EUROGREEN Model of Job Creation in a Post-Growth Economy

The Greens | EFA
in the European Parliament

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Executive Summary

Climate change and increasing inequality have emerged as the main challenges facing our societies over the past few decades. Their impact, as of 2018, is highly visible and well recognized by overall civil societies way beyond the academic circles that first alerted us of these concrete threats to contemporary standards of living, peace, and democracy. A wide range of public policies from basic income programs to radical decarbonization plans, usually as bold and massive as the challenges they aim to overcome, have been proposed, questioned and not rarely deemed economically and politically unfeasible.

This report discusses the viability, effectiveness and possible synergies between alternative policy options for low-carbon transition and social justice based on simulation scenarios from the EUROGREEN model. We argue that the flexibility and comprehensiveness of this system dynamics simulations allow us to envision eventual trade-offs between income distribution and GHG reduction as well as unexpected policy effects due to interactions among different industries and heterogeneous agents that would go unnoticed in more traditional macroeconomic models without similar feedbacks among socio-economic and environmental variables.

Recently, macro-economists began to explicitly include environmental and social variables in their models in order to properly investigate the trade-off between economic growth and physical and social constraints. Among the efforts to contribute to this task is the ongoing development of the so called "Ecological Macroeconomics" (Victor, 2008b; Røpke, 2016; Hardt and O'Neill, 2017; Jackson, 2016). To a large extent, the development of ecological macroeconomics draws upon an ongoing convergence between Post-Keynesian and Ecological Economics, which are also the foundation of the **"EUROGREEN model of Job Creation in a Post-Growth Economy"**.

This model, thought to be a tool to simulate policies for low-carbon transition with social equity, relies on a *demand–driven* economy. Changes in wages, wealth, propensities to consume, taxes, and benefits have direct and indirect effects on the total production, through an Input-Output productive structure. On the supply-side, investment decisions depend on industry demand level and its effects on capacity utilization, but are limited by accumulated profits that must finance a fixed proportion of industry investments together with private debt. However, investments boost the adoption of labour and/or energy saving technologies that, in turn, have subsequent impacts on employment, wages, profits, and greenhouse gases (GHG) emissions.

In what follows, we briefly summarize the main features of the model which aims to capture the complexity of an interconnected macroeconomic system:

- ◇ **System-dynamics** modelling approach to analyze the interconnections and feedbacks among socio-economic and environmental variables.
- ◇ **Dynamic Input-Output** approach with *ten industries*[1] that provides a consistent economic framework, coherent with the official national accounts, to study inter-industry trade. Additionally, innovations in energy efficiency affect the composition of intermediate trade in the two energy industries: the fossil fuel and the electricity and gas supply sectors. An increase in the energy efficiency (i.e., output per unit of energy), by any of the ten industries considered, results in a reduction of the shares of intermediate purchases from the two energy industries.
- ◇ Assessment of the **energy flows**, that arise from industry and household energy demand, produced with five different sources – *nuclear, renewable, gas, coal, and oil* – to evaluate environmental sustainability issues, such as the greenhouse gas emissions, from the implementation of alternative policies.
- ◇ **Heterogeneous households** classified according to their economic status: *employed, unemployed, inactive*, and *retired*.
- ◇ Definition of three kind of employed **workers by skill** – *low, middle,* and *high* – defined by the maximum educational attainment of the working age population.
- ◇ Realistic **welfare system** with a detailed *tax and benefits account* that allows to model of the budgetary consequences of alternative policy instruments over time[2].
- ◇ **Innovation** processes driven by *input-cost ratio* for energy and labour. Each industry selects a combination of old and new technologies (that emerges randomly) to minimize the joint labour and energy costs. A higher investment rate guarantees a faster adoption of innovations due to the renovation of their capital stock, while higher labour or energy costs slightly increase the probability of labour and energy saving innovations, respectively.
- ◇ **Empirical estimation** of unavailable *parameters* to provide realistic and consistent results.
- ◇ The current version of the model is based on the **French** economy, whose structure is reflected on the tax-benefit system modelled on the 2014 initial values used in the simulations.

The **EUROGREEN** model aims at proposing an alternative viewpoint, from the so-called "orthodox" approach, in order to promote concrete solutions to climate change and socio-economic inequalities. The main novelty is the modelization of the main relations among the ecological and socio-economic dimensions, which compose a complex system. Its main task is to build reliable scenarios to assess the aftermaths of alternative policies and to identify and evaluate eventual trade-offs and undesired effects that could emerge

[1]The industries considered are aggregated in ten macro-sectors, on the base of the last EU national accounts classification (NACE Rev.2, 2008), as follow: agriculture, mining, fossil energy, manufacturing, electricity and gas supply, construction, services, public sector, financial sector and other, which includes mostly households as employers.

[2]For the comprehensive list of taxes and social benefits modelled see Section 1.3.

from the application of single and specific policies, due to the presence of interconnection in the real economic system. Moreover, it is a tool to define and develop more refined policies which include a mix of intervention that are able to, at least partially, offset the undesired effects of a single policy.

This Report presents the scenarios coming out from the alternate application of **six single policies** and identifies its pros and cons. In a second step, these single policies are combined in order to evaluate the aftermaths of **three policy mixes**. The purpose is to balance the contrasting tendencies that could result from myopic intervention (e.g., a Basic Income policy might improve income distribution at the cost of increasing GHG emissions; Working Time Reduction might increase employment and the labour share but is less effective than other policies to reduce income inequality, higher technological progress reduces GHG emissions at the expense of employment and income distribution).

In what follows, we briefly describe six alternative single policies (⋄) and the three policy mixes[3] (◈) which are compared to a reference scenario (the Baseline) characterized by the maintenance of the contemporary social welfare system and the current trends in the main macroeconomic and environmental variables. The six single policies are:

⋄ **New Productive Revolution (NPR)**: models a higher rate of labour and energy saving due to technological progress, with greater advances in labour productivity and energy efficiency induced by investments in R&D and technology.

⋄ **Basic Income (BI)**: introduces a basic income program with annual benefits that amount to €5,580 to all working age adults. The basic income either substitutes or reduces other public transfers such as unemployment and sickness and disability benefits.

⋄ **Job Guarantee (JG)**: the public sector hires unemployed workers at the minimum hourly wage up to a maximum intake of *300,000 workers/year*.[4] Those are assumed to contribute either to public and care services or to the maintenance and installation of environmental friendly infrastructure.

⋄ **Working Time Reduction (WTR)**: that is set in order to gradually reduce from about 35 to 30 weekly working hours.

⋄ **Energy Mix (EnM)**: the share of non-renewable sources in electricity production is gradually reduced over a period of 30 years: Gas (from 2.3% to 0.8%), Coal (from 2.9% to 0%), Oil (constant at 0.4%), Renewable (from 17% to 75%), and Nuclear (from 77.5% to 24%). Moreover, an "*electrification*" process is modelled to gradually increase the share of electricity in the total energy demand of all industries.

⋄ **Carbon Tax and Border Carbon Adjustment (BCA)**: includes the carbon tax per ton of GHG emissions until 2030 – on the base of the French National "Energy Transition for Green Growth" program – together with additional increases of the carbon tax from the 2030s on, and a border carbon adjustment intervention that applies similar tax rates according to the GHG content of imports.

The combination of a subset of these policies allow us to build three policy-mix scenarios that reflect alternative viewpoints to face social, economic, and environmental issues. Namely:

◈ **Green Growth (GG)**: the combines the implementation of *New Productive Revolution*,

[3]For a comprehensive description of the policies listed below refer to Chapter 2.

[4]See the box 3.2 for a discussion of the feasibility and the results from a stronger program that aims at hiring 500,000 workers/year.

Energy Mix, and *Carbon Tax and Border Carbon Adjustment* policies. This scenario simulates a transition to a low-carbon production driven by fast technological innovations and green investments that also sustain economic growth.

- **Policies for Social Equity (PSE)**: this scenario considers a mix of environmental and social policies for a low-carbon with social justice. It combines *Job Guarantee*, *Working Time Reduction*, *Energy Mix*, *Carbon Tax and Border Carbon Adjustment* and a higher rate of technical progress on energy efficiency only.
- **De-Growth (DG)**: this policy mix adds to the **PSE** the effects of de-growth in private consumption and exports, together with an increase of a *wealth tax* up to ≈ 1.5% in average.

Relevant Policy Issues and Summary of Results

Mainstream policy recommendations often tend to ignore the interweaves of social, economic and environmental domains and, at the same time, the EU governance architecture reflects this separation. Our study, in contrast, supports the necessity of a holistic vision in order to define the most effective set of social policies.

Taking this broad perspective, our approach highlights that meeting highly ambitious environmental, social, and economic targets (e.g. GHG emissions reduction, EU's implementation of the SDGs) requires severe societal changes. The "EU Climate Action" is a paradigmatic case of how well-established institutions seem to minimize the necessity of radical change. The achievement of at least 80% reduction of GHG emissions by 2050, with respect to 1990 levels, entails a structural change of our societies which involves productive structure, labour market institutions and welfare systems. Moreover, the widespread degree of *technological optimism* tends to overestimate the capacity of technology to solve environmental issues, surpassed only by the current technological pessimism towards employment and automation.

We challenge this viewpoint and argue that there are no simple win-win solutions and that linear cause-and-effect relationships are undermined by the dynamic feed-backs among social, economic, and environmental variables. Indeed, the simulation results presented in this Report suggest that all the policies considered have benefits and significant drawbacks, either economic or environmental. Still, when policies that entail more radical change in our societies are put forward, orthodox answers tend to highlight the risks, usually deeming these policies not viable or economic unsustainable. This line of thinking is advocated by the **De-Growth** critique which argues in favor of policies that directly aim at reducing income inequality and social injustice. For instance, in the de-growth community, three socio-economic policies are often discussed: Basic Income, Job Guarantee, and Working Time Reduction.

Simulations and scenario analysis make it possible to understand and analyze the root causes of the adverse, often unexpected, consequences of each single policy and to draw more complex research questions, such as: (i) What is the best policy to avoid the negative environmental effects (i.e., more GHG emissions) of a Universal Basic Income? (ii) Are top-down policies (e.g., Basic Income or Job Guarantee) and technological innovations sufficient to attain environmental targets with social equity or do they require bottom-up initiatives from the society (e.g., voluntary consumption reduction)? Simulation results highlight that Ecological Macroeconomics and, to some extent the **EUROGREEN** model, have the potential to question established single policies and, alternatively, the possibility to visualize the joint effects and interactions of mixed policies. Indeed, more complex policy mixes – as the three suggested below – are likely better suited to overcome the massive challenges that our societies must face, namely: transitioning to low-carbon emission with social equity. The **EUROGREEN** model, based on the policy simulation outcomes, supports *heterodox* approaches in promoting the debate on (radically) alternative social and environmental solutions.

The main results from the simulated policies are summarized in what follows. Starting from **NPR**, the simulations show that relying exclusively on technological progress is not sufficient to achieve the target of 80% reduction in GHG emissions in 2050, despite a significant fall in total emissions.[5] Moreover, unbridled technological progress determines high social costs – in terms of reduced consumption and production that follows major increases in unemployment – because higher labour productivity (i.e., automation) supersedes human work. Indeed, the comparison with the Baseline scenario shows that the minimal increase in GDP per capita – associated to *NPR* – is paired with higher unemployment rates and income inequality. Such a path might be unsustainable from a social perspective and not highly convenient from the economic side.

R *Technological progress alone fosters the reduction of GHG emissions but it aggravates unemployment and inequality.*

This statement holds even when the **Green Growth** policy mix (i.e., *NPR* + *EnM* + *BCA*) is applied because the same social contradictions emerge – in terms of unemployment and income inequality.

From the environmental side a remarkable reduction in GHG emissions is attained because, in this case, the technological progress is combined with a marked change in the energy mix in favour of cleaner energy sources. These outcomes suggest that the two pillars of the *Green Growth* paradigm (i.e., technological optimism and economic efficiency) produce relevant social problems. Hence, policy makers should consider and debate before electing this as the unique viable path towards low-carbon transition. As an alternative to *GG*, we define the so-called **Policies for Social Equity** mix (i.e., *JG* + *WTR* + *EnM* + *BCA* + Energy Efficiency) which achieves similar environmental results. Indeed, the projected emissions of the latter reach the 25% of the 1990 levels in 2050, while the former is expected to reduce greenhouse gases up to about 26% of the 1990 emissions level. **PSE** also yields far better social outcomes, with very low unemployment rate (less than 2%) and a fairer income distribution. As expected, these results require a stronger public intervention to sustain both the *JG* and the *WTR*.[6] Indeed, the deficit-to-GDP in *PSE* floats around 3.5% throughout the whole simulation time-window, while in *GG*, it falls to less than 1% by 2050.

R *The joint introduction of JG and WTR together with environmental policies significantly reduces emissions while improving income distribution and employment.*

The last policy mix considered takes into account the effects of **De-Growth** proposals, specifically reducing private consumption and exports while increasing wealth taxes together with the *Policies for Social Equity*. The addition of a substantial (voluntary) consumption reduction further improves the positive environmental impact projected

[5] This result refers to the acceleration of technical progress simulated through an increase in the probability of innovation.

[6] We opted not to include a *Basic Income* program because it achieves similar improvements in income distribution with respect to the *JG* program. However, the former generates much higher costs in terms of public expenditure in spite of a relatively low annual benefit of 5,580€. See the comparisons between *BI* and *JG* in Sections 3.4 and 3.5.

in the scenario to a reduction of GHG emissions down to about 18.5% of 1990 levels by 2050.[7] In order to achieve this target and keep low both unemployment rates and income inequality, the *DG* scenario is characterized by a remarkable increase in public expenditure compensated by higher wealth taxes.[8] This entails a deficit-to-GDP ratio that oscillates in the range 3.5-4.5% in the whole period. Note that, in a context of decreasing GDP the increase of this ratio does not imply an increase of public debt. Indeed, if the public debt decreased at a slower pace with respect to GDP, the ratio would increase.

R *The De-Growth policy mix generates improvements in social equity and is the only scenario to achieve the GHG reduction goal by 2050 combining bold public policies (i.e., PSE + wealth taxation) with a voluntary social choice to reduce consumption.*

A take-home message of this study is that Ecological Macroeconomic models, like **EUROGREEN**, might envision and highlight the unexpected, non-trivial trade-offs and adverse effects of myopic policies. These drawbacks can be overcome by fine-tuned policy designs. Although the post-growth society entails significant changes in the productive structure and in the distribution of economic rewards, the EUROGREEN model shows the presence of dynamic complementarities between social and environmental policy goals. Identifying and exploiting these opportunities is necessary to address the multitude of crises, but also to guarantee the survival and the flourishing of our democratic institutions (Beddoe et al., 2009; Piketty, 2018). Finally, the **EUROGREEN** model encourages further investigations and innovative policy proposals which need a supporting network of field specialists to evaluate the impact of alternative policies and compare them with previous experiences, a process where organized civil society plays a crucial role.

The report contains two major Parts. Part I consists of three Chapters; Chapter 1 introduces the topic providing an overview of the model and a brief description of the methodology and of the main results. Chapter 2 provides a detailed description of six single-target policies and of the three proposed policy mixes. Chapter 3 discusses the results of the numerical simulation on the main economic, social, and environmental indicators. Part II consists of Chapter 4 which presents the building blocks of the model, explaining the drivers of the main variables and their reciprocal relations and feedbacks. It also contains Appendix A with a sensitivity test for the random innovation process, to check the robustness of the model. Supplementary Material and the list of the equations, parameters can be found at the following link **Supplementary Material**. Finally, an interactive and user-friendly version of the model which allows interested users to create personalized scenarios is available at **The Eurogreen Website**.

[7] The reduction of exports is introduced to avoid an increase in exports due to an increase in price competitiveness that follows consumption reduction, partially offsetting the impact of consumption reduction on GHG emissions.

[8] Wealth taxes are assumed to vary in line with the change in the average propensity to save.

1. Introduction

1.1 Objective and Results

The increasing pressure of climate change together with social inequalities are nowadays the main issues in the political agenda worldwide, and in particular in the European Union (EU). This report presents the outcomes of the simulations implemented through the **EUROGREEN** Macroeconomic model – that, as explained below, is grounded on *post-Keynesian* economics and combines the new field of *Ecological Macroeconomics* with *System Dynamics* – that is being developed to provide a concrete understanding of some important policy challenges associated with the transition to ecologically sustainable and socially equitable post-growth societies in the EU. The model aims to test, in a formal setting, the effectiveness and coherence of standard 'green' economic policies and to support the creation of widely attractive narratives about possible futures. For this purpose, the model generates a range of scenarios from the present (2014) to the year 2050. Data for the French economy provide the (empirically grounded) initial conditions of the current simulations.

The main focus lies on a subset of challenges for attaining the overall goal of *sustainable prosperity*, namely full employment (or – more broadly – decent livelihoods), low inequality, fiscal sustainability, and a sustainable energy system. In particular, we analyze how the implementation of low-carbon policies is likely to impact upon current trends toward industrial automation and technological unemployment. We also focus on how the implementation of such policies may change the political economy of Working Time Reduction and work sharing, in comparison with recent history.

Our model aims at representing an alternative to the so-called "orthodox" solutions to climate change and socio-economic inequalities by capturing the complex relations between the ecological and socio-economic systems and to show the possible trade-offs that could emerge from the application of mono-thematic policies. For these reasons, other than discussing the results of six *single-policy* scenarios, we introduce three alternative **policy mixes** to balance the contrasting tendencies that could result from myopic intervention (e.g., a Basic Income policy might improve income distribution at the cost of increasing GHG emissions; Working time reduction increases employment and the labour shares but it is less effective in reducing income inequality).

