Structural Change and Economic Dynamics 57 (2021) 265–278

Contents lists available at ScienceDirect

Structural Change and Economic Dynamics

journal homepage: www.elsevier.com/locate/strueco

Coupling environmental transition and social prosperity: a scenario-analysis of the Italian case

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ARTICLE INFO

Article history:
Received 2 July 2020
Revised 20 March 2021
Accepted 21 March 2021
Available online 15 April 2021

Keywords:
Ecological Macroeconomics
CO_2 Emissions
Green Growth
Working Time Reduction
Basic Income

ABSTRACT

This paper investigates to what extent green growth is able to promote social equity and which social policies can complement environmental policies to achieve social prosperity and sustainability. We develop a dynamic macrosimulation model to explore the social and structural effects of the Italian national energy and climate plan. We show that green growth alone will not result in better societal conditions and needs to be compensated with social policies that directly tackle inequality. Consequently, we select two social policies that are expected to improve income distribution, namely a basic income programme and working time reduction. Our scenario analysis shows that working time reduction leads to an increase in employment and a parallel decrease in aggregate demand that causes a reduction in emissions and inequality. The basic income programme reduces inequality by sustaining aggregate demand which, in turn, partially offsets the positive environmental effects of the energy plan.

1. Introduction

The socio-economic impacts of COVID-19 crisis has diverted away the policy agenda from tackling the climate emergency. Just before the outbreak of the pandemics, on December 2019, the European Commission released an ambitious plan aimed at making "Europe the first climate neutral continent by 2050" (Euopean Commission, 2019c). The plan, named European Green Deal, was based on a series of measures to convert the European economy by de-carbonizing the energy system, increasing investment in energy efficiency and renewable energy sources, sustaining the circular economy and, as a consequence, boosting the economy and sustaining prosperity through the creation of new job opportunities. In the words of the European Commission President, Ursula von der Leyen, the European Green Deal should have become "our new growth strategy" and remained just and inclusive ensuring "that no one is left behind" (Euopean Commission, 2019c).

This announcement echoed the proposal – actually rejected by the Congress – of a Green New Deal for the US economy, advanced by Representative Alexandria Ocasio-Cortez and Senator Ed Markey on February, 2019.[1] The rhetoric of green deals supports the paradigm of green growth that has become mainstream in the last decades in the environmental policy debate. The core idea of this paradigm is the project of "making growth processes resource-efficient, cleaner and more resilient, without necessarily slowing them" (Hallegatte et al., 2011). This idea stands as a pillar of worldwide strategies for combating climate change. It is included in the sustainable development goals pursued by the United Nations (Programme des Nations Unies pour l'environnement, 2011) and sustains the project of an "inclusive green economy" (United Nations, 2019a; 2019b).[2]

What the green deal proposal adds to the green growth approach is the acknowledgment that the environmental issues faced by modern societies are interwoven with social ones, especially with inequality and social exclusion. Climate change and environ-

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[1] These resolutions (H. Res. 109 and S. Res. 59 US Congress, 2019a; US Congress, 2019b) contained principles and policy indications for a 10-year programme pursuing the objectives of eliminating pollution and greenhouse gas emissions from infrastructures, manufacturing, farming and transportation, of completely switching to clean, renewable and zero-emission energy sources and of maximizing energy efficiency in electricity production and distribution, in buildings and industries. Accordingly, the Gren New Deal project views the public investment in greening the US economy as an "opportunity (1) to create millions of good, high-wage jobs in the United States; (2) to provide unprecedented levels of prosperity and economic security for all people of the United States; and (3) to counteract systemic injustices by making the US economy a prosperous green economy.".

[2] Furthermore, the OECD relies on green growth as a development policy able to "deliver economic growth that is both green and inclusive" to developing countries (OECD, 2011; 2015; 2019). Green growth is also at the centre of the European Commission's development and environmental strategies (Euopean Commission, 2018) and is expected to lead to an "inclusive green economy that generates growth, creates jobs and helps reduce poverty through sustainable management of natural capital" both in the EU and globally (Euopean Commission, 2019a; 2019b).

https://doi.org/10.1016/j.strueco.2021.03.007
0954-349X/

mental damage are seen as a threat mainly afflicting the more vulnerable parts of society and hence worsening inequality.[3] However, this acknowledgement does not seem to be sustained by concrete plans and has been criticized by scientists and climate activists who call for an actual Green New Deal for Europe (Adler et al., 2019) capable to change the structural conditions that actually produced the climate crisis, i.e. the dependence of prosperity on growth.[4]

The academic debate behind green growth has been reactivated by the green deal proposals and mainly focuses on whether decoupling between energy-material use and economic growth will be feasible. This debate sets aside the potential of social innovation, driven by social policies, that may counteract the detrimental impacts of green growth. At the same time, the COVID-19 crisis has rekindled the discussion about radical social policies, such as basic income and reduced working hours, which were deemed economically and politically unfeasible before the crisis. However, the contribution of these policies to the struggle against climate change is as important for sustainable transition as it is often neglected in the scientific and economic literature.

In this paper, we aim to fill this gap by applying an extended version of the *EUROGREEN* model (D'Alessandro et al., 2020) to clarify the social impacts of green growth strategies and to show that the achievement of environmental goals may be either complemented or slowed down by social policies which directly aim to reduce inequality and foster social inclusion.

To this purpose, we take the Italian economy as a case study and simulate the Italian "National Integrated Energy and Climate Plan" (PNIEC) published at the beginning of 2020 as an example of green growth strategy (MiSE-MATTM-MIT, 2020). Our exercise consists in exploring how policies which aimed at improving efficiency and developing renewable energy sources impact socio-economic indicators and structural change. Furthermore, we integrate this analysis by simulating the effects of social policies, in addition to energy policy, to hinder inequality. In particular, we take into consideration two alternative social policies that affect employment and income distribution through different channels: a *basic income* (BI) and a *working time reduction* (WTR). In line with the systemic approach to policy mix (Crespi, 2016; Edmondson et al., 2019; Kern et al., 2019), we investigate whether the interactions and dynamics activated by these social policies a) improve the social outcomes of the energy policies and b) complement them by providing favourable conditions to achieve the environmental goals.

Our general aim is to show that the socio-economic and structural impacts of environmental policies are not negligible. Our model makes it clear that pursuing economic growth, exclusively through energy efficiency plans, will not improve well-being indicators and does not contribute to reduce economic inequality. While both the simulated social policies, when coupled with the environmental ones, result in significant reductions in income inequality, the *BI* also makes it harder to achieve environmental goals due to increased aggregate demand and production. The opposite holds once *PNIEC* policies are coupled with *WTR* since total demand and production is reduced as a result of a lower, albeit much better distributed, income per capita.

