Macroeconomic challenges of energy transitions: the case of Algeria

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Hadjer Haned[a], Saloua Chaouche[b], Bruno Michoud[c], Frédéric Ghersi[d]

[a] LEQAD, ENSSEA, Pôle universitaire, KOLEA, ALGERIE

[b] LEQAD, ENSSEA, Pôle universitaire, KOLEA, ALGERIE

[c] SMASH, CIRED, 45 bis avenue de la Belle Gabrielle, 94736 Nogent-sur-Marne CEDEX, France.

[d] CNRS, CIRED, 45 bis avenue de la Belle Gabrielle, 94736 Nogent-sur-Marne CEDEX, France.

Abstract

This paper explores the macro and socioeconomic consequences of deep decarburization pathways for the Algerian economy in the medium term. It is possible through a hybrid modeling connecting KLEM-DZA, a dynamic and recursive bisectoral macroeconomic model (energy and non-energy) model considering the specificities of the Algerian economy, for the technology-rich BU EnerNEO model of the Algerian energy sector. The economy suffers negative consequences in terms of GDP and unemployment with the pro-environment-scenarios. The trade shock strategy needs to be better explained, as it has positive impacts on the economy. The authors can also try to measure the positive environmental impacts and compare them with the negative economic impacts on the Algerian economy.

Keywords: Hybrid models, Algeria, Energy policies.

Introduction

Within the framework of the Paris Agreement, long-term climate strategies were introduced as a tool used by Parties to set ambitious emission reduction pathways, while considering country-specific development objectives (Waisman et al., 2019). With the next round of submissions of Nationally Determined Contributions (NDCs) approaching and the global stocktake (GST) process's intention to periodically assess the collective progress towards achieving the purpose of the Agreement, mid-century low-carbon scenarios are key to set further climate actions (UNFCCC, n.d.). They aim to support the design of tailored policy packages and industrial strategies, while revealing necessary technological, financial and institutional enabling conditions to reach climate and socioeconomic objectives.

Whereas the energy sector is crucial to achieve temperature objectives, it also plays an important role in economic development (Stern, 2011; Bauer et al, 2017). In addition, it is of high importance for fossil fuel-exporting countries, generating significant revenues and representing a large share of their exports.

Consequently, the cost associated with the transformation of energy systems and the underlying socioeconomic consequences are at the core of preoccupations for policy-makers around the globe setting climate-related targets at national and sectoral level. In order to design and implement suitable climate policies, it is thus key to understand the macroeconomic impacts of decarbonisation processes and the interactions of this disruptive change with socioeconomic and development indicators.

The Algerian macroeconomic context and the country's energy sector

Algeria, the largest country and fourth biggest economy in the African continent, has based its economic model mainly on its fossil resources, creating a situation of strong dependency on hydrocarbon revenues. Yet, considering fluctuations in global energy prices together with undergoing changes in low-carbon technologies and resources driven by the climate crisis, the depletion of fossil fuels and international geopolitical tensions, it is becoming urgent for Algeria to adopt a new and sustainable development model, able to meet the population's growing energy demand and reduce its dependency on the oil and gas rent. Indeed, rent-seeking activities hinder the diversification of the Algerian economy, limiting it to fossil fuel extraction and production, thus complicating the country's low-carbon transition.

During the 2000s, Algeria's rich fossil fuel endowment combined with the rise in the prices of hydrocarbons on international markets provided the government with significant financial resources to implement ambitious economic and social policies. Oil and gas represented on average 93% of the country's exports, xx% of tax revenues and xx% of GDP over the period 2004-2019 (add source), allowing to reduce the risks linked with a balance of payments crisis despite price fluctuation. However, the reduction in hydrocarbon commercialisation observed in the last decade combined with the decline in prices since late 2014 have led to a significant decrease in the energy's share of GDP in Algeria.

Recently, the double macroeconomic shock associated with the sanitary crisis and the conflict in Ukraine severely affected the Algerian economy and the country's population, exacerbating the vulnerabilities of its economic model. The measures undertaken by the government helped mitigate some negative social and economic consequences. After a 5.1%

contraction in 2020, economic growth reached 3.5% in 2021 (World Bank data), mainly driven by a rise in international demand for fossil fuels, together with the increase in global energy prices and national production of oil and gas. While the recovery is on its way yet still not catching up pre-pandemic growth levels, the global and domestic macroeconomic contexts allow to partly offset public investment spending and reduced the public budget deficit from 1,270 billion Dinars to 842, reaching 3.8% of GDP in 2021 (add source). In 2022 and 2023, the Algerian economy should generate current account surpluses and accumulate foreign exchange reserves equivalent to one year's imports of goods and services[1].

Despite important oil reserves, oil production (crude oil and condensate) has been gradually declining since 2010, reaching 64 million tons of oil equivalent (Mtoe) in 2019 compared to 85 Mtoe in 2005[2], as a result of mature wells and production cuts imposed by the OPEC+ agreements. In 2019, oil export volumes accounted for about 1% of total world oil exports. The country's export volumes have dropped significantly over the past decade (by about 40% since 2010), making Algeria an important, but relatively small oil exporter (add source).

Efforts have been intensified to search for and exploit hydrocarbons, while improving their production. The oil processing rate is expected to reach 50% in 20xx against 32% currently, thanks to the development of the petrochemical, refining and conversion industries (add source). Regarding production, the objective of the energy authorities is to increase primary production by 2% per year, with the aim of achieving 205 Mtoe by 2025[3]. By the end of 2022, the production reached 191 Mtoe, compared to 186 Mtoe in 2021 (add source).

Moreover, 1.1 million tons of liquefied petroleum gas (LPG) were marketed in 2021, an increase of 50% aimed at meeting the growing global demand for this energy resource, offsetting the reduction of Russian imports for certain countries and compensating the decline in demand for other types of fuels (add source).

At a national level, the energy sector remains based on fossil fuels (see Figure 1 below), whereas energy efficiency is still weak[4] and the growing energy consumption (driven by economic growth) stays very little influenced by public policies. Algeria has witnessed an increase in domestic demand for gas, with an average annual growth rate of 6% over the last ten years (add source). This rapid growth, coupled with declining production, has largely contributed to the deterioration of Algeria's gas balance, with domestic consumption now absorbing nearly 53% of national production, thus limiting the export capacity (add source).

Despite the importance of fossil fuels in Algeria’s energy mix and GDP, the government announced an energy transition plan as part of its 2020 Five Year Development Plan, representing a significant shift for the country (add source). The plan encompasses three structural components: (i) the creation of a new ministry, the Ministry of Energy Transition and Renewable Energies (METRE), aimed at managing and carrying out the transition plan; (ii) a regulatory reform to promote renewable deployment; (iii) the creation of the National Renewable Energy Company (SHAEMS, under the authority of METRE), serving as a one-stop

[1] *Évolution économique et monétaire en Algérie*, annual report 2021, Banque D’Algérie, June 2022.

[2] Energy balance, the Algerian Ministry of Energy and Mines.

[3] Statement of the Prime Minister to the National People's Congress, October 3, 2022.

[4] The energy use (kg of oil equivalent) per $1,000 GDP (constant 2017 PPP) in 2014 in Algeria reached 115.3, while being at 85.5 in Tunisia and 73.2 in Morocco (World Bank data).

shop for all stakeholders in the renewable energy ecosystem (investors, EPC[5] contractors, service providers, etc.). The plan has the main objectives to improve energy efficiency by 10% per year in transportation, housing and industry, to reach 30% of power generated by renewable energy resources by 2030, and to generate 25 gigawatt-hours of power from green and blue hydrogen by 2050.

A hybrid energy-economy prospective to support decision-making

The significant contribution of the energy sector in the Algerian economy together with the inevitable depletion of its fossil resources call for the use of an energy-economy framework to assess how future changes in fossil fuel production, domestic consumption and trade may affect the country's economic development and decarbonisation pathways. This hybrid structure, rather than producing a deterministic projection of the Algerian economy, should allow to bring into consistency diverse fields of expertise, with the objective of providing comprehensive support for public decision-making for both the evolution of energy systems, from primary energy to final consumption, and socioeconomic development paths.

BU and TD models

The combination of technology-rich, energy system models (so-called bottom-up or BU models) with macroeconomic models (so-called top-down or TD models) has been widely applied to the analysis of climate strategies and their socioeconomic implications, in particular for the cost of low-carbon transformations. Each modelling framework has strengths and weaknesses that are widely discussed in the scientific literature.

On the one side, engineers' BU models contain detailed representation of energy-related technologies, allowing a deep assessment of energy transformation pathways, the underlying investment and associated fuel costs. Yet, being partial equilibrium models, they neither reflect the consequences of changes in energy systems on other sectors of the economy, nor consider socioeconomic implications (e.g. unemployment rates, purchasing power evolution), both highly relevant for policymaking. Conversely, economists' TD models describe economic mechanisms and relationships using a general equilibrium framework encompassing the entire economy. Nevertheless, they neither provide technical details enabling to guide the implementation of low carbon strategies, especially at sectoral level, nor capture the reality of rigidities and flexibilities of technical systems in transition. Since they offer less granularity compared to BU structures, TD models are based on behavioural representations of producers and consumers, with supply and demand represented by production and utility functions.

Because of the key role of energy systems in an economy and their direct and indirect connection with other sectors, the integration of these two modelling frameworks (BU and TD) provides comprehensive information for policy- and decision-making (Hourcade et al., 2006). Indeed, low-carbon transitions will generate significant changes and require consequential investment, not only in the energy sector but also in other economic activities. Accordingly, the use of "hybrid models", referring to modelling structures that link TD and BU frameworks, are of high importance in a context of transition towards low-carbon economies. A hybrid structure is particularly relevant for Algeria, considering the importance and size of the country's energy sector.

[5] Engineering, procurement, construction

While different linking approaches exist, we adopt here Wene's definition of “soft linking” as information exchange supported by human intervention, and “hard-linking" as a computer-controlled, automated exchange (Wene, 1996).

Main objective of the paper

In this paper, the macroeconomic TD KLEM-DZA model is linked to the BU EnerNEO model of the Algerian energy sector through a soft-linking strategy. In addition, a hybrid energy-economy dataset is built, in order to improve the consistency of the BU and TD model linkage through data calibration (Hourcade et al., 2006). This hybrid approach goes therefore beyond the linkage of two different modelling frameworks, by further developing an original hybrid database combining national accounting and energy balance data.

By using this consistent, hybrid modelling structure, the overarching objective of this paper is to explore the macro- and socio-economic consequences of deep decarbonisation pathways for the Algerian economy in the medium run.

Our paper is organised as follows: After the introduction, in section 2, we review the scientific literature on Algeria’s macroeconomic situation and the country’s energy sector. We then introduce our methodology in section 3, encompassing the development of a hybrid database, our TD and BU models, as well as the linking strategy. In section 4, we present the different scenarios and discuss the results, before concluding in section 5.

Literature review

Considering its natural endowment, economic size and geographical position, Algeria has been at the centre of the attention of various studies from the research community, including modelling teams using computable general equilibrium (CGE) models. In addition, while being the fourth biggest economy of the African continent[6], Algeria is confronted to various socioeconomic challenges, adding concerns to its low-carbon transition.

The Algerian economy is highly dependent on its fossil resources (Bouraiou et al., 2020). Indeed, since 1970s, the country based its development model on its hydrocarbon reserves (Abado et al., 2019), considering their optimal exploitation as a vector of economic development and a guarantee for energy security.

However, this economic model is currently at risk due to several reasons. First, the climate crisis pushes oil and gas importing countries to change the structure of their energy demand, looking for cleaner energy resources, and adapt their technologies to meet mitigation targets. Second, Algeria is witnessing the depletion of its fossil fuel reserves (Sahnoune et al., 2016; Abado et al., 2019). Third, domestic energy demand has been rapidly growing within the country (Abado et al., 2019, Zahraoui et al., 2021), driven by economic growth (Amri, 2017; Bélaïd et al., 2017; Khraief et al., 2018), while domestic energy demand forecasts seem to confirm this trend for the coming years (Ghedamsi et al., 2016; Semahi et al., 2020). Yet, as the current energy mix is mainly composed of carbon intensive resources (99%, see Figure 1), the economic growth-energy consumption relationship has led Algeria to become the third largest CO_2 emitter in Africa, notwithstanding its high vulnerability to climate change (Bouznit et al., 2020). Finally, even though Algeria’s past macroeconomic performances were supported by its oil and gas rent, oil price drops cause a resource curse phenomenon due to

[6] World Bank data, retrieved December 20, 2022

the country’s dependency on international fossil fuel markets (Benramdane, 2017; Omolade et al., 2019; Matallah, 2022). Indeed, while an increase in oil exports is favourable to Algeria’s macroeconomic indicators, international energy factors (e.g. demand, prices) are the major elements influencing its trade balance (Bala et al., 2022), rather than internal aspects such as public spending (Fatih, 2021).

Figure 1: Primary energy consumption, Algeria, 2021

Energy	**Solar**	**Wind**	**Hydro**	**Natural gas**	**Coal**	**Oil**
TWh	1.73	0.03	0.02	458.15	4.80	219.84
Percentage	0.254 %	0.004 %	0.004 %	66.924 %	0.702 %	32.113 %

Source: BP Statistical Review of World Energy 2022

The 2007-2008 financial crisis, the 2014 global energy price crisis, the Covid-19 pandemic and the current economic slowdown in Europe associated with the conflict in Ukraine are all events that threaten Algeria’s economic development and impact its trade balance as international oil prices fluctuate, while revealing structural concerns that are otherwise offset by fossil fuel export revenues (Dagdag, 2020; Zahraoui et al., 2021; Bala et al., 2022).

Rent-seeking activities seem to hamper the prospects for development and diversification of the economy in Algeria (Matallah, 2022), limiting it to a specialization in fossil fuel production. Nevertheless, a new development model is needed, able to meet energy needs, support inclusive growth and decrease climate-related risks (Abado et al., 2019; Dagdag, 2020; Zahraoui et al., 2021).

Numerous studies revealed the abundance, high potential and economic viability of renewable resources within the country, including solar, wind, biomass and geothermal energies (Bouraiou et al., 2020; Bouznit et al., 2020; Himri et al., 2020; Díaz-Cuevas et al., 2021; Zahraoui et al., 2021). In order to promote their deployment as well as energy efficiency, the Algerian government reinforced its legislation and enacted new regulations, encompassing financial support, tax incentives, feed-in-tariffs and auctions (Sahnoune et al., 2016; Bouznit et al., 2020; Zahraoui et al., 2021). As a matter of fact, Algeria has important mitigation potential, especially in the energy, building, transportation and waste management sectors, as well as in gas flaring (Sahnoune et al., 2016).

Due to the importance of the energy sector for the Algerian economy, several energy scenarios were conducted targeting the country’s energy systems, with a particular focus on sustainability issues (e.g. the scarcity of water resources), energy policies aimed at increasing the share of renewables in the energy mix, the investment required to develop the use of low-carbon resources and mitigation opportunities (Stambouli et al, 2012; Hamiche et al., 2015; Sahnoune et al., 2016; Saiah et al., 2017; Abada et al., 2018; Zahraoui et al., 2021).

Moreover, some studies analysed the interactions between ecological footprint and economic growth. Bouznit et al. (2016) confirmed the Environmental Kuznets Curve (EKC) hypothesis in Algeria, yet highlighting that the turning point occurring at a high GDP level has still not been reached. Therefore, economic growth will keep on generating emissions in Algeria, underlying the need to implement clean energy and energy efficiency policies. While affirming a N-shaped EKC[7] in Algeria, Chaouachi et al. (2022) showed evidence that foreign direct investment (FDI) fosters the transition towards a cleaner energy mix, underlining the role of the public sector in implementing policies able to attract foreign capital providers. The positive environmental impact of FDI and the importance of policy framing in attracting them was also highlighted by Udemba et al. (2021) for Algeria.