1.2 Methodology

The increasing general awareness of the accelerating deterioration of the global environment, together with a growing body of evidence on the close links between economic growth and environmental impacts, are making the provision of coherent alternatives to 'growthism' an ever more urgent task.[1] A growing number of macro-economists are directly including environmental variables in their models in order to properly face these issues. Among the efforts to contribute to this task is the ongoing development of the so called "**Ecological Macroeconomics**" (e.g. Victor, 2008b; Røpke, 2016; Jackson, 2016; Hardt and O'Neill, 2017). To a large extent, the development of ecological macroeconomics draws upon an ongoing convergence between post-Keynesian and Ecological Economics. Until recently, post-Keynesian economics rarely paid attention to environmental issues, and ecological economics strongly favoured Micro-economic themes over macroeconomics, which is the level of analysis of most post-Keynesian economics. This is now changing, as latent synergies are exploited for the development of Ecological Macroeconomics.

The EUROGREEN model is part of this field, drawing upon works such as Caverzasi and Godin (2014), Victor and Jackson (2015), Naqvi (2015), Dafermos et al. (2015, 2017), and Naqvi and Stockhammer (2018). The model also shares the system dynamics approach of ecological macroeconomic models such as Jackson and Victor (2015), and Bernardo and D'Alessandro (2016). Compared to other macroeconomic models, EUROGREEN offers a more detailed description of the social protection system. Macroeconomic models, if at all they include a *public sector*, typically treat public expenditure as a single aggregate. The greater detail allows the dynamic modelling of the budgetary consequences of the introduction of basic income or job guarantee programs. However, EUROGREEN only captures the macroeconomic effects of these policies, while an assessment of the distribution consequences of income and wealth among households requires a micro-economic approach (e.g., by distinguishing households by specific characteristics such as marital status, number of children, disabilities).

Below, we briefly summarize the main features introduced in the model in order to capture the high complexity of the economic systems:

- **System-dynamics** approach to analyze the interconnections and feed-backs among the socio-economic and environmental components.
- **Dynamic Input-Output** approach with ten main industries that provides a consistent economic framework, coherent with the official national accounts, to study inter-industry connections.
- Assessment of the **energy flows** with the distinction of different sources (nuclear, renewable, gas, coal, and oil) to evaluate the environmental sustainability and the level of greenhouse gas emissions.
- **Heterogeneous households** classified according to their economic status: employed, unemployed, inactive, retired and capitalists.
- Distinction of employed workers in three **skill levels** determined by their maximum educational attainment.
- Realistic macroeconomic **welfare state model**: a detailed tax and benefits system allows the dynamic modelling of the budgetary consequences of the introduction of a basic income or job guarantee.

[1] Pioneering works in this field include Victor (2008a); Jackson (2009). See also Hall and Klitgaard (2011); Antal and van den Bergh (2013); Smil (2016).

- Partially **endogenous innovation process** (driven by the input-cost ratio) that affects energy efficiency, labour productivity and the sectoral technological-mix.
- **Empirical** estimation of the main parameters to provide realistic and consistent results.

1.2.1 System Dynamics

System Dynamics (**SD**) is an approach to policy analysis and design which is applied to complex system (Richardson, 2013). The field developed initially from the work of Forrester (1970). Over the following decades, SD methodology was applied to a wide range of economic and social issues, from corporate and industrial problems to the limits of world's economic growth. Indeed, "The limits to growth" report (Meadows et al., 1972) was the first endeavour to use SD for the analysis of the interweaves between biophysical constraints, population dynamics and economic growth.

SD has a high degree of flexibility and a graphical structure which allows identification of feedback mechanisms (Costanza et al., 1993; Costanza and Ruth, 1998). In fact, there are few attempts to apply system dynamics to the study of macroeconomics. One exception is Yamaguchi (2011) who develops a detailed model in SD representing the conventional macroeconomic relationships. Moreover, Victor and Rosenbluth (2007), Victor (2008a, 2012) develop a macroeconomic model calibrated for Canada with the aim of investigating the consequences of low growth or negative growth on environmental, social and economic variables.[2] These contributions revived the interests on dynamical simulation models for the analysis of low carbon transition and social equity which is at the basis of the development of ecological macroeconomics.

1.2.2 Post-Keynesian Economics

The post-Keynesian literature takes inspiration on the seminal works of John Maynard Keynes and Michal Kalecki as well as other prominent XX^{th} century economists such as Nicholas Kaldor, Joan Robinson, Piero Sraffa, Luigi Pasinetti, Abba Lerner and Wynne Godley.[3] Historically the post-Keynesian literature has focused most of its efforts in macroeconomic topics such as growth, distribution, public finance, inflation, investments, and international trade as well as on financial and monetary economics.

The foundations of modern post-Keynesian economics consist in a combination of the principle of effective demand as the main driver of output, cost-push inflation, and endogenous money supply or exogenous interest rates set by the monetary authority. These are elements of an economy whose dynamics are determined by the demand-side as opposed to theories based on the marginalist theory of value in which only supply-side factors have a real impact on production and prices, to which demand efficiently adapts.[4]

In post-Keynesian economics, aggregate demand determines production and income. Hence, it relies on the assumption that firms have idle capacity and are able to adapt production to demand. In other words, productive factors such as capital and labour are not fully employed. Therefore, output and growth dynamics are determined by aggregate demand due to the elasticity of the productive structure of an economy idle resources.

[2]Furthermore, the Millennium Institute develops the T21 project, the results being summarised in the report entitled "Towards a Green Economy" (UNEP, 2011). See, also, Bassi (2008); Bassi et al. (2010).

[3]A comprehensive review of post-Keynesian economic foundations and its sub-strands of literature is presented by Lavoie (2014a).

[4]Other strands of literature, such as new Keynesian economics, introduce demand-side effects on the short-run assuming market failures and price rigidity. Their underlying economic foundations, however, are neoclassical and supply-side dictates the long-term trends in new Keynesian models.

Consequently, if economies do not operate at full capacity inflation cannot be a demand-side phenomenon.[5] Prices are usually determined in the post-Keynesian literature as a mark-up over cost of production given by intermediate goods, machines and labour. Inflation then is considered the outcome of a conflict in distribution among workers and capitalists that takes place within the determination of wages and prices, and consequently profit margins.

On the monetary and banking side too demand, for loans and money, plays a relevant role. According to endogenous money theory (Moore, 1988) banks create monetary base creating deposits for the clients to whom they lend money. The process of money creation, therefore, starts from firms and households demand for loans that if accepted by banks are converted into deposits. Banks then adjust the reserves either directly accessing inter-bank or central bank credit lines or selling assets. The monetary authority, therefore, accommodates banks' demand for reserves and money supply is endogenously determined while central banks keep control over basic interest rates.

Fiscal policy as a stabilizer during crisis has also been on the forefront of post-Keynesian ideas Neto and Vernengo (2004). Over the following Chapters we simulate the macroeconomic effects of a job guarantee program. This idea was pioneered by Lerner's (1943) proposal of functional finance within the post-Keynesian literature. The government acts as an employer of last resort for citizens, as central banks do for commercial and investment banks.

1.2.3 Ecological Macroeconomics

Ecological Macroeconomics is a new field of research that is emerging in the "post-growth" community. The main motivation is to address the macroeconomic consequences of a low-carbon transition and viable alternative to economic growth (Jackson and Victor, 2016). Indeed, nowadays, only few attempts tried to deal with the complex interconnections and feed-backs between macroeconomic factors, such as unemployment, growth and inflation, and natural resources exploitation and environmental damages (e.g., Rezai et al., 2013; Dafermos et al., 2017).

The need of a proper understanding of the dependence of the macro-economy on the natural environment together with the rejection of orthodox growth models have led to the combination of post-Keynesian and ecological economics approaches. This approach offers the possibility of finding counter-intuitive macroeconomic effects due to specific policies (Rezai and Stagl, 2016). However, Ecological Macroeconomics tries to go ahead post-Keynesian approach in directly addressing ecological problems (e.g., climate change, loss of biodiversity, and so forth) and social justice. In the latter case, many social policies are discussed, such as basic income, job guarantee and working time reduction.

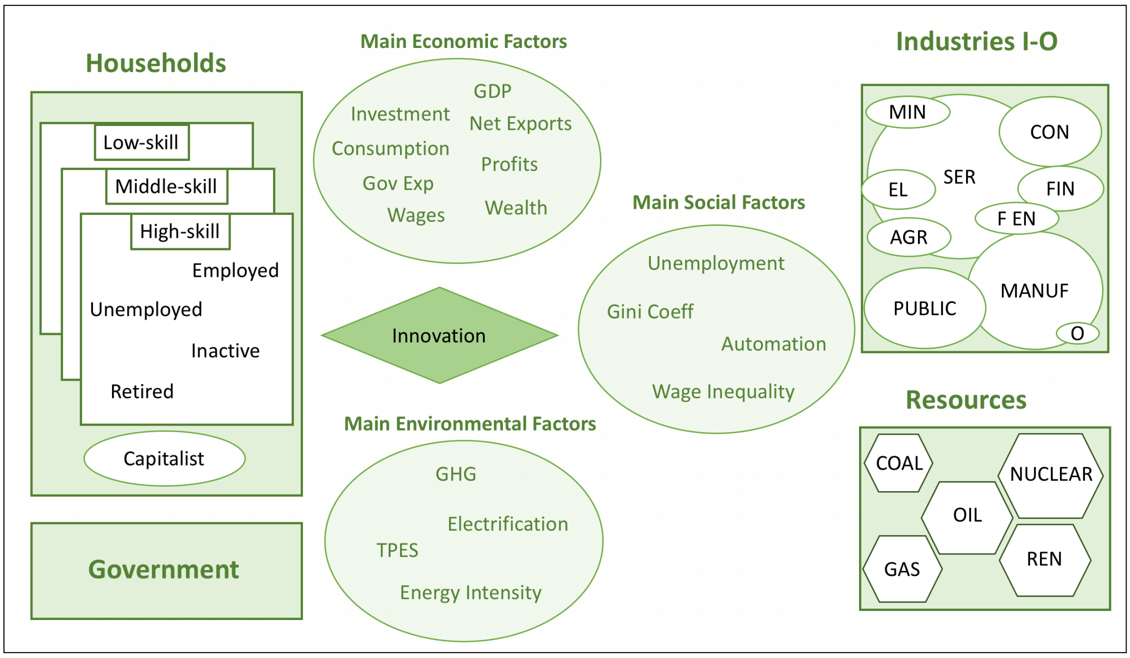
In summary, the EUROGREEN model, in line with the Ecological Macroeconomic literature, offers an analytic framework to understand economy-environment interactions on a macro-scale. It provides a tool to assess the direct and indirect consequences of policy interventions, through a scenario analyses.

[5] Inflation is the neoclassical literature is broadly understood as a consequence of demand in excess of full capacity production.

1.3 Overview of the EUROGREEN Model

Fig. 1.1 offers a broad picture of the main variables included in the model, such us heterogeneous agents, multiple industries and different energy source, other than the main indicators.

Figure 1.1: Macro-view of EUROGREEN model



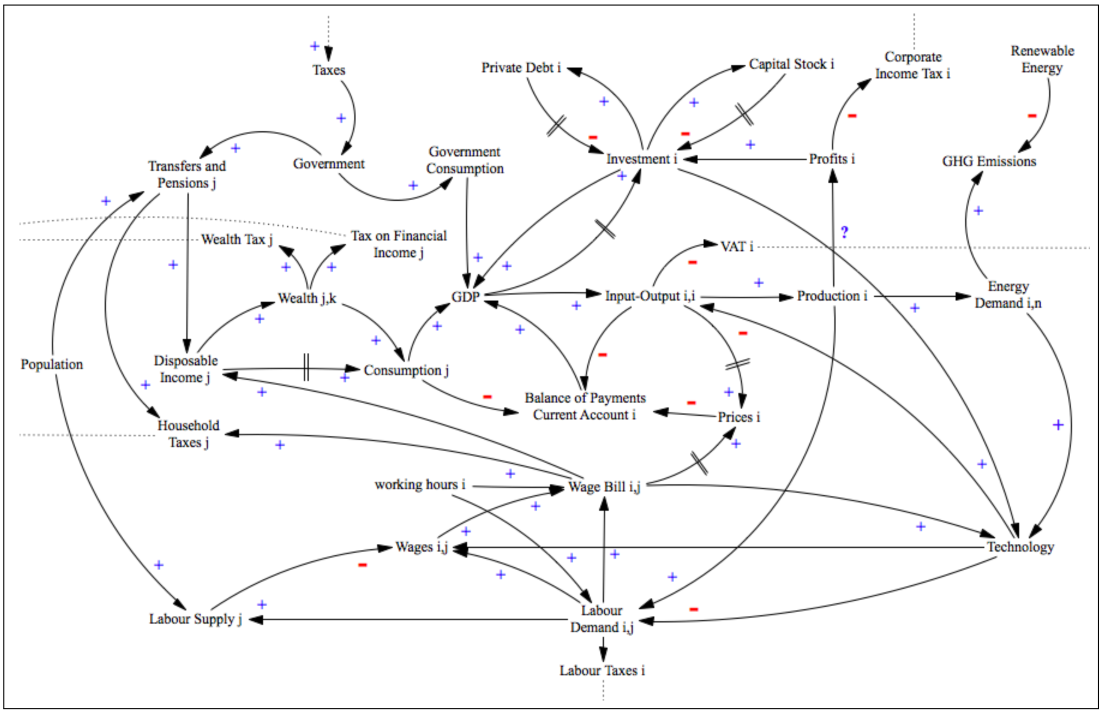
On the left the description of heterogeneous agents, on the right the supply-side structure (including industries and energy sources), in the center the main variables and indicators of the economic, social, and environmental dimensions.

The economy is *demand–driven*. Changes in wages, wealth, and propensity to consume have direct and indirect effects on the total production, through the inter-industrial trade (Leontief coefficients). Moreover, investment decisions depend on industry level demand, through capacity utilization and are limited by accumulated profits that must finance a fixed proportion of industry investments. On the other hand, investments impact on labour productivity and energy efficiency that, in turns, affect wages, profits, and environmental performances. Profits are partially used to self-financing producing a self-reinforcing feedback on investments. Finally, innovations in energy efficiency affect the composition of intermediate trade of the energetic sectors, in particular the higher the energy efficiency of a particular sector, the lower its share of purchases from the energetic sectors.

Fig. 1.2 shows a conceptual representation of the EUROGREEN model through SD. Although we highly simplify the structure, the figure highlights positive and negative feedback loops and the circular causality which characterize our model. Note that the current version of the model is based on the French economy (2014 values), although the framework can be easily extended to other European countries for comparisons.

Table 1.1 shows the tendencies of the main macroeconomic and environmental indicators until 2050 in the reference scenario. For further details on the main assumptions and the description of the building blocks of the model see Chapter 4

Figure 1.2: Scheme of the System Dynamic model



Graphical representation of the feedback effects and lags among the main variables. Subscript i and j denote the industry and the skills, respectively. The signs on the arrows indicate a positive (+) or a negative (−) causal relationship, while the vertical double bar denotes a delayed effect.

Table 1.1: Main indicators of the Baseline scenario

	Indicator (%)	*2014 – 2019*	*2020 – 2029*	*2030 – 2039*	*2040 – 2050*
Economic Performance	*Real GDP growth*	1.27	1.07	0.98	0.93
	Real per capita GDP growth	0.76	0.73	0.75	0.77
	Deficit/GDP	2.27	3.84	2.71	1.60
	Labour Productivity growth	0.18	0.65	1.11	1.71
Labour market	*Unemployment rate*	11.27	8.49	8.38	10.59
	Unemployment rate low-skill	18.93	12.87	11.64	13.01
	Unemployment rate middle-skill	11.09	8.83	9.66	13.81
	Unemployment rate high-skill	7.64	5.93	5.29	5.72
Inequality and Environment	*Labour Share*	79.20	64.62	64.08	67.46
	Gini Coefficient	34.58	34.07	34.23	39.32
	Energy intensity growth	−1.15	−1.66	−2.78	−3.95
	GHG emissions growth	0.17	−0.59	−1.97	−3.23

The values in the cell are the yearly averages by decade, in percentage.

2. Simulated Policies

The **EUROGREEN** model is thought to be a tool to define and simulate the economic, social, and environmental impacts of alternative policy scenarios. These are evaluated by detecting the propagation of all the direct and indirect effects throughout the economy, with a focus on GHG emissions. The sub-section 2.1 describes the six single-policies assessed, whose results will later be presented in Section 3. In a second step, these six single-policies will be combined to compose policy mixes, which are presented in sub-section 2.2. While some of the following policies can be directly implemented, such as a Basic Income program or Carbon Taxation, others are better described as scenarios in which alternative economic conditions are simulated. That is the case presented in the New Productive Revolution scenario in which a faster pace of technological progress is simulated. Appendix B presents a summary of all the single policies used in the simulations, with a brief comment and an overview of the individual impact on our main indicators (see B.1 and B.2).

2.1 Single Policies

The following single-policies are simulated independently. The first one assumes an acceleration of technological progress, while the following three define alternative social policies for employment and income distribution. Finally, the last two are mostly focused on environmental targets.

2.1.1 New Productive Revolution (NPR)

Technological progress is modelled assuming that the emergence of innovative processes, affecting labour productivity (λ) and energy efficiency (η), follows a random distribution. In each period, each industry,[1] knowing the available technological solutions, selects the

[1] Here, we can apply the common approach of a representative firm, within each industry, that represent the behaviour that we would expect on average.

cost minimizing technology among all the four possible combinations (Ω_i), as showed in Table 2.1.[2]

New labour and energy saving technologies are available to industries if their probabilities of arrival, given by a random uniform distribution, are above a certain threshold (ω_i) that is endogenous in the model (and it depends on the variations in energy-labour cost ratio). Hence, the *New Productive Revolution* scenario is simulated reducing these thresholds for labour saving (ω_2), energy saving (ω_3), and for both together (ω_4) such that new technologies are available more often. The overall impact of increasing labour productivity and its effective adoption and application in different industries is explained in sub-section 4.4 of Chapter 4.