The rest of the paper is organized as follows. Section 2 places our theoretical contribution in the context of the decoupling debate. Section 3, while presenting the model, points out the main differences with other models supporting the predictions of *PNIEC*. Section 4 presents the simulation results of our three policy scenarios with respect to a baseline. Section 5 discusses these results and concludes.

2. The decoupling debate

Green growth has emerged as the mainstream paradigm in which sustainability policies have been discussed in the policy arena. Its theoretical tenet is that market incentives foster technological efficiency via innovation and the expansion of renewable energy which, in turn, may fuel economic growth. Accordingly, green growth theorists argue that technological substitution will allow energy-material consumption and carbon emissions to be decoupled from economic growth (Aghion et al., 2009; Andreoni and Galmarini, 2012; Hallegatte et al., 2011). On the other hand, environmental scientists, ecologists and interdisciplinary researchers provided evidence that the market mechanisms alone do not lead to changes able to reduce the material footprint (Wiedmann et al., 2015) and avoid overshooting the planetary boundaries (Steffen et al., 2015) as well as critical transitions (Scheffer et al., 2012).

The political proposal of the GND has stimulated the scientific debate about the desirability of green growth (for a review see Seaton, 2019). Robert Pollin revisited his argument in favour of green growth (Pollin, 2015), arguing in favour of the GND and opposing de-growth (Pollin, 2018a). His argument is based on two theoretical assumptions. The first is that decoupling economic growth and energy-material use will be possible.[5] The second is that new investments in sustainable production and consequent overall growth will increase living standards and reduce inequality by supporting employment in countries at all levels of development (Pollin, 2018b).[6] Growth is seen not only as a desirable outcome, but also acts as a driving force since higher levels of GDP will further sustain future investments toward decoupling.

Pollin's position has triggered the reaction of de-growth advocates who have pointed out the shortcomings of the GND project and the need to decouple energy transition from economic growth (Burton and Somerville, 2019; Kallis, 2019). Kallis (2019) provided counterarguments to Pollin's position by highlighting inconsistencies in the foundation of the Green New Deal in (green) growth.

[3] In the document launching the European Green Deal, this acknowledgement was plainly declared: "The transition can only succeed if it is conducted in a fair and inclusive way. The most vulnerable are the most exposed to the harmful effects of climate change and environmental degradation. At the same time, managing the transition will lead to significant structural changes in business models, skill requirements and relative prices. Citizens, depending on their social and geographic circumstances, will be affected in different ways. Not all Member States, regions and cities start the transition from the same point or have the same capacity to respond. These challenges require a strong policy response at all levels." The same acknowledgment was expressed by the proposers of the US green new deal. The economic growth driven by the Green New Deal – as it was for Roosevelt's New Deal – could have been beneficial only to the middle and upper classes and exclude poorer citizens (US Congress, 2019a, p. 4-5). For these reasons, GND includes specific policy indications to ensure democratic participation, workers' rights and "family-sustaining wages", the satisfaction of basic needs (e.g. health and food) and equal opportunities (e.g. education) for all people in the US. These indications were translated by the labour supporters of the US GND into the concrete proposals of universal health insurance, basic income and job guarantee (Brecher, 2019).

[4] In a similar perspective, EEA (2021) highlights the necessity of a rapid intensification of environmental policies and a fundamental transformation instead of incremental improvements within established production and consumption systems.

[5] Specifically, according to Pollin, the economy will be able to grow along an environmentally sustainable path thanks to the substitution of oil, coal and natural gas with clean energy and the improvement in energy efficiency. Hence, the green new deal should be developed through an investment of between 1.5 and 2% of global GDP per year in green growth in order to obtain a 40% cut in global CO_2 in twenty years' time (and eventually the elimination of emissions in fifty years).

[6] However, Pollin and Callaci (2019) acknowledges that energy transition will also cause job losses and a decline in welfare for communities tied to fossil-fuel industries. This makes it necessary to complement the green new deal project with policies aimed at supporting workers and communities that will suffer the consequences of the abandonment of fossil fuels.

First, while admitting that a higher growth level may translate into higher investments in clean-energy activities, it is also likely to cause even more investments in non-green activities. Secondly, while shifting to a renewable energy infrastructure in a short time span is difficult at the present growth scale, it will be *a fortiori* more difficult at a larger scale. Thirdly, the 2% of GDP investment does not require deficit spending (it could be achieved by replacing non-clean or socially detrimental investments such as armaments) and consequently it does not require growth to be compensated. Fourthly, the shift from fossil fuels to the clean-energy economy entails a transition from a capital-intensive, high-productivity and high-profit industry to a labour-intensive, low-productivity and low-profit industry, which in turn hardly implies growth. Lastly, the relative reduction in CO_2 emissions due to the increase in energy efficiency and the change in the energy mix may be rapidly offset by the absolute increase in CO_2 emissions in the event of growth.

Numerous studies have pointed out the non-negligible energy-material costs connected to the transition to clean energy and disputed green growth expectations about the feasibility of absolute decoupling, especially if growth further fuels energy demand. Hickel and Kallis (2019) collect relevant evidence showing that a) absolute decoupling of GDP growth and resource use cannot persist in the long run at the global level, but only modestly in high-income countries under unrealistic assumptions concerning technical efficiency gains, and b) while absolute decoupling of GDP growth and CO_2 emissions is theoretically possible and is actually occurring in some regions, due to economic growth, it cannot be achieved in time to respect the Paris agreement on the carbon budget for 1.5 - 2 degrees centigrade. Clack et al. (2017) estimate that going 100% renewable is not sustainable as a path towards a low-carbon-emission energy system. Actually, the extent of substitution between renewable and fossil fuel sources is very limited (York, 2012) and does not result in a significant reduction in CO_2 emissions (Thombs, 2018). Overall, the increase in investments (and growth) is proved to be tied to higher carbon emissions by Burke et al. (2015b).

A further argument against decoupling is advanced by Schor and Jorgenson (2019) who point out that green growth is already worsening global inequality. The reported evidence shows that decoupling is occurring only marginally in developed countries, while in developing countries growth is continuing apace with higher emissions due to a shift towards energy-intensive technology (Jorgenson et al., 2019). The social impacts of green growth are also highlighted by the *Institute for Sustainable Futures* of The Sydney University of Technology which describes how renewable energy sources are mainly based on massive extraction of minerals whose costs are mainly incurred by vulnerable communities and workers (Dominish et al., 2019).