Direct public expenditure seems to stimulate inclusiveness in Algeria by fostering access to job opportunities for the population (Adeosun et al., 2020), whereas the effects on economic growth appear to suffer from hurdles associated with weak development strategies and poor management (Bakari, 2018), and should be thus combined with public investment in education (and health) to strengthen its impact on the economy (Ramli et al., 2022). In addition, total factor productivity (TFP) appears quite low in Algeria, mainly due to a weak education system, a lack of technology and innovation, as well as poor management, and should be increased to reinforce competitiveness and improve living standards (ElObeidy, 2016). Accordingly, economic growth is predominantly associated with labour and capital, partly explaining productivity reduction in the fossil fuel sector since 2000s (Rey et al., 2019). Moreover, despite a decrease in unemployment rate from 17.7% to 11.7% between 2003 and 2018, it has remained significant among the youth (at around 60%), highlighting the inability of the labour market to integrate young professionals (Abdelkader, 2019).

A number of long-term macroeconomic studies focused on fiscal policies' effects on economic growth (Moreira et al., 2021), the impact of monetary policies (Chaouche, n.d.) and the effects of the Covid-19 pandemic (Gueddal et al., n.d.). Furthermore, Nawel et al. (2018) focused on the consequences of trade liberalization in Algeria, revealing that, with adjustments aimed at avoiding a reduction in government revenues, output and employment are not significantly affected, whereas private consumption decreases while imports and exports increase.

Mohammed (2017) used a CGE model to assess the macroeconomic consequences of limiting carbon emissions in Algeria, focusing on different levels of carbon taxes. The results reveal the effects on nominal GDP, exports, government revenues and fixed capital investment, and suggest that the lowest carbon tax should be adopted, allowing to reach a reasonable environmental target without significantly negatively impacting macroeconomic indicators. Considering the importance of fossil resources for Algeria, Semouk et al. (n.d.) concentrated on the consequences of global oil price shocks (a 10% increase and a 30% drop) on the country's economy, using a CGE model and national accounts data. The authors reaffirm the strong dependency of Algeria on international hydrocarbon markets, as a fall in oil prices generates a significant reduction in the level of production and value-added in most sectors according to their model.

The above-mentioned studies using CGE models provide important insights regarding carbon pricing policies and their macroeconomic impacts, as well as on the exposure and dependency of the Algerian economy on international fossil fuel markets. Nonetheless, Algeria also introduced non-market mechanisms and is planning to implement additional measures aimed at fostering its energy transition (add source from the Algerian government). Their socioeconomic implications should be analysed by providing more details of the energy

[7] The N-shaped is explained by the fact that energy consumption leads to economic growth, which in turn attracts FDI. Algeria having currently a carbon intensive energy mix, an increase in economic growth then generates GHG emissions (Chaouachi et al., 2022).

system in CGE modelling structure, either through its disaggregation or by adding a specific representation module (Su et al., 2022).

In addition, according to our knowledge, currently no study uses hybrid models to analyse the macroeconomic consequences of achieving specific emission reduction targets at a country-level for Algeria. Moreover, the CGE models used for the Algerian economy use input-output tables (IOT) based on Social Accounting Matrix (SAM) as the main dataset. This implies the following drawbacks: First, some differences may exist between IOT and national energy balances, leading to data inconsistency when using a hybrid structure. Second, they cannot properly represent the heterogeneity of energy prices among economic sectors and agents, and thus assume uniformity. Finally, key variables should be adjusted to reflect the specific definitions of TD and BU models.

The use of a hybrid framework combining BU and TD modelling structures to investigate the macroeconomic implications of a low-carbon transition in Algeria would have the great advantage to integrate detailed information from energy systems into economic models, while representing important feedbacks between both frameworks (Su et al., 2022). A hybrid approach can be either hard-linked, soft-linked, or fully integrated (Helgesen and Tomasgard, 2018). The first two methods are based on pre-existing TD and BU models, thus offering greater flexibility and transparency, and have witnessed a wide application to low-carbon transition analysis for different countries around the globe (Anderson et al., 2011; Fortes et al., 2013; Krook-Riekkola et al., 2017; Fujimori et al., 2019; Soummane et al., 2019; Wu et al., 2019; Su et al., 2022). Yet, some inconsistencies between the models may remain unresolved. The fully integrated method addresses the inconsistency issue, but needs to present highly detailed technologies in an economy-wide framework, which limits its application in empirical studies (Su et al., 2022).

Accordingly, in order to investigate the socioeconomic challenges Algeria may face in its decarbonisation process, this study uses a hybrid soft-linking approach that combines the economy-wide model KLEM-DZA with the BU model of the Algerian energy sector EnerNEO. Furthermore, a consistent hybrid dataset was built, reconciling the country's IOT and national energy balance, and used in the modelling framework.

Methodology

This section presents the methodology used to model the energy-economy outlooks of the Algerian economy. We developed a hybrid modelling structure that combines the strengths of the BU, technology-rich EnerNEO model of Algeria's energy system and the TD, macroeconomic KLEM-DZA model.

We first build a consistent, hybrid dataset reconciling Algeria's input-output table and the country's energy balance. Second, we develop the TD KLEM-DZA macroeconomic model, and calibrate it based on the hybrid dataset. The KLEM-DZA model is then linked to the BU Algeria-EnerNEO model using a soft-linking strategy.

A consistent hybrid dataset

Some of the KLEM's variables, namely the set of numerical values used in the model without modification, come from statistical sources, while others are extracted from the EnerNEO model following a coupling described below. Both sources may require processing to make them consistent with KLEM's framework: its level of aggregation, the specific scope of flows, its treatment of time, etc. More specifically, for the calibration year (2015), efforts to make the data used in KLEM on the one hand and EnerNEO on the other hand consistent, guaranteeing the relevance of their coupling, consist in the construction of an original hybrid input-output table reconciling Algerian statistics of national accounting, energy balance and energy prices. Yet, the aggregated nature of KLEM together with the recent extensive calibration of EnerNEO, allowed the implementation of a less time-consuming method, bypassing the procedures applied in a multi-sectoral framework.

This method is based on the aggregation of domestic expenditure/consumption and international energy trade represented by EnerNEO, which has the advantage compared to other engineering models (TIMES, LEAP) of calculating market prices considering all commercial energy consumption included in the model, into five energy flows: (1) energy imports and (2) energy exports in monetary value and volume (tons of oil equivalent); (3) energy expenditure/consumption of producers of non-energy goods and services; (4) energy expenditure/consumption of energy producers (essentially, inputs to power generation and refining); (5) energy expenditure/consumption of households (residential energy and fuels).

Regarding national accounts, the matrix provided by the DGP[8] is first reduced to a number of uses and resources corresponding to the level of disaggregation of the KLEM model, from which the aggregate value of all sectors is calculated. For energy uses and imports, the monetary flows coming from EnerNEO can then be subtracted from the aggregates previously calculated. By definition, the balance of each item aggregates trade flows as well as expenditures on non-energy goods and services.

For the resources, we force the rent of energy production to the level of the oil and gas rent estimated by the State Statistical Office (ONS[9]). The balance of resources required for the production of energy goods is then deducted from the necessary uses/resources equilibrium, and allocated to the categories not indicated (non-energy inputs, labour, capital, taxes) in proportion to their values as estimated in DGPP matrix.

Annex 1 describes in details the matrix resulting from this procedure, which is the basis of the coupling process between KLEM-DZA and EnerNEO, and proposes a visualization of the steps in its construction.

The KLEM model

The purpose of the KLEM model (for Capital, Labour, Energy and Materials) is to compute macroeconomic trajectories under constraint of exogenous energy flows and prices informed by a BU model, on both international and domestic markets (a complete description of the KLEM model is available in Annex 3). Its modelling structure is aggregated into two sectors, one sector representing energy supply and the other the rest of the economy, with the objective to focus on the analysis of overall macroeconomic impacts. Consequently, one important assumption underlying such aggregation is that further sectoral specificities in the non-energy sector are without significant influence on the simulation results.

A constrained Solow growth model

KLEM is a dynamic, recursive macroeconomic model deriving from a Solow-Swan growth model, projecting economic growth in yearly time steps. Economic growth is driven by

[8] *Direction Générale de la Fonction Publique* in French.

[9] *Office National de la Statistique* in French.

exogenous assumptions on the investment rate, labour supply and labour productivity. The vector of domestic energy and non-energy outputs at year t, Y, is a function f of the stock of capital K, of the labour force L, and of the intermediate consumption of energy and non-energy resources. The t index to f conveys that f varies with time via exogenous labour productivity gains, corresponding to the Harrod-neutral assumption on technical progress. Capital stock dynamics follow the standard accumulation rule $K_{t+1} = (1 - \delta)\, K_t + I_t$, with δ the depreciation rate, constant over the entire projected period. Investment It is the amount of non-energy output used to build up K at period t. Beyond these core specifications, the KLEM model deviates from the Solow standard model by a set of constraints that are partly imposed by its treatment of energy systems, and partly called for by its modelling of trajectories encompassing short-term horizons (Solow, 2000).

Since KLEM's structure is designed to couple with a BU energy modelling framework, full exogeneity of the energy system is a first constraint of the model (Ghersi, 2015). Accordingly, the growth trajectories traced by KLEM are built around exogenous energy volumes. The cost structure of energy supply beyond its own energy intensity, as well as the specific net taxes and trade margin on each energy sale, can also be exogenously adjusted to match any assumption on the dynamics of annualised investment, operational expenses or domestic and trade prices. These constraints on volumes, costs and prices weigh on economic growth, by reserving part of value-added to a fixed energy expense and part of primary factors endowments to the supply of some exogenous volume of energy.

Outside energy systems, a first short-term constraint, especially meaningful when modelling large energy producers like Algeria, is on capital mobility: KLEM forbids any reallocation of energy-supply capital to the non-energy sector by imposing that the capital stock of energy supply K_E does not contract faster than the depreciation rate δ. A second short-term constraint is on the potential under-utilization of labour, particularly relevant for the Algerian labour market. KLEM considers that some inertia of real wages prevents full market clearing, i.e. induces unemployment. Rather than specifying labour supply behaviour, it merely correlates the unemployment rate and the real wage in a "wage curve" following Blanchflower and Oswald (2005). It relates the dynamics of this static correlation to labour productivity ϕ by conditioning a stable unemployment rate to real wages progressing at the same pace as ϕ.

Behavioural specifications

Because all dimensions of energy trade, supply and demand (including the input intensities of energy supply) are exogenous (drawn from the EnerNEO model, see below), the behavioural specifications of KLEM are limited to non-energy trade-offs in the production of non-energy goods and to non-energy trade.

KLEM models non-energy production as a nested structure of trade-offs between inputs, which are settled via Constant Elasticity of Substitution (CES) functions. At the foot of the structure, labour and capital combine into value-added KL, which combines with energy into the aggregate input KLE, which finally combines with the non-energy good into non-energy output. Capital costs are calibrated on fixed capital consumption accounts rather than on the full gross operating surplus. KLEM models the net operating surplus as a constant mark-up rate on output costs. This is a simple way of assuming the constancy of non-optimal market characteristics.

Regarding international trade of the non-energy good, KLEM relies on price elasticities that impact, for imports M_Q, the share of foreign production in total (domestic and foreign) resource; for exports X_Q, an exogenous trend. Regarding the trade balance, our KLEM application to Algeria (hereafter KLEM-DZA) considers specificities associated with the Algerian economy (see below).

One last behavioural specification concerns KLEM's treatment of the investment decision. Because economy-wide models must accommodate the basic national accounting constraint of resources equating uses, they would be overdetermined equation systems if they enforced behavioural specifications for all resources and uses elements. The "closure rule" (Sen, 1963) is how models address this issue, with quantitative and qualitative consequences on their results (Decaluwé et al., 1987). Concerning investment and savings, the neoclassical closure of standard CGE models considers endogenous investment efforts balancing out domestic and international savings flows. Conversely, the 'Johansen closure' (after Johansen, 1960) enforces some exogenous level of investment (controlled by public policy) and endogenizes savings to let them adjust. We choose the Johansen closure for KLEM-DZA, letting domestic savings adjusting rather than investment, in order to reflect the degree of control by the government on the Algerian economy. This implies a more robust growth path, at the cost of variations in final consumption due to non-constant savings. The investment effort is specified in money terms as a share of GDP that evolves to ensure that the physical capital stock grows at the same rate as labour supply when potential growth, defined by labour supply and productivity, materializes. Labour and capital markets adjust via the wage w and the rental price of capital r. The trade balance is exogenous, following neoclassical practice.

Calibration of KLEM-DZA

We calibrate KLEM-DZA at base year 2015, using an extensive energy-economy dataset that reconciles Algeria's national accounting, energy flows and prices data as described above.

Additionally, with the aim of further reinforcing the relevance of the projected estimates, we calibrate the model dynamically to replicate GDP, unemployment and the trade balance of years 2016 to 2020 (World Bank data) by applying exogenous shocks on productivity factors, real wage demands by the labour force and the volume of international trade.

Beyond 2020, we specifically calibrate the model's exogenous trend of investment efforts (our choice of a Johansen closure, see above) to deliver a stable unemployment trajectory under baseline conditions. Macroeconomic specifications are presented in the following section.

The EnerNEO model of the Algerian energy system

The EnerNEO model (for National Energy Outlook) is a partial equilibrium simulation model focusing on the energy sector at a country level. Its simulation process uses a dynamic recursive modelling structure on annual time-steps, providing full development outcomes of energy systems to various long-term horizons. Throughout the creation of customised scenarios, the main objective of the EnerNEO model is to establish projections of the energy sector, based on historical data, in order to allow a quantitative assessment of energy and climate policies over the long-term.

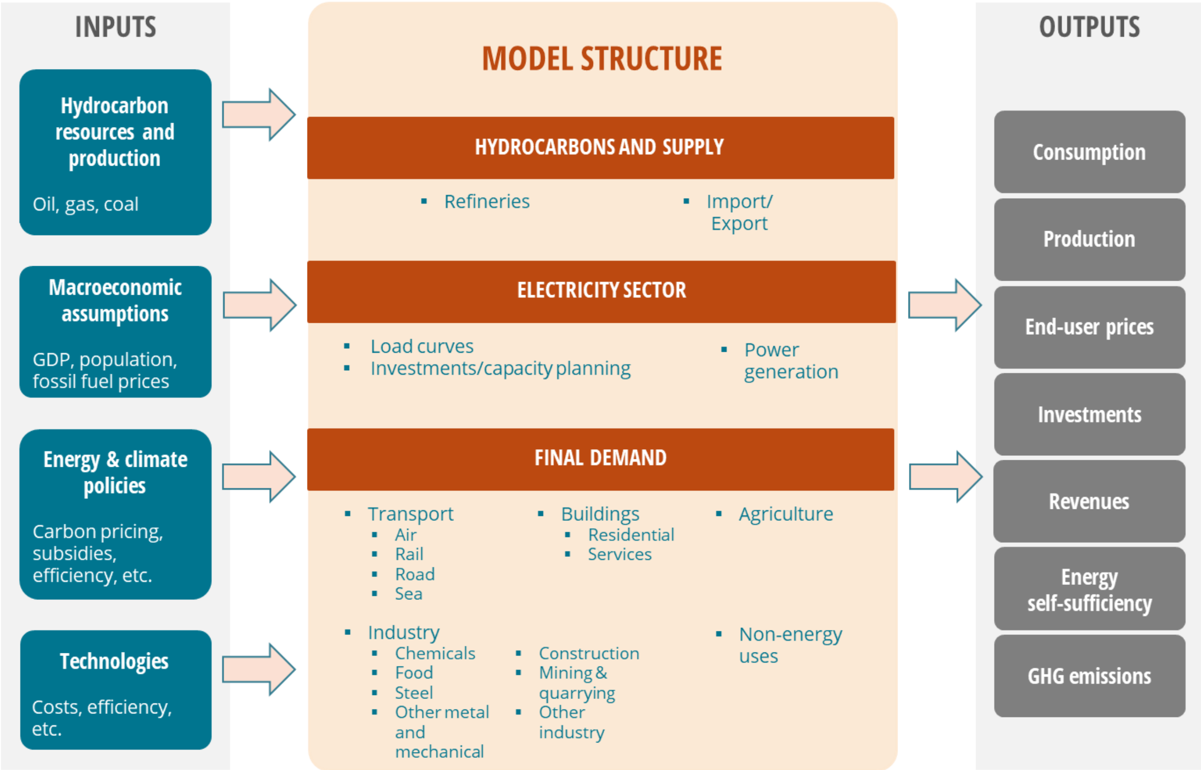
The model provides a comprehensive description of final energy demand by fuel and sector (disaggregation into 15 energy demand sectors, see Figure 2), as well as energy supply, with a particularly high level of details for the power sector, integrating final energy demand, the diffusion of new and renewable technologies, and feedback effects on other energy resources. EnerNEO considers climate policies (e.g. energy subsidies) in end-user energy prices, as well as the impacts of energy prices, tax policies and abatement strategies on energy systems. Moreover, EnerNEO covers a wide range of greenhouse gas (GHG) emissions, including CO_2 emissions from fossil fuel combustion of final energy demand and energy supply sectors, but also CO_2 emissions from industrial processes, as well as several other non-CO_2 emission sources emanating from different sectors. Accordingly, EnerNEO allows to produce projections of energy demand, energy supply and GHG emissions, and to analyse the evolution of energy systems according to different socio-economic assumptions and according to different sets of energy efficiency, renewable energy development and GHG emission reduction policies.