Table 2.1: List of available technological innovations

Techn. Mix	Labour Productivity	Energy Efficiency
Ω_1	$\lambda_t = \lambda_{t-1}$	$\eta_t = \eta_{t-1}$
Ω_2	$\lambda_t > \lambda_{t-1}$	$\eta_t < \eta_{t-1}$
Ω_3	$\lambda_t < \lambda_{t-1}$	$\eta_t > \eta_{t-1}$
Ω_4	$\lambda_t > \lambda_{t-1}$	$\eta_t > \eta_{t-1}$

The Table shows all possible combinations of technological innovations that can emerge. In each period (t) the labour productivity (λ_t) and the energy efficiency (η_t), might be higher, lower, or equal to the previous period levels ($\lambda_{t-1}, \eta_{t-1}$). Then, combining all the economic viable possible cases, we define four technological mix.

Ω_1 is the old technology, Ω_2 represents a technology which favours labour productivity w.r.t. energy efficiency (which could also worsen), while Ω_3 is specular to the last case. Finally, Ω_4 is a win-win technology where both labour productivity and energy efficiency improve with respect to the previous period. The difference between labour and energy saving technologies in the Baseline and New Productive Revolution are illustrated in Fig. 4.1. While in the Baseline simulation average labour productivity and energy efficiency increase 1.17% and 2.47% per year, their respective yearly growth rate in the *NPR* scenario are of 1.47% and 2.87%, respectively.

2.1.2 Basic Income (BI)

The *Basic Income* program simulated is unconditional but not universal, meaning that is applied to all working age population (15-64 years), but not to retired citizens. An yearly monetary benefit of **€5,580** per person is introduced gradually, over a time-window of 5 years (it adds €1,116 each year until it attains the total benefit of €5,580), and it substitute the other social transfers, such as the unemployment benefits, the *Revenu de solidarité active*, and the sickness and disability benefits.

2.1.3 Job Guarantee (JG)

The second policy for income distribution and employment simulated is the *Job Guarantee* program in which the government directly hires unemployed workers acting as an

[2] A more thorough explanation of the innovation modelling in EUROGREEN is presented in subsection 4.6.

employer of last resort Wray (1997); Sawyer (2003). We assume a maximum of **300,000** workers per year which are paid the minimum hourly wage.

For the sake of simplicity, the skill distribution of those hired from the *JG* program is assumed to follow the distribution of unemployed workers. That is, if in a certain year, the 30% of the unemployed are low-skill, the same share of the newly hired *JG* employees will be low-skill individuals. Finally, we assume that these workers take part of two different productive activities, in equal proportion, such as: (i) *services*, such as care work and and public services that substitute for part of the private sector services, and (ii) *ecological activities* for the maintenance and implementation of ecological infrastructure such as photo-voltaic panels and double glazed windows that increase households' energy efficiency.

Note that, as in the *BI* policy, the *JG* program substitutes the *Revenu de Solidarité Active* paid to unemployed workers, but not the same benefits for citizens out of the labour force. Moreover, the *JG* directly reduces the amount of government expenditure on unemployment benefits as workers are pulled out of unemployment and into the program.

2.1.4 Working Time Reduction (WTR)

In the simplest of the job creation and distribution policies we simulate a reduction of legal working time from 35 to **30** weekly hours.[3] As stated above, the implementation of this policy is assumed to take 5 years to be fully implemented.

2.1.5 Energy Mix (EnM)

This scenario simulates a gradual increase in the share of renewable energy sources in the **electricity** production at the expense of gas, coal, and nuclear sources, over a period of *30* years (from year 2020 to 2050). The simulated variation in the energy-mix for electricity production is presented in Table 2.2. The *EnM* policy also presumes an *electrification* process in the demand for energy. Industries and households demand for coal, oil, and gas is assumed to be reduced by 0.5% per year and replaced by electricity, once the *energy mix* policy is introduced.

Table 2.2: Energy Mix composition for Electricity generation

Energy Sources	**2014 (%)**	**2050 (%)**
Renewable	16.98	74.74
Nuclear	77.51	24.21
Oil	0.37	0.37
Gas	2.26	0.81
Coal	2.87	0.00

The percentages of year 2014 refers to the actual composition of the French power generation (Source: IEA, `https://www.iea.org/statistics`), while those of 2050 are the results of the presented energy policy.

[3]France had already introduced 35 hours work weeks in the turn of the century.

2.1.6 Carbon Tax and Border Carbon Adjustment (BCA)

The last single policy refers to the application of two environmental taxes. The first one is a common *carbon tax* that has been introduced in France in 2014 (€7 per ton of CO_2) and that, based on the actual French environmental plan, must attain €100 per ton of GHG emissions in 2030. In this context, we assume an additional increase of 4.4% per year,[4] which sum up to €188 per ton in 2050.

The second fiscal instrument introduced is a *Border Carbon Adjustment* tax that imposes the same carbon tax levels on polluting imports, according to their GHG contents, to all industries except agriculture.

2.2 Policy Mixes

This Section presents the three policy-mix scenarios, the main idea is to suggest alternatives solutions for low-carbon transition, considering also the social and economic effects.

2.2.1 Green Growth (GG)

Definition 2.1
Green Growth = New Productive Revolution + Energy Mix + Carbon Tax and Border Carbon Adjustment

This scenario simulates a low-carbon transition based on: higher rates of technological progress (**NPR**) toward labour and energy saving innovations, energy power generation mix variation (**EnM**), and the application of the **BCA** policy. This policy-mix mirrors the mainstream paradigm for which a significant reduction of GHG emissions **(REF)**, can be boosted exclusively by new and clean technologies, neglecting indirect social consequences, such as the job destruction that might emerge from increased labour productivity (i.e. automation).

2.2.2 Policies for Social Equity (PSE)

Definition 2.2
Policies for Social Equity = Job Guarantee + Working Time Reduction + Energy Mix + Carbon Tax and Border Carbon Adjustment + High Energy Efficiency

As a direct alternative to **GG** we combine **EnM** and **BCA** together with policies devoted to sustain higher employment levels and to avoid deleterious effects income inequality, namely the **JG** and **WTR** programs.[5] Additionally, it is assumed a higher rate of technological progress in energy saving innovations or **High Energy Efficiency (HEnE)**. That is, an increased probability of arrival of technology Ω_3 presented in Table 2.1 on the **NPR** scenario. In contrast to **GG**, this policy mix should simulate a transition to low-carbon with more social equity, but likely at the expense of private profits and public expenditure.

[4] This percentage corresponds to the linear increase to pass from €56 in 2020 to €100 per ton in 2030, as planned by the French government.

[5] We opted not to include a *Basic Income* program because it achieves similar improvements in income distribution with respect to the *JG* program. However, the former generates much higher costs in terms of public expenditure although a relatively low annual benefit of 5,580€. See the comparisons between *BI* and *JG* in Sections 3.4 and 3.5.

2.2.3 De-Growth (DG)

The last policy mix considers also the necessity to reduce growth and consumption to respect the biophysical limits and to reduce the economic ties among people, the sweeping dependency on markets, and the concentration of wealth (Kallis, 2018).

Definition 2.3
De-Growth = Job Guarantee + Working Time Reduction + Energy Mix + Carbon Tax and Border Carbon Adjustment + High Energy Efficiency + Consumption Reduction + De-Growth Wealth Tax

With respect to *PSE*, the **De-Growth** policy imposes higher **Wealth Taxes** (below the 1.5% at the end of the period) that increase in line with the average propensity to save, to fund the government expenditure. Moreover, it introduces a so-called *Consumption Reduction* action, to say a reduction in household consumption levels. This option is not a policy, rather is an assumption that accounts for the possibility that citizens, aware of the already highly visible challenges posed by climate change, voluntarily reduces their material needs. We calibrate this so that, starting from 2020, the marginal propensities to consume of households decrease by 1.61% per year.[6]

[6] The yearly reduction of 1.61% in the propensity to consume is set in order to obtain a fall of 50% in 2050.

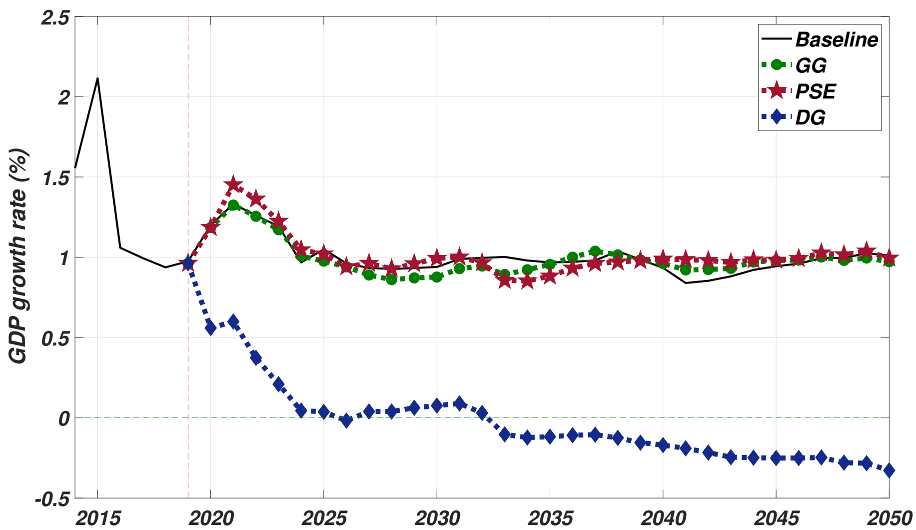
3. Main Simulation Results

This Chapter presents the main results, divided in five Sections, with a focus on the three policy mixes. Although comments on single policies are present along the following paragraphs their simulation results are summarized in a unique set of graphs (see Fig. 3.10) at the end of the current Chapter.

3.1 GDP and Growth

Fig. 3.1 shows the simulated dynamics of real GDP growth rate under each scenario.

Figure 3.1: Real GDP Growth rate (%)

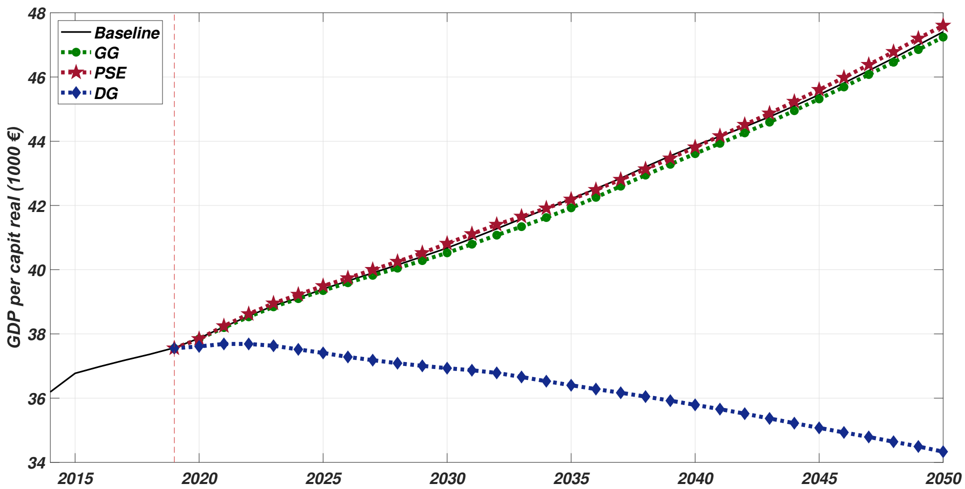


Yearly percentage change in the economy wide real GDP (deflated), from 2014 to 2050, for the Baseline scenario and the three policy-mix scenarios.

The effect of each policy mix is visible from the 2020*s* onward (vertical red dotted line), year in which they are activated in the model. Three cases out of four attain a similar rate of growth which converges to about 1%, although **PSE** and **GG** yield qualitative and quantitative differences with respect to employment, income distribution, and public deficit-to-GDP ratios. The main exception is the **DG** policy mix that, as expected, is characterized by declining yearly rates – negative from the 2030s, attaining a rate of around −0.3% in 2050. Another distinctive behaviour of the **DG** simulation is that it seems to detach from the baseline simulation at least one period before the other two policy mixes. This is due to the fact that the consumption reduction simulated has a direct impact on final demand and, hence, on GDP, while the other policies only affect it indirectly through increased consumption due to higher employment (as, for instance, in case of **PSE**).

Although **PSE** and **GG** have somewhat identical real growth rates, nominal GDP expands the most under **PSE** due to its slightly higher inflation rates which also have a negative impact in the balance of payments current account in this policy mix. The effect of prices is evident in Fig. 3.2 that shows the real GDP per capita, in levels, deflated by the base year (2014) prices.[1] Once again, the paths of **GG**, **PSE**, and of the Baseline are tightly close each other. **DG** shows a slightly decreasing trend, attaining a reduction of ≈ 5% below the starting year (2014) value and of about 28% with respect to the Baseline simulation value for 2050. Although important, this indicator does not capture the different social consequences (e.g., income distribution) as explained in Section 3.4.

Figure 3.2: Real GDP per Capita (1000 €)



Yearly average real GDP per capita, from 2014 to 2050, for the Baseline scenario and the three policy-mix scenarios.

These results are determined by the alternate combination of the single policies that compose each policy mix. **GG** and the Baseline show similar GDP growth rates because the economic policies of the former (**NPR** and **EnM**) have no significant impacts on output. Growth rate dynamics in **PSE** are a mix between the effects of **JG** and **WTR**. While **JG**

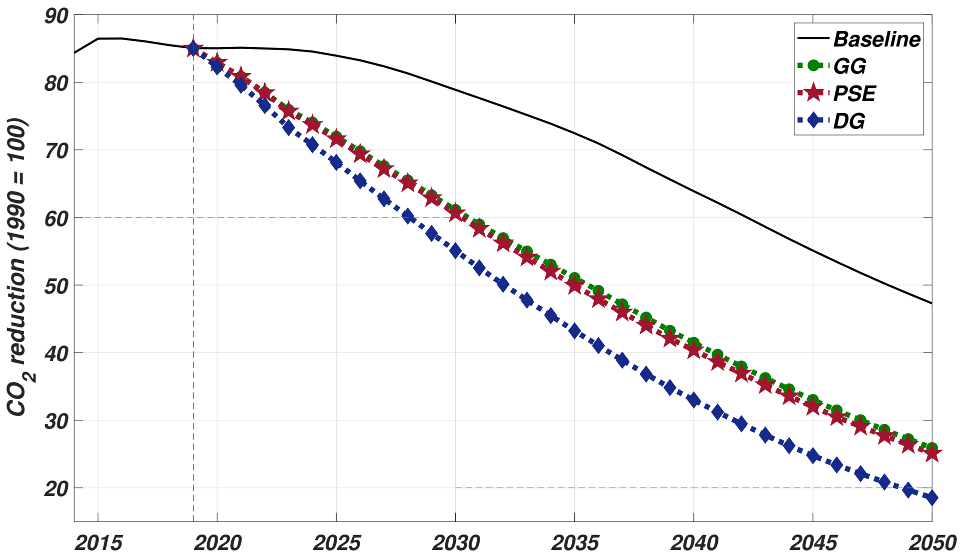
[1]Note that the real values are obtained by setting the prices of the initial year (2014) to 1 and then measuring the other years in terms of annual variations. Notably, the Baseline and *GG* are characterized by rather stable prices (in terms of consumer price index), while *PSE* shows an increasing trend, the opposite to what happen in *DG*.

alone permanently increases growth rates, **WTR** is characterized by lower growth in its first six years (2020 – 2026), followed by higher rates between 2027 and 2036 and then a convergence to Baseline growth rates in 2050. The dynamic of **DG** is mostly dominated by the *Consumption Reduction* assumption and, to a lesser extent, by the exports dynamics which overwhelm the effects of **JG** and **WTR**. Note that the **BI** program is the single policy attaining the highest GDP growth rates, around 2% for 7 years. This effect though dissipates over time while the **JG** program induces more persistent growth since it directly sustains aggregate demand through employment. This, together with the higher cost of **BI** in terms of public deficits, is the reason for which it was excluded from both the **PSE** and **DG**.

3.2 Greenhouse Gas Emissions

The variation in greenhouse gas emissions is mostly driven by: the level of economic activity (that tend to push up air pollution), the energy sources mix, and the energy efficiency. Fig. 3.3. shows the total air emissions as a percentage of 1990 levels. The only policy mix whose projected emissions reach the EU target – 20% of the 1990 levels in 2050 – is **DG**, while **PSE** and **GG** bring down GHG emissions to approximately 25%. These three scenarios are qualitatively different from the Baseline that reduces GHG to only 47% of 1990 emissions.

Figure 3.3: Greenhouse Gas Emissions Reduction (1990 = 100)



Yearly fraction of GHG reduction (compared with 1990), from 2014 to 2050, for the Baseline scenario and the three policy-mix scenarios.