We aim at contributing to the decoupling debate by shifting the focus from an assessment of feasibility of green strategies centred only on environmental (dacarbonization) and merely economic (growth) criteria, to one that integrates social impacts (inequality) in order to analyze the social viability of sustainable transition. This perspective presupposes recognizing that climate change widens global inequality (Burke et al., 2015a), inequality results in environmental degradation (Boyce, 1994), and environmental and climate policies entail diverse and widespread social impacts (Lamb et al., 2020; Markkanen and Anger-Kraavi, 2019) that may prevent their social viability (Baland et al., 2018; Drews and Van den Bergh, 2016). Once this social dimension of transition to sustainability is taken into account, the focus shifts from the capability to stimulate eco-innovation to sustain decoupling (Aldieri et al., 2019), to the possibility that fine-tuned policy mixes including specific social policies can promote social innovation, i.e. "various non-technological innovations and active contribution from consumers, citizens and organizations beyond the purchase and adoption of low-carbon technologies" (Wittmayer et al., 2020, see also Van der Have and Rubalcaba, 2016) in our case pursued through policies reducing inequality on different dimensions.

This focus on social policies and their potentialities as a catalyst of environmental objectives represents a novelty in the ecological macroeconomic literature (Hardt and O'Neill, 2017). In line with Van den Bergh (2011); Van den Bergh and Kallis (2012), it entails a methodological approach to sustainability which instead of embracing an *ex-ante* position on the desirability of growth *versus* de-growth, concentrates on policy mixes and policy making to analyse alternative feasible paths to sustain social welfare within planetary boundaries. This in turn implies not directly addressing the issues concerning the relation between environmental degradation and GDP *per se* and the debate on the existence of an Environmental Kuznets Curve. Although there is no evidence of a causal link between the increase in income and a reduction of environmental impact and energy consumption (Carson, 2010; Luzzati and Orsini, 2009), some studies highlight a high degree of heterogeneity among countries and the crucial role of cultural and institutional factors, the intensity of policy regulation as well as of R&D investment (see, e.g., Mazzanti and Musolesi, 2013; Shahbaz et al., 2016). In this regard, an all-around human development perspective, beyond one-dimensional and reductionist GDP considerations (see, for instance, UNDP, 2020) appears more suitable to interpret and evaluate the kind of social and institutional transformation that the social policies discussed in this paper aim to achieve.

3. Model

The issue of energy transition is gaining momentum both at the academic and political level due to the necessary and tremendous transformation that the economic system must face to avoid a temperature rise greater than 1.5$\circ$ Celsius (IPCC, 2018). The literature on this topic followed alternative approaches. On the one hand, several scholars develop bottom-up (Capros et al., 2018) or partial equilibrium models that usually apply optimisation and simulation to the energy sector, at a high level of detail, to estimate the costs and effectiveness of specific technologies or policy options. Macroeconomic variables and dynamics are not considered and/or taken as exogenous conditions. Examples are TIMES[7] and PRIMES[8] models also implemented by the Italian PNIEC.

On the other hand, top-down macroeconomic models have flourished over time following alternatives branches. The first one is grounded on computable general equilibrium (CGE) that models supply and demand across all markets in an economy (Lofgren and Díaz-Bonilla, 2010). To evaluate the macroeconomic effects, the system is shocked – e.g. by introducing a carbon tax (e.g. Shi et al., 2019) – and the long-term outcomes are then quantified. Several CGE models have been developed and applied to environmental studies (Laha and Chakraborty, 2017) also based on the GTAP database (EEA, 2019). A dynamic energy version is represented by the GDyn-E (Antimiani et al., 2013) that has been recently integrated with the GTAP-Power database to analyse the impacts of climate change (Antimiani et al., 2017). As in the previous examples, CGE models are also based on optimisation. These models represent the common practise among policymakers and not, as the IPCC reports (IPCC, 2018) shows. Despite their wide use, there are several simplifying assumptions – such as representative agents, rationality, marginal analysis, optimising behaviour, full employment and perfect competition – that might undermine their reliability (Stiglitz, 2018).

[7] See https://iea-etsap.org/index.php/documentation.

[8] See http://www.e3mlab.ntua.gr/e3mlab/PRIMES%20Manual/The_PRIMES_MODEL_2010.pdf.