In terms of methodology, EnerNEO is an econometric model providing long-term projections of energy demand, production and transformation, as well as GHG emissions, with an annual temporal resolution. On the demand side, the model adopts a "top-down" approach, first calculating the total sectoral demand level, before allocating this demand by energy vector in a second step, using a distribution methodology. Then, the model calculates the final energy consumption for each sector and each energy source, and deduces the GHG emissions of the different final demand sectors.

On the energy supply side, the model distinguishes power generation from other energy sectors. This is represented through a relatively detailed, bottom-up approach, incorporating an endogenous calculation of investments in generation capacity by technology, as well as the electricity dispatch, which impacts the price of electricity perceived in the final demand sectors. As an output, the module provides electricity capacities, electricity production, as well as operating hours and discounted costs by technology, even though the latter depend directly on the assumptions made (notably fuel prices, carbon pricing). The other energy supply sectors (primary production and transformations of oil, natural gas, coal and bioenergy) are modelled in a specific module, with significantly less details, partly based on exogenous primary production assumptions. The technologies included in the model are diffused under constraints of sectoral demand and inter-technology competition based on relative costs and merit orders.

Thanks to all these elements (final energy demand, power sector, and energy supply), EnerNEO is able to provide a complete energy balance for each simulated year. Furthermore, the results in terms of GHG emissions allow us to situate the different scenarios in relation to the Nationally Determined Contribution (NDC) or to the country's climate policies, and to analyse their level of climate ambition. Thus, the use of EnerNEO allows to contribute to the elaboration and updating of the Algerian NDC for the energy sector.

Figure 2: Visualisation of the EnerNEO model



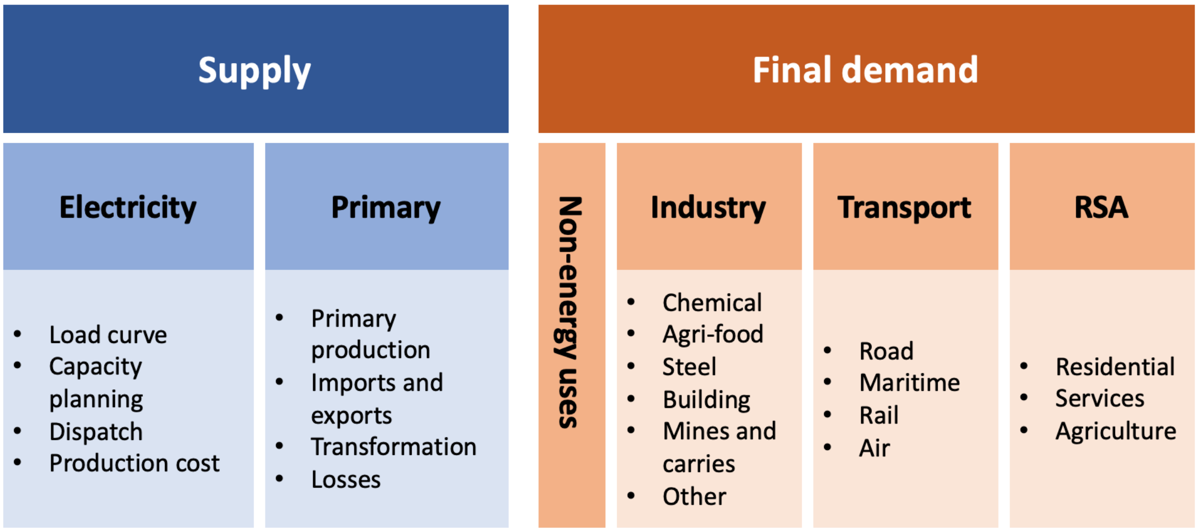
Source: ENERDATA

The temporal scope of the model covers the horizon 2000-2050, at annual time-steps. In the power sector, the model takes into account intra-day considerations in a simplified manner, using two typical days corresponding to the summer and winter seasons, each divided into twelve time-steps of two hours.

The geographical scope of the model is the national energy grid, in this case Algeria. Assumptions of fossil fuel prices on the international market are considered. In the absence of a user assumption, electricity trade over the simulation period is assumed to be similar to historical exchanges. On the other hand, fossil fuel trade evolves according to national supply and demand, with the underlying hypothesis that the international market adapts perfectly to the country's export balance.

The sectoral perimeter covers all sectors of the energy market at a level of aggregation similar to that of the International Energy Agency's balance sheets (see Figure 3).

Figure 3: Sectoral granularity in EnerNEO



Source: ENERDATA

EnerNEO's scope covers all energy resources used and transformed in Algeria. The final energy sources considered are LPG, gasoline, diesel, kerosene, other petroleum products, natural gas, coal, electricity and bioenergy. In addition, the modelling of the final energy demand distinguishes between specific uses of electricity (including air conditioning) and thermal uses. The model encompasses twelve power generation technologies: natural gas (steam turbine, combustion turbine, combined cycle), oil (steam turbine), coal (conventional, supercritical), nuclear, hydro, wind, solar photovoltaic, concentrated solar, bioenergy. EnerNEO also considers electricity storage using electrolytic batteries.

The GHG emissions perimeter includes the six greenhouse gases of the Kyoto Protocol (CO_2, CH_4, N_2O, SF_6, HFCs and PFCs). It covers all GHG emissions from the energy sector, as well as from industrial processes, and methane emissions from the waste management sector. The model does not cover non-energy emissions from agriculture, land use and forests.

Calibration of EnerNEO

For the purpose of our hybrid modelling framework, the Algeria-EnerNEO model reproduces the energy balance of the Algerian Ministry of Energy and Mines from the year 2000 to the year 2017.

KLEM-DZA and BU Algeria-EnerNEO linkage

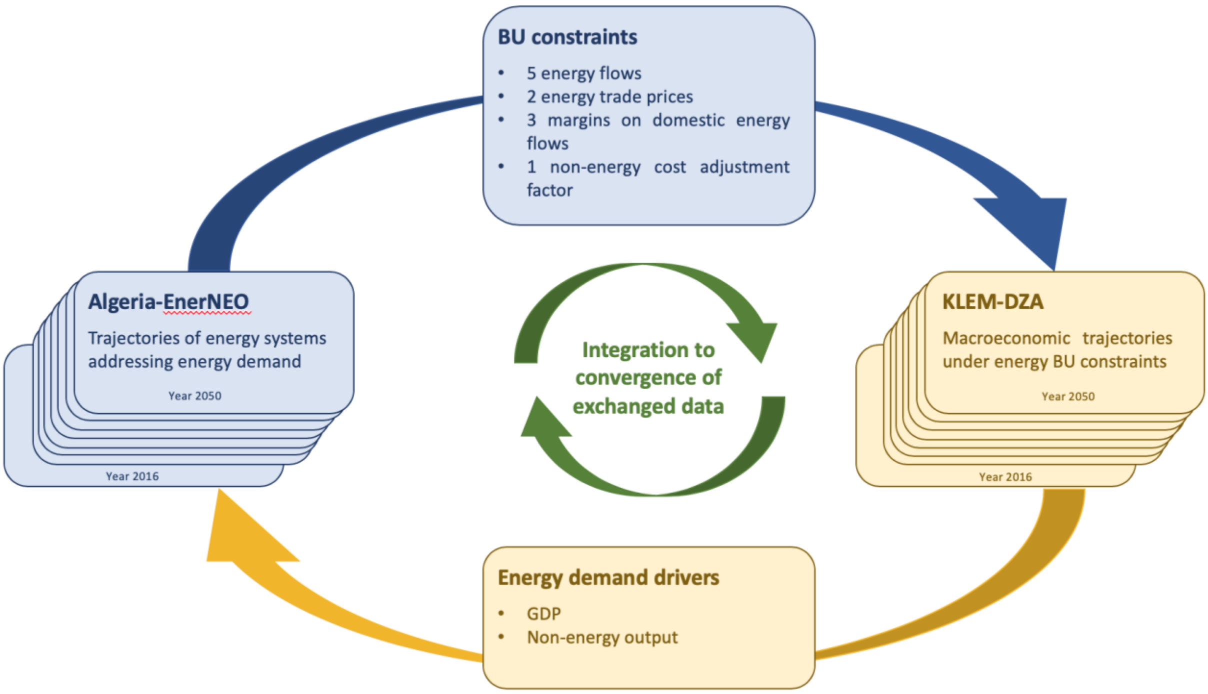
The KLEM-DZA and Algeria-EnerNEO models are coupled by the iterative exchange of modelling results up to convergence (see Figure 4 for the information exchanged between the two models).

The iterative process starts by running KLEM-DZA on annual time steps under the energy system data constraints provided by EnerNEO and assumptions on international energy prices (five energy flows, five associated energy prices, cost structures for the aggregated domestic energy production) for each projected year since 2015, the calibration year, until 2050, the common time horizon of both models. Among the different variables constituting the macroeconomic trajectory produced by KLEM-DZA, two indicators of the economic activity, namely the GDP and the production levels of the non-energy good, are feed back into EnerNEO.

We iterate the process[10] until either dataset varies less than a given tolerance threshold between one iteration and the next (fixed at 1 to 100,000 for the simulations of the paper). The resulting EnerNEO and KLEM-DZA outputs provide a consistent, highly detailed picture of the Algerian energy system embedded into the broader Algerian economy at activity levels that take account of feedback loops between energy, non-energy and primary factors supply, demand and relative prices.

Even though both models start their simulation on two distinct years (2018 in EnerENO, 2016 in KLEM-DZA), it does not represent a technical barrier for this convergence procedure, as on the one hand EnerENO includes a statistical coverage going back to 2001 coherently built using the energy balances of the Algerian Minister of Energy and Mine, and on the other hand KLEM-DZA operates between 2016 and 2020 a dynamic calibration ensuring the replication of the observed real GDP, thus the 2016 and 2017 projections consider energy statistics underlying the EnerNEO data for those years.

Figure 4: Model coupling architecture



Source: The authors

Methodological contribution

Compared to previous modelling efforts of the Algerian economy using a computable general equilibrium framework, our methodological contribution has several dimensions. Yet, it does

[10] This convergence process could have start by running KLEM-DZA using exogenous constraints regarding energy consumption, trade and prices, providing EnerNEO with trajectories for GDP and production levels of the non-energy good. The deterministic mechanism of the convergence process warrants that the equilibrium obtained is equivalent to the one reached by starting with EnerNEO simulations based on growth assumptions other than those stemming from KLEM-DZA.

not lie in the iterative procedure previously described, which Hoffman and Jorgenson proposed more than 40 years ago (Hoffman and Jorgenson, 1977).

First of all, it lies in the upstream efforts to make the energy balance and national accounting data consistent, as well as in the processing of the prospective results produced by the EnerNEO techno-economic model in a format that can be assimilated by the KLEM-DZA macroeconomic model and its input-output accounting framework. These efforts, which result in particular in the modelling of energy prices specific to each economic agent (an original feature of the KLEM/IMACLIM[11] approach), guarantee an optimal relevance of the coupling exercise, allowing the prospective to be based on the joint strengths of the two modelling paradigms.

It is also due to the fact that the results produced constitute a dynamic exploration of growth up to the medium term of the year 2050, rather than a static and counterfactual analysis. As indicated above, this exploration is conducted in full coherence with energy supply and demand trajectories produced by the EnerNEO techno-economic model, designed and maintained by the Algerian Ministry of Energy and Mines.

Finally, it lies on the specific features of the KLEM model, allowing, on the one hand, the adaptation to the specific conditions of the Algerian economy (rigidity of real wages, external constraint), and on the other hand, the exploration of macroeconomic stabilization scenarios through the controlled extension of the model to additional constraints and variables.

Scenario description

We apply the above described methodology to the exploration of eight different scenarios, defined by crossing two variants of the macroeconomic context and four contrasted evolutions of the Algerian energy system. Some macroeconomic assumptions are common to all scenarios. The latter are presented below, before the description of macroeconomic specifications and each evolution of the energy sector.

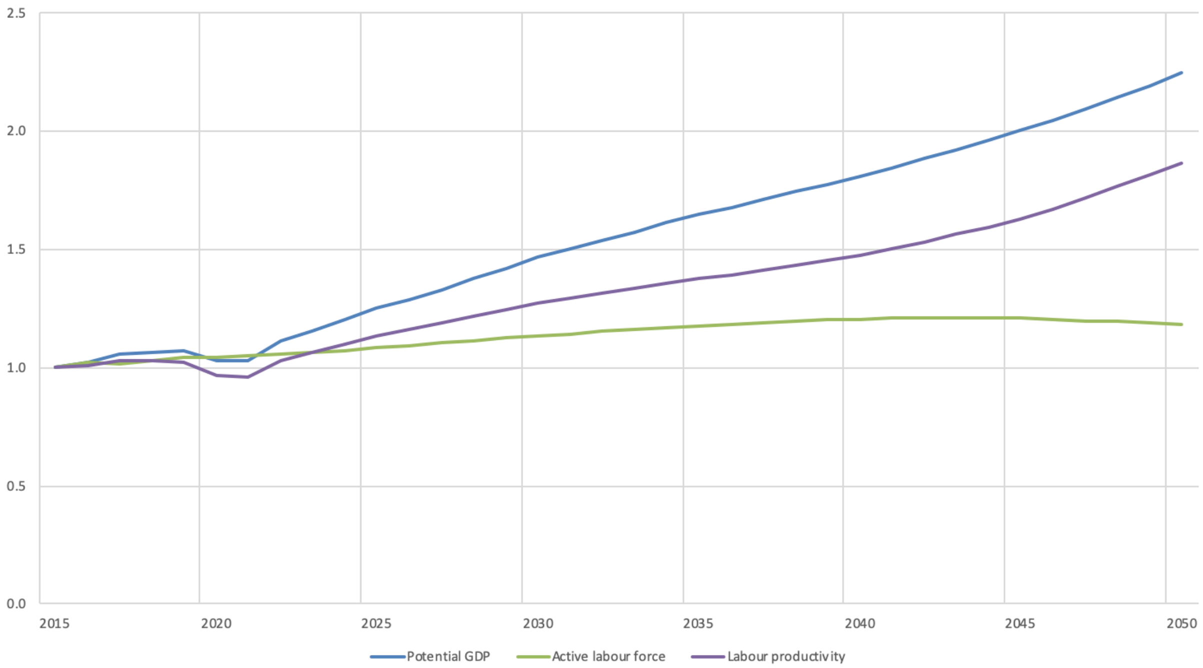
Common macroeconomic assumptions

The KLEM-DZA model, and therefore all the simulations built by coupling with the EnerNEO model, is based on macroeconomic assumptions common to all explored scenarios.