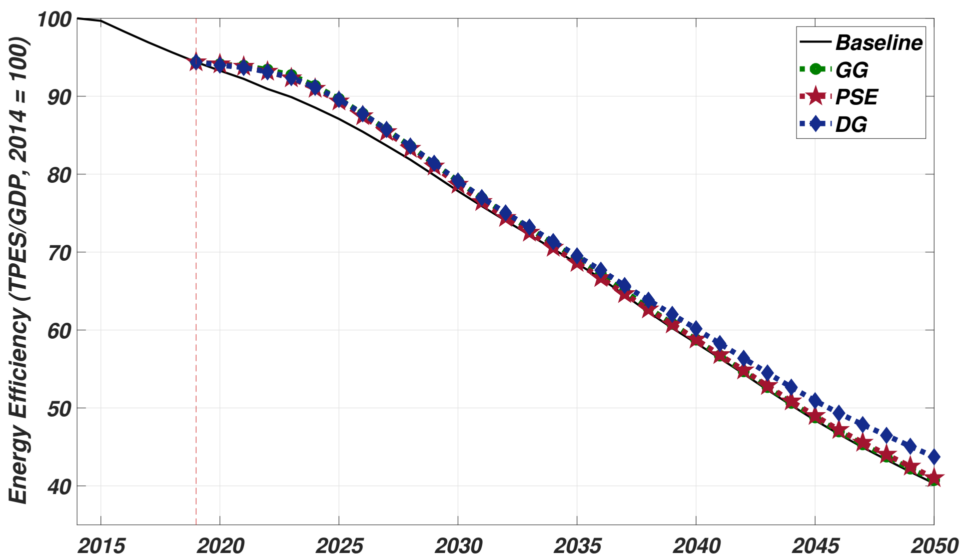
Most of the reduction in the Baseline scenario (which does not include any specific carbon reduction strategy)[2] is due to technological progress that improve energy efficiency and labour productivity. Thus, more efficient technologies seem to have a remarkable impact on emissions even on the Baseline scenario. While energy efficiency has a direct impact on GHG emissions – through reduced energy intensity (i.e., *TPES/GDP*) – labour productivity has indirect effects – through reducing consumption and production – due to

[2]In each scenario we set the carbon taxes as explained in sub-section 2.1.6.

higher unemployment rates. In case of **PSE** and **GG** scenarios, the main positive impact on GHG emissions is due to **EnM** that alone ensures a reduction to almost the 28% of 1990 levels (see panel (b) of Fig. 3.10, bottom-right plot). A further push is given by the introduction of the **HEnE** assumption. The **DG** policy mix too also benefits from an indirect effect on emissions via production. The further reduction from around 25%, of the other two policies mix, to around 18% is explained by the fall in private consumption of households and in exports which reduce production and energy demand. What emerges from the **EUROGREEN** simulations is that massive efforts, both from the demand and supply side – such as consumption reduction, increase of renewables, EnM, HEnE – are required to fulfill the EU targets also entailing relevant structural economic change and, possibly, institutional adaptations.

Note that, the technological side alone is not able to utterly account for the outcomes of each policy mix. Indeed, Fig. 3.10b clearly shows that each scenario is characterized by almost the same path of declining use of energy per unit of output, unless slight differences in case of **DG**. Hence, it is a further clue that similar environmental results (in terms of GHG reductions) can be attained through alternative routes. The main reason being that the greatest reduction in emissions comes from a change in the energy mix utilized to produce electricity and not from technological progress. Moreover, a significant part of GHG reductions that result from accelerated technological progress seems to depend on the indirect effect that increased labour productivity has on reducing employment and, hence, aggregate demand and production.

Figure 3.4: Energy Intensity (2014 = 100)



Yearly change in energy per unit of output (compared with 2014), from 2014 to 2050, for the Baseline scenario and the three policy-mix scenarios.

On the effects of single policy we further comment on graph 3.10b, on the south-east quadrant of Fig. 3.10. It depicts the economy-wide average energy intensity, that is the amount of energy required to produce a unit of GDP. While, as expected, the **NPR** scenario outperforms all the others achieving the largest reduction in energy intensity, the highest energy intensity is verified on the **EnM** scenario. The increase in renewable energies at the expense of nuclear, oil, coal and gas results in a less efficient energy and electricity production, however the shift to clean sources more than compensates this loss in efficiency when it comes to the reduction of GHG emissions.

3.1 Zero-Nuclear Energy

An alternative formulation of the **EnM** policy, included in all the three policy mixes, simulates a more radical change in energy mix that induces the *share of nuclear energy in electricity production to zero* whereas in the standard **EnM** it goes from 77.5% to 24.2%. We assume that the electricity production from nuclear power is compensated by the same increase of renewable energy sources that in the zero-nuclear case sh should rise from 17% in 2014 to 98.9% in 2050, instead of 74.7% foreseen in the standard **EnM** scenario.

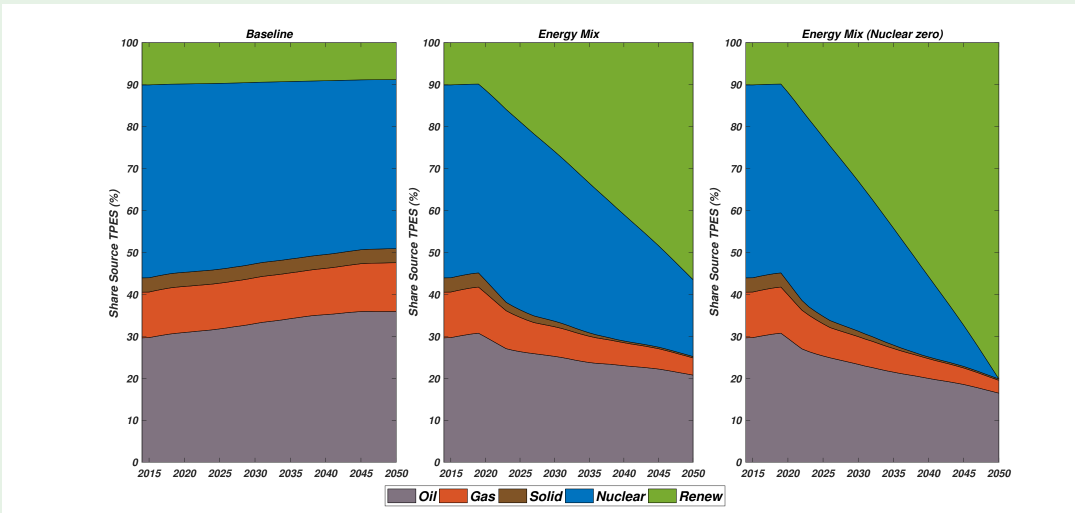
Given the massive change required to transit toward a zero-nuclear energy, we assume that starting from 2020 the share of nuclear energy falls by 2.5% per year instead of the 1.7% simulated in **EnM**.[a] Based on the idea that a zero nuclear strategy should foster clean energy production, we introduce, in this case, a bolder decarbonization plan that promotes a faster substitution from polluting (liquid and gas) to renewable sources, by further increasing the dependence on electricity power. Looking at the reduction in GHG emissions in 2050 with respect to the 1990 level, a comparison between the standard and zero nuclear **EnM** in the three policy mixes analyzed in this Chapter is summarized below:

Energy Mix (Standard): 25.9% (*GG*), 25.1% (*PSE*), 18.5% (*DG*);

Energy Mix (Zero Nuclear): 22.4% (*GG*), 21.3% (*PSE*), 15.9% (*DG*).

Note that this improvement in environmental performance is not a consequence of the substitution between nuclear and renewable in energy production since both have no direct GHG emissions to produce energy.[b] Therefore, the further reduction in emissions is a consequence of the additional stronger electrification process that increases the substitution of oil and gas by an additional 0.5% and 0.2% per year.

Share of energy sources for TPES



The change in the mix of energy sources utilized for electricity production under the Baseline, **EnM** and **Zero Nuclear EnM** is illustrated on the graphs above. It allows us to visualize the challenge ahead of our societies in the transition to low-carbon economies based on renewable energies. As seen, burdensome actions seem necessary to fulfill the EU targets without nuclear energy, such as a drastic energy mix change, social policies, and a different lifestyle with lower consumption (i.e., *DG*).

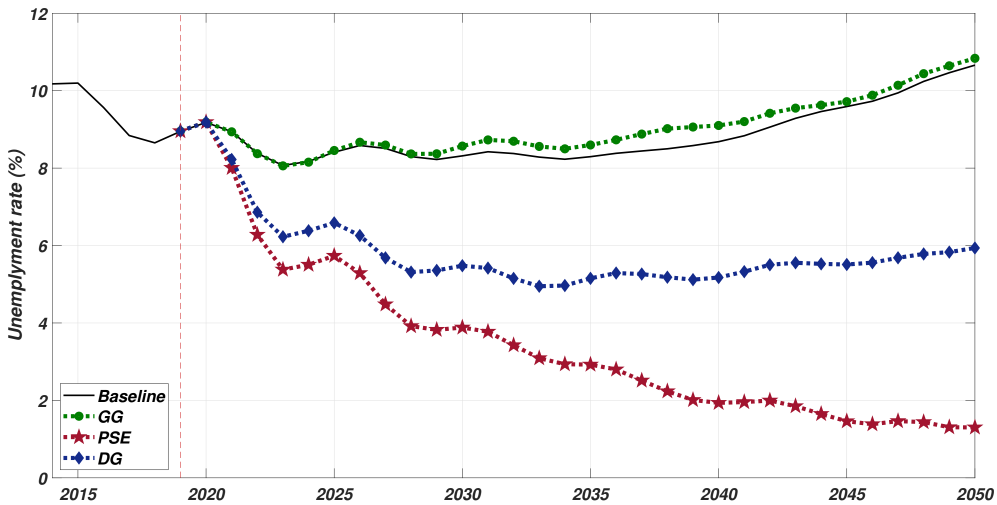
[a]See in figures 3.3, 3.4, 3.10a and 3.10b for the results coming from *EnM* alone

[b]The EUROGREEN model does not assess the potential environmental impacts of nuclear energy production from nuclear waste and contamination, for instance.

3.3 Employment

The most striking divergences among the alternative policy mixes come from the social indicators, as in case of unemployment rates that are depicted in Fig. 3.5.

Figure 3.5: Unemployment Rates (%)



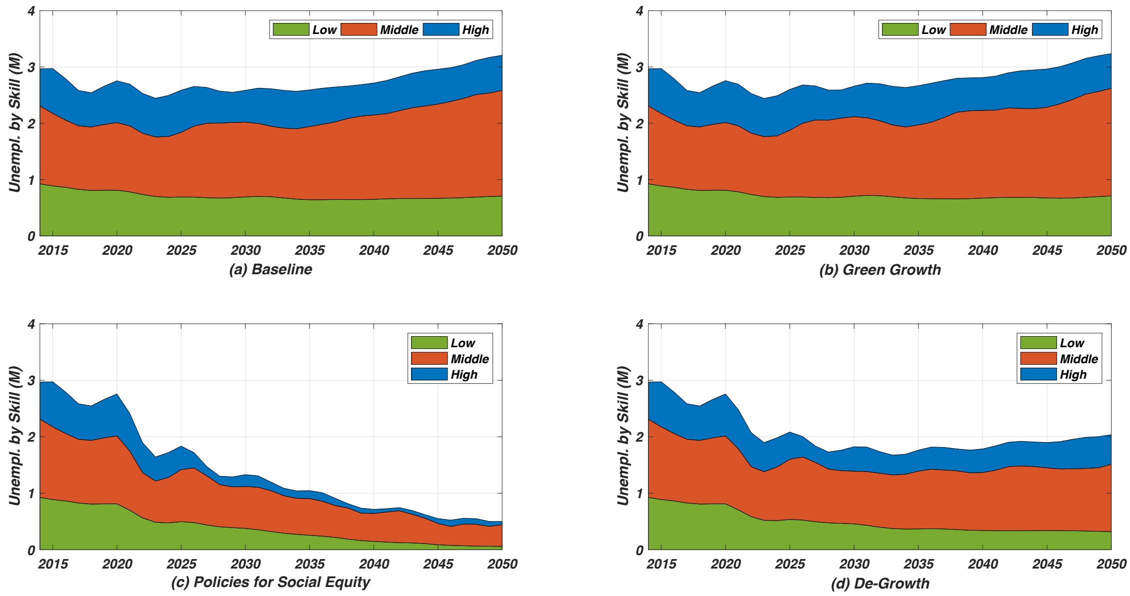
Yearly unemployment rates, from 2014 to 2050, for the Baseline scenario and the three policy-mix scenarios.

In the Baseline and **GG** scenarios unemployment increases up to 11% in 2050, after an initial fall until 2024. The increase in unemployment is mostly due to labour saving technical progress which is higher under **GG**. In case of **PSE** and **DG** unemployment rates are lower and around 1.3% and 5.9% by 2050, respectively, because they include policies that directly stimulate employment (*JG* and *WTR*).

On the other hand, both **PSE** and **DG** ensure larger improvements in unemployment rates, mostly in the former case. This difference, despite identical employment policies in both scenarios, is due to indirect effects that aggregate demand has on the supply and thus on production and employment. The reductions in consumption and export, simulated in **DG**, offsets the possible expansion of the private sector that would follow from the increase in demand due to higher employment (pushed by the *JG* and *WTR* programs). Hence, the divergence between these last two scenarios reflects both direct and indirect effects of the labour market policies simulated.

Although important, the unemployment rate is a highly-aggregated indicator that hides the distribution of unemployed people, in base of their educational attainments. Fig. 3.6 shows the composition of the unemployment, by skills, expressed in millions of unemployed workers. There is a visible relative increase in the proportion of middle-skill workers in the pool of unemployed, although this trend is mitigated in the **PSE** and **DG** scenarios by the sharp fall in total unemployment. This trend in middle-skill employment reflects the *job polarization* modelled in EUROGREEN, following recent empirical evidence on this phenomenon (e.g., Goos et al., 2009; Acemoglu and Autor, 2011; Coelli and Borland, 2016). Even though we model transitions across skill levels,[3] towards those with lower unemployment rates, it is not enough to offset trends in employment demand. Note that the initial high share of unemployed middle-skill workers mirrors the actual structure of the French labour market in 2014. High-skill workers start from the lowest unemployment rates, roughly 6%, which continues to fall in all four scenarios because it is favoured by new technologies. At last, the share of low-skill in the pool of unemployed also falls but at a lower pace than that of high-skill workers.

Figure 3.6: Unemployment level by skill (millions of workers)



The four graphs represent: (a) Baseline, (b) Green Growth, (c) Policies for Social Equity, (d) De-Growth.

The effects of the single-target policies on unemployment are, once again, presented in Fig. 3.10, at the end of this Chapter. The two policies included in **PSE** and **DG**, that is **JG** and **WTR**, have a direct impact on employment and, hence, are those that reduce unemployment rates the most. However, the effects of a **JG** are much larger since the public sector keeps hiring workers at the established maximum rate of 300,000 per year until there are no more unemployed. **WTR**, on the other hand, has a direct but once-and-for-all effect. Hence, it reduces unemployment until industries continue to adapt to the new 30 working hours' week. Additional effects of an increased aggregate demand from the newly hired workers on employment accelerate the fall of unemployment rates in **WTR** and **JG** as we argued in the comparison between **PSE** and **DG** in Fig. 3.5. Towards the final years of the simulation unemployment rates in **WTR** tend to increase following the same trend of the Baseline and **NPR** scenarios, although at a lower level.

Finally, Table 3.1 compares the outcomes, for some key labour market indicators from both demand and supply side, of the **EUROGREEN** Baseline against the long-term

[3]A more detailed description of the distribution of labour supply between skills is found in Section 4.1 of Chapter 4.

projections of "The 2018 Ageing Report" (European Commission, 2017).[4] Overall trends look very much alike with one important difference. While in the EU report all variables follow a trend, that is unemployment rates decrease and participation rates increase monotonically from 2016 to 2050, some of EUROGREEN projections show non-linear dynamics. Participation rates first increase from 71.2% to 75.8% between 2016 and 2040 and then decrease to 72.7% in 2050. Total employment also increases from 26.4 to 28.6 million workers between 2016 and 2040,[5] and later decreases to 26.9 millions in the end of the simulation. This inflection, in the EUROGREEN Baseline scenario, are due to the long-term effects of labour saving technological progress which increases unemployment and reduces aggregate demand in the final years of the simulation whenever there are no direct labour market policies to offset automation.

Table 3.1: Employment Indicators EUROGREEN Baseline and EU Report 2018

Employment Indicators	2016	2020	2030	2040	2050
Unemployment rate (15-64)	9.6%	9.2%	8.3%	8.7%	10.7%
	10.2%	*9.3%*	*8.5%*	*8.2%*	*7.9%*
Participation rate (15-64)	71.2%	73.1%	75.6%	75.8%	72.7%
	71.2%	*71.7%*	*72.9%*	*73.9%*	*74.3%*
Labour productivity growth	0.1%	0.3%	0.9%	1.4%	1.7%
	0.7%	*0.9%*	*1.0%*	*1.4%*	*1.5%*
Employment growth	0.8%	0.7%	0.1%	−0.2%	−0.8%
	0.7%	*0.4%*	*0.2%*	*0.3%*	*0.3%*
Employment (millions)	26.4	27.3	28.5	28.6	26.9
	26.7	*27.2*	*27.7*	*28.1*	*29.0*
Labour force (15-67) (M)	29.2	30.0	31.1	31.3	30.1
	29.8	*29.9*	*30.3*	*30.6*	*31.5*

Comparison of the Employment Indicators in the Baseline scenario as simulated in the EUROGREEN model (black) and in the EU Ageing Report of 2018 (blue/italic).

The simulation of a **BI** policy has a moderate impact on the labour market. That was expected given that the **BI** only affects employment indirectly, through the increase in aggregate demand, particularly from inactive, out of the labour force, households whose incomes increase significantly with the introduction of a basic income.

[4]See "The 2018 Ageing Report: economic and budgetary projections for the 28 EU member states (2016-2070)" (European Commission, 2017, pp. 303-305), `https://ec.europa.eu/info/sites/info/files/economy-finance/ip079_en.pdf`.

