPP construction in Viet Nam. The IOT and other macroeconomic characteristics, capacities and costs in the energy sector, properties of the assumed nuclear plant, investment costs and schedules, and other model parameters are specified as presented in Section 3.10.2.

Table 28 presents impacts of the NPP construction. The baseline case shows the indicator values in the absence of a nuclear new build, scenario values show the changes triggered by the plant construction in relative terms.

The investment in building an NPP in Viet Nam will affect various economic sectors differently. Sectoral impacts on employment and total production under the four impact mechanisms (direct and indirect in submodule A, induced in submodule AB, labour market effects in submodule ABC and financing feedback impacts in submodule ABCD) reflect the allocation of investment costs across industries according to their ability to contribute to the construction activities as discussed in Section 3.10.2.

Table 29 presents impacts of the NPP construction on employment in the 35 sectors of the national economy included in the IOT. The baseline case shows employment values in the absence of a nuclear new build, the next four columns show changes triggered by the plant construction in sectoral employment under the four impact mechanisms.

TABLE 28. IMPACTS OF NPP CONSTRUCTION IN VIET NAM

Indicator	Baseline *(million 2011 USD, employment in person)*	Direct and indirect	Induced	Labour market current prices	Labour market constant prices	Financing feedback current prices	Financing feedback constant prices
		Change (%)	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)
Gross domestic product	130 216	0.267	0.375	0.409	0.046	0.370	0.291
Disposable income	96 050	0.279	0.373	0.403	0.363	-0.008	-0.045
Total production	332 716	0.341	0.436	0.466	0.414	0.431	0.384
Public net savings	3 790	0.637	0.860	0.931	—[a]	0.352	—[a]
Imports	113 207	0.266	0.363	0.394	0.394	0.359	0.359
Employment	50 938	0.20	0.30	—[a]	0.322	—[a]	0.292

[a] —: data not available.

TABLE 29. IMPACTS OF NPP CONSTRUCTION ON SECTORAL EMPLOYMENT IN VIET NAM IN 2021
(thousand person) (courtesy of A. T. Nguyen, Ministry of Industry and Trade)

Sector	Baseline	Direct and indirect	Induced	Labour market	Financing feedback
Electricity	425	426	426	426	426
Agriculture	10 357	10 359	10 374	10 377	10 372
Crude oil, natural gas	600	602	602	602	602
Mining and quarrying	285	285	286	286	286
Food, beverages, tobacco	438	438	438	438	438
Textiles	18 546	18 570	18 581	18 576	18 573
Leather, footwear	1 600	1 601	1 604	1 604	1 603
Wood and cork	307	307	308	308	308
Pulp, paper	420	420	421	421	421
Coke, refinery	110	110	110	110	110
Chemicals	219	222	222	222	222
Rubber and plastics	337	339	339	339	339
Non-metallic minerals	165	166	166	166	166
Basic metals	800	800	800	800	800
Machinery	202	202	202	202	202
Electrical equipment	561	568	568	568	568
Transport equipment	543	543	544	544	543
Other manufacturing	668	668	668	668	668
Water	127	127	127	126	126
Construction	3 271	3 347	3 347	3 346	3 346
Trade	245	245	246	245	245
Hotels, restaurants	2 137	2 139	2 143	2 143	2 142
Road transport	765	765	766	765	765
Rail transport	29	29	29	29	29
Pipelines transport	1 233	1 234	1 237	1 237	1 236
Other water transport	53	53	53	53	53
Other air transport	8	8	8	8	8
Other transport activities	228	229	229	229	229
Post, telecommunications	105	105	105	105	105
Other business activities	1 851	1 851	1 851	1 849	1 849
Financial intermediation	802	803	804	804	803
Real estate activities	148	148	148	148	148
Public administration	1 583	1 584	1 587	1 586	1 585
Education	1 767	1 767	1 772	1 769	1 767
Health	—[a]	—[a]	—[a]	—[a]	—[a]
Total	50 938	51 062	51 112	51 102	51 086

[a] —: data not available.

3.10.4. Main conclusions

The subject of this study is a fictitious case of NPP construction and operation based on considerations before the nuclear programme was cancelled. The objective of this study is to evaluate the economic impacts of nuclear power development in Viet Nam in broad aggregates such as GDP, employment, disposable income, net public savings, exports and imports. Four successively broadening impact mechanisms are considered ranging from direct and indirect to induced effects, and further to labour market effects and feedback from financing the NPP investment.

According to assessments with EMPOWER, the assumed scenario of building an NPP in Viet Nam has positive impacts on the national economy as a whole. Almost all assessed macroeconomic indicators are affected favourably under all four impact mechanisms when calculated at current prices. For example, the increase in GDP can be as much as 0.409% when considering direct, indirect, induced and labour market effects (calculated with submodule ABC) relative to the baseline scenario in which no NPP is built. In the same case, employment is estimated to increase by 0.322% relative to the base case. The only exception is disposable income when feedback from financing the nuclear power investment is also considered (submodule ABCD). In this instance, disposable income declines negligibly by 0.008%.

Running EMPOWER with constant prices, macroeconomic impacts of the nuclear power investment are somewhat lower but remain mostly positive. The only exception is disposable income in the case when impacts of financing feedback are considered (submodule ABCD) with a somewhat worse value than at nominal prices but still a rather small negative impact at 0.045%.

Some data conversion is needed to produce the sectoral model structure (IOT with 35 × 35 sectors) required by EMPOWER:

— Aggregating rows from the original domestic IOT into a sectoral structure (IOT in a 35 × 121 format) and moving the electricity sector to the first row;
— Aggregating the reduced domestic IOT (35 × 121 format) into the sectoral structure of EMPOWER (35 × 35) and moving the electricity sector to the first column.

The aggregation routine from 121 into 35 sectors functions accurately without any problem. Yet totals in the row total intermediate inputs need to be checked.

EMPOWER is a convenient tool to assess economy-wide and sectoral impacts of investing in an NPP construction. Data requirements are considerable but most data are available from national or international sources.

4. SUMMARY AND SYNTHESIS

4.1. NATIONAL CONTEXTS

The relative impacts of building and operating new NPPs on the national economy depend on many factors. The socioeconomic characteristics of the country in which a nuclear power programme is initiated or a new NPP is built largely determine the relative impacts of any major investment even of a similar absolute size. Another related set of factors is linked to the country's ability to construct and operate an NPP (domestic contribution) as discussed in Section 4.3 below.

The population size shows the number of people to be served by safe, reliable and environmentally benign electricity. The geographical location (climate), lifestyle and level of economic affluence of people determine the amount of electricity they need per capita and in total. All these factors are captured by the IOTs. In addition to the natural and human resource endowments and the ensuing industrial structure, the size of the national economy is a key determinant of electricity demand.

The magnitude of a country's GDP and closely related properties such as total economic output, disposable income of households and labour force influence the relative scale of macroeconomic impacts of a major investment like building an NPP. The level of economic development measured as GDP per capita plays an important role in determining the degree of economic burden associated with a large investment, especially if a part of the investment finance is raised from changing social transfers (e.g. increasing taxes, decreasing social support). Similarly, even if the net electric generation capacities of the new NPPs are similar across the countries, the magnitude of their effect on electricity supply depends on the total installed generation capacity and the total power production before the new nuclear plants are built.

Table 30 presents the most important features of the countries that participated in the CRP and prepared various kinds of economic impact assessments at the national and sectoral level. In order to ensure the comparability of basic national data, widely recognized and methodologically consistent international data sets are used for compiling the table. Data available for the latest year as of May 2020 are included. Similar data shown in the national sections in Section 3 may deviate due to differences in the reference year, data sources, methodologies or other reasons.

Table 30 shows a rather diverse picture. The population of participating countries ranges between 3 million (Uruguay) and 268 million (Indonesia). The volume of GDP measured in 2018 USD spreads from about USD 40 billion (Tunisia) to 1658 billion (Russian Federation). The range of economic development measured in terms of GDP per capita calculated at purchasing power parity is also rather large, spanning between 6609 (Viet Nam) and 36 777 (Republic of Korea) constant 2011 international dollars. The installed power generation capacity in participating countries varies by a factor of 60 between less than 4.6 GW (Uruguay) and more than 270.1 GW (Russian Federation). Due to the widely varying proportions of electricity exports and imports across these countries, total electricity generation has an even larger spread by a factor of 90, ranging from about 11.4 TW·h (Croatia) to more than 1034.4 TW·h (Russian Federation). This diversity of socioeconomic and power sector circumstances across participating countries are important to consider when comparing and evaluating the results of macroeconomic impact assessments of their nuclear power programmes.