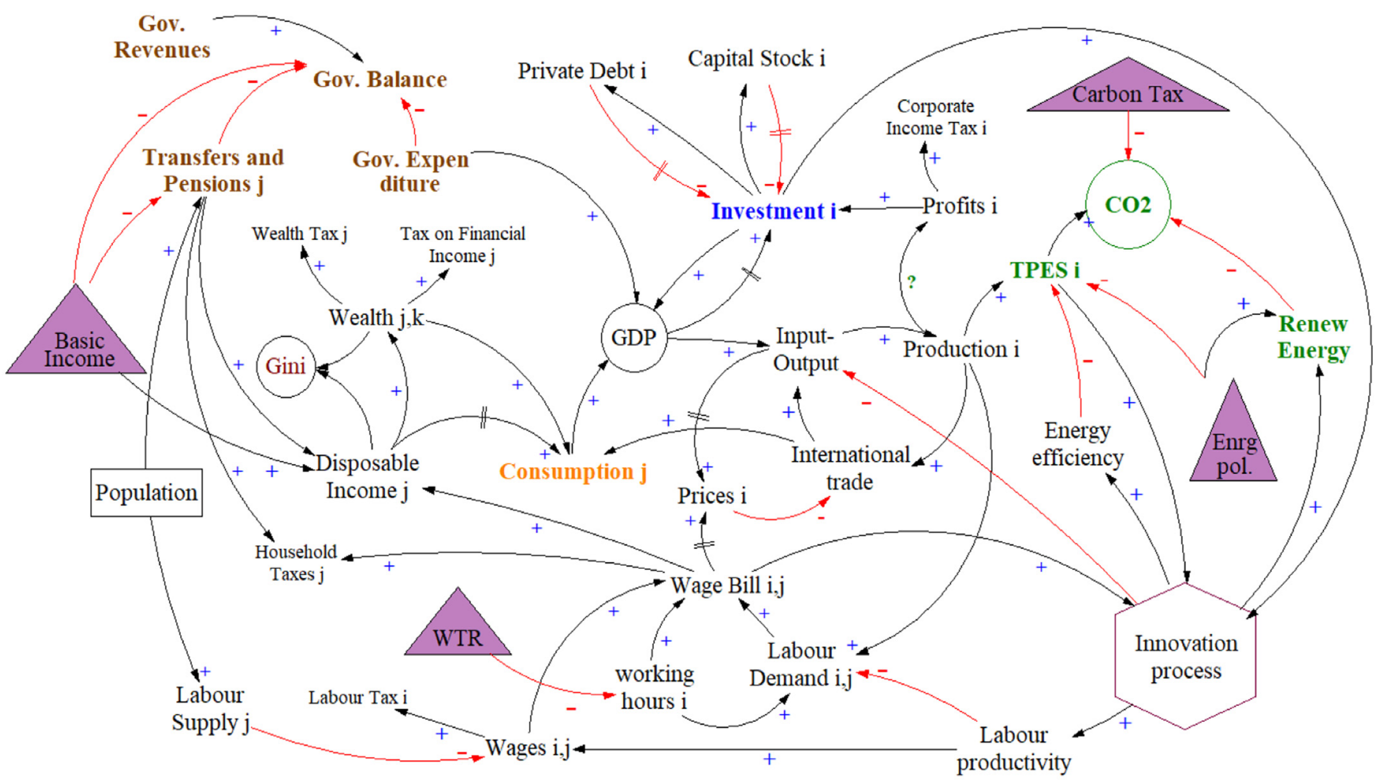


Fig. 1. Macroview. It represents the main variables and connections of the model. Violet triangles represent the policies implemented in the scenarios, where WTR is working time reduction, and the Enrg Pol. includes electrification and energy mix (see subsection 3.3). Double marked arrows mean lagged (one-period) effects. The main indicators are shown within circles, where Gini is a measure of inequality. Subscript *j* stands for skill (high, middle, low), *i* for industry (29 NACE sectors), and *k* for financial assets (deposits, bonds and equities). All the tax variables presented in the Figure enter Gov. Revenues.

These shortcomings call for a new economic approach able to take into account complexity, non-linear dynamics, uncertainty, agents' heterogeneity and the institutional context (see Hafner et al., 2020, for a review). The emergence of ecological macroeconomics has contributed in proposing alternative modelling frameworks based on post-Keynesian and ecological economics (Hardt and O'Neill, 2017; Lavoie, 2014; Rezai et al., 2013). Most of them are based on system dynamics (Bassi et al., 2020), Input-Output tables (Nieto et al., 2020), stock-flow consistency principles (Dafermos et al., 2017), interdisciplinary approach (Spash, 2012), and numerical simulations (Jackson and Victor, 2016). These features make it possible to describe dynamics, feedback loops and non-linearity, and trade-off and synergies across economic, social and ecological systems.

In this vein, we apply and extend the *EUROGREEN* model (D'Alessandro et al., 2020), based on system dynamics and ecological macroeconomics, by introducing two main novelties: i) the technological progress determines endogenous variations in the technical coefficients of the Input-Output matrix, and ii) the energy system has been updated in order to provide a fine-tuned representation of the PNIEC targets.

Fig. 1 shows the core structure of the model by representing the main variables and feedback loops. The model comprises 29 industries (i), three skill levels (j), four occupational status (employed, unemployed, inactive and retired), and three financial assets. The welfare system is managed by the government that receives revenues from taxation and it ensures transfers and subsidies. Each individual policy is represented by a purple triangle whose arrows indicate their direct effects. Population dynamics are taken as exogenous. The innovation process and the energy system are described below. The main social (Gini), economic (GDP), and environmental (CO_2 emissions) indicators are shown within circles. Data sources are listed and described in the Appendix A.[9]

This study aims to evaluate the linkages between the socio-economic and environmental energy spheres and provides support for radical social policies – e.g., working time reduction and basic income – able to balance the lack of positive social effects of the energy policies included in the PNIEC. To this purpose, we define alternative scenarios applied to Italy, from 2010 to 2050. As in macro-econometric models (Dagoumas and Barker, 2010), we make use of real data to calibrate the initial conditions. The model endogenously determines GDP, labour demand, income distribution, energy demand, and CO_2 emissions. Morevoer, we complement our analysis by comparing a wide set of social (inequality, unemployment), economic (deficit-to GDP, labour productivity), and energy (CO_2, emissions. renewable sources, energy intensity) indicators to provide a comprehensive evaluation of the PNIEC plan.

Note that our approach presents some limitations. First, our simulation exercise instead of exploring the potentials of knowledge diffusion and human development triggered by eco-innovation, investigates to what extent policies targeting technical innovation may generate detrimental effects on the social side that can constitute barriers to the success of those policies themselves. Secondly, although official available data were used, uncertainties remain related to the use of several databases that might present inconsistency for which simplifying assumptions are required. From a methodological perspective, the simulation of com-

[9] The interested reader can find the full analytical description of each module in the Supplementary Information of the *EUROGREEN* model at the following link: https://static-content.springer.com/esm/art%3A10.1038%2Fs41893-020-0484-y/MediaObjects/41893_2020_484_MOESM1_ESM.pdf.

plex system dynamics does not entail the forecast of future events; rather, it is a tool to compare the possible consequences of alternative policies. Finally, given the focus at the national level, our model does not consider the effects of climate change as it would require *ad-hoc* assumptions on the form of the damage function associated to global emissions. However, we acknowledge that a global picture might provide insights regarding the effect of technology and innovation (UNIDO, 2016), and demand for manufacturing (UNIDO, 2018) on sustainability (see, e.g., Marin and Mazzanti, 2021). Although important, these issues go beyond the scope of the present study and they would also require additional computational costs and data requirements that might be difficult to manage.

3.1. Technological progress

The process of technological change that increases labour productivity and changes the technical coefficients of the input-output matrix – including increases in energy efficiency – is endogenous in the model. Technological progress and its adoption is defined at the industry level and, depending on the relative costs of labour and intermediate inputs, will be either labour-saving or resource-saving. The key modelling procedures concerning the innovation process can be summarized in four steps: *i*. extraction of available technologies, *ii*. extraction of the scale of the change in technical coefficients and labour productivity of these new available technologies, *iii*. cost minimization and choice of techniques and *iv*. implementation.

The first step randomly draws, for each industry separately in every simulated year, three technologies from a uniform distribution. If extracted these are available and can be chosen and implemented. These three technologies are: *a*. labour-saving and intermediate input-augmenting, *b*. intermediate input-saving and labour-augmenting and *c*. labour and intermediate input-saving. We assume that the probabilities of extraction are equal for technologies *a* and *b*, but lower for *c*.