[5]There is an apparent contradiction in Table 3.1 since total employment in 2040 is larger than in 2030 and employment growth in negative in 2040. Employment growth rates are calculated with respect to the previous year in the simulation, hence 2039 for 2040, and not the previous year shown on the table (2030). That means that total employment reaches its maximum value in the Baseline scenario somewhere between 2030 and 2040 and was already falling by the end of that decade.

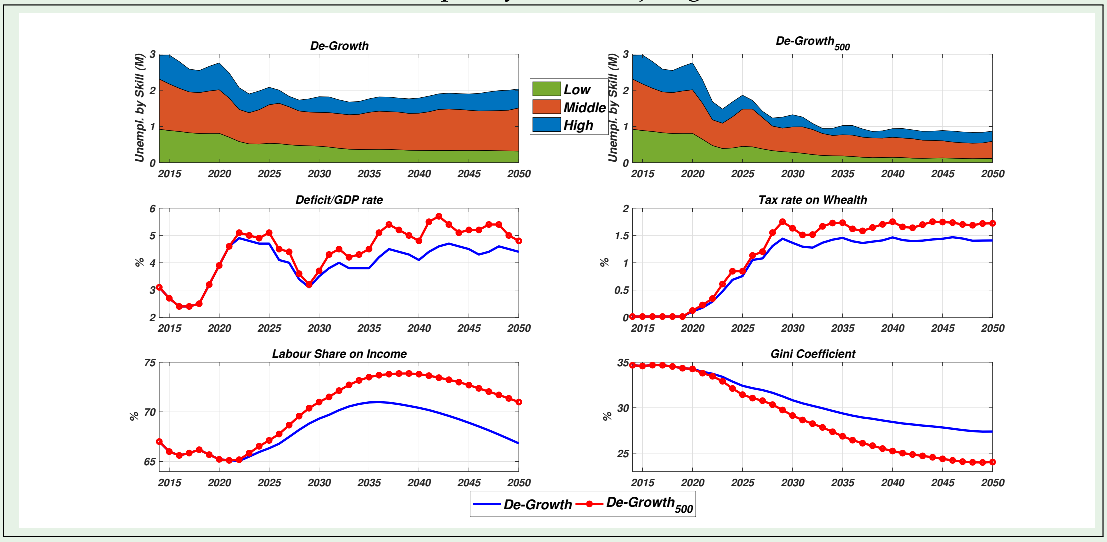
3.2 De-Growth with different sized Job Guarantee programs

Here, we discuss the impact of alternative designs of the *JG* program with a maximum yearly hiring of 300,000 workers, as in all the policy-mix simulations presented in this Chapter, and with an increased absorption capacity of 500,000 workers/year. This digression serves to illustrate the indirect effects of the job guarantee program over private sector demand, production and, consequently, employment. It demonstrates that an adjustment in the size of the **JG** policy could lead to unemployment rates close to those achieved in the **PSE** policy mix in Fig. 3.5 and Fig. 3.6 even with the consumption reduction simulated in **DG**.

The following Figure compares the composition of unemployment by skill (top), the deficit-to-GDP ratio and the wealth tax rates (middle), and two income inequality indicators (bottom). The number of unemployed workers falls sharply with the extra 200,000 workers per year in the job guarantee reaching a lower overall unemployment rate very close to the one achieved in **PSE** (see Fig. 3.5). The further improvement is not without costs, though. Government's deficit-to-GDP rate further increases with the larger job guarantee program, even with the additional increase in wealth tax rates. On the other hand, income distribution become more equitable both in terms of labour share the Gini coefficient.

To conclude, non-trivial and relevant trade-offs emerge from the introduction of bold policies. If maintaining government's deficit-to-GDP ratio under a certain threshold is considered an objective or a pre-condition for the continued functioning of a country's economy or the government in charge of it, the introduction of costly public policies such as a *JG* or a *BI* program would probably demand a further increase in taxes. Hence, the effective possibility of choosing for these radical policies, that ensure relevant and direct impact on income distribution and unemployment, asks for striking political efforts that should be paired bottom-up citizens' initiatives devoted to (partly) finance these policies in the long-run.

De-Growth policy mix and job guarantee



*De-Growth policy mix with **300,000** (left) and **500,000** (right) workers/year in the job guarantee program.*

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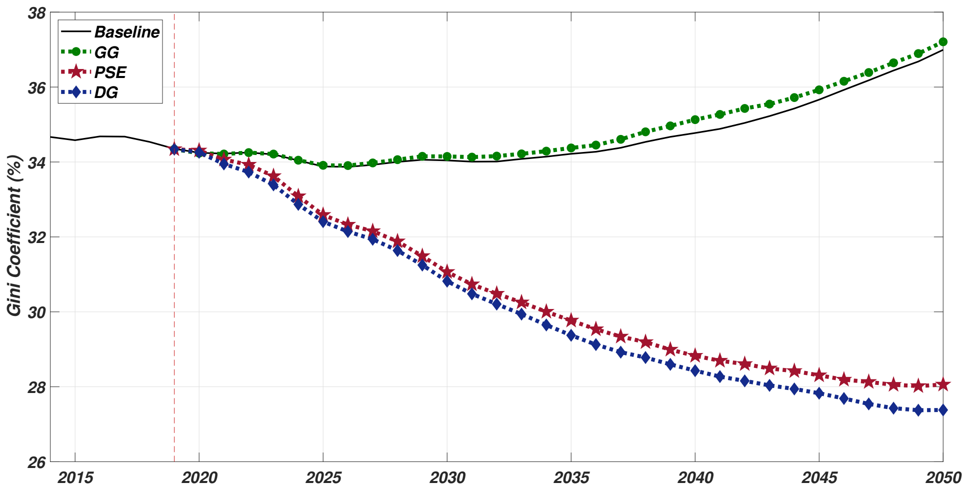
3.4 Income Inequality

Changes in income distribution in our three policy mixes and the Baseline scenario are illustrated by two different measures. The first is the Gini coefficient plotted in Fig. 3.7. It measures overall income inequality among thirteen different classes of households.[6] The second, in Fig. 3.8, regards the labour market exclusively and measures functional income distribution between wages, given by the total gross wage bill, and profits.

Figure 3.7: Gini Index



Yearly index of inequality in income distribution, from 2014 to 2050, for the Baseline scenario and the three policy-mix scenarios.

The calculated Gini coefficient is of 34.7 in 2014, quite close to the values reported for France in that period of 32.3 (Federal Reserve Bank of St. Louis),[7] 29.3 (OECD),[8] and 32.7 (World Bank, in 2015). The divergence in the Gini coefficients after the policy mixes are activated in 2020 resembles that of unemployment rates with a clear distinction between the increase in inequality projected by the Baseline and **GG** scenarios on one side, and a decrease of the coefficient in **PSE** and **DG**, on the other.

While **GG** increases inequality only marginally with respect to the Baseline, there is a more pronounced difference between the reduction of the Gini coefficient that follows the introduction of **PSE** and the stronger one observed in **DG**. The value for the coefficients in the end of the simulations are of 28 (**PSE**) and 27.4 (**DG**). This difference must be a result of the assumptions included in this scenario, namely consumption and, to a lesser extent, export reduction and the wealth tax that increases accordingly.

The reduction in private consumption certainly plays an important role decreasing profits a thus improving income distribution, this interpretation is only partially corroborated by Fig. 3.8 in which the labour share in **DG** is higher than the one in **PSE** until 2033. Therefore, the further reduction in income inequality verified in **DG** is a consequence of a contraction of income inequality between workers. In fact, even though wages and employment in all three skills grow more in the **PSE** policy mix, high-skill wage gains

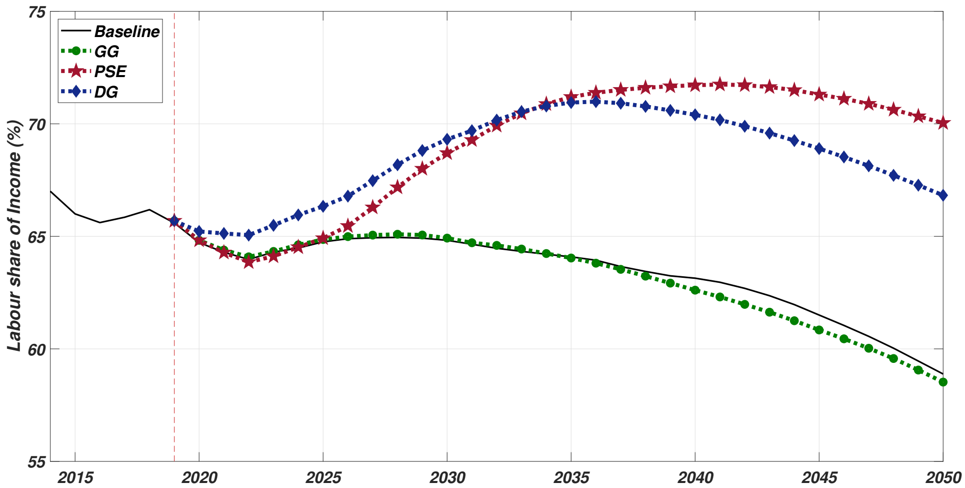
[6]These are capitalists and households of the three skill levels - low, middle and high - in each of the four possible occupational statuses: employed, unemployed, inactive and retired.

[7]`https://fred.stlouisfed.org/series/SIPOVGINIFRA`

[8]`https://stats.oecd.org`

surpass by far those of the other two skills in this scenario. Hence, the wage moderation under **DG** avoids an increase in inequality between employed workers of different skills.

Figure 3.8: Functional Income Distribution: Labour Share (%)



Yearly percentage of wages share on functional income distribution, from 2014 to 2050, for the Baseline scenario and the three policy-mix scenarios.

Functional income distribution, measured by the labour share, depicts similar trends in income inequality. The labour share decreases in the Baseline and **GG**, and increases in the other two policy mixes. As before, trends in the Baseline and **GG** simulations are practically indistinguishable. The greater increase in the labour share in **PSE** at the end of the simulation, with respect to **DG**, is a consequence of de-growth's double effect on the labour share which is more pronounced in the long-term as private consumption falls. It curtails the indirect effect of active labour market policies - **JG** and **WTR** - on employment, as seen by the difference in unemployment rates in Fig. 3.5, and consequently also contains wage increases.

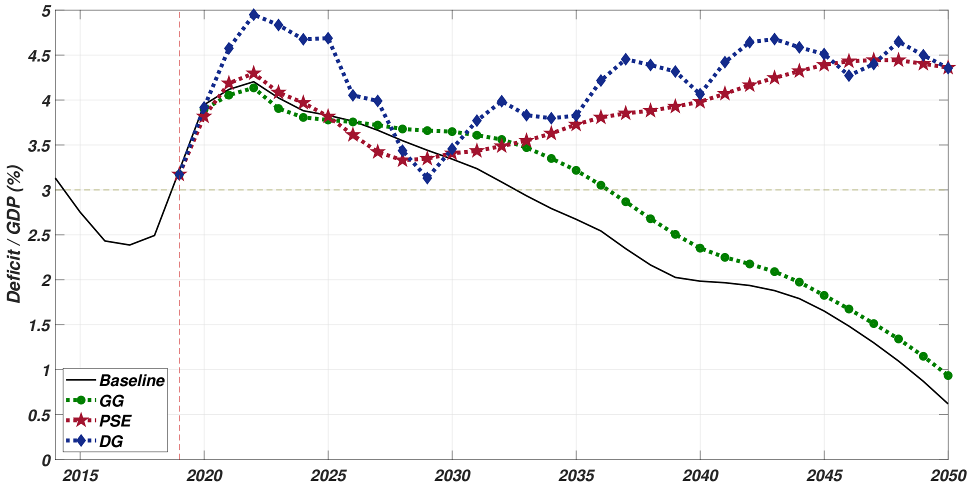
Individually, the three single policies directly aimed at employment and distribution have desirable impacts on income inequality. As seen in the top-left graph of panel (b) of Fig. 3.10 the labour share increases the most after the introduction of the two direct employment policies: **JG** and **WTR**. The Gini coefficient, the top-right graph of panel (b) (Fig. 3.10), indicates the **JG** program as the most effective single policy for income distribution, mostly because its effects are spread throughout the whole simulation period due to the continuous fall in unemployment rates. **WTR** and **BI** achieve similar Gini coefficients by 2050 with values close to the initial 2014 coefficient while other single policies tend to increase inequality by the end of the simulation window. In both inequality measures the largest increase in income inequality is observed after the introduction of faster technological progress in the **NPR** scenario.

3.5 Public Sector

Finally, we comment on the impact of the simulated policies on the government accounts, measured by the deficit-to-GDP ratio in Fig. 3.9. In contrast to the previous Sections, in which **PSE** and **DG** had the better results in terms of employment and income distribution, here the Baseline and **GG** scenarios are projected to reduce government deficit the most.

Hence, the cost of the bold employment policies that are included in **PSE** and **DG** translates into higher government expenditure, whereas the technological progress by itself induces a downward in the deficit-to-GDP ratio.

Figure 3.9: Government Deficit-to-GDP Ratio (%)



Yearly percentage of public deficit over GDP, from 2014 to 2050, for the Baseline scenario and the three policy-mix scenarios.

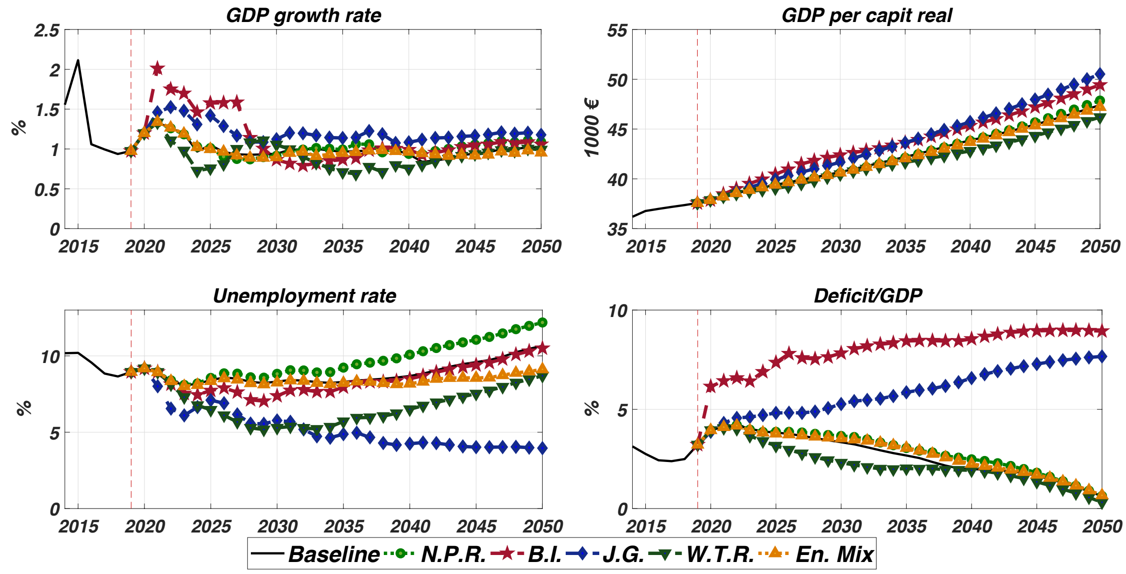
Given that GDP growth rates are similar in two of the policy mix and the Baseline scenarios, with the exception of **DG**, the higher deficit-to-GDP ratio in **PSE** with respect to **GG** is explained by differences in government expenditure in the **JG** program which is partially compensated by a greater labour tax revenue expands together with private employment[9]. The lower deficit in the Baseline simulation with respect to **GG** is a consequence of higher unemployment under the later. Faster labour saving technological progress undermines government's revenue from labour and value added taxes in particular which causes deficits under **GG** to be consistently higher than those in the Baseline simulation.

The highest public deficit-to-GDP ratio, on average, is verified in **DG**. The difference in public deficit is explained mostly by the denominator of the ratio, that is GDP level that decreases after households' consumption reduction. Still, the **DG** policy mix is able to contain continuous increases in deficit and remain close to the values simulated in **PSE** due to the introduction of a wealth tax to compensate the loss of government's revenue that follows GDP de-growth. We note that consumption reduction has a "double" effect on wealth tax revenue. First, a reduction in consumption naturally increases savings and the accumulation of wealth, particularly among high skill workers that hold a significant share of it. Second, in the **DG** policy mix, explained in Section 2.2.3, it is assumed that wealth tax rates increase in line with the population's average propensity to save, or in other words as consumption falls wealth tax are raised to sustain the public policies to improve employment and income distribution. Certainly, if a similar tax increase was introduced in **PSE** as well government deficit under this policy mix.