TABLE 30. SOCIOECONOMIC AND ELECTRICITY DATA FOR PARTICIPATING COUNTRIES
(data sources: Refs [48], [49])

Country	Population (million)	GDP (current USD, million)	GDP, PPP[a] (current int[b] $, million)	GDP per capita, PPP[a] (constant 2011 int[b] $)	Electricity installed capacity (GW[c])	Electricity generation (TW·h[d])
	2018	2018	2018	2018	2017	2017
Croatia	4	60 972	112 785	23 664	5.013	11.362
Indonesia	268	1 042 173	3 500 936	11 606	62.588	241.326
Korea, Republic of	52	1 619 424	2 071 182	36 777	122.916	530.551
Malaysia	32	358 582	1 002 046	28 201	34.467	156.031
Poland	38	585 664	1 190 119	28 786	42.955	160.604
Russian Federation.	144	1 657 555	4 050 786	25 629	270.163	1034.436
South Africa	58	368 289	790 823	12 145	51.265	236.373
Tunisia	12	39 871	144 598	11 094	5.778	19.172
Uruguay	3	59 597	81 307	20 916	4.557	13.546
Viet Nam	96	245 214	711 567	6 609	41.313	173.299

[a] PPP: purchasing power parity.
[b] int: international.
[c] GW: gigawatt.
[d] TW·h: terawatt-hour.

4.2. MODELS AND DATA

All national research teams participating in this CRP use EMPOWER developed and made available by the IAEA (see Section 2). In addition, a few teams (Poland, Russian Federation, Uruguay) also apply other models to compare calculations or alternative formulations of EMPOWER (e.g. Tunisia and Uruguay) to compare results they obtained with those from working with the IAEA model.

The key input to EMPOWER — and, in fact, to any IOM — is a properly assembled IOT. National statistical offices, central banks and other organizations prepare IOTs of various types in all participating countries but almost half of the teams were unable to use national IOTs because they did not fulfil requirements of EMPOWER such as the need for separate domestic and import IOTs. However, the latter is needed for an up-to-date representation of trade flows. In such cases, international sources of standardized national IOTs are used, for example the WIO Database [14] or the OECD collection [34]. Table 31 presents an overview of the modelling tools and the IOT sources applied in the national impact assessment studies.

TABLE 31. MODELS AND DATA SOURCES

Country	Model(s)	Input–output table source
Croatia	EMPOWER[a]	National
Indonesia	EMPOWER	WIO DB[b]
Korea, Republic of	EMPOWER*	National
Malaysia	EMPOWER	National
Poland	EMPOWER, PL-ATOM	WIO DB
Russian Federation	EMPOWER, IEF RAS[c]	National
South Africa	EMPOWER	OECD[d]
Tunisia	EMPOWER*	OECD[d]
Uruguay	EMPOWER*, KPMG	National
Viet Nam	EMPOWER	National

[a] EMPOWER: Extended input–output model for sustainable power generation.
[b] WIOD DB: World Input–Output Database.
[c] IEF RAS: Institute of Economic Forecasting, Russian Academy of Sciences.
[d] OECD: Organisation for Economic Co-operation and Development.
* Two versions of EMPOWER are used.

Specifications of the NPPs considered for the economic impact assessments vary somewhat across countries depending on the size of the current electricity generation capacity. The assumed investment arrangements also differ in terms of the assumed construction time and costs, the ability of domestic industries to contribute to the construction work and installed equipment, temporal patterns of the investment flows and sources of funding. Table 32 shows the provisions of the NPP investments serving as input to assessing the economic impacts in participating countries. The Republic of Korea is not included in Table 32 because the ex post assessment of the contribution of nuclear energy to national economic development is very valuable in itself but it is not meaningful to compare it to the economic impacts of investing in building and operating new NPPs.

TABLE 32. NPP INVESTMENT SPECIFICATIONS

Country	Capacity[a] (MW(e))	Time (year)	Cost ($ bill[b])	Domes[c] (%)	Investment pattern	Financing
Croatia	1 × 1147	7	5.75	40	Even	50% external, 50% ex ante income tax
Indonesia	2 × 1000	10	11.5[d]	26	Peak in years 5–9	75% external, 25% income tax
Malaysia	2 × 1000	13	12.5 bill MYR	64	Peak five years in second half	90% external, 10% income tax
Poland	2 × 1500	13	15	50	Peak in first half	EMPOWER 100% pri[e], PLA[f]: 100% pri[e], 50%–50% pri[e]-pub[g], 100% pub[g]
Russian Federation	2 × 1000	17	6.77	100	Peak in second half	100% public
South Africa	2800	6	14.4[h]	—[i]	Peak in mid two years	85% external, 15% ex ante revenue tax
Tunisia	1 × 1000	6	5[h]	10	Peak in mid two years	90% external, 10% income tax
Uruguay	1 × 740	8	5.9	23	Even	70% external, 30% profit and bonds
Viet Nam	2 × 1000	—[i]	8.4[h]	7	S-shaped, peaks in years 1, 4, 5	—[i]

[a] Capacity: Capacity of the considered NPP.
[b] $ bill: USD billion.
[c] Domes: Domestic share.
[d] Including interest during construction.
[e] pri: private.
[f] PLA: PL-ATOM.
[g] pub: public
[h] Excluding interest during construction.
[i] —: data not available.

It is not surprising that having the smallest generation capacity in 2017, the Uruguayan team assumes the smallest reactor for the impact assessment at 740 MW(e) to be built in eight years. The Croatian assumption of adding a reactor of 1147 MW(e) capacity to the 2017 total capacity of about 5 GW signifies a major extension. The Polish study specifies the most ambitious programme with 2 × 1500 MW(e) albeit with a construction period of 13 years. The assumed construction time of one reactor varies between six years (Tunisia) and eight years (Uruguay). Nuclear plants with two units are assumed to be completed over a time period of six years (South Africa) to 17 years (Russian Federation). Variations in the assumed costs of the NPP construction reflect differences in the sources used for the estimations and the time when they were prepared.

All national studies (except South Africa) indicate the assumed share of domestic contribution to the construction work. It is not surprising that a new NPP construction in the Russian Federation can be fully supplied by the domestic nuclear industry, itself a provider of turnkey reactors for export. The specified national contributions in Table 32 are based on thorough assessments of the ability of domestic industries to contribute labour, equipment and other services to the NPP construction and are arranged according to the economic sectors included in the national IOTs.

In addition to the magnitude of domestic contribution, the assumed timetable of the construction work and hence the annual investment outlays also affect the yearly impulse of the nuclear plant construction for domestic industries over the construction period. Two studies (Croatia and Uruguay) assume even annual distribution of investment disbursements while most countries specify that they peak in the middle or the second half of the building phase. Notable exceptions are the Polish models (assuming the bulk of investments occurring in the first half) and Viet Nam (supposing a surge in the first year).

Assumptions about the financing arrangements for the nuclear plant investments are crucial for any economic impact assessment (especially for Submodule ABCD of EMPOWER) in order to consider feedback effects running through the entire economy that arise from raising funds from various sources. The Viet Nam study does not specify the assumed financing arrangements. Most countries assume that a large share of the financial resources come from external sources. According to the legal status of the nuclear energy industry in the Russian Federation, the entire investment is financed from government sources. The Polish study explores the impacts of different combinations of private and public financing.

4.3. MACROECONOMIC IMPACTS OF NPP CONSTRUCTION

Comparing results of the national studies is challenging for various reasons. First, the size and development level of the national economies, the electricity sector contexts (see Section 4.1) and the assumed construction times differ considerably. Second, characteristics of the assumed NPP, its construction and financing attributes are also rather different. Third, the appraised ability of domestic industries to contribute to building an NPP and the representation of this contribution in the applied models also vary (see Section 4.2). Finally, the specification and operation of EMPOWER by national study teams also differ somewhat, e.g. not all impact mechanisms (submodules) are successfully activated by some of the research teams and alternative approaches to updating the IOT (Uruguay, see Section 3.9) or devising feedbacks from changing import situations (Tunisia, Section 3.8) are adopted. Comparison of EMPOWER results with findings of other models applied by some research teams are not always straightforward even if the models belong to the same type (IOMs) and becomes more contentious when the alternative models are based on different methodological postulates such as CGEs.

Table 33 presents a summary of the calculated impacts of NPP construction on GDP and employment. Two studies are missing from the table. Results of the Republic of Korea team are not included because they are based on the analyses of a multidecade national programme while all other studies assess impacts of individual nuclear new build projects and because the ex post assessment of the contribution of nuclear energy to economic development cannot be meaningfully compared to the ex ante analyses of economic impacts of hypothetical nuclear new builds in the future. The report of the Russian Federation team does not present impacts on GDP and employment from either of the applied models. It should be remembered that employment associated with construction activities is transitional, while it is permanent during the operation phase.