First, potential growth results from the combination of exogenous assumptions about labour force growth (interpreted by KLEM as the labour supply growth) and labour productivity (Figure 5). These assumptions are deduced from statistical series reported by the World Bank for Algeria from 2015 to 2020 regarding real GDP and employed population. Their forecasts then follow the second scenario of the 'Shared Socioeconomic Pathways' (SSP2) developed by the IPCC. More specifically, labour productivity gains inferred from the SSP2 projections for Algeria are applied after the economic crisis caused by the Covid-19 pandemic, which is recorded in the 2020 statistics. Moreover, economic growth is assumed to be zero in 2021, before returning to its 2019 level increased by half the growth rate projected by the SSP2 for the year 2022. The potential average annual growth rate of real GDP resulting from these assumptions over the period 2021-2050 is 2.79 percent.

[11] The KLEM model is a precursor of IMACLIM, with the latter disaggregating the economy into more sectors of the economy.

Figure 5: Exogenous trajectories of labour productivity and active population in KLEM-DZA, defining potential growth (index 1 in 2015)



Sources: World Bank data (2015-2020) and SSP2 (2021-2050), including additional treatment by the authors regarding the specific assumptions for 2021 and 2022.

Second, the investment effort is maintained at its 2020 level of 37.5% of GDP, almost identical to the average rate observed from 2011 to 2020 (World Bank data), in all the scenarios. This high level is characteristic of economies with an intermediate standard of living and rather sustained growth, such as Algeria. This fixed investment effort over the entire projected period is accompanied by the absence of changes in trend for capital productivity[12].

Third, a gradual (linear) reduction of the trade deficit in goods and services (including energy) is assumed in all scenarios, from its estimated level of -11.0 percent in 2020 to equilibrium in 2030 and beyond (Figure 6)[13]. This assumption aims at reflecting the expectations and development objectives of the Algerian economy over the medium term. Equilibrium is expected to be attained in 2030, due to the high external debt level faced by the Algerian economy, representing 50.7% of the GDP in 2020 (add source in bibliography, FMI).

In the absence of additional macroeconomic assumptions, this constraint strongly impacts the country’s development path and induces a downward adjustment of the 'real effective

[12] Transformations, mainly linked to structural changes in the economic activity, will be deeply analysed within the multisectoral framework of IMACLIM-DZA, of which KLEM-DZA is the precursor.

[13] The choice of exogenous investment effort and trade balance is related to the so-called Johansen macroeconomic closure, in which public policies control the level of savings in the national economy in order to warrant a certain investment effort, given the contribution of imported savings (the opposite of the goods and services balance).

exchange rate' (REER)[14] of the Algerian economy in KLEM-DZA. This implies an increase in the cost of imports relative to domestic consumption and a gain in the competitiveness of Algerian exports on international markets, in order to allow the taregted equilibrium to be achieved.

Nevertheless, this downward adjustment also inevitably leads to a decline in the purchasing power of Algerian wages, as imported consumption, which currently constitutes a significant proportion of total consumption, is more expensive. Since the constraint associated with the gradual control of the trade deficit, therefore of an external debt, is achieved through relative prices equilibrium, macroeconomic and social performances far below the growth potential of 2.79% (deduced by the assumed growth of labour endowment and productivity) can be expected.

This element is what motivated the definition of an additional macroeconomic specification, encompassing a proactive involvement of the public sphere (see below).

Macroeconomic specification

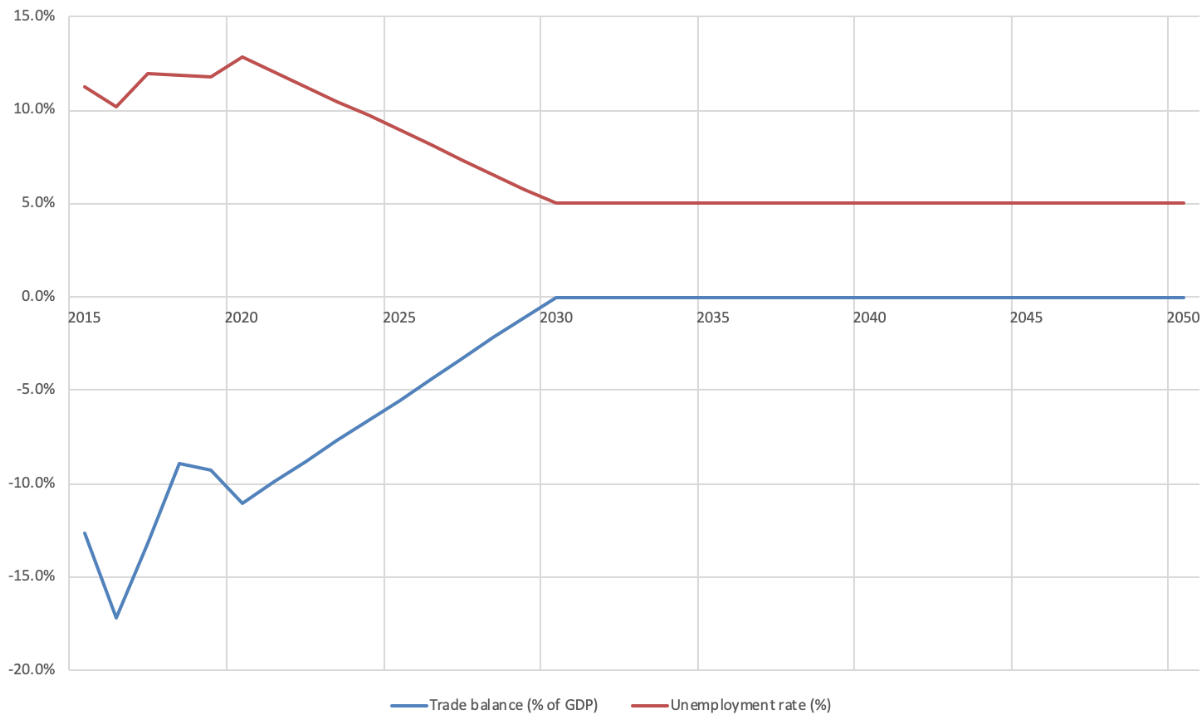
At the macroeconomic level, four of the eight scenarios explored are therefore based on the single set of common assumptions defined in the previous sub-section, which can be considered as a context of constrained trade deficit control under strong economic policy inertia, a sort of "worst case scenario" that poorly reflects the actions and ambitions of the Algerian government.

A second set of four scenarios is therefore constructed in an alternative context, suggesting a strong transformation of the national economy, combining the above described assumptions with a positive, non-price competitive shock, symmetrically decreasing imports and increasing exports of non-energy goods and services. Rather than considering a certain level of shock and measuring its consequences, the flexibility of the KLEM-DZA model allows to reveal which shock is numerically necessary for a convergence towards a stabilized growth path achieving both macro- and socio-economic equilibrium, at least at the aggregation level available in KLEM.

In order to define the magnitude and timing of the competitive shock, the hypothesis of a gradual reduction of the trade deficit is completed by an ambitious assumption of a reduction in unemployment, from a rate of 12.8 percent recorded in 2020 (World Bank data reproduced by the dynamic calibration of KLEM-DZA) to a rate of 5.0 percent in 2030. The objective is to assess which level of competitive shock is compatible with the successful transformation of the Algerian economy, so that the country' growth regime can combine both desirable macroeconomic features of a stabilised trade balance (zero deficit) and a close to frictional 5.0 percent unemployment rate.

Figure 6: Assumptions linked to the reduction of the trade deficit and the unemployment rate

[14] The REER is defined as the relative price level of the domestic household consumption basket and overall imports of the Algerian economy. Like the overwhelming majority of macroeconomic models used in the energy/economy outlook, KLEM does not represent money, which it therefore implicitly considers neutral. However, the fluctuations in the REER that it calculates can be interpreted as adjustments in the nominal exchange rate of the same magnitude, which would have a similar effect on the competitiveness of the economy.



Sources: World Bank data (2015-2020), coupled with exogenous assumptions (2020-2050). The trade deficit reduction constraint is common to all scenarios, thus to both macroeconomic contexts previously described (inertia and successful transformation of the Algerian economy). The assumption regarding the unemployment rate is forced only in the context of a favourable transformation of the economic activity.

Distinct evolutions of the Algerian energy sector

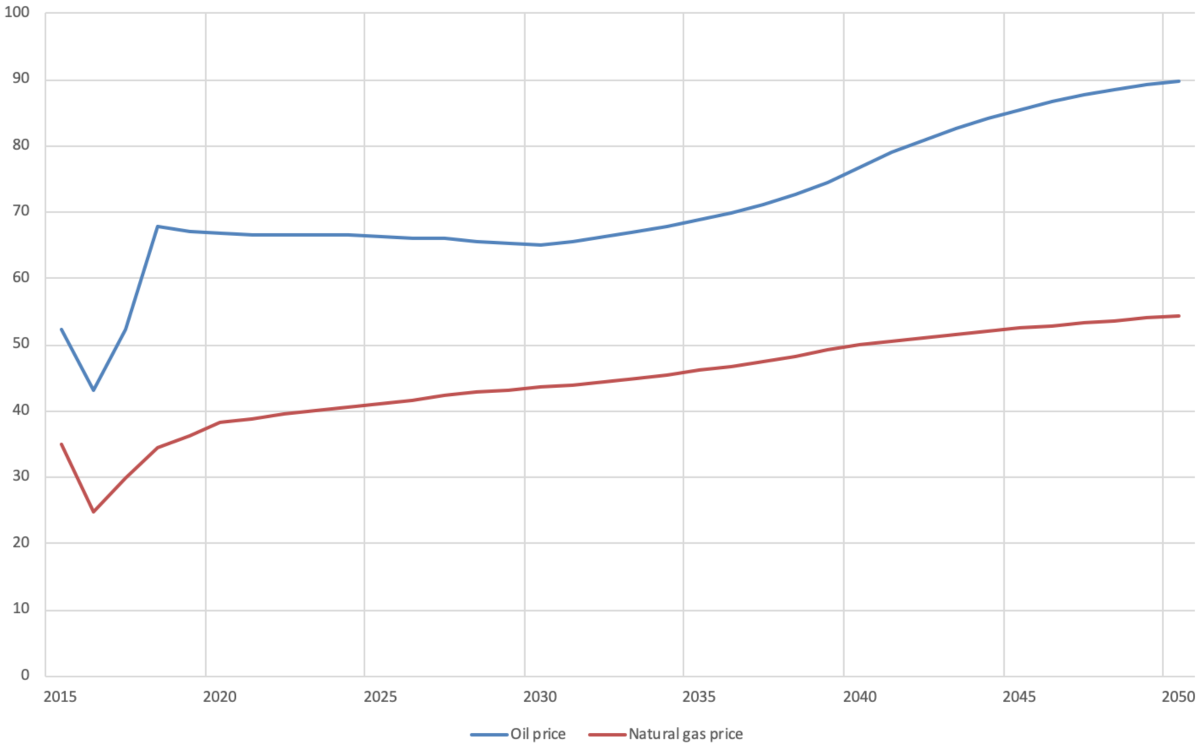
The two distinct macroeconomic contexts previously described serve as a backdrop for the deployment of four energy scenarios, initially built on exogenous growth assumptions when developing the EnerNEO model.

The international context is considered constant in all energy scenarios, expressed in international oil and gas price trajectories, assumed insensitive to variations in Algeria's export capacity and import needs (Figure 7).

Moreover, all assumptions made regarding the technical (efficiency, average life, load factor for power generation technologies, etc.) and economic (investment, operation and maintenance costs) characteristics of energy supply and consumption equipment are identical in all scenarios. The availability of certain technical options is a potential lever defining the scenarios, yet none consider the implementation of a nuclear program in Algeria.

Developed in 2020, these energy scenarios initially neither consider the consequences of the Covid-19 pandemic nor the current conflict in Ukraine, which would have an impact, at least in the short-run, on economic growth and the energy sector. However, as indicated above, the macroeconomic trajectories of the KLEM-DZA model capture the sanitary crisis through its impact on effective labour productivity in 2020, as described by World Bank statistics, as well as catch-up assumptions in 2021 and 2022. The energy consumptions calculated by EnerNEO after convergence with KLEM-DZA for each of the four energy scenarios developed are therefore, for the years 2020 to 2022, defined by activity levels taking the COVID crisis into consideration. On the other hand, the international price levels remain those taken from a global modelling exercise produced by ENERDATA (EnerNEO's designer) in 2019 (Figure 7). Scenarios built on higher price assumptions at least in the short-run to reflect the transitionary period could be developed at a later stage.

Figure 7: Assumptions on oil and natural gas import and export prices



Source: ENERDATA, 2019. These prices are those at which Algerian crude oil and natural gas exports and imports are valued over the projected period, for all scenarios, in constant (2015) dollars per barrel of oil equivalent (boe). Imported and exported refined product prices are derived from crude oil prices plus an average refining margin calibrated in 2015, held constant.

Besides, those common assumptions, each of the four scenarios provides a specific prospective vision of the Algerian energy system, as described in the following sub-section.

The REFERENCE scenario

The REFERENCE energy scenario (REF) describes a conservative trajectory of the Algerian energy system, largely based on the extension of current trends, under the assumption that the price and subsidy policies observed in the calibration year remain in place.

The changes in energy demand per capita for transport and residential uses are thus fixed by variations ranging from -0.4% to +0.5% per year for the latter and from -0.5% to +0.5% per year for the different types of transport, with however the assumption of electrification of passenger rail traffic. The energy demands of the productive sectors are assumed to follow the growth of their associated activity with efficiency variations ranging from +1.3% to -0.5% (efficiency losses) depending on the sector.

On the supply side, the development of renewable energy resources remains limited, while hydrocarbon production continues to grow following historical trends. However, the exploitation of unconventional deposits is excluded and the progressive depletion of conventional resources will eventually reduce dramatically the production volumes of gas and oil. These developments lead to the threat of a gradual disappearance of the oil and gas rent, which the converged KLEM-EnerNEO simulations will confirm.

The BROWN scenario

On the demand side, the BROWN energy scenario is based on the same trend assumptions as the REF scenario, i.e. growth in household energy consumption and a relatively high energy intensity of the economic activity.

On the supply side, however, it envisages continued efforts to develop the hydrocarbon sector in Algeria, particularly with respect to conventional and non-conventional gas production. For the latter, it envisages a growing production capacity, from 19 Mtoe in 2030 to 65 Mtoe in 2050, in line with the objectives of the Vision SH2030 developed by Sonatrach[15]. It also assumes an increase in refining capacity of 5 million tons every 5 years until 2035. Compared to the REF scenario, the threat to the rent posed by the uncontrolled increase in domestic consumption is therefore tempered by further development of the country's fossil resources.

The BLUE scenario

The BLUE energy scenario describes an energy future in which Algeria is committed to significant changes, both on the control of energy consumption and on the deployment of renewable energy resources. It includes a number of elements of the Government's action plan of February 2020, particularly with respect to renewable energies.

On the demand side, it differs from the REF scenario as it considers significant efforts to improve energy efficiency and change the energy mix in various consumption sectors (rationalization of consumption, more efficient equipment, electrification of uses). These changes are based on an overhaul of the energy pricing policy, with carbon pricing rising from 56 DA_{2015}/tCO_2 in 2025 to 1,500 DA_{2015}/tCO_2 in 2050, as well as on the gradual introduction of energy-related norms and standards.