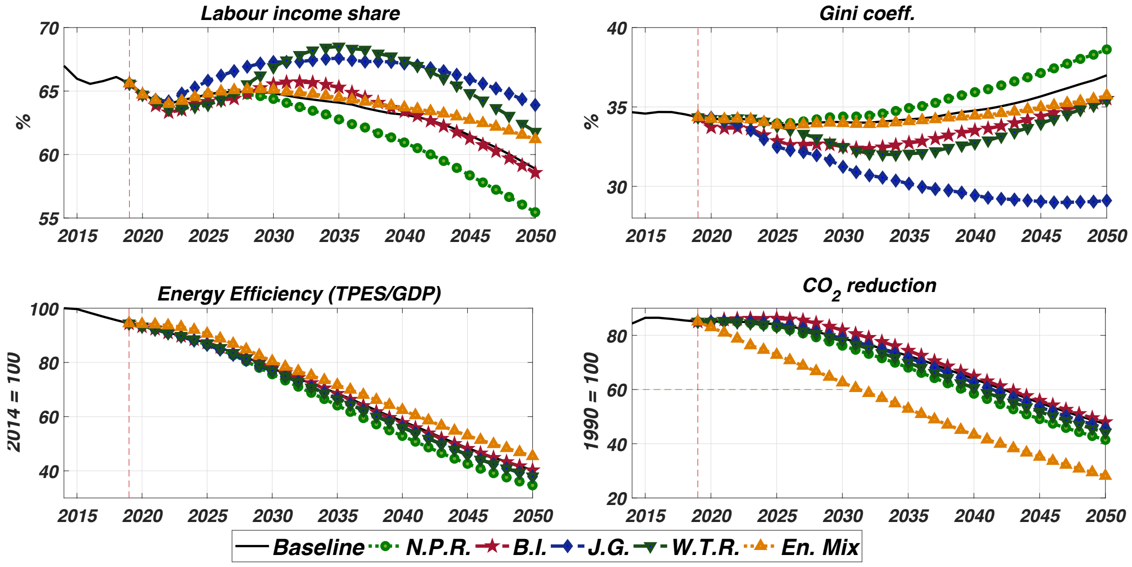
[9]Once more here we refer to the indirect effects of the policy on total disposable income and therefore consumption and aggregate demand.

The figures are quite distinct if we focus on single policies and their effects on government deficit-to-GDP ratio shown in Fig. 3.10 (bottom-right graph of panel (a)).

Figure 3.10: Scenario analysis from selected single policies



(a) Economic indicators



(b) Social Justice and Environment

Panel (a) shows the main economic indicators, while (b) presents some environmental and social indicators.

Two policies - **JG** and **BI** - exhibit increasing trends that surpass the values achieved in any of the policy mixes. **WTR**, in contrast, seems to improve government balances while increasing employment and income distribution, which may be attributed to the increase in labour and income taxes collected from a larger number of employed workers after working time reduction from 35 to 30 hours per week takes place. However, the **WTR** policy is not free of costs. As seen in graph 3.10a, it tends to decrease GDP growth immediately after its introduction as a result of diminished private investments that follow the profit squeeze imposed by the necessity to hire more workers that work less hours. Hence, the relative stability of **PSE** presented in Fig. 3.9 seems to be the result of a combination of JG that increases and **WTR** that decreases deficit-to-GDP ratio, partially offsetting each other.

4. Building Blocks

This part describes the structure of the EUROGREEN model and some of main relations among key variables. All graphs and tables that follow serve to illustrate important *building blocks* of the model and, unlike in the previous part, are based on the Baseline scenario exclusively. We opt for a largely discursive exposition in his Chapter whic aims at clarifying the mechanism behind the results in Part I. The complete list of equations is available in the online Supplementary Materials to this Report which can be downloaded at the following link **Supplementary Material**.

4.1 Population and Labour Force Supply

The population dynamics of the model are, to a certain degree, the most exogenous part of EUROGREEN. That is, fertility, mortality rates and life expectancy are fixed throughout the simulation period and do not suffer any influence from economy variables. The population is modelled in four age groups: 0 to 14, 15 to 44, 45 to 64 and 65 plus. Workers aged between 15 and 64 compose the working age population that is later allocated into employed, unemployed and inactive workers.

The total initial population sums up to 65,942,300 citizens in 2014. The fertility rate is of 2.11 and life expectancy of 80 years. The different mortality rates calculate for each age group are of 0.1%, 0.05%, 0.17% and 4%.

The labour force and its skill composition, in contrast to the total population, is endogenous and follows the unemployment trends of the economy. Starting from an initial labour force participation rate of 0.71 in 2014, the amount of working age adults that transition from inactivity for the labour force increases whenever the unemployment rate of the economy falls below its initial level.

The model also considers the possibility of transition between skills in the labour force. These are modelled according to differences in the skill-specific unemployment rates with coefficients that make transitions from lower to higher-skills harder or less frequent than the other way around. In other words, the amount of workers that transit, say, from middle to high-skill is given by the difference between the unemployment rates of these skills multiplied by a coefficient $\tau_{m,h}$ where subscripts m and h indicate a transition from middle to high-skill. We set these coefficients such that:

$$\tau_{m,h} < \tau_{l,m} < \tau_{h,m} < \tau_{m,l} \tag{4.1}$$

The **EUROGREEN** model capture the decoupling between total and working age population through a simulated ageing process. The share of individual aged 65 or more grows from 17% in 2014 to 25% in 2050. On the skill composition side, all skill supplies increase, in line with the general labour force trend. The supply of high-skill workers though increases more than the other two, especially after 2018, due to the lower unemployment rates of this skill group.

4.2 Households' Income and Taxes

In addition to the allocation of labour supply, households are further differentiated according to their occupational status into employed, unemployed, inactive or out of the labour force and retired, each with distinct income and taxation. These income sources are summarized, by skill, in Table 4.1 below.

Unemployment rates and pensions are calculated as fractions of yearly wages which are given by the ratio of the total actual unemployment benefits and pensions paid by the French government to the gross wage bill in 2014. Hence, the dynamics of these two variables in our simulations follow general trends of the economy in terms of employment and income distribution which directly impact the gross wage bill. Additional social transfers, such as sickness and disability, family and children benefits and the *Revenu de Solidarité Active* are simply given by their actual initial values corrected by the simulated inflation. The coverage of each benefit and transfer are fixed and were calculated based on actual initial values using the same procedure described for unemployment benefits and pensions.

The last income source of households is from financial assets. It is assumed that households of different skills hold their wealth in distinct financial assets. Wealth accumulation and portfolio choice are described in greater detail in the next Section. For now, it suffices to mention that financial income is equal to the net capital gains on bonds and equities as well as dividends held by middle, high skill workers and capitalists The later, assumed to be the 0.1% of the adult population, have financial income as their only earnings. Dividends are distributed between high-skill workers and capitalists according to their equity holdings. We further include mixed income in the model obtained from its initial value in the 2014 French national accounts that is adjusted to grow in line with the GDP during the simulation. The share of total wealth held by households of each skill group and capitalists determines the allocation of total mixed income among them.

Disposable income is determined by the sum of all income sources listed in Table 4.1 net of taxes which are also specific to the occupational status and income level of households. The EUROGREEN model considers a progressive income tax with five brackets on wages, unemployment benefits and pensions described in Table 4.2. Moreover, we combine employed workers contribute to an additional tax levied on 98.25% of gross pay that combines the *contribution sociale généralisée* and the *remboursement de la dette sociale* into a single 9.7% flat tax. Unemployed and retired households contribute to a similar tax with lower 6.7% and 8.8% rates, respectively. The final tax levied on labour income and benefits is the aggregate social contribution with 14%, 5.3% and 7.3% rates on gross wages, unemployment benefits and pensions.

Table 4.1: List of the income source for workers and capitalists

Category	Employed	Unemployed	Inactive	Retired
Low skill	Wages	Unempl. benefits	*FCB*	Pensions
		RSA	*RSA*	
			SDB	
Middle skill	Wages	Unempl. benefits	*FCB*	Pensions
			SDB	
	Financial Income: Public Bonds			
High skill	Wages	Unempl. benefits	*FCB*	Pensions
			SDB	
	Financial Income: Public Bonds, Equity, Dividends			
Capitalists	Financial Income: Public Bonds, Equity, Dividends			

Working class is divided by skill (high, middle, and low). *RSA* is the *Revenu de Solidarité Active*, *SDB* are the Sickness and Disability benefits, while *FCB* are the Family and Children benefits.

Income from financial gains is also taxed at 30%. The total finacial tax rate represents the sum of income taxes on financial income (12.8%) and the *contribution sociale généralisée* (17.2%). Therefore, the total disposable income, by skill, in the EUROGREEN model is obtained as the sum of all the labour, financial, and transfer incomes mentioned above, net of taxes. It will then be split between consumption and savings, as detailed in Sections 4.5 and 4.3. The EUROGREEN model includes also a progressive taxation module (so-calle type B tax), varying according to the income bracket floors, as described in Table 4.2.

4.3 Wealth, Portfolio Choice and Finance

In the EUROGREEN model households also differ by the type of assets in which they hold their wealth. The portfolio choice model is based on deposits, public bonds and equity which are distributed initially to households according to Table 4.3. The total and relative amount of assets held by each skill change in time as a function of savings that are allocated among the three asset types according to their return. We assume, though, that low-skill households have all their wealth in deposits and that middle-skill ones do not own any equity whatsoever.

In the beginning of each period, the total disposable income of the previous year is added to the wealth stocks and then reduced by the amount that corresponds to their total consumption. Thus, in each simulation period, the increase in accumulated wealth is equal to households' savings. The allocation of accumulated wealth between deposits, bonds and equity differs by skill. Low and Middle-skill agents simply distribute their saving in fixed proportions, that is all low-skill savings are converted into deposits while middle-skill ones are split between bonds and deposits. High-skill households and capitalists, on

Table 4.2: Progressive France tax schedule

Bracket	Taxable Income (€/*years*)	Tax Rate (%)
1	0 - 9,690	0
2	9,690 - 26,674	14
3	26,674 - 71,754	30
4	71,754 - 151,956	41
5	151,956+	45

Progressive tax schedule for taxable annual income, in France (2014). Source: European Commission, 2015; OECD, 2015: 264.

the other hand, have a proper portfolio choice. They divert a larger proportion of their savings to the asset with the highest return[1].

The supply of new equities is modelled as an aggregate and hinges on private industries investment behaviour and profits, described in Sections 4.8 and 4.7. The value of equities issued in a certain simulation period is given by the sum of nominal gross capital formation and profits, net of interest payments, multiplied by one minus the desired leverage ratio of industries and corrected by the price of equities. Put simply, the private sector issues equities whenever the necessary private debt to finance investments takes their leverage, defined as private debt over fixed capital, above the desired level. The total demand for equities is equal to the total savings allocated as equities by high-skill households and capitalists in the portfolio choice model.

Table 4.3: Initial Asset Holdings (%)

Category	Deposits (%)	Bonds (%)	Equity (%)	Total Category (%)
Low	2.2	0.0	0.0	2.2
Middle	7.8	3.5	0.0	11.3%
High	14.3	60.9	4.3	79.5
Capitalists	0.1	3.6	3.3	7.0
Total Asset	24.4	68.0	7.6	100

Working class is divided by skill (high, middle, and low).

The last part of the financial model is a simple Central Bank reaction function to

[1]Capitalists are assumed to be more sensitive to asset returns, reallocating a large part of their savings when the net return on equities and bonds vary.

determine basic interest rate. The Central bank increases rates inflation in the previous period surpasses the target of 2%. These changes in the basic rate affect the interest rate on debt that determines the cost of private debt for industries.

4.4 Employment and Wages

Employment and wages are defined by skill and industry which correspond to a total of 40 independent hourly wages and employment variables for each skill-industry pairing. The main drivers of both employment and wages are the quantity produced by industries and technology, that increases labour productivity.

4.4.1 Employment

The number of individuals employed in each industry by skill ($L_{i,j}$) is determined by its real output (y_i), which in its turn depends on final demand[2], divided by industry specific labour productivity (λ_i) and yearly hours worked (h_i). Industry employed is further distributed among the three skill levels ($\sigma_{i,j}$) using coefficients obtained from the EU KLEMS project.[3] Additionally, following the contemporary literature in labour economics (e.g., Goos et al., 2009; Acemoglu and Autor, 2011), we assume that technical improvements that increase labour productivity ($g_{\lambda,i}$) substitute middle-skill and complement high and, to a lesser extent, low-skill work in the job polarization coefficient (ψ). The effects of this labour polarization process on relative employment by skill are portrayed in Table 4.5. Hence, the distribution of industry employment by skill changes over the simulations in line with the pace of technological progress. The determination of employment is presented in equation 4.2.

$$L_{i,j} = (1 + \psi g_\lambda) \frac{\sigma_{i,j} y_i}{\lambda_i * h_i} \tag{4.2}$$

Yearly hours differ by industry but not skill. The 35 weekly work hours are multiplied by 43 weeks for all industries which gives an economy wide average of 1,509 work hours per year. We then calculate a vector dividing the average yearly work hours per industry obtained from EU KLEMS by 1,509 which serves to differentiate the number of hours worked in the ten sectors of the economy. The option to calculate hours instead of using directly the average hours worked in each industry is taken in order to allow the proper implementation of the **working time reduction** policy.

The actual labour productivity by industry (λ_i) is a weighted average of the labour productivity that corresponds to the latest technology adopted[4] and that of the previously adopted one. That is, if industry i adopts technology α with labour productivity λ_α in period t, while in $t-1$ it produced using technology β with labour productivity λ_β its actual labour productivity in period t will be given by the expression in equation 4.3. The weights for the new and old labour productivities are the amount of the fixed capital that embodies these technologies: gross fixed capital formation ($I_{i,t}$) and the stock of fixed capital after depreciation ($(1-\delta)K_{i,t}$).

$$\lambda_{i,t} = \frac{\lambda_\alpha I_{i,t} + \lambda_\beta (1-\delta_i) K_{i,t}}{I_{i,t} + (1-\delta_i) K_{i,t}} \tag{4.3}$$

[2] Limited by its full capacity output

[3] See `http://www.euklems.net/project_site.html`

[4] See Section 4.6.

Hence, the gradual adoption of new technologies and its impact on employment is a realistic feature of the EUROGREEN model. Even a radical labour saving innovation takes time to affect employment and its impact is larger the faster fixed capital is renewed. The difference between the newest available and actually adopted technology in the model can be seen in Fig. 4.2 in Section 4.6. The determination of employment here described is consistent with the general input-output production technologies explained in Section 4.9. It also adds to the dynamic nature of the input-output structure of the EUROGREEN model since the change in the skill demand represented by the job polarization coefficients (ψ) is equivalent to the adoption of gradual changes in three labour or skill requirements by unit of output in a Leontieff technology.

The dynamics of employment by industry and skill in the Baseline scenario are illustrated in tables 4.4 and 4.5, respectively. Even in the Baseline simulation with relatively low technological progress and without direct policies for the reduction of GHG emissions the changes in structure of employment in the model reflect some of the current trends in developed economies. Relative employment increases in services and decreases in manufacturing industries. Other industries that employ more workers by 2050 in the simulation include the Financial sector and construction. A decreased share of workers instead is seen on the public sector, agriculture, mining, fossil energy and electricity.[5]

Table 4.4: Employment by Industry as % of Total

Industries	**2014**	**2030**	**2050**
Agriculture	3.07%	2.9%	2.88%
Mining	0.15%	0.15%	0.13%
Fossil Energy	0.05%	0.04%	0.03%
Manufacturing	11.87%	11.33%	11.57%
Electricity	0.87%	0.75%	0.60%
Construction	7.11%	7.50%	8.56%
Services	35.17%	38.11%	39.62%
Financial	3.24%	3.35%	3.42%
Public	37.00%	34.38%	31.76%
Other	1.48%	1.48%	1.46%

4.4.2 Wages

Wage dynamics are somewhat similar to employment in that it depends directly on employment and, therefore, on its determinants and technology. Hourly wages are projected starting from initial values given by actual average hourly wages by skill in our ten aggregated industries calculated with data from EU KLEMS.[6] The evolution of this

[5] The industry named other that includes mostly households as employers remains relatively stable through the simulation.

[6] The EU KLEMS project calculates hourly wages by skill for the NACE Rev. 2 industries presented listed in Table 4.7 to which we apply weighted averages to obtain hourly wages for ten aggregated industries

Table 4.5: Employment by Skill as % of Total

Skills	2014	2030	2050
Low	17.2%	17.6%	18.4%
Middle	44.9%	43.5%	41.7%
High	37.8%	39.0%	39.9%

initial wages is then affected by the simulate economic conditions via employment and labour productivity.

The option to render wages sensitive to the growth of employment instead of the perhaps more usual response to unemployment rates was taken to reflect a higher degree of stratification between occupations in the economy. Setting wages as a function of employment makes wages responsive to industry specific dynamics and couples the labour cost of an industry to its growth and profits. Moreover, it is assumed that high skill wages are more sensitive to changes in employment than middle and low-skill ones.

The alternative formulation, varying wages with unemployment rates, would enable a fictitious increase in the profits of industries that expand the most since their labour cost would depend on the general pool of unemployed workers in each of the three skills. Therefore, assuming wages respond to unemployment rates, given the structure of the model, would ultimately be equivalent to accepting an unreal degree of substitution between workers which certainly does not reflect the highly segmented contemporary labour markets.

Technology and labour productivity are also positively correlated to hourly wages, once again with a higher coefficient for high-skill workers. We simply assume that part of the monetary gains that emerge from an increase in labour productivity are captured by workers through increases in hourly wages.

4.5 Consumption

Households' consumption is relatively simple and is modelled according to Keynesian tradition. Workers spend part of their disposable income, defined in Section 4.2, in consumption given their marginal propensities to consume. Workers of the three skills and capitalists also consume part of their financial income, therefore dividends and capital gains out of equities and bonds, according to different marginal propensities to consume.

The share of disposable income selected through the marginal propensities determines the total consumption of households in all three skill levels and capitalists, which is later allocated between industries and imports. The share of consumption spent in each industry is initially fixed for all households and is obtained from actual consumption data in the 2014 French national accounts. Part of this consumption by industry is then destined to imports, once again according to data from the national accounts.

Two more refined, dynamic, effects are then added to this fixed allocation of consumption between industries. First, the increase in energy efficiency reduces the share of disposable income spend on the Electricity and Fossil Fuel industries. Thus, households consume the same energy but at a lower price due to increase efficiency or, alternatively, they are able to obtain the same performance using less energy and therefore consume

modelled in the EUROGREEN model.

less of it. This decline in the share of income assigned to electricity and fossil fuel is then redistributed to the other industries according to their initial shares in the allocation of consumption.