TABLE 33. IMPACTS OF NPP CONSTRUCTION ON GDP AND EMPLOYMENT RELATIVE TO THE BASE CASE (%)

Country	Impacts on GDP according to impact mechanisms (modules) (%)				Impacts on employment according to impact mechanisms (modules) (%)			
	A	AB	ABC	ABCD	A	AB	ABC	ABCD
Croatia	0.35–0.40	0.67–0.75	0.75–0.81	—[a]	0.46–0.51	0.72–0.79	0.47–0.62	—[a]
Indonesia	0.001–0.035	0.001–0.054	0.002–0.065	0.002–0.065	0.000–0.027	0.001–0.051	0.001–0.055	0.001–0.055
Malaysia	0.28	0.31	0.31	0.31	—[a]	—[a]	—[a]	—[a]
Poland EMP[b]	0.02–0.11	0.03–0.15	—[a]	—[a]	0.02–0.10	0.03–0.14	—[a]	—[a]
PLA private[c]	n.a.[d]	n.a.[d]	n.a.[d]	-0.25–0.61	n.a.[d]	n.a.[d]	n.a.[d]	—[a]
PLA half-half[e]	n.a.[d]	n.a.[d]	n.a.[d]	-0.04–0.72	n.a.[d]	n.a.[d]	n.a.[d]	—[a]
PLA public[f]	n.a.[d]	n.a.[d]	n.a.[d]	0.10–0.83	n.a.[d]	n.a.[d]	n.a.[d]	—[a]
South Africa	0.6–2.2	0.8–2.8	0.8–3.0	0.8–2.9	0.5–4.9	0.6–5.4	0.6–4.9	0.6–4.8
Tunisia	0.03–0.13	0.04–0.18	0.03–0.17	0.02–0.12	0.02–0.15	0.03–0.26	0.03–0.26	0.02–0.22
Uruguay E30[g]	0.5	0.8	0.9	—[a]	0.7	1.0	0.9	—[a]
Uruguay E05[h]	1.1	1.6	1.6	—[a]	1.1	1.6	1.5	—[a]
Uruguay K05[i]	n.a.[d]	n.a.[d]	n.a.[d]	n.a.[d]	0.7	n.a.[d]	n.a.[d]	n.a.[d]
Viet Nam	0.267	0.375	0.409	0.370	0.2	0.3	0.322	0.292

[a] —: data not available.
[b] EMP: EMPOWER, private financing.
[c] PLA private: PL-ATOM model, private financing, Poland.
[d] n.a.: not applicable.
[e] PLA half-half: PL-ATOM model, 50% private, 50% public financing, Poland.
[f] PLA public: PL-ATOM model, public financing, Poland.
[g] E30: EMPOWER with input–output table extrapolated to 2030.
[h] E05: EMPOWER with 2005 input–output table.
[i] K05: KPMG model with 2005 input–output table.

Table 33 shows ranges of annual impacts for cases when annual investment disbursements vary over the construction period. The Croatian and Uruguayan versions of EMPOWER assume even distribution of the total investment costs, i.e. the same amount of outlays in every year of the construction time. The impacts in Malaysia are presented for 2028, the peak year of NPP construction relative to the real GDP in 2020, the reference year of the IOT because no model data are available for the base case or reference year. The PL-ATOM is a CGE model, hence impact modules of the input–output based EMPOWER are not applicable, the calculated ranges of annual general equilibrium impacts on GDP are shown in the ABCD column for three financing scenarios. Impacts calculated with different arrangements of EMPOWER and a national model for Uruguay are related to the year 2030.

Notwithstanding the caveats about the diversity of national circumstances and modelling arrangements, results summarized in Table 33 depict an essentially reasonable picture. According to expectations based on macroeconomic reasoning, estimated impacts on GDP and employment increase in most countries as the scope of assessments is broadened from direct and indirect effects (submodule A) to induced impacts (submodule AB) and further to outcomes of labour market response (submodule ABC). Assessed GDP and employment impacts are somewhat lower than labour market impacts when the feedback of financing the nuclear plant investment running through the whole economy is also considered (submodule ABCD). The extent of how much lower this impact is depends on and largely consistent with the assumed sources of financing and the ways of raising the public part of the investment fund.

Relative impacts of building a nuclear plant on GDP are largely proportional with the size of the national economy even if differences in the number and size of assumed reactors are taken into account. Ratios of GDP volumes calculated at market exchange rates and at purchasing power parity vary considerably across the countries included in Table 30. National studies use market exchange rates, which is perfectly reasonable for assessing the impacts of a nuclear energy investment where — with some exceptions — considerable shares of the equipment are imported and paid for in foreign currencies purchased at market rates.

Countries with smaller GDP volumes are projected to experience relatively larger GDP increases than larger economies. The calculated impacts on GDP for Croatia and Uruguay, two smaller economies among the participating countries and both assuming to build one new reactor, are rather similar, although the expected domestic participation rate in Croatia is almost twice as high as in Uruguay. Interestingly, Tunisia, with the smallest economy in terms of GDP volume, is projected to have considerably lower impacts from building a reactor of comparable size on GDP than the two previous countries, partly because the model assumes a significantly lower share of domestic industries in the construction work.

Impacts of nuclear new builds on GDP follow comparable patterns but their magnitudes differ considerably in two economies of very similar size: Malaysia and South Africa. The estimated impacts are twice to ten times as high in South Africa than in Malaysia under corresponding impact mechanisms. This is particularly interesting because the assumed financing schemes are very similar in the two countries. Part of the explanation might be that the capacity of the assumed reactors is considerably higher in South Africa (2800 MW(e)) than in Malaysia (2000 MW(e)). Another major difference is that South Africa is assumed to complete the NPP building in six years whereas the construction work in Malaysia extends over 13 years, hence annual economic impacts even in the peak year are much lower in Malaysia than those in South Africa where annual investment disbursements are apparently much higher. Moreover, South Africa has almost three decades of experience in building and operating nuclear power reactors. Yet missing data inhibit a better analysis of the differences: the assumed investment cost is not available in the Malaysian case and the estimated domestic contribution to the nuclear construction is not known in the South African model. Results for Viet Nam, with a somewhat lower GDP volume than Malaysia, indicate plausible impacts, very close to those in Malaysia.

Indonesia has by far the largest economy measured by GDP at market exchange rate among the countries in Table 33. This is part of the explanation why the assessed impacts of building two large reactors on GDP are far lower than in any other country considering nuclear investments of similar size. In the Polish study, a modified version of EMPOWER is used, therefore labour market impacts (submodule ABC) and financing feedback results (submodule ABCD) are not included in Table 33. Results calculated for direct and indirect (submodule A) and induced (submodule AB) impacts are perfectly plausible.

Several study teams apply different versions of EMPOWER to explore specific issues of interest to their countries. The study of the Republic of Korea has two versions to explore the contribution of nuclear energy to the country's economic development: the first version is based on a specially modified IOT prepared by KAERI, while the second version adopts a framing properly adopted to undertake a comparable ex post analysis. In contrast to all other studies in this CRP, the counterfactual against which economic impacts of nuclear programmes are measured is not the case of building the first or additional NPPs in a country. The case study of the Republic of Korea investigates what would have happened in the national economy and electric power sector in the absence nuclear energy. Both versions of EMPOWER find significant positive impacts of nuclear power on the overall development of the country, although the estimated level of impacts on GDP differ somewhat. The disparity is caused by the different methods of calculating GDP in the two versions (see Section 3.3). Yet this case demonstrate the flexibility of EMPOWER and its applicability for historical studies.

The Uruguayan team presents results from two versions of EMPOWER. The first one is employing the customary approach, i.e. updating the historical IOT by using assumptions about growth rates of key economic drivers in the RAS process to approximate a baseline representation of the national economy for the period when the NPP construction is assumed to commence. The other version takes the 2005 IOT and superimposes the assumed nuclear energy investment on it. The second version is intended to compare results of EMPOWER with those of a national model. Not surprisingly, impacts of the same NPP investment turn out to be about twice as great under the 2005 conditions of the national economy as in the 2030 case when 25 years of economic development is manifested in the state of the economy in which the nuclear plant is built, e.g. much larger GDP, total production, disposable income and other macroeconomic aggregates.

Although the purpose of EMPOWER with the 2005 IOT is to make results comparable with those of the national KPMG model, the comparison is difficult to include in Table 33 because the latter calculates only direct and indirect impacts and only on total production (output) and employment but not on GDP. As discussed in Section 3.9, the direct and indirect impacts of the nuclear plant investment on total production under the 2005 conditions are very similar (1.3% in EMPOWER, 1.1% in KPMG) despite the broader spreading of investment demand across more economic sectors in the KPMG model. It is reasonable to assume that impacts on GDP calculated by the two models would also be very close.

In addition to Uruguay, two other national teams present results of other models. As noted above, the PL-ATOM model applied by the Polish study team is a recursive dynamic CGE model. Therefore, impact modules of the input–output based EMPOWER are not applicable. Calculated ranges of annual general equilibrium impacts on GDP shown in the ABCD column of Table 33 are slightly negative in the scenarios when the NPP construction is financed entirely or at the level of 50% from private sources but they become positive in the case of 100% public financing. This is a noteworthy contrast to the EMPOWER results that show small but positive direct and indirect (submodule A) and induced (submodule AB) impacts on GDP in the case of 100% private financing. Including labour market feedback (submodule ABC) would come closer to the general equilibrium framing but the Polish version of EMPOWER calculates counter-intuitive results that are not meaningful to compare with results of PL-ATOM.