In the second step, the magnitude of the variations in labour productivity and technical coefficients are drawn from Gaussian distributions whose first two moments reflect observed values of past (over the last 20 years) variations in labour productivity and technical coefficients. It is further assumed that an increase in labour productivity given by technology *a*. also entails an increase in the demand for intermediate inputs per unit of GDP, and thus an increase in technical coefficients. Symmetrically, technology *b*. results in a decrease in technical coefficients together with an increase in labour intensity. Technology *c*. improves both labour productivity and intermediate goods efficiency, thus reducing the output-to-GDP ratio.

In the third step, industries compare the total costs of each available technology and choose the cost-minimizing one. Note that they face a trade-off between the costs of labour and intermediate inputs when choosing between technologies *a*. and *b*.. For instance, if only technology *a*. is available, it will be chosen if and only if the reduction in labour costs from increased labour productivity more than offsets the increased expenditure in intermediate inputs – otherwise the cost-minimizing choice is to maintain the old technology. Thus, the extraction of technologies *a*. or *b*., in the first step, does not necessarily result in their adoption. On the other hand, technology *c*. is always cost minimizing and therefore will be chosen whenever available.

The fourth and final step consists in implementing the chosen technologies. These are not immediately applied to the whole industry, but rather gradually implemented in line with the pace of fixed capital renovation. Thus, once again taking technology *a*. in industry *i* as an example, the actual labour productivity of *i* will be given by a weighted average between the newly extracted labour productivity ($\hat{\lambda}$) and the labour productivity from its older technology ($\bar{\lambda}$). The weights are defined by new investments in fixed capital (I_t) and the stock of older fixed capital after depreciation ($(1-\delta)K_{t-1}$)[10], respectively:

$$\lambda_t^i = \frac{\hat{\lambda} I_t + \bar{\lambda} K_{t-1}(1-\delta)}{K_t}. \tag{1}$$

Hence, the level of investment determines how fast new technologies are implemented and have an effect on employment and wages. A similar reasoning applies to intermediate input-saving innovations. We calibrate the variations of technical coefficients, in step *ii*, through a decomposition analysis on the historical changes in the input-output matrix (based on NIOT data from 1995 to 2009). Thus, the changes in technical coefficients when, for instance, technology *b*. is implemented in our model reflect the pace of historical variations of these coefficients. Moreover, whenever an industry *i* adopts a new technology, it will change how much intermediate inputs it demands from all other industries. In other words, an intermediate input-saving innovation in industry *i* will affect the total demand and output of all other industries.

The process of technological change here described generates non-trivial dynamics across and within industries in the simulated economy. Labour-intensive (intermediate input-intensive) industries are more prone to adopt technology *a*. (*b*.) if it is available. However, over time, increases in labour productivity reduce the incentives to adopt further labour-saving technologies and increase those to adopt intermediate input-saving ones. Policies may also affect the choice of technologies. For instance, an increase in CO_2 prices also increases the inventive for an industry to adopt technology *b*. which requires less resources per unit of output.

Technological progress also causes overarching consequences in the simulated economy. A new technology that increases labour productivity will reduce the number of workers hired per unit of output. However, it will also increase hourly wages and, consequently, aggregate demand. The balance between the increase in labour income from higher wages and its decrease from reduced employment will ultimately decide the macroeconomic effects of a labour-saving technology. Likewise, an industry that adopts an intermediate input-saving technology will increase its value added per unit of output. The resulting increase in its profit rate, assuming labour costs do not vary, will enable further investments and a faster adoption of new technologies. Still, the same new technology will reduce the output of the industries whose goods and services are used as an input in the productive processes of other industries. In the baseline scenario that follows, for the whole period 2010-2050, we obtain an average increase in labour productivity of 59.12%, an average decrease in energy intensity of −42.25% and an average decrease in the output-to-GPD ratio of −11.63%.

3.2. The Energy Framework

The main modelling purpose of the energy module is to convert each unit of monetary output into energy flows and CO_2 emissions. We focus on the distinction made by the Italian Institute of Statistics (ISTAT) between natural resources and energy products used at the industrial and residential level. The *natural resources* are directly supplied by the environment and split between renewable ($\sim$ 65%) and fossil ($\sim$ 35%).[11] The energy products are aggregated into four main sources: solid, liquid, gas and electricity. Again, to avoid double counting, the latter – that is generated through both

[10] Note that in the equation below $K_t = I_t + K_{t-1}(1-\delta)$.

[11] Note that, from the ISTAT database, natural fossil resources are not accounted for under CO_2 emissions to avoid double counting, since they are transformed into energy products used by the industries.

fossil and renewable energy sources – is not considered as air-pollutant.[12]

In brief, given the level of real output, we convert the total production in energy flows by applying industry-specific coefficients of conversion for each energy source. In particular, knowing the level of production, we obtain the total energy use – in tons of oil equivalent (toe) – by energy source and industry. Then, we convert total energy use into final energy consumption to obtain the energy which reaches the final consumer, excluding the energy used in transformation and transmission by energy industries. This conversion is required to associate the level of air pollution to each sector and source. Given the energy mix and the source composition, we obtain industry (i) emissions per unit of output ($\mathrm{CO}_2^i/\mathrm{Output}_i$), from which we can compute the total yearly carbon dioxide emissions ($CO_2 = \sum_i \mathrm{CO}_2^i$).[13]

Regarding the energy transition towards a low-carbon economy, the share of renewable sources depends on green investments and on the activation of energy policies such as electrification, a change in the energy mix and carbon taxes as described below. In each period, a share of investment is earmarked towards green technologies[14]. Moreover, households also invest part of their wealth in efficiency improvements and renewable energy development. This combination of firms' and consumers' investments to expand clean energy and efficiency affects the share of renewable energy in final energy consumption, thus contributing to reduce CO_2 emissions.

3.3. Policies

This subsection describes each of the individual policies that are combined to set up the three scenarios to be compared with the baseline in section 4. The first three policies – namely electrification, energy mix and carbon tax – are those that replicate the *PNIEC* target of renewable energy generation and energy efficiency which forms our first policy scenario. Additionally, the basic income and working time reduction plan, are integrated with the *PNIEC*'s policies to form our second and third policy scenarios. All the simulated policies are introduced in the year 2020 with smoothed variations over the first five-years (until 2025).