On the supply side, the BLUE scenario foresees a moderate development of unconventional gas, with however a slowdown of total hydrocarbon production. Regarding power generation, an increased effort is made to develop renewable energy resources, mainly through competitive tenders for solar and wind farms, whose contributions to the mix are set as constraints. In contrast to the REF scenario, the BLUE scenario envisages both decreases in energy demand and increases in renewable supply, which combine may design a better maintenance over time of the oil and gas rent and its contribution to macroeconomic balances.

The GREEN scenario

Finally, the GREEN energy scenario constructs a trajectory supposedly compatible with the objective defined by the Paris Agreement on climate to limit the increase in global average temperature to +2°C compared to the pre-industrial era. For Algeria, this objective is defined in a constraint of 1.7 tons of CO_2 (tCO_2) per capita in 2050 for direct emissions from the energy

[15] https://sonatrach.com/actualites/pour-sa-strategie-a-lhorizon-2030-le-groupe-sonatrach-bien-parti/

sector, in accordance with the work conducted by the Deep Decarbonisation Pathways Project (DDPP[16]) of IDDRI (IEP Paris).

Therefore, all the constraints and assumptions included in the BLUE scenario are accentuated for the GREEN scenario, leading to an in-depth transformation of the structure of the Algerian energy system. Beyond slowing down the exploitation of hydrocarbons and abandoning non-conventional deposits, these levers include much greater efforts on energy demand management policies, with carbon pricing rising from 281 DA_{2015}/tCO_2 in 2025 to 7,500 DA_{2015}/tCO_2 in 2050, as well as a strong electrification of uses, and the massive development of renewable energy resources for electricity generation, combined with natural gas power plants providing flexibility to the electrical system to manage intermittency.

Results

The two economic variants, extremely contrasting by construction, clearly delimit two sets of macroeconomic trajectories that the energy variants modify only more marginally. The presentation of the modelling results follows this divide by first detailing the scenarios produced under the assumption of a strong economic fabric inertia, which turns out to be strictly incompatible with sustainable economic development, then by approaching the scenarios deliberately constructed as visions similarly successful economic transitions, but underpinned by distinct energy futures.

Four 'repellent' scenarios built on assumptions of economic inertia and strong external constraints

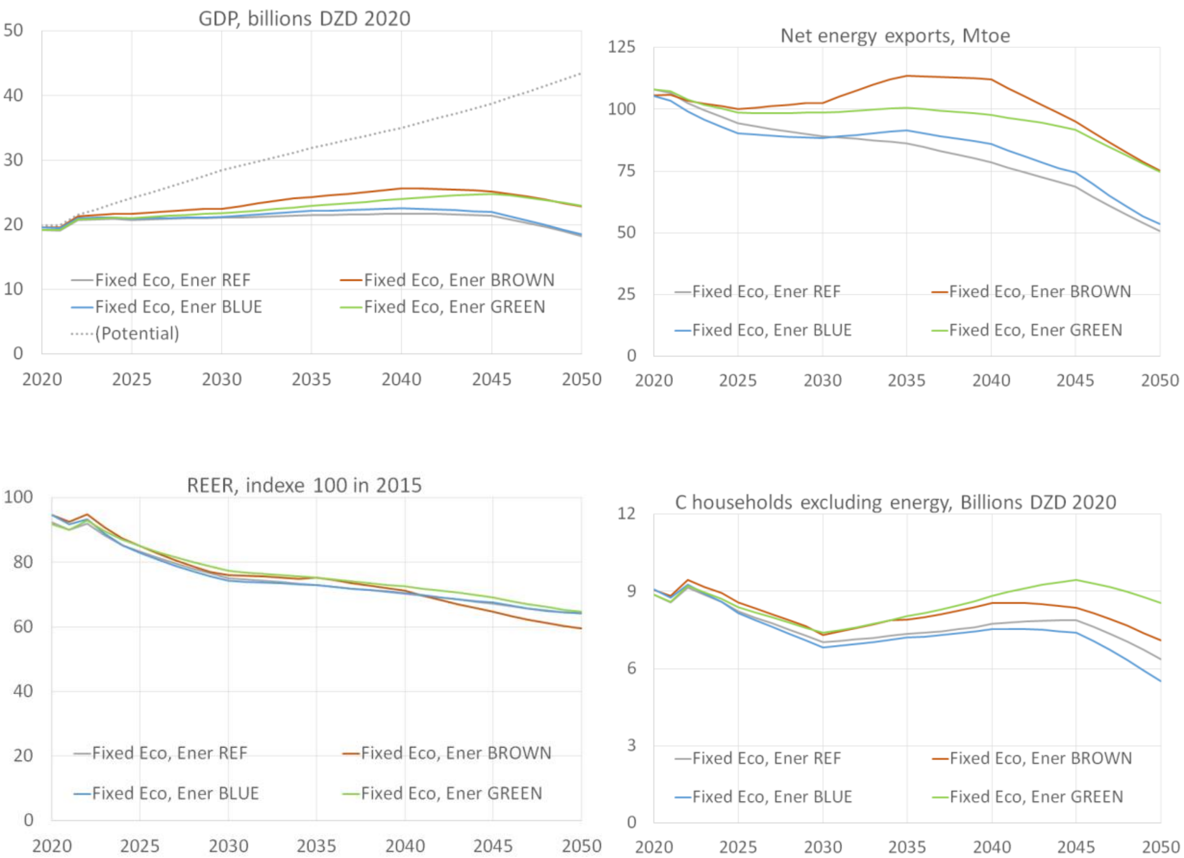
Considering the absence of transformations in the economic fabric, giving rise to a positive non-price competitiveness shock, the strong external constraint materialized by the requirement to reduce the trade deficit by 2030 requires a downward adjustment of the effective rate of change (REER) in all scenarios. Although none of the four energies trajectories thus projected under the assumption of the economic fabric inertia is sustainable, we shall note that the BRUN and GREEN scenarios display GDP and employment performance slightly less degraded than the REF and BLUE scenarios. This is directly linked to maintaining higher rental levels in export markets (upper right panel). However, the BRUN scenario achieves this result by exploiting unconventional deposits, while the GREEN scenario plays on strong control of domestic consumption to generate additional export capacity. This marked difference in approach is reflected in the divergent trends in non-energy consumption of household induced at the end of the trajectory by the two scenarios (central right panel). The lack of control of the height development in energy consumption in the BRUN scenario leads to dedicating a larger share of the income to them (substantially identical in the two scenarios between 2045 and 2050), which mechanically reduces the budget allocated to consumption non-energetic expenditure. It would still be necessary to take into account the capital

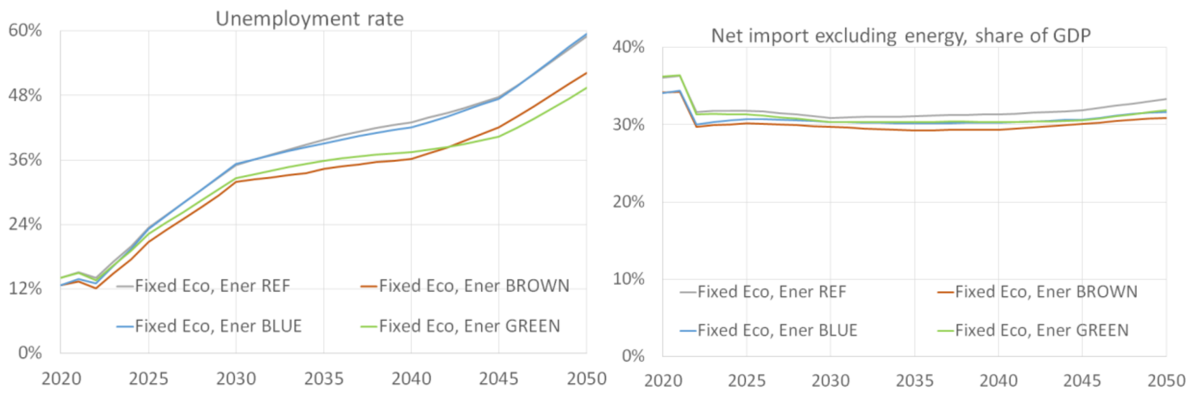
[16] The Deep Decarbonization Pathways Project (DDPP) is an initiative of IDDRI and the Sustainable Development Solutions Network (SDSN) to promote deep decarbonization trajectories by country in connection with local research teams. More information is available at http://deepdecarbonization.org/.

expenditure underlying part of the energy savings projected by the GREEN scenario, to confirm its relative superiority over the BRUN scenario at the end of the period.

This increase contributes to the economic stagnation, which sees real GDP progress very slightly in the first years of the projection (upper left quadrant), and even decline at the end of the horizon when hydrocarbon exports accelerate their decline (upper quadrant right). The fact remains, as a last resort, that the KLEM-EnerNEO modeling unambiguously rejects hypotheses of a strong rigidity of the economic fabric and a short-term control of the trade deficit, and therefore of the external indebtedness. Whatever the energy system scenario retained (Figure 5, central left quadrant), including in the BRUN case where unconventional resources compensate as much as possible for the depletion of conventional deposits.

Figure X Unsustainable trajectories in a context of economic inertia and strong external constraints





Source: KLEM-EnerNEO modelling. The 4 scenarios are designated by their macro-economic context (FREEZE economy) and their energy specification.

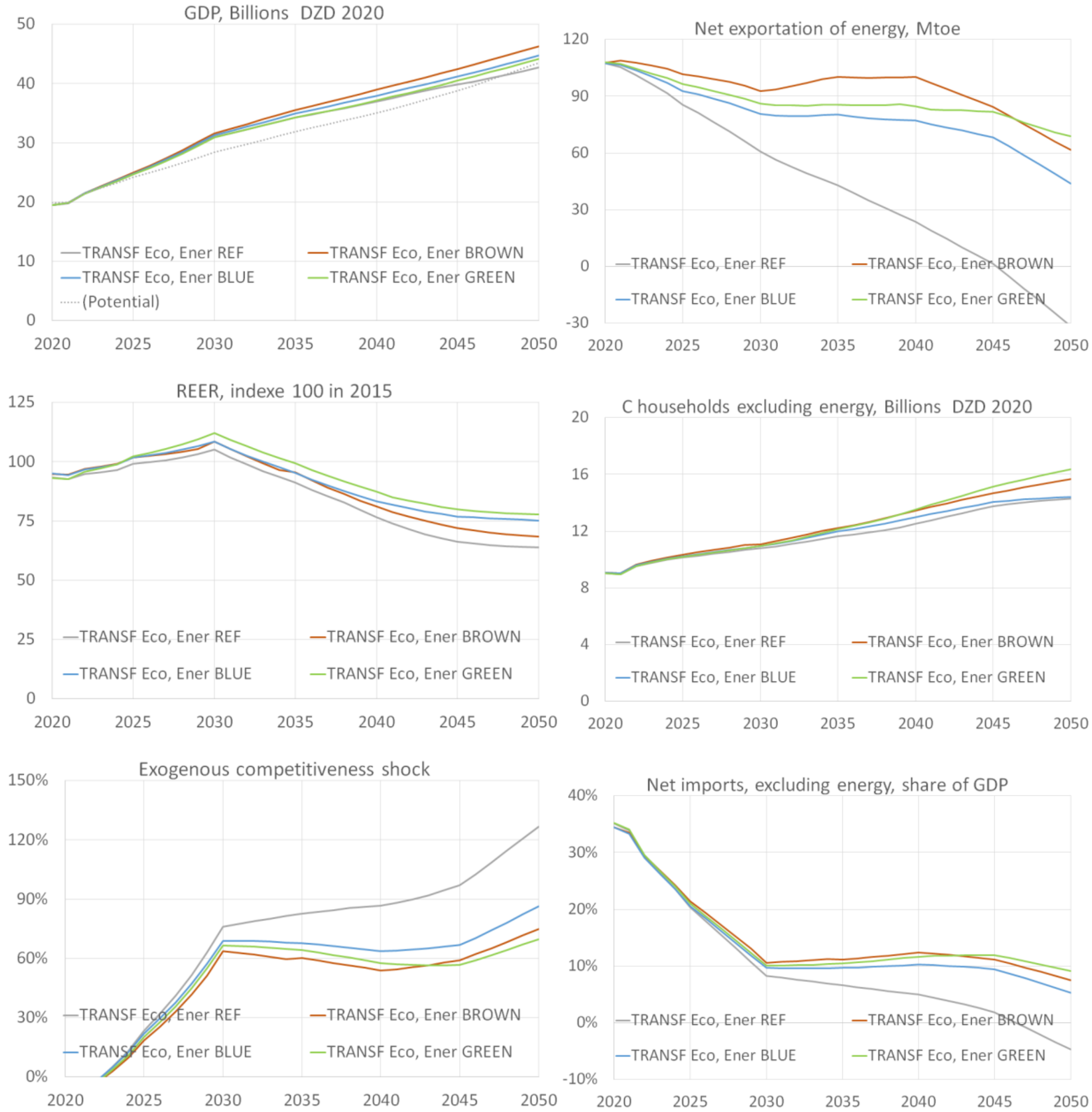
Four successful economic transformation scenarios underpinned by distinct energy systems

The scenarios of successful economic transformation, voluntarily located at the other end - the most favourable - of the prospective field, produce a completely different image of the Algerian economy for the next 30 years.

We must begin by highlighting the methodological result that the extension of KLEM-DZA to the constraint of stabilizing unemployment, associated with the variable of a positive trade shock (simultaneous fall in imports and rise in exports, see Appendix C.X) is resolved for each of the 4 proposed energy scenarios. The variations of the REER index, freed from the constraint of being the only lever for achieving the objective of reducing the trade deficit, can be set at the levels necessary for household purchasing power to support activity to the point of achieve the additional objective of stabilizing employment. In the first decade of simulation, they thereby follow an appreciation trend. In terms of trade, the economic performance recorded in a first decade of successful economic transformations reduces the hydrocarbon export capacity (upper right quadrant), in particular in the REF scenario which combines the absence of any particular effort to control energy consumption (domestic consumption strongly correlated with activity) and the failure to exploit unconventional resources. Consequently, balancing the trade balance requires a rapid reduction in the share of the wealth produced devoted to net imports of non-energy goods and services (lower right quadrant), precisely made possible by the competitiveness shock commented on above.

From 2030, the stabilization of the unemployment rate at the low level it has reached puts an end to the particular dynamics of the period of its decline, to the point of constituting a visible inflection point for several indicators. The REER (central left quadrant) stops rising so as not to generate additional purchasing power gains that would create a new stimulus for activity, and therefore employment. This change in trajectory benefits the terms of trade since it indicates that Algerian production is no longer becoming more expensive in comparison with imported production. Consequently, the competitiveness shock necessary to control the trade deficit also shows a break in trend, towards a semblance of stabilization (lower left quadrant).

Figure X Macroeconomic trajectories supported by a positive competitiveness shock ensuring full employment



Source: KLEM-EnerNEO modelling. The 4 scenarios are designated by their macro-economic context (TRANSFormed economy) and their energy specification.

This decrease in the unemployment rate over the years 2020 to 2030 mechanically leads activity (real GDP) to exceed its potential growth rate (calculated excluding fluctuations in the unemployment rate), without any notable influence by the trajectory of the energy system followed. On the trade side, the economic performance recorded in a first decade of successful economic transformations reduces the ability to export hydrocarbons (upper right quadrant), especially in the REF scenario which combines the absence of any particular effort to control energy consumption (domestic consumption strongly correlated to the activity) and the failure to exploit non-conventional resources.

However, we must not lose sight of the fact that this excellent economic performance is conditional on the implementation of public policies likely to generate a positive shock to competitiveness. The extent of this shock must increase rapidly to reach, from 2030, 60% to 80% additional development of exports of non-energy goods and services (and not exploiting non-conventional resources). Consequently, equilibrate the trade balance requires a rapid reduction in the share of the wealth produced devoted to net imports of non-energy goods and services (lower quadrant right), precisely allowed by the competitiveness shock mentioned above.