The study team of the Russian Federation is the third team that applies a second model in addition to EMPOWER. Their results are omitted from Table 33 because they only present impacts on gross output but neither on GDP, nor on employment. The IEF RAS model is conceptually very similar to EMPOWER but it also considers long term efficiency improvements in the economy by decreasing the technological coefficients, it does not balance future IOTs and it also considers the macroeconomic effects of additional taxes and profits in specifying final demand. Estimates of annual and cumulative increases in gross output triggered by indirect and induced effects of the NPP project obtained with the two models are very close for the construction phase. Results diverge to a certain degree for the operational phase due to the stated differences.

When comparing impacts of nuclear energy investments on employment, the same caveats apply as those mentioned in the opening paragraph of this section. In addition to the various GDP indicators listed in Table 30, demographic and other socioeconomic characteristics of participating countries are important to consider when comparing impacts of nuclear power programmes on employment. Long term trends in labour force participation rate, unemployment, human capital, labour and total factor productivity and other related factors influence the extent and ways of how building NPPs affect various segments of job markets and wages and the number of new job openings for domestic employees in construction works directly as well as in other sectors of the economy more broadly.

Similarly to GDP effects, employment impacts calculated by the EMPOWER applications of participating research teams appear to be plausible and realistic. The general observation is that employment impacts follow similar patterns as GDP impacts. With a few exceptions, the broader the range of impact mechanisms considered (moving from submodule A to ABCD), the larger is the estimated impact on employment. It is not surprising that induced impacts (submodule AB) are higher in all studies included in Table 33 than direct and indirect impacts (submodule A). The slightly lower employment impacts in a few countries can be explained by special features of labour markets and wage formation, the marginal propensity to consume, the wage reaction to unemployment rate and the ways these factors are incorporated in the national models. Lower employment impacts in the case when feedback from financing is also considered (submodule ABCD) relative to the case of labour market impacts (submodule ABC) mirror impacts assessed for GDP for these cases.

Countries with smaller population are projected to experience relatively larger employment increases than more populous ones. Estimated employment impacts for Croatia and Uruguay, two countries with the fewest inhabitants and both assuming to build a single reactor, are rather similar but somewhat higher in Uruguay despite the supposed higher domestic participation rate in Croatia. The reason may well be that the productivity of the newly hired labour is lower, hence the required number is higher in Uruguay. Curiously, Tunisia, with the third smallest population in the group, is assessed to have considerably lower employment impacts from building a reactor of comparable size than the two previous countries. The likely explanation is the significantly lower participation of domestic industries in the construction work.

Impacts of nuclear new builds on employment follow similar curves across impact mechanisms in two countries with mid-size population in the group: Malaysia (32 million) and South Africa (58 million). However, the magnitudes of impacts differ widely. The estimated impacts are twice to ten times as high in South Africa than in Malaysia under the various impact mechanisms. This may be partly explained by the fact that South Africa is assumed to build larger reactors (2800 MW(e)) in a much shorter time frame (six years) than Malaysia (2000 MW(e) in 13 years). This means that the impulse for the labour market is concentrated in a few years, therefore economic impacts in top years are much higher in South Africa than even in the peak year in Malaysia. Furthermore, although South Africa has experience in building nuclear plants, this goes back to almost three decades, the average labour productivity is likely to be considerably lower as suggested by the three-fold difference in GDP per capita measured at purchasing power parity between the two countries. Employment impacts in Viet Nam with a population 60% larger than South Africa are estimated at well above the upper end of the range for South Africa despite the smaller reactors and similar construction time assumed.

Indonesia has by far the largest population among the countries in Table 33. This largely explains why assessed impacts of building two large reactors on employment are immensely lower than in any other country that calculated employment impacts of nuclear investments of similar size. Since employment impacts of labour market feedback (submodule ABC) and financing feedback (submodule ABCD) in the modified version of EMPOWER applied in the Polish study appear to be counter-intuitive, they are not included in Table 33. Results calculated for direct and indirect (submodule A) and induced (submodule AB) impacts are conceivable.

Two versions of EMPOWER specified by the Uruguayan team differ in whether the historical IOT for 2005 is updated for 2030 when the NPP construction is assumed to finish or not. Similarly to impacts on GDP, the same NPP investment is assessed to generate about 50% higher employment impacts under the 2005 conditions (1.1%) than in the 2030 case (0.7%) when the population is larger and more affluent and the economy in which the nuclear plant is built is much larger and more productive. The national KPMG model, the other tool used in the Uruguayan study, reflects the 2005 situation and estimates only direct and indirect impacts of the hypothetical NPP construction. It is comparable to the 2005 specification of EMPOWER but investment demand generated by the NPP construction is spread across more economic sectors. This may partly explain why employment impacts of the same investment on the same economy estimated by the KPMG model are significantly higher than those assessed by EMPOWER. In addition, the KPMG model does not calculate direct impacts on employment (see Section 3.9).

Employment impacts of EMPOWER cannot be compared with results of the additional models used by participating teams. The CGE model PL-ATOM applied by the Polish study team does not calculate impacts on employment, hence no results can be presented in Table 33. Results about employment impacts of NPP construction are not available from the IEF RAS model either.

Irrespective of the differences in the magnitude and relative extent of impacts of NPP construction on employment, these employment impacts are transitory. They decline as construction work nears completion and will be replaced by operational impacts when the new plant starts generating electricity and is connected to the grid.

4.4. ECONOMIC IMPACTS OF NPP OPERATION

Not all research teams apply the operational module of EMPOWER and only four of them present results of their calculations about impacts on GDP and employment. Table 34 presents impacts of operating the NPPs assumed to be built on GDP and employment.

Research teams from Indonesia, Poland, South Africa and Viet Nam do not use the operational module at all. The most frequently mentioned reasons for this include difficulties to obtain data required for specifying the operational module, including techno–economic specifications of future power generation technologies and the evolution of the generation mix, the cost of power generation technologies, the related technical challenges to specify the demand vector and the allocation of fuel commodities to sectors.

Two studies are missing from Table 34 due to reasons mentioned in the previous section. The ex post assessment of the contribution of nuclear energy to economic development in the Republic of Korea cannot be meaningfully compared to the economic impacts of operating a newly built NPP. The report of the Russian Federation team does not include impacts on GDP and employment from either of the applied models.

Impact of operating the newly build NPPs on GDP are expected to be proportional to the ratio of its capacity to the total installed power generation capacity and to the share of electricity generated by the new NPP in total electricity generation in the year for which impacts are assessed, typically the first year or initial period of its operation.

In three countries with the smallest total generation capacities in 2017 (Croatia, Tunisia and Uruguay), adding only one reactor increases generation capacity immensely. Even if more generation capacity of various sorts is added during the time until the assumed NPPs start operation, the additional capacity represented by the new NPP is likely to add at least 10% or more. Accordingly, the new NPPs will provide a larger share of total generation in these countries: 23% in Croatia, 25% in Tunisia and 28% in Uruguay. Considering these similarities in shares of the new NPPs in total electricity output, their impacts on GDP vary considerably. While direct and indirect impacts (submodule A) as well as induced impacts (submodule AB) on GDP are very similar in Croatia and Uruguay, Tunisia is obviously a special case.

Of the two lines for Tunisia in Table 34, the first line presents impacts on GDP based on the original EMPOWER redistribution of intermediate consumption due to reduced imports of natural gas, the second line is based on a modified redistribution. As discussed in Section 3.8, a major effect of the assumed NPP is a large reduction in gas imports for fuelling gas fired plants. This does not affect intermediate demand of gas based generation from domestic sources much and affects only modestly the power generation sector as a whole, hence direct and indirect impacts on employment (submodule A) are slightly negative. Employment remain negative when induced effects (submodule AB) are also considered. Direct and indirect impacts on employment become zero when effects of lower gas consumption in power generation are assigned to domestic production but they still remain far below the comparable impacts in the two other countries with small total generation capacities.

TABLE 34. IMPACTS OF NPP OPERATION ON GDP AND EMPLOYMENT

Country	Output[a] (%)	Impacts on GDP according to impact mechanisms (modules) (%)				Impact on employment according to impact mechanisms (%)			
		A	AB	ABC	ABCD	A	AB	ABC	ABCD
Croatia	35	2.87–2.93	3.27–3.34	3.54–3.75	--	1.72–1.77	2.06–2.11	0.39–1.17	--
Malaysia	2.37	0.28	0.30	0.30	0.30	—	—	—	—
Tunisia[b]	25	0.1	-0.1	—	—	-0.1	-0.2	—	—
Tunisia[c]	25	0.5	—	—	—	0.0	—	—	—
Uruguay	28	3.1	3.6	—	—	0.6	1.0	—	—

[a] Output: Share of the new NPP output in total electricity generation.
[b] Original EMPOWER redistribution of intermediate consumption due to reduced imports of natural gas (see Section 3.8).
[c] Modified redistribution of intermediate consumption due to reduced imports of natural gas (see Section 3.8).

The increase in total generation capacity caused by the hypothetical NPP in Malaysia is likely to be significant even at the time when it is assumed to be completed. It is expected to provide 2.37% of total power generation in 2032. The estimated direct and indirect impacts (submodule A) on GDP seem to be plausible.