- *Electrification* simulates a gradual increase in the demand for electricity by productive industries which substitutes other non-renewable energy products. Simultaneously, this policy increases the share of each non-energy industries' investments in renewable energy generation.
- *Energy Mix* implies that electricity generation from solid and liquid fuels is gradually substituted – until it is phased out in 2025 and 2050, respectively – by natural gas. As in electrification, the energy mix policy also includes an expansion in renewable energy by the electricity generation industry.
- *Carbon Tax* includes a carbon tax of € 70 per ton of CO_2 emissions, paid by industries not included in the EU-ETS market.
- *Basic Income (BI)* introduces a basic income programme with annual benefits that amount to € 6,480 (i.e. 540 euros per month) for all inactive and unemployed low-skill households in the year of the policy introduction. The value of the benefit is then increased in line with the growth of economy-wide average wages. The simulated *Basic Income* programme is neither unconditional nor universal in an attempt to replicate, at least in part, the current proposal of the Italian Government to implement an income transfer programme that benefits the lower-income strata exclusively.[15] However, our scenario analysis considers a much larger number of beneficiaries, varying between 7 and 9 million (i.e. about 13% of the Italian population), instead of the one million currently enrolled to receive the benefit which corresponds to 1.7% of the population. Total government expenditure in the *Basic Income* programme rises from 50 billion in 2020 to 59 billion nominal euros in 2050. We opt to simulate a much larger programme than that actually implemented for the Italian economy to remain in line with the large-scale policies of income distribution and poverty reduction proposed in the American Green New Deal. Consequently, the *BI* simulated in our analysis has large-scale economic effects both in terms of income distribution and economic activity and production.
- *Working Time Reduction (WTR)* gradually reduces weekly working hours from about 39 in 2010 to 25 in 2050. That is, average weekly working hours decline by 0.5 hours per year which corresponds to roughly twice the rate of working hours reduction in Italy between 1900 and 1990 (Huberman and Minns, 2007).

These policies affect the pathways of our simulated economy in many respects. Interestingly, both environmental and social policies influence the choice of techniques and the direction of technical progress. While the causal link between environmental policies and resource-saving innovation is obvious, it is worth highlighting how also the two social policies affect the innovation process. Indeed, on the one hand, BI increases consumption expenditure, fosters investments which, in turns, strengthen labour productivity. On the other hand, WTR increases hourly wages through the increase in employment per industry. This change in relative cost between labour and intermediate goods promotes labour-saving innovation. However, these links are indirect. We are not considering the effect of specific training and educational programmes that might complement BI and WTR by increasing labour productivity and promoting eco-innovations (see, for instance Antonioli et al., 2013).

4. Results

We present the simulation outcomes of three policy mixes made by a combination of the single policies presented above. In particular, we compare a reference scenario, i.e. the baseline, with the *PNIEC* scenario, composed of the three energy policies discussed above. Moreover, we define the *PNIEC + BI* scenario which adds to the same policies of the *PNIEC* the basic income programme, and the *PNIEC + WTR* scenario which includes the working time reduction policy.

For the sake of clarity, we present the simulated scenarios in four separate subsections: low-carbon transition (4.1), socio-economic impacts (4.2), technological progress (4.3) and structural change (4.4).

The dynamics of the simulations depend in part on the outcomes of the technological progress adopted by each industry which, in turn, is rooted on a random process. Thus, to avoid arbitrary results from specific extractions, each scenario plotted below is the averages of 250 simulations.[16]

We assume that the policies start in 2020. Hence, in all the Figures below our three policy scenarios differ from the baseline

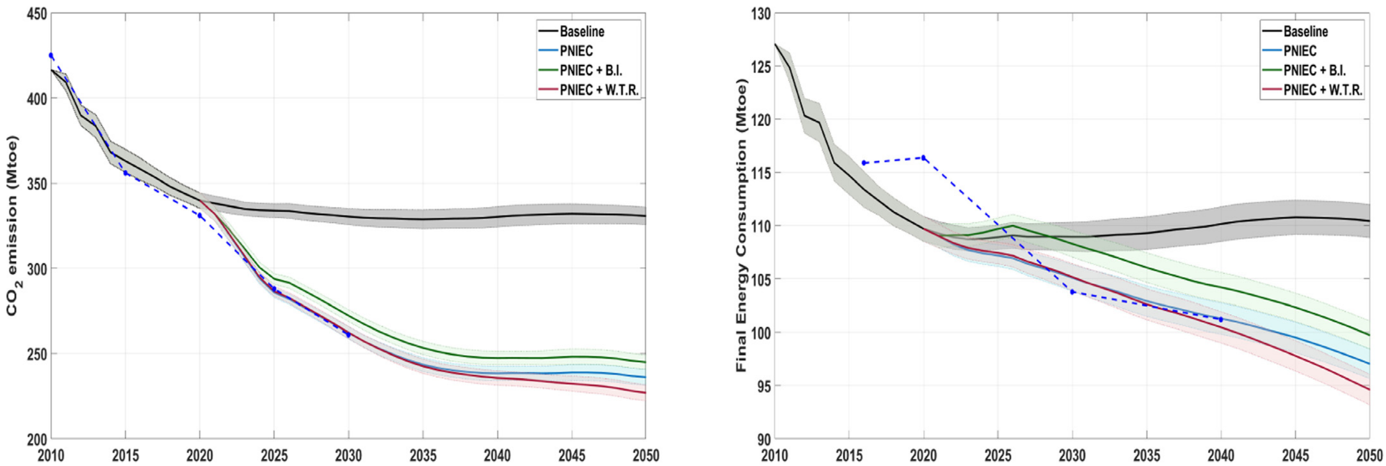
[12] In particular, *solid* includes coke, carbon and derivatives, whereas *liquid* consists of crude oil, petroleum and refined products, while *gas* mostly concerns natural gas.

[13] In this study, we opt to model CO_2 emissions alone instead of total greenhouse gas emissions in CO_2 equivalents because the former reflect more accurately the emissions from production and household consumption while the latter include emissions from agriculture which are less responsive to improvements in energy efficiency and the introduction of renewable energy generation.

[14] This share is first calculated to the investments that correspond to the currently installed capacity in renewable energy and then increased once energy policies are activated to reach the target share of renewable energy sources in final energy consumption

[15] In Italian, the transfer programme is called *"Reddito di Cittadinanza"* as laid down Decreto Legge 28 gennaio 2019, n. 4.

[16] As explained in section 3.1, we select runs with a one-standard deviation confidence interval, from different seeds of the random uniform distributions.