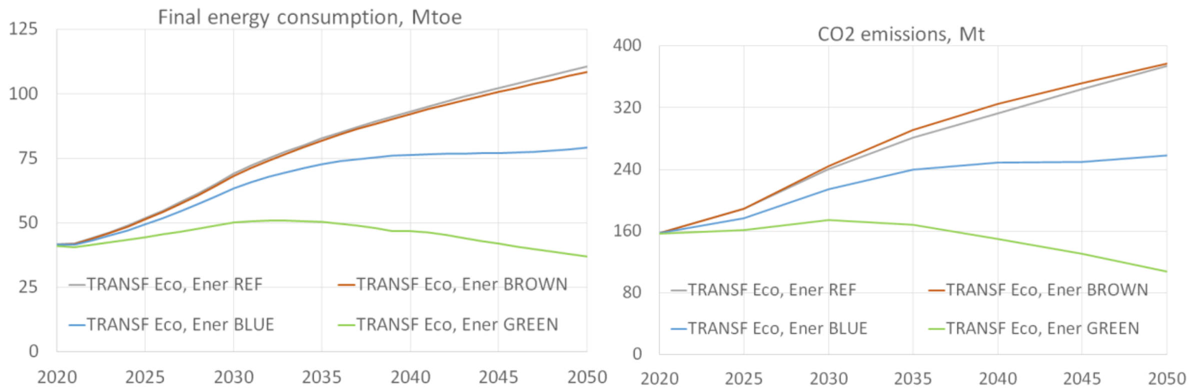
However, the decline in the REER index also induces a slight shift in the growth trajectory (upper left quadrant): the decoupling from potential growth ceases for all the scenarios, and is even ended. This is particularly the case for the REF energy scenario, which increasingly stands out from the other scenarios up to the projection horizon. As previously underlined, its particularity lies in the fact that it considers neither special efforts to control energy demand nor the development of unconventional resources. In a growth regime that is nevertheless much sustained (+2.65% annual average 2020-2050), these cross hypotheses lead to a rapid drop in net energy exports (upper right quadrant). Halved compared to 2020 started from 2032, they are cancelled out in 2045 and the net imports that follow them already amount to 32 Mtoe in 2050, and follow a strong upward trend.

Consequently, the sustainability of the REF scenario assumes an increasingly high competitiveness shock compared to those required for the other scenarios (lower left quadrant). This shock exceeds 100% in 2046, so on that date should allow more than a doubling of the volumes of non-energy goods and services exported, and more than a reduction by 2 of the volumes of these same goods imported, in comparison with what only the evolution of prices would allow. In 2050, it already reaches 127%.

The BROWN scenario is able to bearing the lack of action to control energy demand in the REF scenario, by bringing unconventional deposits into production. This feature allows it both to maintain net hydrocarbon exports at a level higher than that of the other three scenarios, almost until the end of the horizon explored, and to post the best growth performance (+2, 92% annual average 2020-2050) by the simple fact of the unconventional income that it is the only one to exploit.

However, from 2045, its net hydrocarbon exports drop off and end up falling below those of the GREEN scenario, whose downward trajectory is less marked. We see here the interest of the efforts to control energy demand made in the GREEN scenario, whose final energy consumption in 2050, at 37 Mtoe, is almost two-thirds lower than that of the BRUN scenario (109 Mtoe) — and 10% below their own level in 2020 (Figure 7, left). This interest is also reflected in the cross-referencing of the competitiveness shocks necessary for the two scenarios.

Figure x: Final energy consumption and CO2 emissions of the 4 transformed economic scenarios



Source: KLEM-EnerNEO modelling. The 4 scenarios are designated by their macro-economic context (TRANSFormed economy) and their energy specification.

The advantage of the GREEN scenario (energy savings) over the BROWN (trend consumption) is also reflected in the non-energy consumption trajectory of households induced by the two scenario. As the gap in energy consumption widens, the non-energy consumption of the BROWN scenario, initially maintained at the same levelof the GREEN scenario by the benefit of the rent on unconventional resources, ends up by detaching from the trend authorized by the energy savings of the GREEN scenario. As in the case of the unsustainable scenarios developed in a fixed economic context, the non-energy expenditure of the GREEN scenario would still have to be corrected by the cost of the equipment necessary for the energy efficiency gains recorded. However, the effort to curb the energy intensity of growth is only temporary for many of its components, particularly given the expected learning effects. In the short term beyond 2045, end-of-horizon trends make it very likely that the GREEN scenario will eventually outpace the BRUN in economic well-being.

For similar reasons, it is likely that the BLUE scenario will also end up supplanting the BROWN scenario, but on a more distant horizon. The BLUE scenario allows an average annual GDP growth of 2.80% between 2020 and 2050, slightly lower than that of 2.92% of the BROWN. However, its final energy consumption increases to 77 Mtoe in 2050, which reflects energy savings that are too low to generate sufficient budget margins to compensate for the lack of rent on conventional resources compared to the BROWN scenario. As a result, the non-energy consumption of households in the BLUE scenario is 8% lower than that of the BROWN one in 2050. Over the horizon of the simulations carried out, only the environmental argument clearly plays in favour of BLUE in its comparison to BROWN. BROWN's CO2 emissions follow a steady upward trend to increase by 140% in thirty years (+2.96% per year, i.e. a rate very slightly higher than that of real GDP), while those of BRUN are close to peak beyond 2040, and have only grown by 65% in 2050 (+1.63% per year) (Figure 7, right). Of course, the environmental performance of the GREEN scenario is much higher since it manages to reduce CO2 emissions by 1.25% per year on average, i.e. 31% below their 2020 level in 2050.

Sensitivity Analysis

Conclusion and discussion

In this paper, the KLEM-DZA and EnerNEO models are combined to provide the first set of potential future scenarios for the Algerian economy and energy system. Four development paths for the energy system are examined in two different economic contexts: on the one hand, a context of strong inertia of the economic system combined with a strong external constraint; and on the other hand, a context of successful transformations postulating a convergence of the Algerian economy towards a trajectory of stabilized economic growth, full employment and commercial equilibrium during the decade of 2020 - thus on the verge of reaching commercial equilibrium.

The results show that the assumptions of economic inertia and reduced external imbalances are incompatible, regardless of the path chosen for energy development. The terms of trade adjustments required to gradually reduce the trade deficit will have an unsustainable impact on activity and employment within a few years in the absence of economic change. The development of conventional deposits and the associated additional rent (the "brown scenario"), or an ambitious energy transition program reserving the majority of conventional production for export (the "green scenario"), only moderately slows the deterioration of economic and social conditions.

The economic transformations required to overcome these barriers are modelled as a symmetric positive competitiveness shock that increases exports while decreasing non-energy imports. In the highly aggregated framework of the KLEM-DZA model, this hypothesis materializes the consequences of the Algerian government's economic policies and institutional reforms, particularly in favour of diversifying the economic fabric and developing domestic import-substitution and export industries. The nature and effectiveness of these policies and reforms are beyond the scope of the analyses conducted, which assume that they have fully achieved their objectives and instead aim to measure the effort that has been made possible - the magnitude and dynamics of the required competitiveness shock - and its consequences on the economic outlook based on the energy development paths followed.

In the context of successful economic development, the benefit of an energy transition (BLUE or GREEN scenarios) is thus evident when compared to a reference that does not take into account the exploitation of non-conventional oil resources (REF scenario). The energy savings gained through the energy transition slow the depletion of the volume of hydrocarbons available for export, and thus the rent's contribution to the external balance. This suggests that the competitiveness shock required for the economic transition to a stabilized growth regime will be less severe, particularly in the years following the first decade of macroeconomic rebalancing. After reaching 66% (GREEN scenario) versus 76% (REF scenario) in 2030, it stabilizes (BLUE scenario) or even decreases until 2045, when it is only 57% in the GREEN scenario and nearly 100% in the REF scenario. It is only in 2048 that the necessary shock exceeds 76% in a BLUE scenario (78%). Two years later, at the end of the horizon explored, it is still 70% in a GREEN scenario. Thus, an energy transition has the potential to add 20 years, or even more if ambitious, to the implementation of economic diversification and development reforms, as well as the full diffusion of the resulting transformations.

Due to the bias caused by the additional rent rejected on one hand (BLUE or GREEN scenario) and captured on the other, the benefit of an energy transition is less clear-cut when compared to an unconventional hydrocarbon exploitation scenario (BROWN scenario). Thus, only the most ambitious energy transition scenario (the GREEN scenario) leaves room for conventional exports to compete with the unconventional windfall by 2050. To achieve macroeconomic stability, the rejection of this windfall necessitates up to 5 points of additional competitiveness shock in the transition years.

However, when the benefit of energy savings in the "green" scenario outweighs the benefit of additional resources in the "brown" scenario, the comparison eventually reverses (in 2043). In 2050, the brown scenario necessitates a trade rebalancing policy that is 5 points more effective than the green scenario. This crossover indicates a long-term dynamic that is becoming more favourable to the energy transition, which is consistent with the intuition that the availability of non-conventional resources only postpones the ultimate barrier in the opposing trends of production (resource depletion) and consumption (too little energy saving)

Annexes

Annex X: KLEM-DZA simulations

Simulation	Scenario	Closure	Specification
S2 S5 S8 S10	REFERENCE GREEN BLUE BROWN	Neo-Keynesian	Wages rigidity
S3 S7 S9 S11	REFERENCE GREEN BLUE BROWN	Neo-Keynesian	Application of an exogenous trade shock

Annex X Scenario description

Figure X: Exogenous labour productivity and labour force trajectories defining potential growth in KLEM-DZA

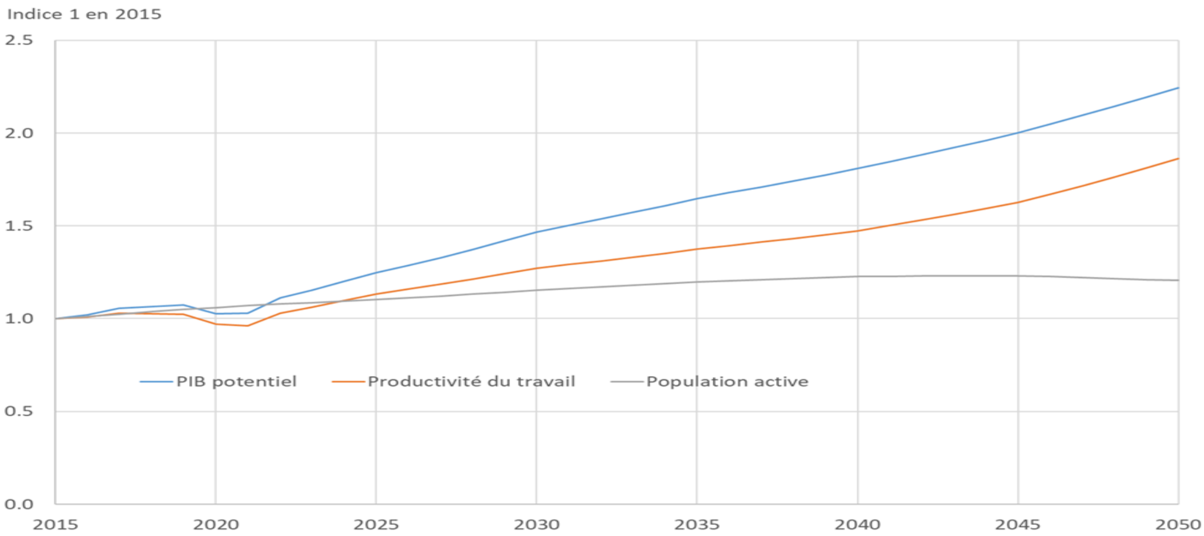
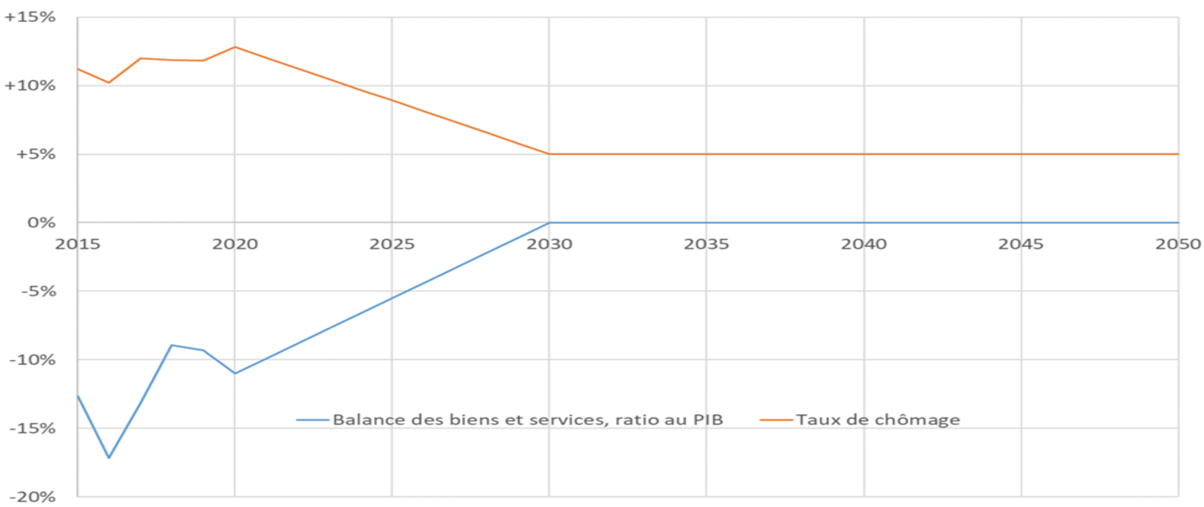


Figure Y: Hypotheses for reducing the goods and services deficit and unemployment



Annex X: A hybrid energy-economy matrix

Presentation of the hybrid IOT and the underlying energy flows

The 2015 Algerian IOT stemming from the hybridisation process, introduced in section 3.1 and described below, is organised as follow:

Figure xxx: Hybrid Input-Output Table (IOT) in KLEM format, Algeria, 2015

Billions DZD	NON-E	ENERGY	C	G	I	X	
NON-E	6 101	460	6 803	4 361	7 159	1 378	**26 264**
ENERGY	281	507 565	597 996	-	-	3 009	**4 396**
L net	4 661	161					
L taxes	-	-					
Y taxes	417	631					
K	5 924	560					
R	1 708	1 820					
M	6 338	173					
SM non-E	-	-					
SM E	-	-					
SM C	-	-					
SM X	-						
SALES T	833	83					
	26 264	**4 396**					

Source: ONS, DGP, calculation released by the authors as described below

On the resource side (columns), the supply of non-energy (non-E) or energy (E) goods and services comes from intermediate consumption (non-E and E inputs); labour costs L; capital costs (gross operating surplus) K; production taxes 'Y taxes'; natural resource rents R; imports M; specific margins MS on various domestic and export bills, and taxes and subsidies on products T. The specific margins on energy uses (in non-E and E production, in household consumption C, in exports X), an original addition of CIRED's KLEM-IMACLIM modelling method to the standard national accounts' framework, are a major consequence of the hybridisation of the calibration data and a salient feature of KLEM. For each energy use, they represent the difference between sales at observed prices and sales at the average resource price (an average of producer and import prices) plus taxes and subsidies on products (by construction, their sum is therefore zero). They allow the modelling of prices specific to each economic agent represented in KLEM, i.e. to circumvent the undesirable consequences of the CGE standard of normalising output prices explored by Combet et al. (2014). All the specific margins of the non-energy good uses are zero, in the absence of a 'satellite account' of physical flows underlying the economic flows that might require agent-specific pricing.

On the use side, the goods produced or imported contribute to non-E and E production, are consumed by households (C) and public administrations (G), immobilised in investment (I) or exported (X). For energy, the correspondence with the energy balance aggregates is as follows. The energy consumption of the non-energy sector (281 billion dinars) corresponds to the total final energy consumption net of household consumption (C, 598 billion), which covers the energy consumption of the residential sector and a share of the consumption of refined products for transport (that whose expenditure is directly paid by households). Energy consumption in the energy sector (508 billion) includes all trade flows between energy enterprises, in particular those relating to natural gas inputs into electricity generation.