The OECD NEA and the IAEA present an in-depth analysis of employment generated by the nuclear power sector [3], including employment impacts in the operational phase. Based on the bi-annual survey of the Nuclear Energy Institute, the study finds that in 2013, the US commercial nuclear industry provided direct jobs for between 480 and 1040 employees at one unit plants, 640–1520 employees at two unit plants and 1130–2260 employees at three unit plants (an average of 598 per unit). This is a rather large variation in a country with the greatest number of operable reactors and the highest amount of nuclear electricity supplied.

Jobs at fuel cycle facilities, vendors and regulatory agencies are considered indirect employment by this study. Indirect impacts in the strict economic input–output sense include not only these jobs but also those created by companies providing goods and services for the operation of NPPs. Indirect employment impacts in the OECD NEA-IAEA sense are difficult to estimate in general because the largest share of jobs in this category is associated with uranium mining and nuclear fuel preparation. They are beyond the borders of many countries operating nuclear plants and this is the case in most countries participating in this study as well.

Nuclear power generation has a low labour intensity even on a life cycle basis that includes all jobs associated with the power plant from construction to decommissioning and dismantling reactors and from uranium mining to final disposal of radioactive waste in the fuel cycle. Life cycle employment calculated on this basis is about 40 jobs/PJ (about 278 GW·h) electricity output per year and it is not found to be sensitive to fuel transport and plant efficiency variability, and very little sensitive to load factor variability [50].

A comparative analysis of employment factors of various energy technologies shows that nuclear energy is in the middle of the range with 16 person-years in the investment phase (construction, installation and manufacturing) spanning from 3.4 (gas) to 38.8 (photovoltaic) person-years. However, in the operational phase, nuclear plants require very low labour input at 0.32 jobs/MW capacity. Only hydropower plants need less labour to run (0.22 jobs/MW) while solar thermal and ocean energy require about the same amount at 0.3 and 0.32 jobs/MW, respectively. Coal and gas fuelled power plants also require less labour to run but they require a lot more labour for providing fuel (about 30% more for gas and up to ten times more for coal). Labour input for operation and maintenance of photovoltaic and on-shore wind are somewhat higher than for nuclear at 0.40 jobs/MW and more than twice as high for off-shore wind at 0.77 jobs/MW) [51].

Impacts of operating the newly built NPPs on employment are expected to be proportional to the relative increase they produce in the total generation capacity and their relative expansion of total electricity generation. Results of this CRP summarized in Table 34 show that, similarly to impacts of building NPPs, impacts of their operation on employment show comparable patterns to those on GDP, albeit at a somewhat lower level in general.

The large increase in total electricity output produced by the newly added reactor in two of the three countries with the smallest total generation capacities in 2017 (Croatia and Uruguay) increases employment considerably. Direct and indirect impacts (submodule A) expand employment by 1.72–1.77% during the assessed period of operation in Croatia and by 0.6% in Uruguay when impacts with the updated IOT are calculated for 2032. As mentioned above, Tunisia is a special case where operation of the nuclear plant reduces gas imports but affects demand of intermediate inputs to the power sector. Here, employment impacts are slightly negative when calculated according to the EMPOWER method and become zero when implications of reduced gas imports do not affect the demand of the power sector for intermediate input.

Induced impacts (submodule AB) account for the amount of money that new workers spend on goods and services. Their expenditures trigger increases not only in the output of sectors from which they purchase these good and services but affect the entire economy as these purchases induce expansions in demand for and outputs of other sectors. This effect is clearly reflected in the results calculated for Croatia and Uruguay. The special case of Tunisia is also obvious in the assessed induced impacts.

Modelling results in Table 33 show that impacts of NPP construction on GDP and employment are rather similar in most assessed economies. In contrast, impacts of NPP operation on GDP are much higher than on employment (Table 34). This suggests that labour productivity in nuclear electric power generation is rather high. A smaller amount of labour added to the national employment pool is associated with a much higher increase in GDP.

4.5. SECTORAL IMPACTS

Not all research teams calculate or present results of sectoral impacts of NPP construction and operation in their reports. Results are difficult to evaluate in a quantitative way as they are compared in the two preceding sections due to the numerous reasons stated earlier. Comparison of sectoral impacts is even more challenging because delineations of economic sectors do not exactly overlap in the IOTs of different countries. Branches and activities included in sectors of even similar names vary across national IOTs, therefore their roles in intersectoral linkages and the impacts of NPP construction and operation on them may differ.

This section summarizes the findings of national research teams about impacts of NPP construction and operation on the most affected sectors country-by-country. It is followed by a short comparative analysis.

Only four of the 35 sectors in the IOT of Indonesia contribute directly to building NPPs: construction, mechanical equipment, financial services and electrical equipment (see Table 35). A few other sectors are affected indirectly. The biggest impact of NPP construction is on the manufacturing industries called machinery in Table 35. This seems sensible because the output of these industries is used by others sectors such construction, mechanical and electrical equipment (including several branches not included in Table 35 below. Table 35 shows indirect (including direct) and induced impacts of NPP construction on total production output of the most affected sectors in the peak years of the construction period relative to the base case (no NPP construction).

TABLE 35. SECTORAL IMPACTS OF NPP CONSTRUCTION ON TOTAL PRODUCTION IN THE PEAK YEARS IN INDONESIA
(courtesy of Suparman, National Nuclear Energy Agency)

Sector	Indirect impact (%)	Induced impact (%)
Machinery	1.60	1.60
Construction	0.10	0.10
Financial intermediation	0.10	0.10
Non-metallic minerals	0.08	0.09
Wood and cork	0.08	0.08
Crude oil and natural gas	0.05	0.07
Other business activities	0.05	0.06

The Polish multisector CGE model PL-ATOM calculates for the scenario in which the NPP construction is fully financed by the private sector (nuc_yes_prv) a significant increase in the total production of industries whose products constitute important elements of investment demand: construction, other mining, manufacture of metal products, manufacture of computer, electronic and optical products, electrical equipment, machinery and equipment. This increase is to a large extent transitory and diminishes as the investment impulse fades away. However, electricity from the first nuclear reactor as of 2025 increases the competitiveness and output volume in almost all industrial sectors, in particular in the most energy intensive industries such as manufacture of basic metals, construction, manufacture of rubber and plastic products, manufacture of motor vehicles, trailers and semi-trailers and other transport equipment. The lignite industry is the most negatively affected sector by nuclear energy because after 2025 demand for electricity produced by lignite fired power plants is reduced by the availability of nuclear electricity. The hard coal industry is affected similarly for the same reason, albeit at a much lower magnitude.

A recent report [29] presents a new application of the Polish version of EMPOWER called Empower.pl. It is based on slightly modified but comparable assumptions relative to those presented in Section 3.5.2 above. In the new model runs, construction is assumed to start in 2020, the first block of the NPP will be launched in 2029, the second one in 2033. In the first three years, annual expenditures are relatively small but growing, amounting to 6% of the total investment cost. Expenditures peak in the eighth year (2027) and amount to USD 2100 million, about 14% of the total cost, and then decline gradually.

This report [29] presents employment impacts under the assumed NPP construction scenario on 35 sectors included in the IOT of the model for the case when the investment is funded entirely by private sources (scenario nuc_yes_prv) and all four types of impacts from direct and indirect to feedback from financing the nuclear plant construction are considered (submodule ABCD). Results confirm earlier estimates. In the year when investment disbursements peak (2027), economy-wide employment is about 12 000 persons higher than in the base case. The largest increases occur in sectors providing investment products and services, i.e. construction (6500), machinery industry (1300) and electro-technical industry (800). They are followed by agriculture (400), and wholesale trade and retail trade (500 each). All other sectors lag far behind.

The study of the Russian Federation team presents easily comparable sectoral impacts in the construction and in the operational phase from two models. Not surprisingly, the EMPOWER estimates that the most affected sectors ranked according to their total gross output increases are rather different in the construction phase from those in operational phase, The ordering of the five most affected sectors in the construction phase includes trade with 15.4% of the cumulative gross output increase, electrical equipment (13.7%), machinery (9.0%), construction (8.7%) and other business activities (8.1%). These five sectors account for more than half (54.9%) of the cumulative gross output increase in the construction phase.

Only two of these sectors remain in the top five group in the operational phase led by financial intermediation with 18% of the cumulative gross output increase, followed by trade (15.3%), real estate activities (10.4%), food, beverages and tobacco (7.1%) and other business activities (6.6%). The combined share of these five sectors in the cumulative gross output increase comes to 57.4% in the operational phase.

The distribution of gross output increases across economic sectors in the construction phase estimated with the IEF RAS model is similar to that estimated with EMPOWER. The five sectors with the largest impacts on gross output are the same according to both models but their ranking varies slightly. According to the IEF RAS model, impacts on electrical equipment are slightly higher at 14.5% of the cumulative impacts than on trade (13.2%), and construction has a somewhat higher share (12.9%) in the cumulative impacts than machinery (9.7%). The sector other business activities remains fifth in the IEF RAS list as well with its 7.8% share in the cumulative impacts. The share of the top five sectors in the cumulative impacts is 58.1%, very close to the corresponding share calculated by EMPOWER.