Second, we assume there is a certain degree of substitution between private and public services which functions whenever the Job Guarantee program is active. As mentioned in Section 2.1.3, part of the workers hired in the Job Guarantee program are assumed to perform services such as care work, social services, waste management and emergency services. Hence, the share of consumption destined to services decreases as a function of the ratio between public, from the job guarantee, and private service production, substituting a maximum of 24% of private services consumed.

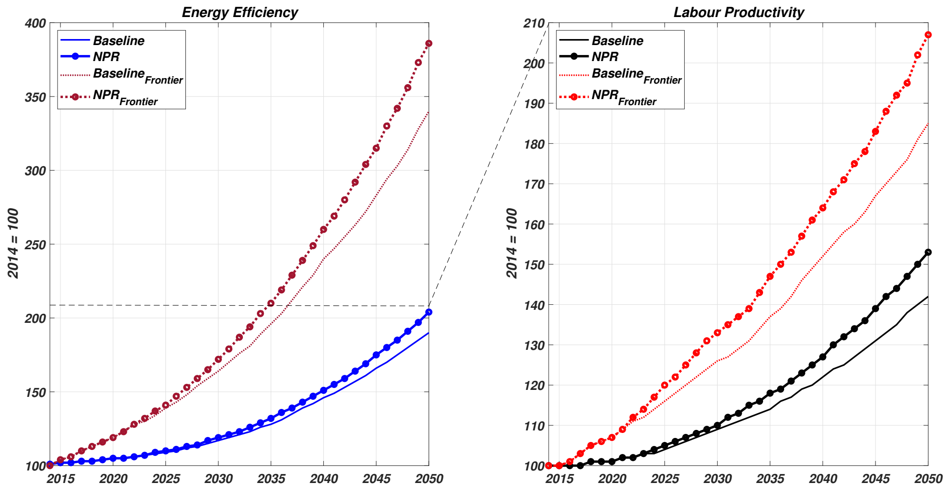
4.6 Innovation: automation and energy efficiency

This Section describes in further detail the innovation processes and choice of technology modelled in EUROGREEN. First, it is important to distinguish between innovations and technology. By innovation or technology frontier we mean the latest, most advanced, available techniques, whereas technology refers to the chosen cost-minimizing techniques. The difference between these is illustrated in Fig. 4.1 where the two top graphs plot the evolution of the average adopted labour productivity and energy efficiency in the whole economy while the two bottom graphs depict the technological respective frontiers. As in real economies, in our simulations the average adopted technology lags behind the technical frontier.

The rest of this Section first proceeds to explain the innovation processes in labour and energy saving techniques and then describes the adoption of technologies by each industry. Innovations are modelled as a random process that industries the values of this random uniform distribution surpass a given innovation threshold. A graphical illustration of this process is provided in Fig. 4.2. The green line represents the random probability of arrival of, say, a new labour saving technique in manufacturing that is available in every period in which this green line is above the innovation threshold given by the blue and red lines in the figure. This threshold depends on a fixed coefficient and on the difference between the growth rates of labour and energy costs. For instance, if Fig. 4.2 represents techniques that increase labour productivity, the decreasing trend in the innovation thresholds corresponds to a higher relative increase in labour costs with respect to energy costs. The level of the threshold, on the other hand, depends on fixed coefficient that are used to model faster or slower technological progress, as in the New Productive Revolution scenario (Section 2.1.1). Hence, setting a decrease in the threshold shifts it down, from the blue to the red line in Fig. 4.2 which will render new techniques available more often.

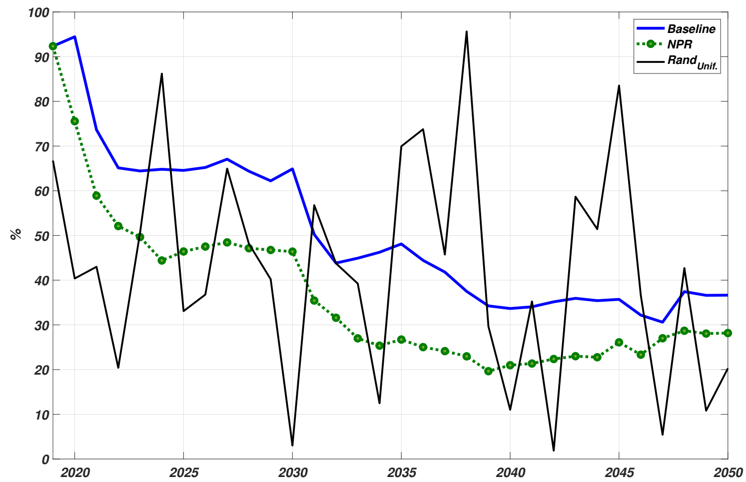
Once these new techniques for labour productivity and energy efficiency are obtained for each industry depending on their specific labour and energy costs, they proceed to choose among the four possible combinations of these techniques described in Table 2.1. If in a certain simulation period t labour but not energy saving innovation is available, an industry will choose between the technology with the new labour productivity and the old energy efficiency (Ω_2) or its previous technology with both old techniques (Ω_1) depending on which presents the lowest sum of labour and energy costs. whenerver there is an available innovation in both techniques it will be cost-minimizing and, therefore, adopted.

Figure 4.1: *Innovation and Technological Frontier*



Comparison of the actual and maximum (i.e., the technological frontier) index of Energy Efficiency (left) and of Labour Productivity (right).

Figure 4.2: *Example of Innovation Dynamics*



Comparison of the threshold for technological innovation in the Baseline scenario (blue), under *NPR* (green), and by random (e.g., uniform distribution) draws (black).

4.7 Prices and Profits

The determination of prices in each of the ten aggregated industries follows the usual post-Keynesian literature and are defined as a mark-up over unit cost of production. Gross profits depend on nominal revenue and costs and are calculated as the difference between value added, net of value added taxes, and labour costs. The following paragraphs describe the calculation of these two important variables in greater detail.

The two main variables in price determination are the unit labour and intermediate costs to which a mark-up is added by industries. In each period an industry takes as reference its past, last period, costs to set prices. Total labour cost is simply given by the sum of wages paid to workers of all three skill levels employed in an industry incremented by the cost of labour taxes. Unit labour cost is obtained dividing total labour cost by the nominal value of output. Intermediate costs are the sum of an industry's intermediate demand for goods and services produced by the other ten industries, including itself, at home and abroad, thus, imports. The cost of carbon taxes and, whenever the carbon tax policy is active, border carbon adjustments is included as well before dividing then by output to obtain unit intermediate costs.

The mark-up is slightly more complex and takes into account productivity gains, variations in capacity utilization, value added tax rates and a fixed, exogenous mark-up. Increases in labour productivity add to the exogenous mark-ups, thus reflecting changes in competitiveness and monopoly rents from innovation. The sensibility of mark-up increases to productivity gains are different among industries and is assumed to be higher in those closely related to manufacturing; fossil fuel, manufacturing, electricity and construction, followed by services and the financial sector with a lower sensitivity, and then agriculture and mining. The public sector and other, which represents households as employers, does not increase mark-ups following an increase in labour productivity.

Another component of industries' mark-ups is their capacity utilization. More specifically the deviation of actual with respect to normal capacity utilization. An increase in this difference leads to higher prices, but a decrease of capacity below normal does not decrease prices which are assumed to be rigid downwards. Finally, industries add the value added tax rates to prices.

Gross profits are obtained in a similar fashion: subtracting labour costs from value added net of taxes. An industry's total value added is calculated as its nominal output minus intermediate costs, including imported raw materials, goods and services. Net profits are equal gross profits net of corporate income taxes, whose rate is set to 33% in 2014 and then reduced according to the plans announced by the French governments to 31% in 2019, 28% in 2020, 26.5% in 2021 and 25% after 2022. Out of these net profits, 30% are distributed as dividends, if profits are positive, and the rest is accumulated for investments and to pay private debt from previous periods.

4.8 Investment

The modelling of investment in the EUROGREEN model takes into account its dual character as demand, in the short term, and supply, increasing productive capacity, in the middle to long term. It also considers finance as a limit to private investments and capital accumulation. The main drivers of investment are capacity utilization, a consequently aggregate demand, and profits both as an incentive to further investments and as the limits of an industry's capacity to invest. Gross fixed capital formation is determined in the model as an investment rate multiplied by current capital stock. The investment rate is given by four components: capacity utilization, profit rates, investments to cover capital depreciation and a fixed non-capacity creating investment component.

Capacity utilization is determined as the ratio between an industry's demand for output and its full capacity output. The latter is obtained as the capital stock multiplied by industry specific capital productivity. An increase in capacity utilization then leads to a less than proportional acceleration of the investments rate. While actual industry output cannot surpass the full capacity output in the model allows, capacity utilization itself may be greater than one since it is based on a notional output. In other words, even if production is at the maximum level possible, determined by the fixed capital stock, an industry knows when its actual demand is higher and invests accordingly.

The two minor components of investment are the non-capacity generating component and depreciation. It is assumed in the model that industries invest to cover the capital that depreciates every year. Moreover, the fixed non-capacity creating component represents the share of investment that are not strictly connected to current economic conditions but that are necessary for continued production and competition such as research and development, housing, some types of infrastructure such as logistics and, in the case of the public sector, military expenditure that are often complementary to productive investments in machinery and raw materials.

Profits, as investment itself, have a dual character in the model. Investments are a function of the profit rate, but they are also limited by it since at least part of the total investment must be financed by accumulated profits. The financing of investment is modelled as follows. Accumulated profits, net of dividends and interest payments, determine the maximum investment an industry is able to perform when divided by a fixed equity-to-debt ratio. Hence, an industry's self-financing capacity establishes the ceiling for its investments in each period. Additionally, past investments also work as a stabilizer for current ones since they increase private debt which, in turn, demands more interest payments in future periods, thus reducing future available profits to finance investment.

4.9 Input-Output and International Trade

The productive sectors are defined in accordance with the Statistical Classification of Economic Activities in the European Community (NACE Rev. 2, 2008).[7] The industries are aggregated into **10** main productive sectors (see Table 4.6). The initial values are calculated for 2014 using the National Input-Output Table (NIOT) of France from the World Input-Output Database (WIOD, Release 2016).[8]

Our model follows the Leontief and the post-Keynesian traditions,[9] by acknowledging that the economy is demand-driven and that sectors are involved in inter-industry trade (both at national and international level). Each industry is involved in the exchanges of *intermediate* good and service, which monetary amount is defined as Z_{si} where s is the seller and i the buyer, to say products that are used in the productive process. The main novelty introduced in the EUROGREEN model, is the application of **dynamic "technical coefficients"**, defined as the amount of material inputs required per unit of output of industry i (i.e., $a_{si} = Z_{si}/X_i$,[10] where X_i is the total output of i), which are crucial to define the productive mix of each sector because their distribution indicate the share of the different kind of products bought by each industry in the along the supply-chain. Most of literature that applies IO for scenario analyses assumes constant technical coefficient due to the lack of projections on future total sectoral output. In our case, instead, we allow technical coefficient of the energy sectors (num. 3 and 5) to vary according to the dynamic of the energy efficiency (i.e., η as described in subsections 4.10 and 4.6). We assume that, for both the Fossil Fuel and Electricity and Gas supply industries, the technical coefficient can be further decomposed in base of the energy sources utilized, since their shares must sum up to 1. Their technical coefficients then decrease in case of an increase of energy

[7] See `http://ec.europa.eu/eurostat/ramon/nomenclatures`

[8] See Timmer et al. (2015) and `http://www.wiod.org/release16` for the construction of WIOD.

[9] See Miller and Blair (2009) and Lavoie (2014b) for a description.

[10] Let Z be the square matrix of inter-industrial exchanges of intermediate goods and X the vector of total output, included final consumption, for each sector. We derive the matrix of technical coefficients as $A = Z \cdot \hat{X}^{-1}$, where the hat stands for diagonal matrix. Each entry a_{ij} returns the share of goods produced by sector j in the total intermediate input use of firms in sector i.

Table 4.6: NIOT Classification in EUROGREEN

Num.	**Name**	*NACE Rev. 2 code*	**NACE Rev. 2 description**
1	**Agriculture**	*A*	Agriculture, forestry and fishing
2	**Mining**	*B*	Mining and quarrying
3	**Fossil Fuels**	*C19*	Manufacture of coke and refined petroleum products
4	**Manufacturing**	*C (excl. C19)*	Manufacturing
5	**Electricity and Gas (ELG)**	*D*	Electricity, gas, steam and air conditioning supply
6	**Construction**	*F*	Construction
		L	Real estate activities
7	**Services**	*G*	Wholesale and retail trade
		H	Transportation and storage
		I	Accommodation and food service activities
		J	Information and communication
		M	Professional, scientific and technical activities
		N	Administrative and support service activities
		R	Arts, entertainment and recreation
		S	Other service activities
8	**Finance**	*K*	Financial and insurance
9	**Public**	*E*	Water supply
		O	Public administration and defence
		P	Education
		Q	Human health and social work activities
10	**Other**	*T*	Activities of households as employers
-	**Not included**	*U*	Activities of extraterritorial organizations and bodies

Definition and aggregation criteria of the ten productive sectors in EUROGREEN model, in accordance with the NACE classification. Column two shows the name of the macro-sectors used in the EUROGREEN model.

efficiency of whatever buying sector and/or in case of a decrease of the price of an energy source. In this way, we can capture the effects of a variation of energy prices on the technological mix which is crucial for the transition to a low-carbon society. From the consumer side, each industry s sells also good and services for final consumption, mainly toward households (f_s^{hh}) and government (f_s^{gov}).

In an open economy firms and consumers face the **international market**, then imports and exports are included in the model. For the sake of simplicity, whenever imports were less than 10% of domestic output of a certain good or service (in the original WIOD database), imports have been shifted to domestic production. Then, to keep domestic sectoral output unchanged, exports have been reduced by equivalent amounts.[11] From this simplification, it results that the French economy only imports from five sectors, namely: Agriculture, Mining, Fossil Fuel, Manufacturing, and Services. Given the stability of import shares over time,[12] we assume constant fractions of *imports* from the rest of the world. In case of industries the share of import of a French sector i from a foreign sector j reads: $\mu_j^i = Z_{j,i}^m / X_i$, where $Z_{j,i}^m$ is the monetary amount of intermediate import and X_i is the total output of domestic sector i. In case of consumers hh the ratio is computed as: $\mu_j^{hh} = f_{j,hh}^m / f_{j,hh}$, where $f_{j,hh}^m$ is the monetary amount of final goods imported from sector j and $f_{j,hh}$ is the total final household consumption, including domestic purchasing ($f_{j,hh}^d$). The same reasoning applies for government imports. In case of *exports* (Θ_i) we assume that they are negatively affected by an increase in domestic industry price and that they are also driven by an exogenous variation not modelled (around 1% per year, depending on the scenario). The total output of each sector can be written as:

$$X_j = (1 - \mu_j^{hh}) \cdot f_{j,hh} + (1 - \mu_j^{gov}) \cdot f_{j,gov} + (1 - \mu_j^i) \cdot Z_{j,i} + GFCF_j + \Theta_j \tag{4.4}$$

Finally, the IO approach allows us to determine the value of gross domestic product (**GDP**) with at least two procedures. The first method consists in recovering the GDP as the sum of the Value added of each sector within the country. In the second method, we have that the GDP is:

$$GDP = \mathcal{P}_j (f_{j,hh}^d + f_{j,hh}^d + GFCF_j) \tag{4.5}$$

4.10 Energy, Greenhouse Gas Emissions, and Carbon Taxes

We assume that the demand of energy consists of four sources: *gas*, *oil*, *coal*, and *electricity*. Electricity, in turn, is produced with different sources: *nuclear*, *renewable*, *gas*, *coal*, and *oil* as described in Table 2.2. Table 4.7 shows the fuel shares for **Total Primary Energy Supply (TPES)** in France in 2014. Note that the *ELG* industry includes both the electricity production which, in turns, uses also nuclear and renewable sources that are not polluting (in terms of gas emissions). In order to take into account of the change in the use of different sources, mostly for renewable, we decompose the total energy of *ELG* to account for the use of gas and electricity separately.

Fossil energy and Electricity are also demanded by households.[13] Households' consumption module determines the consumption expenditure level in the energy sector. For the sake of simplicity, we assume that the share of energy consumption expenditure, going to each source, is exogenous and constant (excepting for the activation of the **EnM** policy). In order to impute the energy use to the final expenditure, we assume that the

[11] When this would make exports negative, the amount is instead subtracted from Gross fixed capital formation (GFCF).

[12] We computed the import shares for each industry, and for government and household consumption from year 2000 to 2014, and they resulted constant and stable in the whole period. For this reason, we apply the shares of the last year (2014).

[13] In EUROGREEN, all energy consumption by the public sector is intermediate consumption; none of it is included in final consumption expenditure.