By national accounting convention, government consumption of energy goods is zero. Investment in energy goods is also zero, once the changes in stocks have been cancelled out by implementing an extended Leontief method. Exports (X) and imports (M) are close in scope to their counterparts in volume in the energy balance. The price of each energy use is specific thanks to the specific MS margins (see above). It should be noted that the volume of energy production that balances domestic consumption and net trade is a mixture of primary and

SALES T	833	83

transformed energy. This double counting, from the perspective of an energy engineer, is a standard feature of the national accounting framework.

This hybrid dataset confirms the contribution of the energy sector to Algerian economic activity in 2015: it accounted for 14.3% of total employment or resources, 23.8% of gross operating surplus (K + R) and 68.6% of exports. These data are, however, only provisional and will be revised when the hybridisation effort undertaken at the most disaggregated level available is completed.

Construction process of the hybrid IOT

The energy uses and imports are re-built based on the prices and quantities provided by ENerNEO, with the latter calibrated on DGP data.

Billions DZD	NON-E	ENERGY	C	G	I	X	
NON-E	6 101	460	6 803	4 361	7 159	1 378	**26 264**
ENERGY	281	507 565	597 996	-	-	3 009	**4 396**
L net	4 661	161					
L taxes	-	-					
Y taxes	417	631					
K	5 924	560					
R	1 708	**1 820**					
M	6 338	173					
SM non-E	-	-					
SM E	-	-					
SM C	-	-					
SM X	-						
SALES T	833	83					
	26 264	**4 396**					

The rest of energy resources, aggregated from the DGP matrix, are adjusted in order to balance uses and resources, as the total of energy good uses has been defined in the first step

Billions DZD	NON-E	ENERGY	C	G	I	X	
NON-E	6 101	**460**	6 803	4 361	7 159	1 378	**26 264**
ENERGY	281	507 565	597 996	-	-	3 009	**4 396**
L net	4 661	**161**					
L taxes	-	-					
Y taxes	417	**631**					
K	5 924	**560**					
R	1 708	1 820					
M	6 338	173					
SM non-E	-	-					
SM E	-	-					
SM C	-	-					
SM X	-						
SALES T	833	**83**					
	26 264	**4 396**					

Specific margins are adjusted in order to warrant specific prices for each energy use. This process is necessary as KLEM's aggregation level supposes highly heterogenous energy consumption by the different energy uses, thus with specific prices.

Billions DZD	NON-E	ENERGY	C	G	I	X	
NON-E	6 101	460	6 803	4 361	7 159	1 378	**26 264**
ENERGY	281	507 565	597 996	-	-	3 009	**4 396**
L net	4 661	161					
L taxes	-	-					
Y taxes	417	631					
K	5 924	560					
R	1 708	1 820					
M	6 338	173					
SM non-E	-	**-93**					
SM E	-	**-618**					
SM C		**-33**					
SM X	-	**744**					
SALES T	833	83					
	26 264	**4 396**					

Non-energy data are deduced from the DGP matrix totals, subtracting energy data.

Billions DZD	NON-E	ENERGY	C	G	I	X	
NON-E	**6 101**	460	**6 803**	**4 361**	**7 159**	**1 378**	26 264
ENERGY	281	507 565	597 996	-	-	3 009	4 396
L net	**4 661**	161					
L taxes	**-**	-					
Y taxes	**417**	631					
K	**5 924**	560					
R	**1 708**	1 820					
M	**6 338**	173					
SM non-E	-	-93					
SM E	-	-618					
SM C		-33					
SM X	-	744					
SALES T	**833**	83					
	26 264	**4 396**					

Annex X: Simplified energy balances underlying the developed scenarios

Add this part

Annex X:

Table Y: macroeconomic and energy indicators by scenario, without trade shock

	Reference (S2)		GREEN (S5)		BLUE (S8)		BROWN (S10)	
	Average Evolution	Variation 2015-2050	Average Evolution	Variation 2015-2050	Average Evolution	Variation 2015-2050	Average Evolution	Variation 2015-2050
Real GDP	-0,14%	-5,6%	0,5%	18,5%	-0,1%	-4,4%	0,5%	17,9%
Unemployment rate	5%	426%	4,5%	340%	5,1%	430%	4,7%	365%
Energy production	-1%	-18%	-0.5%	-16%	0,2%	6%	1%	50%
Non-energy production	0,2%	7%	1%	28%	0,2%	5%	1%	24%
Energy consumption	1%	24%	-1%	-40%	2%	83%	3%	170%
Non-energy consumption	-1%	-19%	0,3%	9%	-1%	-30%	-0,2%	-10%
Investment volume	-0.5%	-17%	0.23%	7%	-0,42%	-15%	0,16	5%
Capital stock	1%	34%	1%	47%	1%	37%	1%	49%
Taxes, % of GDP	-1%	-34%	-1%	-42%	-0,2%	-9%	-1%	-28%
Purchasing power of wage	1%	57%	1%	60,2%	1%	57%	1%	59,5%
REER index	-1%	-36%	-1%	-35%	-1%	-35,5%	-1%	-40%

Table Z: macroeconomic and energy indicators by scenario, with trade shock

	REFERENCE (S3)		GREEN (S7)		BLUE (S9)		BROWN (S11)	
	Average Evolution	Variation 2015-2050	Average Evolution	Variation 2015-2050	Average Evolution	Variation 2015-2050	Average Evolution	Variation 2015-2050
Real GDP	2,3%	120%	2,4%	128%	2,4%	131%	2,5%	139%
Unemployment	Average evolution : -2,1%, Variation 2015-2050 : -55%							
Energy production	~0%	-0,3%	-0,3%	-11%	0,3%	11%	1%	54%
Non-energy production	2,6%	148%	2,5%	140%	2,6%	143%	2,6%	146%
Energy consumption	3%	201%	-0,1%	-4%	2%	117%	3%	199%
Non-energy consumption	2%	82%	2,1%	109%	2%	84%	2%	100%
Investment volume	2,03%	99%	2,3%	118%	2,36%	123%	2,33%	121%
Capital stock	2%	107%	2%	116%	2%	118%	2%	118%

Taxes, % du PIB	-1%	-34%	-1%	-19%	-0,2%	-8%	-1%	-28%
Purchasing power of wages	2%	101%	2%	101,4%	2%	102%	2%	101,7%
REER index	-1%	-36%	-1%	-22%	-1%	-25%	-1%	-32%

Annex X: The TD KLEM-DZA model

KLEM (for Capital, Labour, Energy and Materials) is a TD macroeconomic, dynamic, recursive model deriving from a Solow-Swan growth model, representing two sectors of the economy: the energy sector, encompassing all activities from primary production and transformation to distribution and final consumption, and a non-energy sector aggregating activities of the rest of the economy. The KLEM-DZA version forecasts economic growth in annual time steps, driven by exogenous assumptions on the supply and productivity of labour, as well as on the investment rate. The objective of the KLEM model is to compute macroeconomic trajectories under constraint of exogenous energy flows and prices informed by a BU model, on both international and domestic markets, to focus on the assessment of overall macroeconomic impacts.

Both its labour and capital markets clear by adjustments of the wage w and the rental price of capital r. In the capital market, the endowment is systematically employed in its entirety (neoclassical hypothesis), while the labour market is suboptimal (Keynesian hypothesis) meaning that the wage w is implicitly rigidified by institutional constraints and its effective fluctuations are linked to fluctuations in the unemployment rate through an unemployment wage curve. The trade balance is exogenous (Equation 13) following the neoclassical practice, yet its macroeconomic closure is on domestic savings rather than on investment, following Johansen (1960), to reflect the degree of governmental control on the Algerian economy. This implies a growth trajectory more robust to scenario variants at the cost of final consumption variations. The investment effort is set as a share of GDP (Equation 10) that evolves to warrant that the capital stock grows apace with efficient labour when potential growth, defined by efficient labour increases, concretises.

The rest of this annex presents all the equations of the KLEM model. Before that and for reference purposes, it lists all variables and parameters below (see Table 1). The model counts 44 variables and 44 equations: equations 3, 15, 20, 22, 27, 29 and 32 cover both sectors and thus count twice; equation 28 defines the prices of the IO matrix and thus counts 4 times. All equations prevail at each time period of the model, from 2015 (the calibration year) up to 2050, in yearly time steps. We index good-specific notations with subscript E for the aggregate energy good and subscript Q for the aggregate non-energy good.

Table 1: KLEM-DZA notations

Notation	Description	Status
L	Labour endowment	1 parameter from the ILO and SSP2 (IPCC)

K	Capital endowment	1 parameter calibrated in 2015 then perpetual inventory (see below)
ϕ	Labour productivity (index 1 in 2018)	1 parameter from the ILO and SSP2 (IPCC)
L_i	Volume of labour in good i production	2 variables
K_i	Capital stock in good i production	2 variables
KL	Value-added aggregate of K_Q and L_Q in the production of good Q	1 variable
KLE	Aggregate of value-added KL and energy $\alpha_{EQ}Y_Q$ in the production of good Q	1 variable
C_i	Consumption of good i by households	1 variable C_Q, 1 parameter C_E from EnerNEO (updated at each iteration)
G_Q	Consumption of good Q by public administrations	1 variable
I_Q	Investment in good Q	1 variable
X_i	Export of good i	1 variable X_Q, 1 parameter X_E from EnerNEO (updated at each iteration)
M_i	Import of good i	1 variable M_Q, 1 parameter M_E from EnerNEO (updated at each iteration)
Y_i	Output of good i	2 variables
S_i	Total (domestic and foreign) supply of good i	2 variables
α_{ij}	Intensity of good i in good j	3 variables α_{QQ}, α_{EQ}, α_{EE}, 1 parameter α_{QE} from EnerNEO (updated at each iteration)
λ_i	Labour intensity of good i	1 variable λ_Q, 1 parameter λ_E from EnerNEO (updated at each iteration)
κ_i	Capital intensity of good i	1 variable κ_Q, 1 parameter κ_E from EnerNEO (updated at each iteration)
w	Wage	1 variable
r	Rental price of capital	1 variable
p_{KL}	Price of value-added KL in good Q production	1 variable
p_{KLE}	Price of aggregate KLE in good Q production	1 variable

p_{Y_i}	Output price of good i	2 variables
p_{Si}	Average price of good i supply	2 variables
p_{ij}	Price of good i used in the production of good j	4 variables
p_{C_i}	Price of good i for households	2 variables
p_{G_Q}	Price of good Q for public administrations	1 variable
p_{I_Q}	Price of good Q for investment	1 variable
p_{X_i}	Export price of good i	1 variable p_{X_Q}, 1 parameter p_{X_E} from EnerNEO (updated at each iteration)
p_{M_i}	Import price of good i	1 parameter p_{M_Q} price of the numéraire M_Q 1 paramètre p_{M_E} from EnerNEO (updated at each iteration)
CPI	Consumer Price Index (chained Fischer index)	1 variable
MPI	Import Price Index (chained Fischer index)	1 variable
u	Unemployment rate	1 variable
GDP	Gross Domestic Product	1 variable
R	Household revenue	1 variable
B	Trade balance value	1 variable
Ω_B	Adjustment factors inversely affecting imports and exports of the non-energy good (index 1 in 2015)	1 parameter calibrated on World Bank data from 2015 to 2020, converging to its 2015-2020 average in 2030, constant beyond[17]
Ω_L	Adjustment factors affecting labour productivity (index 1 in 2015)	1 parameter calibrated on World Bank data from 2015 to 2020, converging to its 2015-2020 average in 2030, constant beyond
Ω_K	Adjustment factors affecting capital productivity (index 1 in 2015)	1 parameter calibrated on World Bank data from 2015 to 2020, converging to its 2015-2020 average in 2030, constant beyond
Ω_w	Adjustment factors affecting real wage correlated to unemployment via the wage curve (index 1 in 2015)	1 parameter calibrated on World Bank data from 2015 to 2020, converging to its 2015-2020 average in 2030, constant beyond

[17] Ω_B becomes a variable in the model extended to the stabilisation of the macroeconomy.

α_{KL}	Coefficient of K_Q in the KL_Q CES function	1 parameter calibrated in 2015
β_{KL}	Coefficient of L_Q in the KL_Q CES function	1 parameter calibrated in 2015
σ_{KL}	Elasticity of substitution between K_Q et L_Q in KL_Q	1 parameter, source Koesler and Schymura (2015)
α_{KLE}	Coefficient of KL in the KLE CES function	1 parameter calibrated in 2015
β_{KLE}	Coefficient of $\alpha_{EQ}\ Y_Q$ in KLE CES function	1 parameter calibrated in 2015
σ_{KLE}	Elasticity of substitution between KL and $\alpha_{EQ}\ Y_Q$ in KLE	1 parameter, source Koesler and Schymura (2015)
α_Y	Coefficient of KLE in the Y_Q CES function	1 parameter calibrated in 2015
β_Y	Coefficient of $\alpha_{QQ}\ Y_Q$ in the Y_Q CES function	1 parameter calibrated in 2015
σ_Y	Elasticity of substitution between KLE and $\alpha_{QQ}\ Y_Q$ in Y_Q	1 parameter fixed at 0.77, based on Koesler and Schymura (2015)
σ_W	Elasticity of real wage to the unemployment rate	1 parameter fixed at 0.1, based on Blanchflower and Oswald (2005)
σ_S	Elasticity to relative prices of the share of imports in total non-energy supply	1 parameter fixed at 0.6, based on Koesler and Schymura (2015)
σ_X	Elasticity to relative prices of the non-energy export trend	1 parameter fixed at 1.0
δ	Depreciation rate of the capital stock	1 parameter at 4.00%
s_G	Ratio of public expenditure to GDP	1 parameter calibrated in 2015
s_I	Ratio of investment to GDP	1 parameter calibrated in 2015, calibrated on World Bank data from 2015 to 2020, constant beyond
τ_{ST_i}	Sales tax on good I sales	2 parameters calibrated in 2015
τ_{Yi}	Output tax on good i in production	2 parameters calibrated in 2015
$\tau_{MS_{ij}}$	Specific margins on good i sales to good j	2 parameters $\tau_{MS_{Qi}}$ calibrated in 2015 (nil), 2 parameters $\tau_{MS_{Ei}}$ from EnerNEO
τ_{MSC_i}	Specific margins on good i sales to households	1 parameter τ_{MSC_Q} calibrated in 2015 (nil), 1 parameter τ_{MSC_E} from EnerNEO
τ_{MSX_i}	Specific margins on good i exports	1 parameter τ_{MSX_Q} calibrated in 2015 (nil), 1 variable τ_{MSX_E}

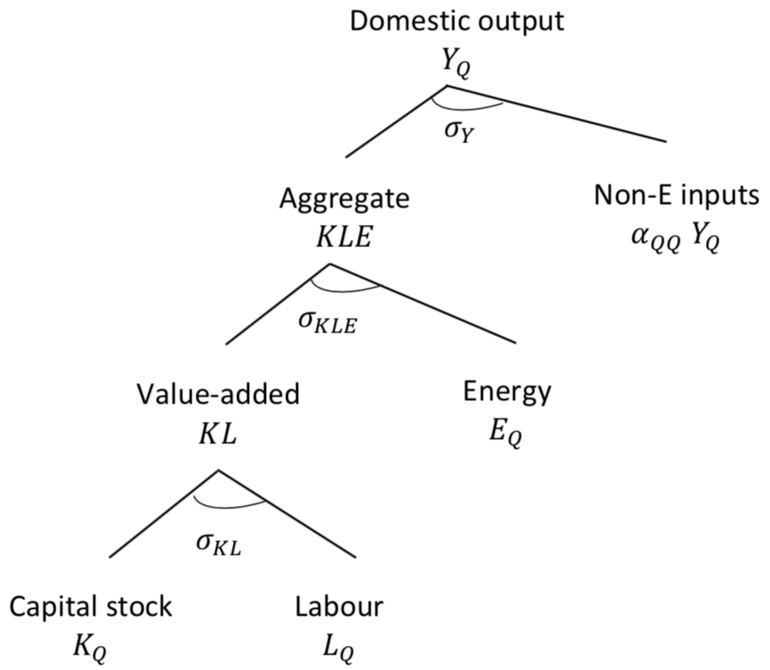
A_B	Ratio of aggregate net trade to GDP	1 parameter
A_i	Consumption of energy in the production of good i.	2 parameters from EnerNEO
A_w	Parameter of the wage curve	1 parameter calibrated in 2015

Production

The production of the energy good proceeds from exogenous energy consumptions $\alpha_{EE}\,Y_E$, directly flowing from the EnerNEO model of the Algerian energy system (Equation 3), as well as from consumptions of other factors dictated by technical coefficients αQE (non-energy goods and services), λE (labour), and κE (capital), whose evolutions are derived from EnerNEO's market price projections, thus exogenous to the KLEM model.