In the operational phase, results of EMPOWER and the IEF RAS model deviate somewhat more. Only two of the five sectors with the highest impacts on total output according to EMPOWER appear among the top five sectors according to the ranking of the IEF RAS model: financial intermediation with a share of 16.1% in the cumulative impacts and other business activities with a 10.0% share. Trade, real estate activities, and food, beverages and tobacco are replaced by public administration (12.8%), mining and quarrying (7.8%) and machinery (7.3%) in the top five group according to the IEF RAS estimates. The 54.7% combined share of the five most affected sectors in the cumulative impacts in the operational phase according to EMPOWER is very close to the 54.0% combined share of the top five sectors in the cumulative impacts calculated by the IEF RAS model.

The Tunisian study finds that the NPP construction increases total domestic production (output) by around 0.2% (relative to the base case of no investment in nuclear power) and this generates more than 11 000 jobs in the peak year of the construction period. Table 36 presents sectoral employment in absolute terms (the number of jobs created) and the increase relative to the base case.

The 11 000 jobs generated by the investment in nuclear energy in the peak year 2026 is estimated to reduce the unemployment rate by 1.8 percentage point. However, considering the calculated increase of 0.2% in GDP, the decline in unemployment rate of this magnitude seems to be overrated. The reason is that economic sectors directly affected by the NPP construction are characterized by a high employment per output ratio.

TABLE 36. SECTORAL IMPACTS OF NPP CONSTRUCTION ON EMPLOYMENT IN TUNISIA IN 2026
(courtesy of C. Zammali, Tunisian Company of Electricity and Gas)

Impact mechanism	Sector	Jobs (number)	Increase (%)
Direct	Other non-metallic mineral products	1238	3.06
	Basic metals	1150	1.48
	Construction	5445	0.83
Indirect	Wholesale and retail trade, repairs	359	0.05
	Wood and products of wood and cork	154	0.44
Induced	Agriculture, hunting, forestry, fishing	510	0.11
	Food products, beverages and tobacco	124	0.10
	Textiles	120	0.06

Due to the special features of the power sector in Tunisia where nuclear electricity generation primarily reduces gas imports, the operation of the NPP generates a decrease in disposable income by 0.4% in one year if impacts of the reduced gas imports are distributed in proportion to the gas sourcing before the advent of nuclear electricity in the standard EMPOWER framing. In the Keynesian economic context, a decrease in disposable income induces a reduction in private consumption and eventually a decrease in total production. Economy-wide impacts show a decline in total production by about 0.3% and a reduction in total employment by about 0.2% implying a loss of more than 7000 jobs. Table 37 shows losses in total production and employment in the most affected sectors in 2030 and in the unaffected electricity sector. Losses in all other sectors remain below 1%. Sectoral impacts from the modified version of EMPOWER presented in Section 3.8 are not available.

TABLE 37. IMPACTS OF NPP OPERATION ON EMPLOYMENT AND TOTAL PRODUCTION IN TUNISIA IN 2030
(courtesy of C. Zammali, Tunisian Company of Electricity and Gas)

Sector	Job loss (number)	Job decrease (%)	Production decrease (%)
Electricity	0	0.00	0.00
Agriculture, hunting, forestry, fishing	1077	0.23	0.23
Mining and quarrying	1258	6.32	6.32
Food products, beverages, tobacco	333	0.24	0.24
Textiles, textile products, leather, footwear	245	0.14	0.14
Wood and products of wood and cork	33	0.08	0.08

In the case of Uruguay, sectoral impacts of the nuclear energy programme in the target year 2030 for which both construction and operational impacts are calculated are identical in relative terms for output and employment. Interestingly, differences between direct and indirect impacts on the one hand and induced impacts on the other are rather small. Table 38 shows the impacts of NPP construction on employment in 2030.

Table 38. IMPACTS OF NPP CONSTRUCTION ON EMPLOYMENT IN URUGUAY IN 2030
(courtesy of G. Ferrer, Secretary of Energy)

Sector	Impact (%)
Manufacture of basic metals, fabricated metal products, machinery and equipment	14.6
Construction	3.4
Manufacture of other non-metallic mineral products	2.8
Mining and quarrying	1.8
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0.9

The sector producing various kinds of metal products, machinery and other equipment stands out far above all other sectors with the highest impacts on employment and total production. The sectors construction as well as mining and quarrying also benefit significantly. Impacts of building a nuclear plant on all other sectors are below 1% in 2030.

In Viet Nam, sectoral impacts of NPP construction on employment and total output are highest in the same five sectors, as shown in Tables 39 and 40, respectively. The construction sector is on top in both lists with very similar numerical impact scores. Rankings of the other four sectors are pairwise inverted. The chemicals sector precedes electrical equipment in the employment list but they swap positions in the total output ranking. Employment in the non-metallic minerals sector is somewhat more strongly affected than in the rubber and plastics industry, while the opposite is the case in the total output ranking.

TABLE 39. SECTORAL IMPACTS OF NPP CONSTRUCTION ON EMPLOYMENT IN VIET NAM

Sector	Baseline (thousand person)	Impact (%)			
		Indirect	Induced	Labour market	Financing
Construction	3271	2.32	2.32	2.29	2.29
Chemicals	219	1.37	1.37	1.37	1.37
Electrical equipment	561	1.25	1.25	1.25	1.25
Non-metallic minerals	165	0.61	0.61	0.61	0.61
Rubber and plastics	337	0.59	0.59	0.59	0.59

It is interesting to note that employment impacts are the same under the four impact mechanisms in all sectors except construction. Sectoral impacts on total output vary somewhat across the four mechanisms but the differences are rather small, on the order of basis points.

TABLE 40. SECTORAL IMPACTS OF NPP CONSTRUCTION ON TOTAL OUTPUT IN VIET NAM

Sector	Baseline (USD million	Impact (%)			
		Indirect	Induced	Labour market	Financing
Construction	30.968	2.31	2.32	2.32	2.32
Electrical equipment	5.075	1.30	1.30	1.32	1.30
Chemicals	8.11	1.01	1.09	1.11	1.09
Rubber and plastics	6.407	0.62	0.64	0.66	0.64
Non-metallic minerals	7.65	0.34	0.39	0.41	0.39

Finally, the retrospective assessment of the contribution of nuclear energy to economic development in the Republic of Korea with the original EMPOWER finds that the magnitude of sectoral impacts is rather different across the indicators. The total output of inorganic basic chemical products and the business services sector is most affected by the nuclear energy programme. The power sector stands out as the most dominant sector in terms of impacts on value added. Impacts of the presence of nuclear energy on the price level are greatest in the manufacturing sectors because their production is electricity intensive. Wholesale and retail trade and the business services sectors are identified to have the greatest employment effects because both are labour intensive sectors and represent high levels of labour engagement.

Due to the wide-ranging differences in the size, level of development and sectoral structure of participating countries and the diverging content of economic sectors in their IOTs, only a qualitative comparison of sectoral impacts is meaningful. Table 41 presents an overview of sectors with the five highest impacts according to the indicated impact measure under the specified impact mechanisms in the construction phase. Numbers indicate the position of the given sector among the top five industries with the highest impacts according to the specified assessment. Sectors are ordered according to the frequency of their occurrence in the reviewed sectoral impact assessments. Result stem from the IAEA EMPOWER model unless otherwise indicated.

Bearing in mind the differences in the exact delineation of economic sectors across the national IOTs and the resulting divergences of sectoral interactions, hence in calculated impacts, scores in Table 41 seem to be rather realistic. Construction, a sector with a reasonably clear activity content, occurs among the top five sectors in all impact studies. The high ranking of electrical equipment in six of the nine sectoral assessments is also sensible, although the activities belonging to this sector deviate somewhat in different countries. The frequent occurrence of the machinery sector among the most affected industries is also reasonable. The diversity of sectors appearing in the group of the top five most affected industries only in one of the reviewed sectoral studies — ranging from financial intermediation to agriculture — reflects the relative importance of these sectors in the national economies and the alterations in clustering economic activities into industrial branches in the national accounts.

TABLE 41. RANKS OF SECTORS ACCORDING TO THE MAGNITUDE OF RELATIVE IMPACTS IN THE CONSTRUCTION PHASE

Sector	Indonesia	Poland	Poland	Russian Federation	Russian Federation	Tunisia	Uruguay	Viet Nam[h]	Viet Nam[i]
Construction	2	1	1	4	3	3	2	1	1
Electrical equipment		4	3	2	1			3	2
Machinery	1	5	2	3	4				
Non-metallic minerals	4					1	3	4	5
Trade			5	1	2	4			
Wood and cork	5					5	5		
Metal products		3				2	1		
Other business activities				5	5				
Chemicals								2	3
Rubber and plastics								5	4
Financial intermediation	3								
Other mining		2							
Agriculture			4						
Mining and quarrying							4		

[a] Indonesia: Total production, direct and indirect and induced impacts.
[b] Poland: PL-ATOM model, total production, equilibrium impacts.
[c] Poland: Empower.pl model, employment.
[d] Russian Federation: Total production, direct and indirect and induced impacts.
[e] Russian Federation: IEF RAS model, total production, direct and indirect and induced impacts.
[f] Tunisia: Employment, direct and indirect and induced impacts.
[g] Uruguay: Employment, direct and indirect and induced impacts.
[h] Viet Nam: Employment, all impacts.
[i] Viet Nam: Total production, all impacts.