(a) CO_2 emissions (b) Final Energy Consumption (Mtoe)

Fig. 2. CO_2emissions and final energy consumption. Comparison – from 2010 to 2050 – of emissions (left) and final energy use (right) under the baseline (black) and the three policy mixes: *PNIEC* (blue), *PNIEC + Basic Income* (green), and *PNIEC + Working Time Reduction* (red). The navy blue dotted line, until 2030, represents the values projected by the official *PNIEC* plan. The shaded areas around the lines indicate one standard deviation confidence intervals.

starting from that year. Real data for the period between 2010 and 2018, when available, are plotted in red. The blue lines represent the *PNIEC* targets.

4.1. Low-carbon transition

The *PNIEC* aims to abate greenhouse gas emissions by boosting electricity generation based on renewable energy sources and fostering energy efficiency. Fig. 2 plots CO_2 emissions and final energy consumption in the baseline and in the other three policy scenarios. The *PNIEC* scenario projects a reduction of CO_2 emission of about 40% by 2030 (From about 425 to 261 Mtoe), in line with the official Italian plan. In spite of a remarkable reduction until 2035, carbon emissions stabilize afterwards.

Overall, the three policy scenarios generate a substantial emission reduction of at least 30% with respect to the baseline which remains around 340 MtCO2eq from the 2020s on. The two social policies have opposing impacts on emissions. The *BI* slows down the curtailment of CO_2 emissions through an increase in income, consumption and production directly induced by the policy. On the other hand, *WTR* further reduces emissions with respect to the *PNIEC* scenario due to a lower, albeit more equally distributed, per-capita income.

Panel 2 b shows the trajectories of total final energy consumption in the four scenarios. The three policy mixes, which share the same energy policies, project a sharp decrease in final energy consumption until 2050.

Once again, the *PNIEC* scenario lies in between the two social policy scenarios. When the *BI* is integrated, it leads to a higher level of final energy consumption. By contrast, *WTR* leads to a slightly lower energy consumption. Interestingly, the introduction of the *BI* programme causes an absolute increase in final energy consumption – from 2020 to 2026 – due to higher GDP growth and consumption despite the contemporaneous introduction of energy policies. The baseline, in the absence of any energy policies, faces a slight increase in final energy consumption from 2025 onwards, reaching about 110 Mtoe at the end of the simulation period.

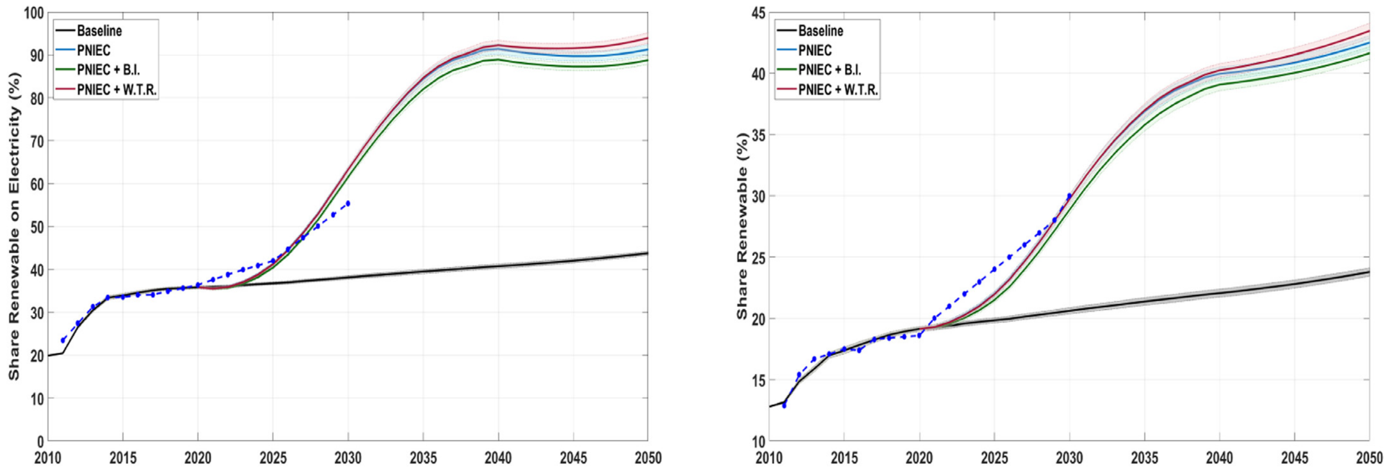
The dynamic of renewable energy production is presented in Fig. 3. It shows the dynamics of the shares of renewable energy on electricity generation (3 a) and on final energy consumption (3 b). After an initial period in which the trajectories are indistinguishable (until around 2023), the policy-mix scenarios diverge from the baseline. The latter shows only a modest linear increase until 2050, reaching about 42% and 25% of renewable energy in electricity and energy consumption, respectively. The three policy-mix scenarios, on the other hand, generate a significant increase in energy production from renewable energy sources whose share in electricity production reaches 90% in 2040, while in energy consumption it continues to increase until 2050, reaching roughly 43%. Unsurprisingly, there are small differences between the *PNIEC* and the two social policy scenarios since they share the same energy policies. Still, the additional aggregate demand from the *BI* increases the total energy demand which results in lower shares of renewable energy.[17] As in Fig. 2 the *PNIEC + WTR* scenario also outperforms all the others in terms of renewable energy production due to lower overall GDP growth.

4.2. Socio-economic impacts

Fig. 4 plots the trajectories of national per capita income (4 a), GDP growth rates (4 b) and the government deficit-to-GDP ratio (4 c). The GDP per capita increases in each scenario from 2020 onward, including in the baseline, with the highest values observed when *BI* is simulated. *WTR* curtails economic growth with respect to the other two policy scenarios and remains closer to the baseline. The results in 4 a and 4 b illustrate the impact in terms of GDP growth of the two social policies which are in line with the results concerning final energy consumption discussed above.