The non-energy production in KLEM follows a nested structure (Figure xxx) of CES functions trade-offs between inputs (Equations 1, 2 and 4 to 6), and non-energy trade as elastic to prices (Equations 11 and 12).

Figure xxx: Production structure of the non-energy good



At the foot of the nested structure, capital and labour trade off with a constant elasticity of substitution, σ_{KL}, to form a KL aggregate. The mobilized quantity of labour, L_Q, is augmented by a productivity factor ϕ, while both inputs labour and capital are adjusted by factors Ω, allowing a dynamic calibration on key macroeconomic variables:

$$KL = \left(\alpha_{KL}\,(\Omega_K\,K_Q)^{\rho_{KL}} + \beta_{KL}\,(\Omega_L\,\phi\,L_Q)^{\,\rho_{KL}}\right)^{\frac{1}{\rho_{KL}}} \tag{1}$$

with here and elsewhere, for convenience, $\rho_i = \frac{\sigma_i - 1}{\sigma_i}$. Facing prices r and w, cost minimization induces:

$$L_Q = \frac{1}{\Omega_L\,\phi}\left(\frac{\Omega_L\,\phi\,\beta_{KL}}{w}\right)^{\sigma_{KL}}\left(\alpha_{KL}^{\sigma_{KL}}\left(\frac{r}{\Omega_K}\right)^{1-\sigma_{KL}} + \beta_{KL}^{\sigma_{KL}}\left(\frac{w}{\Omega_L\,\phi}\right)^{1-\sigma_{KL}}\right)^{-\frac{1}{\rho_{KL}}} KL \qquad (2)$$

$$K_Q = \frac{1}{\Omega_K}\left(\frac{\Omega_K\,\alpha_{KL}}{r}\right)^{\sigma_{KL}}\left(\alpha_{KL}^{\sigma_{KL}}\left(\frac{r}{\Omega_K}\right)^{1-\sigma_{KL}} + \beta_{KL}^{\sigma_{KL}}\left(\frac{w}{\Omega_L\,\phi}\right)^{1-\sigma_{KL}}\right)^{-\frac{1}{\rho_{KL}}} KL \qquad (3)$$

Higher up the tree, the aggregate factor KL (value-added) and energy E again trade off with a constant elasticity of substitution, σ_{KLE}, to form a KLE aggregate. However, $\alpha_{EQ}\,Y_Q$, like $\alpha_{EE}\,Y_E$, is exogenously forced following EnerNEO results:

$$\alpha_{Ei}\,Y_i = A_i \qquad (4)$$

Consequently, KL is deduced from KLE, which we maintain (despite forcing $\alpha_{EQ}\,Y_Q$) as an aggregate following a CES function:

$$KLE = \left(\alpha_{KLE}\,KL^{\rho_{KLE}} + \beta_{KLE}\left(\alpha_{EQ}\,Y_Q\right)^{\rho_{KLE}}\right)^{\frac{1}{\rho_{KLE}}} \qquad (5)$$

Implying:

$$KL = \left(\frac{KLE^{\rho_{KLE}}}{\alpha_{KLE}} - \frac{\beta_{KLE}}{\alpha_{KLE}}\left(\alpha_{EQ}\,Y_Q\right)^{\rho_{KLE}}\right)^{\frac{1}{\rho_{KLE}}} \qquad (6)$$

On the tier immediately above, the KLE aggregate and non-energy input $\alpha_{QQ}\,Y_Q$ trade off with a constant σ_Y elasticity of substitution to form domestic output Y_Q. Facing prices p_{KLE} and p_{QQ}, cost minimization induces:

$$KLE = \left(\frac{\alpha_Y}{p_{KLE}}\right)^{\sigma_Y}\left(\alpha_Y^{\sigma_Y}\,p_{KLE}^{1-\sigma_Y} + \beta_Y^{\sigma_Y}\,p_{QQ}^{1-\sigma_Y}\right)^{-\frac{1}{\rho_Y}} Y_Q \qquad (7)$$

$$\alpha_{QQ}Y_Q = \left(\frac{\beta_Y}{p_{QQ}}\right)^{\sigma_Y}\left(\alpha_Y^{\sigma_Y}\,p_{KLE}^{1-\sigma_Y} + \beta_Y^{\sigma_Y}\,p_{QQ}^{1-\sigma_Y}\right)^{-\frac{1}{\rho_Y}} Y_Q \qquad (8)$$

Final consumption and investment

Household energy consumption C_E is exogenous, prompt by the EnerNEO model. Iterative convergence of the EnerNEO and KLEM models ensures consistency with household income levels.

From its side, household consumption of the non-energy good C_Q adjusts in order to close the model considering household revenue R.

$$p_{CQ}\,C_Q + p_{CE}\,C_E = R \qquad (9)$$

Public spending, p_{GQ}, is a constant share s_G of GDP (public spending in energy goods is zero by national accounting convention):

$$p_{G_Q} G_Q = s_G \, PIB \quad (10)$$

The GDP is defined on the expenditure side as:

$$PIB = \sum_{i=E,Q} p_{C_i} C_i + p_{G_Q} G_Q + p_{I_Q} I_Q + \sum_{i=E,Q} p_{X_i} X_i - \sum_{i=E,Q} p_{M_i} M_i \quad (11)$$

Investment expenses $p_{IQ}\, I_Q$ are an exogenous ratio s_I of GDP (investment in energy goods is zero, except for stock variations that are cancelled out in our hybrid data, see Annex 1).

$$p_{I_Q} I_Q = s_I \, PIB \quad (12)$$

International trade

Energy imports and exports M_E and X_E are exogenous, dictated by EnerNEO results. The convergence by iteration of the EnerNEO and KLEM models ensures consistency with domestic production and domestic demand.

The imports of the non-energy good, M_Q, are imperfectly substitutable to domestic production Y_Q to form total supply S_Q, following the Armington hypothesis (1969) with a CES σ_S. Yet, an exogenous shock Ω_B adjusts the volume resulting from the cost minimisation, in order to allow the dynamic calibration of the model on 2016 to 2020 data.

$$M_Q = \Omega_B \left(\frac{\beta_S}{p_{M_Q}} \right)^{\sigma_S} \left(\alpha_S^{\sigma_S} {p_{Y_Q}}^{1-\sigma_S} + \beta_S^{\sigma_S} {p_{M_Q}}^{1-\sigma_S} \right)^{-\frac{1}{\rho_S}} S_Q \quad (13)$$

The exports of the non-energy good, X_Q, mobilise a share of total supply S_Q, elastic to terms-of-trade (the export price to import price ratio) following a coefficient σ_X:

$$\frac{X_Q}{S_Q} = \frac{1}{\Omega_B} A_X \left(\frac{p_{X_Q}}{p_{M_Q}} \right)^{\sigma_X} \quad (14)$$

with A_M one constant calibrated on 2015 data. Exports are adjusted by Ω_B, the exogenous shock, following the dynamic calibration of the model on 2016 to 2020 data, inversely impacting exports and imports.

The trade balance B is the difference between exports and imports:

$$B = \sum_{i=E,Q} p_{X_i} X_i - p_{M_i} M_i \quad (15)$$

It is exogenous in the sense that its share to GDP maintains at a constant A_B ratio, leading to equilibrium in 2030 until the end of the projected period in all scenarios.

$$\frac{B}{PIB} = A_B \quad (16)$$

Market clearings

Market balance for each good i stems from the definitions of total domestic supply S_i seen from the use and resource sides:

$$S_i = \sum_{i=E,Q} \alpha_{ij} Y_j + C_i + G_i + I_i + X_i \qquad (17)$$

Imports and domestic production of energy good are assumed to be commensurable, so that the supply of energy good results from their sum:

$$S_E = Y_E + M_E \qquad (18)$$

For non-energy goods and services, the Armington assumption prohibits positing such a sum and imposes, by minimizing the costs of S_Q:

$$Y_Q = \left(\frac{\alpha_S}{p_{Y_Q}}\right)^{\sigma_S} \left(\alpha_S^{\sigma_S} {p_{Y_Q}}^{1-\sigma_S} + \beta_S^{\sigma_S} {p_{M_Q}}^{1-\sigma_S}\right)^{-\frac{1}{\rho_S}} S_Q \qquad (19)$$

On the labour market, real wage rigidities prevent the full utilization of labour input. A wage-unemployment curve (Blanchflower and Oswald, 2005) describes the elasticity σ_w of real wages (the purchasing power of wage w) to unemployment u. At each time step, the real wage level $\frac{w}{IPC}$, consistent with the observed unemployment rate at 2015 level (11.2%), is defined as the 2015 real wage multiplied by labour productivity gains ϕ and a 'wage moderation' factor Ω_w that allows the model to be calibrated to observed broad macroeconomic indicators (among them the unemployment rate) from 2016 to 2020, via one constant A_u calibrated in 2015:

$$\frac{w}{CPI} = \phi\, \Omega_w\, A_w\, u^{\sigma_{wu}} \qquad (20)$$

The unemployment rate is defined by the labour demand and the labour endowment:

$$u = 1 - \frac{\sum_{i=E,Q} L_i}{L} \qquad (21)$$

For each sector, labour consumption and output are conventionally related via the labour intensity:

$$L_i = \lambda_i\, Y_i \qquad (22)$$

On capital market, demands of the two productions balance out capital endowment K:

$$\sum_{i=E,Q} K_i = K \qquad (23)$$

Similar to labour, capital consumption and output are conventionally related via the capital intensity:

$$K_i = \kappa_i \, Y_i \tag{24}$$

Producer and consumer prices

Primary factor payments w the wage and r the price of capital rental are common to both sectors. They adjust according to their market balances.

The price of the KL aggregate p_{KL} is the canonical function (KL being a CES product of K and L) of prices r and p_{L}, and of the elasticity of substitution of the two inputs σ_{KL}:

$$p_{KL} = \left(\alpha_{KL}^{\sigma_{KL}} \left(\frac{r}{\Omega_K}\right)^{1-\sigma_{KL}} + \beta_{KL}^{\sigma_{KL}} \left(\frac{w}{\Omega_L \, \phi}\right)^{1-\sigma_{KL}}\right)^{\frac{1}{1-\sigma_{KL}}} \tag{25}$$

Contrary to p_{KL}, the price of the KLE aggregate specific to non-energy production cannot be defined as a function of prices p_{KL} and p_{EQ} and of the elasticity of substitution of the two inputs σ_{KLE} because exogenously setting E_{Q} in the KLE aggregate truncates the underlying cost-minimisation programme. Consequently, $\mathrm{p}_{\mathrm{KLE}}$ is rather inferred from the simple accounting equation:

$$p_{KLE} \, KLE = p_{KL} \, KL + p_{EQ} \, \alpha_{EQ} \, Y_Q \tag{26}$$

The producer price of the non-energy good p_{YQ} is again the canonical CES price of the KLE aggregate as well and the non-energy input to production $\alpha_{\mathrm{QQ}} \, Y_{\mathrm{Q}}$, to which a constant *ad valorem* output tax τ_{YQ}, as well as a constant rent mark-up τ_{RQ}, are added:

$$p_{Y_Q}\left(1 - \tau_{Y_Q} - \tau_{R_Q}\right) = \left(\alpha_Y^{\sigma_Y} \, p_{KLE}^{1-\sigma_Y} + \beta_Y^{\sigma_Y} \, p_{QQ}^{1-\sigma_Y}\right)^{\frac{\rho_Y - 1}{\rho_Y}} \tag{27}$$

For the energy good, the producer price is simply the sum of production costs, augmented by a tax on production and on the energy rent:

$$p_{YE} = p_{QE} \, \alpha_{QE} + p_{EE} \, \alpha_{EE} + w \, \lambda_E + r \, \kappa_E + \tau_{R_E} \, p_{YE} + \tau_{Y_E} \, p_{YE} \tag{28}$$

The import prices of both goods are exogenous: p_{MQ} is constant because the imported non-energy good is the chosen *numéraire* of the model; and p_{ME} follows an exogenous trajectory inferred from the EnerNEO model.

The average supply price of good i, p_{si}, flows from:

$$p_{S_i} \, S_i = p_{Y_i} \, Y_i + p_{M_i} \, M_i \tag{29}$$

Regarding purchasers' prices, the price of good i for the production of good j, p_{ij}, is equal to the supply price of good i augmented from agent-specific margins τ_{MSij} and *ad valorem* sales taxes τ_{STi}:

$$p_{ij} = p_{S_i} \left(1 + \tau_{MS_{ij}}\right)\left(1 + \tau_{ST_i}\right) \tag{30}$$

The consumer prices of households, public administrations, the investment good and exports are constructed similarly but drop the unnecessary specific margins when energy is not concerned (public consumption, investment), as well as sales taxes as regards exports:

$$p_{C_i} = p_{S_i}\left(1 + \tau_{MSC_i}\right)\left(1 + \tau_{ST_i}\right) \quad (31)$$

$$p_{G_Q} = p_{S_Q}\left(1 + \tau_{ST_i}\right) \quad (32)$$

$$p_{I_Q} = p_{S_Q}\left(1 + \tau_{ST_i}\right) \quad (33)$$

$$p_{X_i} = p_{S_i}\left(1 + \tau_{MSX_i}\right) \quad (34)$$

In the case of the energy good, the specific margin τ_{MSXE} endogenously adapts to accommodate the exogenous p_{XE} prescription.

The consumer and import price indexes CPI and MPI are computed as chained indexes, i.e. from one period to the next, according to Fisher's formula:

$$CPI_t = CPI_{t-1} \sqrt{\frac{\Sigma \;\; p_{Ci,t}\, C_{i,t-1}}{\Sigma \;\; p_{Ci,t-1}\, C_{i,t-1}} \frac{\Sigma \;\; p_{Ci,t}\, C_{i,t}}{\Sigma \;\; p_{Ci,t-1}\, C_{i,t}}} \quad (35)$$

$$MPI_t = MPI_{t-1} \sqrt{\frac{\Sigma \;\; p_{Mi,t}\, M_{i,t-1}}{\Sigma \;\; p_{Mi,t-1}\, M_{i,t-1}} \frac{\Sigma \;\; p_{Mi,t}\, M_{i,t}}{\Sigma \;\; p_{Mi,t-1}\, M_{i,t}}} \quad (36)$$

Extension to consider a non-price competitivity shock to achieve the employment objective

The above described model is extended to the evaluation of the trade shock allowing a given employment path to be respected by increasing the constraint

$$\mathrm{u} = A_u \quad (37)$$

with A_u the exogenous unemployment rate, and by making Ω_B, the trade shock that was a parameter calibrated on 2016-2020 observations, a variable. In this extended model, the value taken by Ω_B between 2016 and 2020 reproduces the one that had been obtained by calibration, since this extended model reproduces the conditions of the calibration on the years statistically informed.

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