Only a few studies present sectoral impacts of the new NPPs in their operational phase. Table 42 provides an overview of sectors with the five highest impacts according to the indicated impact measure under the specified impact mechanisms in the operational phase. Entries show rankings according to positive impacts except Tunisia (see below). Here again, numbers indicate the position of the given sector among the top five industries with the highest impacts according to the specified assessment. To some extent, impacts are correlated with the employment level of each sector in each country and with electricity consumption. Sectors are ordered according to the frequency of their occurrence in the sectoral impact assessments.

TABLE 42. RANKS OF SECTORS ACCORDING TO THE MAGNITUDE OF RELATIVE IMPACTS IN THE OPERATIONAL PHASE

Sector	Poland[a]	Russian Federation[b]	Russian Federation[c]	Tunisia[d]
Financial intermediation		1	1	
Other business activities		5	3	
Food, beverages, tobacco		4		2
Mining and quarrying			4	1
Basic metal	1			
Construction	2			
Rubber and plastic	3			
Motor vehicles	4			
Trade		2		
Machinery			5	
Agriculture				3
Textiles, leather				4
Wood products				5
Public administration			2	
Real estate activities		3		

[a] Poland: PL-ATOM model, total production, equilibrium impacts, first reactor.
[b] Russian Federation: EMPOWER, total production, direct and indirect and induced impacts.
[c] Russian Federation: IEF RAS model, total production, direct and indirect and induced impacts.
[d] Tunisia: Employment, direct and indirect and induced impacts.

As mentioned above, due to the special features of the power sector in Tunisia, the operation of the NPP decreases disposable income by 0.4% in a given year if impacts of reduced gas imports are distributed proportionally between imports and domestic gas production according to the situation before nuclear electricity commences in the standard EMPOWER framing. Lower disposable income reduces private consumption and total production, leading to a 0.2% decline in total employment. Therefore, the ranking in Table 42 shows the most affected sectors according to the extent of their losses, i.e. the sector ranked first is assessed to suffer the largest loss in employment in 2030.

The picture emerging in Table 42 is more diverse than the one presented for the construction phase. More sectors rank among the top five most affected industries in these four assessments than in the nine studies evaluating sectoral impacts of NPP constructions. Only four sectors appear twice among the industries with the highest impacts, two of them in the two models applied by the Russian Federation team. In these models, financial intermediation and other business activities seem to play particularly important roles in the operation of the newly built reactors. The reason for the first place of financial intermediation according to both models applied by the Russian Federation team is that the assumption concerning interest payments in the investment phase are related to the operational phase is implemented consistently in the calculation procedure of both models. The number and diversity of other most affected sectors listed in Table 42 reflects the substantial differences in the size and characteristics (resource endowments, technological profiles, export–import situations) of these national economies.

Comparing sectoral impacts across the national studies prepared in this CRP provides noteworthy insights. Lists and rankings of the five most affected sectors in the construction phase show that these results are plausible on the one hand, and consistent across models on the other. Yet a caveat is in order: the samples included in these comparisons, especially in the case of operational impacts, are too small to make sweeping proclamations. One solid conclusion stands out nonetheless: sectoral impacts of nuclear power programmes largely depend on features of the national economies in which the first or additional power plants will be built and operated.

4.6. MODELLING ECONOMIC IMPACTS: A SYNTHESIS

4.6.1. EMPOWER

All national research teams participating in this CRP find that EMPOWER is a useful and appropriate tool to assess macroeconomic and sectoral impacts of building and operating an NPP. Some teams note that the model can also be used for analysing impacts of other types of power plant projects for comparing various options. The flexibility and applicability of EMPOWER is particularly valuable for developing countries where the availability of and experience in using input–output analysis and other quantitative economic tools (e.g. CGE models) is limited.

All research teams confirm that EMPOWER made available by the IAEA for the present CRP is running well. The aggregation tool in the EMPOWER framework is helpful to organize the IOT in the correct order required by modules and submodules in the model. It functions accurately without any problem but totals in the row total intermediate inputs need to be checked. The RAS method is user friendly and easy to understand.

EMPOWER turns out to be sufficiently flexible to allow users to specify alternative versions for comparing results under different assumptions. Examples include the rearrangement to account for effects of reduced gas imports between the domestic and import segments of intermediate demand (Tunisia) or the historical versus the extrapolated version of the IOT to explore issues of special national interests (Uruguay). The case study on the Republic of Korea is a good example to demonstrate how to use different specifications of EMPOWER for analysing the historical contribution of nuclear energy to the evolution of the national economy. Versions of EMPOWER in this study are also proven to be useful for appraising changes in past economic development caused by structural changes in the power sector.

Exercises to compare results of EMPOWER and other IOMs such as the IEF RAS model in the Russian Federation study and the KPMG model in the Uruguayan analysis also reveal interesting lessons. These comparisons improve the analysts' understanding of how different formulations of model equations, alternative assumptions about key variables and their relationships, and deviating specifications of key parameters affect results.

Allowing for conceptual divergences between different types of modelling approaches, e.g. input–output versus CGE models, results obtained from models of different genres can also be compared. Such model comparisons provide valuable insights as well. The case in point is the

Polish study performing economic impact assessments of NPP construction and operation by using a CGE model in addition to a modified version of EMPOWER.

4.6.2. Challenges and limitations

All research teams find that EMPOWER delivers plausible results for both the construction and the operational phase of a nuclear power programme. However, the old proverb of modellers that assumptions drive results remains valid. Various assumptions are required to produce meaningful results. These assumptions might affect the accuracy of the results and might be a hindrance for many countries in which comprehensive and reliable statistical data are not available.

Notwithstanding the merits of EMPOWER, research teams note different kinds of constraints in using the model.

Several factors might influence results that are not possible to address because available data do not allow proper representation of all characteristics of the economy. The main limitations are as follows:

— Future economic structure: updating the IOT for the hypothetical construction period of the NPP in the future is based on averaged time series of IOTs. This implies the assumption that all economic sectors grow uniformly and ignores all other factors that might change the production sectors. The validation and verification of the updated IOT is particularly difficult;
— Cost structures of NPP construction: available total construction costs estimates usually do not include a breakdown of costs into specific construction materials and inputs, let alone according to sectors of the economy. Therefore, total construction costs need to be divided according to specific sectors in the IOT for each year of the construction period. This problem might alleviate once more precise data about reactor types and details of their investment costs become accessible;
— Static analysis: macroeconomic impacts of the NPP construction and operation are assessed without considering changes in other economic circumstances such as trade agreements, taxation and energy prices that might affect the results. Inclusion of other economic variables in EMPOWER requires additional data sets and parameter estimations. However, unavailability of the necessary data might constrain these efforts.

These limitations can be overcome by extending data collection, improving data availability and running sensitivity analysis for key parameters. For example, a detailed cost structure of the NPP construction becomes accessible once the reactor type and the vendor for a specific project are selected. A unique feature of EMPOWER is that it allows users to input new data and rerun the model without modifying the model system itself.

Projecting economic growth is much more complicated in a small developing country than in large developed nations. Greater projection uncertainty may lead to erroneous results when applying them in analytical tools. The evolution of small economies is less predictable because their economic structure represented by the IOTs is prone to major changes. Alterations in the sectoral structure of the economy or technological change in some sectors might occur in a short time frame but the corresponding new technical coefficients cannot be projected by the RAS method.

Data availability and quality pose problems in many developing countries. The most important issue is certainly the availability of IOTs in the required format, i.e. separate domestic and import tables. This is the reason why several teams take IOTs from international sources such as the OECD or the World Input–Output Database. Many other energy and economic data are also required as input for the model.

Search for and preparation and processing of all necessary data requires many hours of research, including inspecting national accounts, publications of national and international organizations such as the OECD and other sources. Data are often unavailable for estimating key parameters such as the marginal propensity to consume, the wage reaction to the unemployment rate and the export price elasticity. EMPOWER manual proposes approximate values for guidance but they might lie far from the proper values for the modelled economies. A possible feedback from this exercise in several participating Member States could be to formulate recommendations to statistical agencies on what data they may wish to collect and publish in the future, so that analyses like those presented in this publication can become more dependable and informative.

The absence of a specific NPP project is a severe restriction for assessing economic impacts for several study teams. Although information is available in the literature about many different technologies, locations, plant capacities and other characteristics of nuclear reactors, they are only inexact substitutes for real data. Lack of information about the temporal distribution of investment expenditures during the construction period is another restriction.