Table 4.7: Energy mix by Industry

EUROGREEN	Tot (ktoe)	coal	oil	gas	elect.
Agriculture	*4,538*	0,00%	76,33%	3,77%	19,90%
Mining	*169*	0,00%	48,52%	14,79%	36,69%
Fossil Fuel	*5,273*	20,57%	14,94%	4,68%	58,26%
Manufacturing	*40,728*	10,10%	35,74%	28,06%	22,98%
ELG	*85909*	2,43%	3,03%	4,35%	90,20%
Construction	*1,027*	0,00%	57,35%	24,73%	17,92%
Services	*49,535*	0,00%	91,78%	0,19%	8,03%
Finance	*2,362*	0,77%	11,59%	30,48%	57,16%
Public	*18,671*	0,77%	11,59%	30,48%	57,16%
TOT	***208,212***	**3,58%**	**33,61%**	**10,74%**	**51,42%**

TPES in ktoe (of oil equivalent) by industry and composition by source of energy. Source: Eurostat - Energy Balances (own calculations). Note that the actual TPES for France in 2014 was 248,648 ktoe and the difference is due to the excluded sector "Households as employers".

real consumption (both out of income and out of wealth) is translated into energy use by the application of the average energy efficiency of the economy. Given the total energy use and the share of energy source is possible to recover the total amount of gas, oil, and coal which are crucial in the computation of the GHG emissions. In EUROGREEN we assume that the shares of each energy source are exogenous, but this does not mean that they are constant. We model the energy share in order to accomplish the objectives of the *Energy Transition for Green Growth Act of 17 August 2015*. According to this official document, France should meet the following targets (IEA, 2016, p. 23):

- reduction of greenhouse gas (GHG) emissions by 40% in 2030 and by a factor of 4 towards 2050 (compared to 1990);
- reduction of final energy consumption by 20% in 2030 and 50% in 2050 (compared to 2012);
- renewable share of 32% in gross final energy consumption and 40% of total electricity generation by 2030;
- reduction of fossil fuel consumption of 30% by 2030 (in comparison to 2012);
- reduction of nuclear share in the electricity mix down to 50% by 2025 (from 78 % today).

From the Eurostat database[14] we recover the Greenhouse gas emissions (in CO_2 equivalents) by source and industry. However, the ratio between total energy and total emissions was not the same, from a cross-industrial point of view, because of the different chemical composition of the pollutants used by each firm. For this reason, we recover the average contribution of each source to GHG emissions[15] in order to translate the energy consumption in air pollution.

[14] See `http://appsso.eurostat.ec.europa.eu/nui/show.do?lang=en&dataset=env_air_gge`

[15] See `https://www.rte-france.com/en/eco2mix/eco2mix-co2-en`

Finally, we take into account the recent French National "Energy Transition for Green Growth" program which introduced a *carbon tax* in 2014 of €7 per ton of CO_2, with increasing value over time (with an average increase of about €8 per ton of CO_2 per year until 2020) and that must attain €56 in 2020 and €100 per ton of GHG emissions in 2030. In this context, we assume an additional increase of 4.4% per year,[16] which sum up to €188 per ton in 2050. In order to be consistent with the real policy, we exclude from the computation of the carbon tax all the emissions already regulated by the EU ETS that, in case of French companies, accounts for about half of the total GHG emissions. As stated in the French Environmental Plan we also exclude the Agricultural sector. The second fiscal instrument introduced is a **Border Carbon Adjustment** tax that imposes the same carbon tax levels on polluting imports, according to their GHG contents, to all industries except agriculture.

4.11 Public Sector

The public sector is modelled in EUGROGREEN as the current balance, given by its expenditures and revenues, and the public debt issued to finance its operations. Government deficit is obtained subtracting all tax revenues from public expenditures, the complete list of public revenue and expenditure by source is shown in Table 4.8. The main public indicator, seen in Fig. 3.9 in Section 3.5, is simply the ratio between government deficit and nominal GDP.

Table 4.8: Government Balance: revenue and expenditure

Expenditure	**Revenue**
Government consumption	Value added tax
Wages	Labour taxes
Investment	Corporate income tax
Interest on public debt	Progressive income tax
Pensions	*Contribution sociale généralisée*
Unemployment benefits	*Remboursement de la dette sociale*
Sickness and disability benefits	Aggregate social contribution
Family and children benefits	Tax on financial income
Revenu de Solidarité Active	Wealth tax
	Carbon taxes

Public debt, on the other hand, is a stock of bonds. In each simulated period the deficit (surplus) adds (reduces) the supply of public debt. The demand for public bonds, as in the case of private equity, is determined by households' portfolio choice which increase in line with the return on public bonds.

[16]This percentage corresponds to the linear increase to pass from €56 in 2020 to €100 per ton in 2030, as planned by the French government.

The rate of return for investments on public debt depends both on its interest rates, set equal to french actual yearly average long term interest rates from 2014 to 2018. Changes in the price of bonds follow the trends of its supply and demand and adjust accordingly.

The sources of revenue and expenditures of the public sector are listed in Table 4.8. Most of these are described in greater detail in the other Sections of this Chapter, except for government consumption. It starts from the actual value verified in the 2014 french national accounts, which is then split between internal goods and services and imports, and corrected by inflation every simulation period. We also add a exogenous rate of increase of government consumption which is set to 0.6% per year, somewhat below the long-term value to which nominal GDP growth converges in the Baseline scenario.

A. Sensitivity

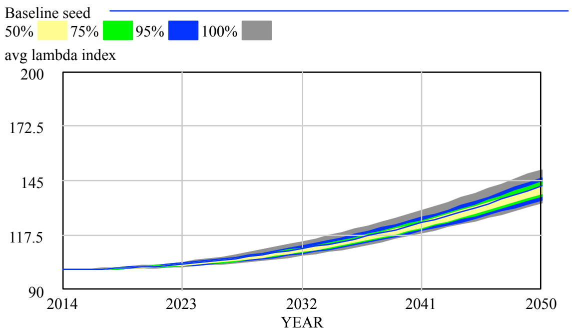
This appendix contains a brief sensitivity analysis of some of the main variables of our model. All the following graphs are based on 400 simulations that vary the random distribution of new labour and energy saving technologies. The blue lines, more often than not close to the center of the simulations confidence interval represents the actual simulated values in the EUROGREEN Baseline scenario. The colored areas indicated the probability that our simulations fall in a specific area. Hence, for instance, there is a 50% probability that our simulations fall in the yellow areas in Fig. A.1, A.2 and A.3. Analogously, 75% of the simulations remain in the areas given by the sum between yellow and green, 95% once we add the blue areas and finally all possible values based on the 400 simulations are contained between the gray areas in the graphs below.

The graphs in Fig. A.1 plot the sensitivity analysis of four of our main economic indicators. It starts from the evolution of labour productivity in A.1a which is directly affected by technological progress. We see that the actual simulation, in the blue line, tends towards the top of the yellow area. Hence, the growth of labour productivity presented throughout this report is above the average obtained in the 400 sensitivity simulations. In the two graphs related to GHG emissions, A.1b and A.1d, our Baseline scenario simulation is right in the middle of the confidence interval for energy efficiency and GHG emissions. GDP growth in A.1c is somewhat less stable, often reaching values in the green and blue area of the confidence interval.

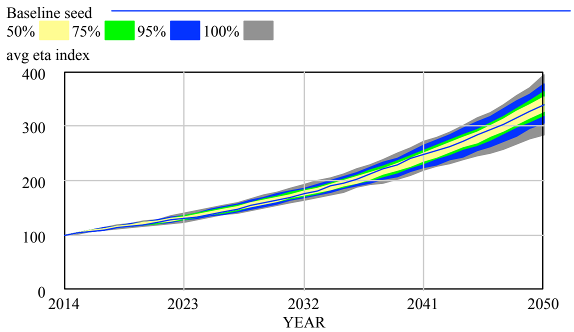
Fig. A.2 presents other three sensitivity graphs for unemployment rates, the deficit-to-GDP ratio and the Gini coefficient. The confidence intervals plotted are in general wider than in the previous figure. While unemployment rates (A.2a) and the Gini coefficient (A.2c) are below the average for the 400 sensitivity simulations for most of the, the deficit-to-GDP retio (A.2b) is above by the end of the simulation.

The last three graphs in Fig. A.3 analyzes the sensitivity our Baseline simulation for the unemployment rates in the three skills. Here our Baseline scenario projects below average unemployment rates for low and high, and above average ones for middle-skill workers. It thus suggests that the specific random innovation process that generates labour saving

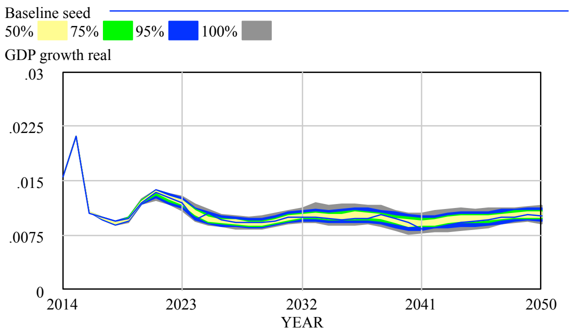
Figure A.1: Sensitivity to changes in random technological progress (A)



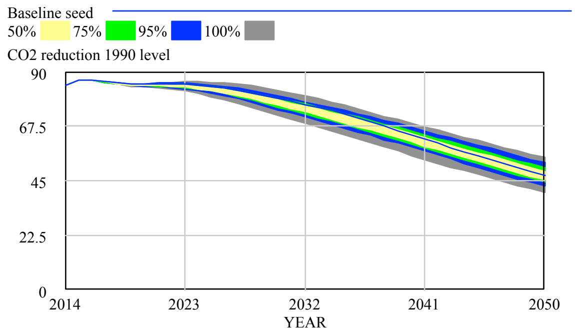
(a) Labour Productivity



(b) Energy efficiency

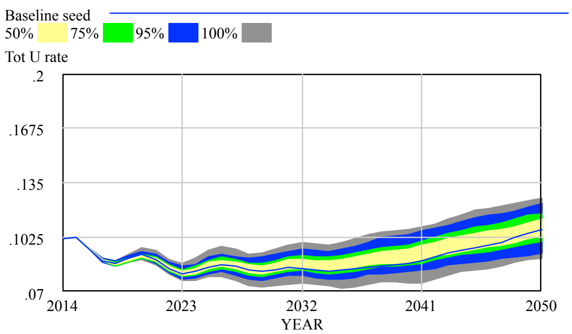


(c) GDP growth

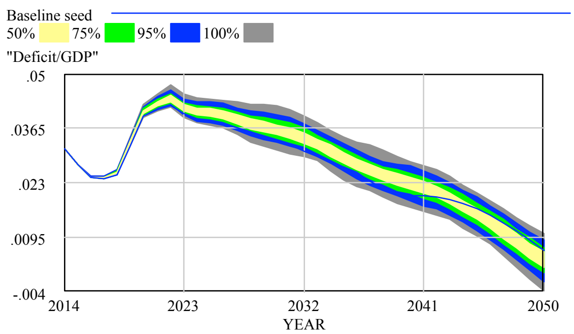


(d) GHG emissions (1990=100)

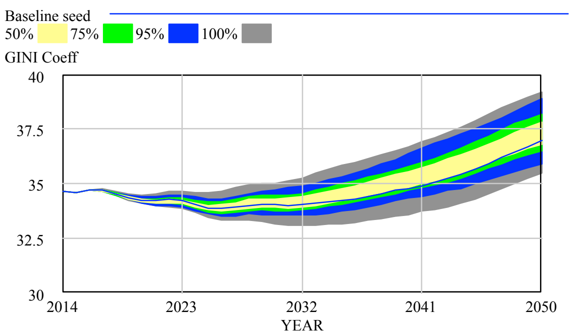
Figure A.2: Sensitivity to changes in random technological progress (B)



(a) Unemployment rate



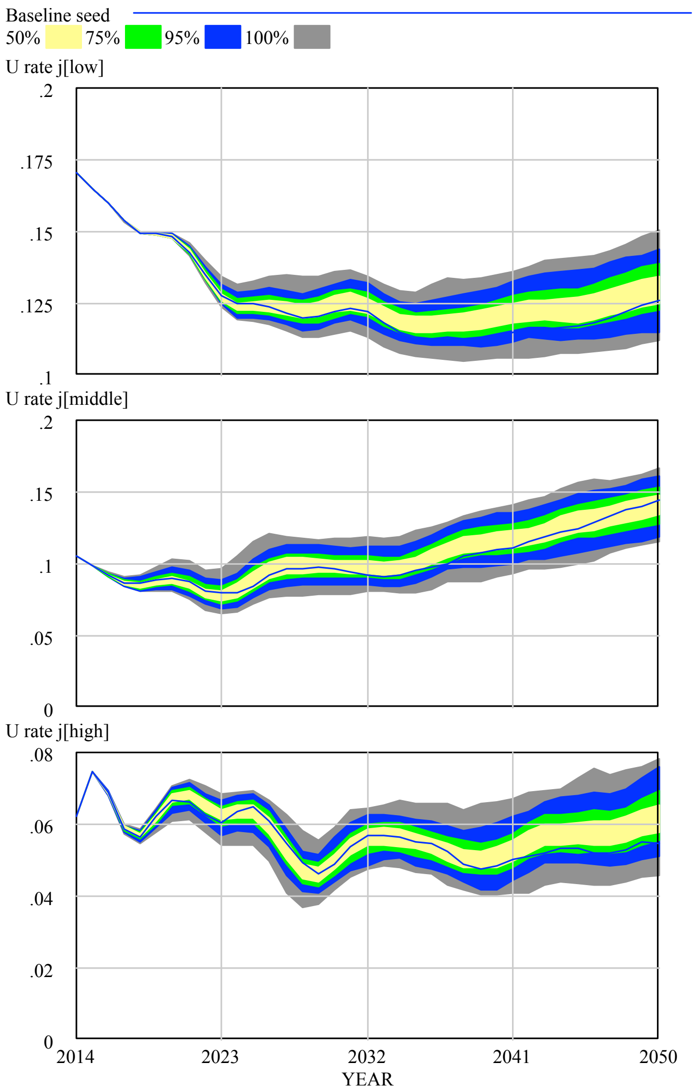
(b) Deficit-to-GDP ratio



(c) Gini coefficient

innovations in the results presented in this report might be overestimating, though not much, the effects of job polarization.

Figure A.3: Sensitivity and unemployment rates by skill



B. Policies Description

Figure B.1: Summary of Single Policies (1)

High Labour Productivity (HLP), Energy Efficiency (HEEF), Basic Income (BI), Job Guarantee (JG)

Policy	Summary	Comment	Real per capita GDP	GHG emissions	Unemployment	Income inequality	Deficif GDP
HLP	Reduces the labour saving innovation threshold parameter from 0.75 to 0.6 and the joint labour and energy saving threshold from 0.8 to 0.65	Average labour productivity increases about 25% more than in the baseline scenario	~ 0	$-$	$+$	$+$	~ 0
HEEF	Reduces the energy saving innovation threshold parameter from 0.5 to 0.3	Average energy efficiency increases about 16% more than in the baseline scenario	~ 0	$-$	~ 0	~ 0	~ 0
BI	Introduces a 5,580 yearly benefit to all working age adults that substitutes or reduces other social transfers	A high initial impact on growth a income distribution dissipates in time while deficit remains relatively high.	$+$	$+$	$-$	$-$	$+++$
JG	Government hires a maximum of 300,000 unemployed workers per year that perform either services or environmental work and are paid the minimum wages	Due to gradual hiring **JG** has a continued impact on employment and income distribution.	$+$	~ 0	$--$	$--$	$++$

The effects of each policy/parameter on selected indicators is represented by + and – which indicate an increase (decrease) of that indicator with respect to the baseline scenario. The signs do not indicate improvement (+) and worsening (–) of the indicators, but rather represent a numerical increase of decrease. Hence, while a ++ in real per capita GDP might be interpreted as an improvement the same sign in greenhouse gas emissions is certainly an undesired effect of a policy. The symbol ~ 0 represents a negligible effect on the indicator.

Figure B.2: Summary of Single Policies (2)

Working Time Reduction (WTR), Energy Mix (EnM) and Border Carbon Adjustment (BCA)

Policy	Summary	Comment	Real per capita GDP	GHG emissions	Unemployment	Income inequality	Deficif GDP
WTR	Weekly working hours are reduced from 35 to 30	Reduction leads industries to increase hiring, particularly in the five years in which the policy is introduced.	–	–	–	–	–
EnM	Gradually substitutes fossil fuels and nuclear power for renewables in electricity production while increasing the share of electricity in total energy consumption	Despite being by far the most effective environmental policy, it only has a mild impact on the other main indicators	~ 0	– – –	–	–	~ 0
BCA	Additional yearly increases of 4.4% in carbon tax rates after 2030 and application of similar taxes on imports CO2 content	Overall carbon taxes have a small impact on the simulations, mostly due to the limited amount of emissions that are subject to the taxes	~ 0	~ 0	–	–	~ 0

Consumption Reduction (CR), Export Reduction (XR), Wealth Tax (WTax)

Policy	Summary	Comment	Real per capita GDP	GHG emissions	Unemployment	Income inequality	Deficif GDP
CR	Yearly reduction of 1.6% in marginal propensities to consume between 2020 and 2050	By 2050 **CR** results in a meaningful reduction of total private consumption and a relevant ,though indirect, reduction in emissions and increase in unemployment	– – –	–	++	+	+++
XR	Yearly reduction of 0.05% of exports between 2020 and 2050	Effects are similar to **CR** but weaker. **XR** serves mostly to contain an undesired increase in emissions from **CR** due to internal price reduction which favor exports	– –	–	+	+	++
CR + XR + WTax	**CR+XR** together with an increase in the wealth tax rate proportional to the fall in average propensities to consume	The joint increase of wealth tax rates, up to around 1.5%, help contain the increase in deficit-to-GDP ratio that follows consumption reduction.	– – –	– –	+++	++	– –

The effects of each policy/parameter on selected indicators is represented by + and – which indicate an increase (decrease) of that indicator with respect to the baseline scenario. The signs do not indicate improvement (+) and worsening (–) of the indicators, but rather represent a numerical increase of decrease. Hence, while a ++ in real per capita GDP might be interpreted as an improvement the same sign in greenhouse gas emissions is certainly an undesired effect of a policy. The symbol ~ 0 *represents a negligible effect on the indicator.*

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