4.6.3. Model results

According to the assessments provided by EMPOWER, the construction of an NPP has positive impacts on the national economy. All aggregated indicators (GDP, disposable income, production output value, exports, imports, private consumption and employment) increase, except net taxes for the government that show some decline during the construction period. The impacts depend on the yearly investment outlays for construction activities in countries where disbursements vary over the years. The magnitude of impacts also mirrors the contribution of domestic industries in a given year.

As the scope of impact calculations is gradually broadened from assessing only direct and indirect impacts of NPP constructions (in submodule A) to include more impact and feedback mechanisms such as induced impacts resulting from increasing personal incomes due to employment creation by the construction work and the ensuing higher household expenditures (in submodule AB) and further to consider additional adjustments in response to changes in the labour market (in submodule ABC), all the way to incorporate impacts of ex ante financing of the related investment costs (in submodule ABCD), results always include impacts calculated in the previous steps. Accordingly, the assessed impacts are increasing as the scope is extended from direct and indirect to labour market impacts, i.e. moving from submodule A to ABC. Impacts of construction when feedback from financing is considered vary depending on the assumed financing source and the way it is included in the model.

This pattern can also be observed when comparing results for particular impact indicators across the extending scope of impact mechanisms. For most indicators, the calculated impacts become higher as the scope of the assessment widens to include labour market effects (i.e. up to submodule ABC). The only exception is disposable income that declines in some cases when effects of financing the nuclear plant investment running through the national economy are also included in the scope of the macroeconomic impact analysis (submodule ABCD) due to the funds diverted to cover the government's share of the construction costs. This is likely to happen when the share of governmental financing is rather high, whereas domestic contribution is rather low.

Comparing impacts of the NPP construction across key macroeconomic indicators of interest provides plausible results. In countries where domestic contributions are low and large shares of the plant components are imported, impacts on imports are relatively large. Considerable relative impacts are measured for total output (production) and disposable income as well.

The overall conclusion is that economic impacts of building and operating an NPP on national economies of participating countries are considerable. Bearing in mind other differences, in countries where the assumed construction period is short (six to eight years, like in Croatia, South Africa, Tunisia and Uruguay), annual increments of total output value, GDP, disposable income and employment tend to be higher than in countries with long construction times (e.g. 13 years in Malaysia and Poland).

The positive contribution of NPP operation to GDP is in some cases higher than that of its construction, especially in countries where the new plants increases power output drastically (e.g. Croatia with 35% or Uruguay with 28% increase in total electricity output when the new nuclear plant starts its operation). In most national models, the new NPP is expected to generate additional electricity (rather than replacing the output of retired plants) which in turn generates additional GDP. In several countries, this is related to the benefit of nuclear energy that produces electricity cheaper than gas based or other technologies, so it decreases the average electricity price. This can give a boost to energy intensive sectors leading to new investments in the economy.

Altogether, it can be concluded that the results obtained in this study with EMPOWER are plausible and comparable to those of other studies that measure economic impacts of NPPs during the construction and operational periods. Two factors may largely explain the divergences in outcomes: differences in the level of economic development across countries and differences in the capacity of the assumed NPPs to supply electricity relative to the total power output in the country before the investment.

Thanks to the credible macroeconomic impacts estimated by EMPOWER, decision makers in governments and governmental agencies are provided with a quantitative base for understanding the macroeconomic effects of nuclear energy programmes on key economic aggregates such as GDP, disposable income, total economic output and employment. It is explicitly noted by some study teams that the analyses conducted with EMPOWER provide useful information for policy decisions.

4.6.4. Possible extensions

Based on their extensive experience in working with EMPOWER, national teams propose various possibilities for improving and extending the model. Yet the feasibility and practicality of these propositions should be evaluated by developers of the model.

One proposed extension of EMPOWER is to expand the economic impact assessments by adding tools for calculating possible welfare improvements as a result of introducing nuclear energy. Another proposition is tools to estimate the effect of nuclear power programmes on the exchange rate of the national currency that is assumed to be negative during the construction period because many elements of the power plant are imported but positive in the operational phase because nuclear electricity may reduce the need for importing other fuels for the power sector.

Another idea is to include the macroeconomic effects of distributing additional taxes and profits on the final demand. Accounting for overall efficiency improvements in the national economy over the long term would make the representation of the future state of the economy in which the NPP will be built more realistic.

Yet another proposition is based on the observation that the introduction of nuclear energy has positive externalities such as reduced greenhouse gas emissions and negative externalities related to radioactive waste. Impacts of such externalities could also be incorporated in future versions of EMPOWER.

Although the historical analysis of an entire national nuclear energy programme conducted by the Republic of Korea team is rather different from the ex ante analyses of building and operating new — in several countries the first — NPPs undertaken by all the other national teams, some of the lessons might imply useable ideas for improving EMPOWER. Specifically, it is suggested that it is more reasonable to calculate electricity price changes due to power sector structural change outside the IOM than within the model. Another idea is to change the calculation of net disposable income after paying taxes and incorporating price feedback between the electricity sector and other economic sectors.

Methods to calculate GDP also differ: in the model formulated by the Republic of Korea team, GDP is calculated by summing value added of each sector in the national economy whereas GDP is computed on the basis of final demand in the original EMPOWER. This methodological difference should be further investigated because GDP is one of the major macroeconomic indicators of the status of a national economy. It might be worthwhile to incorporate both ways of calculating GDP in future versions of EMPOWER to better understand differences in the model's results.

The operational module is considered differently than the construction module because otherwise double counting may arise. This idea is incorporated in the present version of EMPOWER in such a way that the electricity sector is treated as an exogenous sector.

The application of two different types of models to assess macroeconomic and sectoral impacts of a national nuclear power programme also reveals interesting ideas. The input–output based EMPOWER is simpler and contains a narrower range of impact mechanisms than a full-blown CGE model. For example, the crowding out effect is not included in EMPOWER. Such differences can explain dissimilarities in the magnitude of economic effects of the NPP construction calculated by the two types of models. Although EMPOWER is a simpler tool that is easier to control and verify, it can be successfully used to validate results of more complex tools like CGE models. This requires the exclusion of some mechanisms from the more complex models in order to make them analogous with EMPOWER. Comparing results of such modified models could help identify impact mechanisms in the complex models that have disproportionately larger effects on model outcomes than the equivalent mechanisms in EMPOWER. Such comparisons could also reveal relationships in other modelling frameworks that might be considered to include in future versions of EMPOWER.

The overall conclusion is that EMPOWER provides plausible results and it is a valuable instrument for assessing macroeconomic impacts of NPP projects. However, some of these ideas might be useful for improving EMPOWER even further.

APPENDIX

THE OECD HARMONIZED NATIONAL INPUT–OUTPUT TABLES

Table 43 presents the list of industries included in the OECD harmonized national input–output tables (Ref. [34]).

TABLE 43. LIST OF INDUSTRIES IN THE OECD HARMONIZED NATIONAL INPUT–OUTPUT TABLES

1	Agriculture, forestry and fishing
2	Mining and extraction of energy producing products
3	Mining and quarrying of non-energy producing products
4	Mining support service activities
5	Food products, beverages and tobacco
6	Textiles, wearing apparel, leather and related products
7	Wood and of products of wood and cork (except furniture)
8	Paper products and printing
9	Coke and refined petroleum products
10	Chemicals and pharmaceutical products
11	Rubber and plastics products
12	Other non-metallic mineral products
13	Manufacture of basic metals
14	Fabricated metal products, except machinery and equipment
15	Computer, electronic and optical products
16	Electrical equipment
17	Machinery and equipment not elsewhere classified
18	Motor vehicles, trailers and semi-trailers
19	Other transport equipment
20	Other manufacturing; repair and installation of machinery and equipment
21	Electricity, gas, water supply, sewerage, waste and remediation services
22	Construction
23	Wholesale and retail trade; repair of motor vehicles
24	Transportation and storage
25	Accommodation and food services
26	Publishing, audiovisual and broadcasting activities
27	Telecommunications
28	IT and other information services
29	Financial and insurance activities
30	Real estate activities
31	Other business sector services
32	Public administration and defence; compulsory social security
33	Education
34	Human health and social work
35	Arts, entertainment, recreation and other service activities
36	Private households with employed persons

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LIST OF ABBREVIATIONS

ANP	advanced nuclear power
AP	advanced passive pressurized water reactor
CGE	computable general equilibrium
CRP	coordinated research project
EMPOWER	Extended Input–Output Model for Sustainable Power Generation
GDP	gross domestic product
IDR	Rupiah
IEA	International Energy Agency
IEF RAS	Institute of Economic Forecasting of the Russian Academy of Sciences
IO-E	econometric input–output model
IOM	input–output model
IOT	input–output table
KAERI	Korea Atomic Energy Research Institute
KPMG	Klynveld Peat Marwick Goerdeler
KRW	Won
LNG	liquefied natural gas
MYR	Malaysian Ringgit
NEA	Nuclear Energy Agency
NPP	nuclear power plant
OECD	Organisation for Economic Co-operation and Development
PLN	Zloty
PWR	pressurized water reactor
TND	Tunisian Dinar

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1st RCM: Vienna, Austria, 1–4 December 2014

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