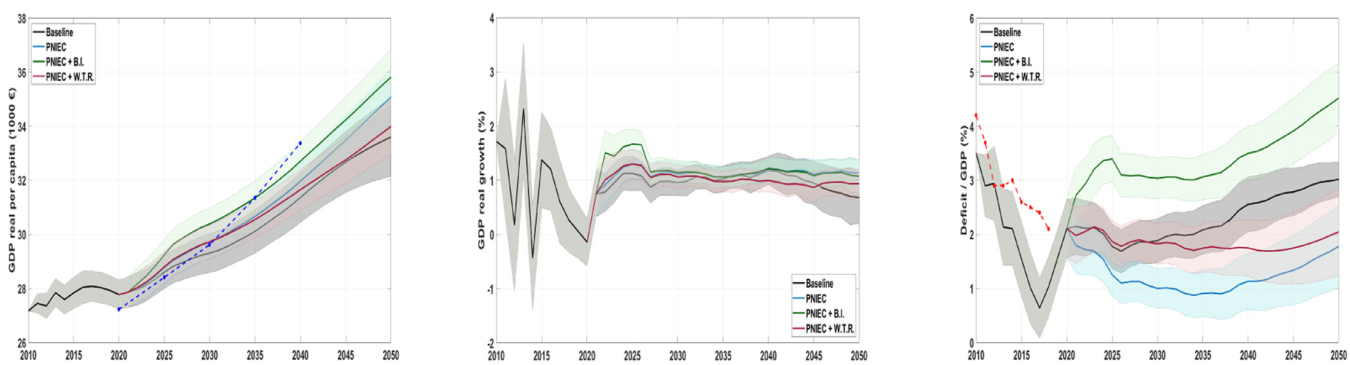
The dynamic of public debt illustrated in Fig. 4c follows diverging paths under each scenario after 2020. Under the baseline it is steady until 2030 and then slightly increases, reaching 3% per year in 2050. The *PNIEC* scenario with and without the introduction of *WTR* reaches almost the same ratio in 2050 ($\sim$ 2%), although the *PNIEC* scenario always remains below *PNIEC + WTR*. The addition of a basic income programme is, as expected, costly to the public sector. The increase in tax revenue from higher income and con-

[17] Since the energy policies are the same, the total installed capacity from renewable energy sources is the same in *PNIEC, PNIEC + BI* and *PNIEC + WTR*, unlike the demand for electricity and total energy consumption, since the latter depends on the level of aggregate demand in the economy which is directly affected by the two social policies.



(a) Share of renewable energy on electricity. (b) Share of total renewable energy.

Fig. 3. Share of renewable energy. Comparison – from 2010 to 2050 – of the share of renewable energy on electricity generation (left) and on final energy use (right) under the baseline (black) and the three policy mixes: *PNIEC* (blue), *PNIEC + Basic Income* (green), and *PNIEC + Working Time Reduction* (red). The navy blue dotted line, until 2030, represents the values projected by the official *PNIEC* plan. The shaded areas around the lines indicate one standard deviation confidence intervals.



(a) GDP per capita (base 2010) (b) GDP growth rate (base 2010) (c) Government's deficit-to-GDP ratio

Fig. 4. Main economic indicators. Comparison – from 2010 to 2050 – of the GDP per capita (left) and GDP growth rate (centre), in real terms (base 2010), and the government deficit-to-GDP ratio (right) under the baseline (black) and the three policy scenarios: *PNIEC* (blue), *PNIEC + Basic Income* (green), and *PNIEC + Working Time Reduction* (red). The dotted navy blue line on the top-left panel indicates the projected GDP per capita in the official *PNIEC* report, while the dotted red line in the right panel plots the actual values of the Italian deficit until 2018. The shaded areas around the lines indicate one standard deviation confidence intervals.

sumption is not enough to offset expenditure in basic income, thus pushing the government deficit-to-GDP ratio beyond 4% after 2045.

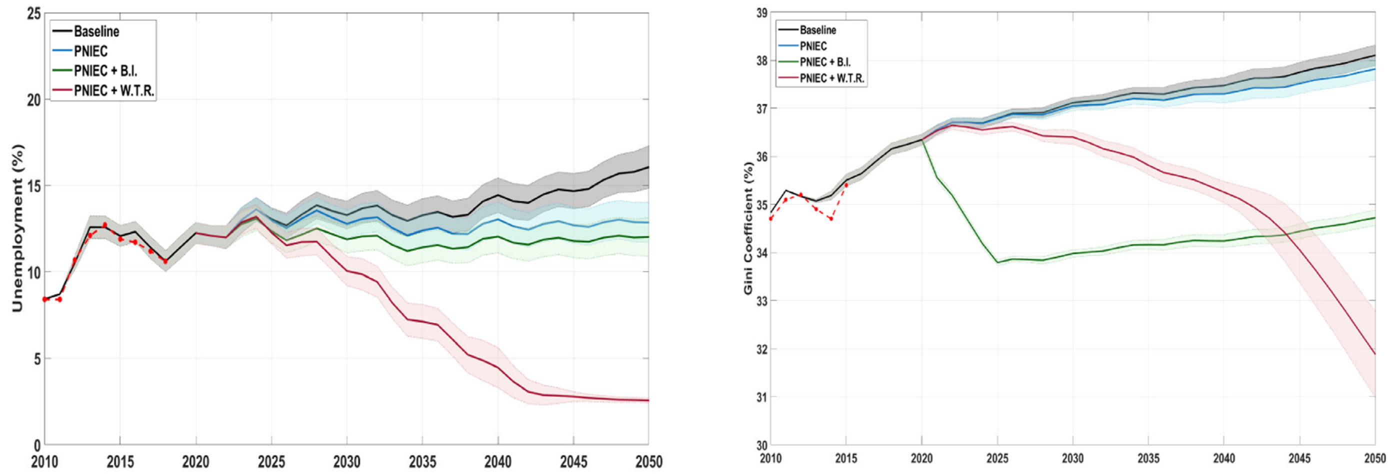
Despite underwhelming economic growth – with yearly growth rates around 1% in all three policy scenarios – the social impacts of the simulated policies differ significantly in terms of unemployment rates and income inequality (i.e., Gini coefficient), as shown in Fig. 5. The labour market is substantially affected by the *WTR* which reduces unemployment rates (5 a) from around 12% in 2020 to ~2.5% in 2050, due to the constant decrease in working hours. However, such a considerable increase in employment is not enough to offset the reduced yearly earnings per capita from working less hours, thus leading to a decrease in the total labour income with respect to the other two policy scenarios. The addition of *BI* reduces unemployment rates by 1% with respect to the *PNIEC* scenario. However, these two policy mixes have similar trends, with unemployment rates stable around 12-13%.

These contrasting effects of *WTR* and *BI* on unemployment rates are explained by how directly such policies affect employment. While the former directly increases labour demand, as measured by the number of workers required to attain production levels compatible with aggregate demand, the latter is only indirectly related to labour demand through the increase in consumption, mostly of low-skill inactive and unemployed individuals who benefit from the basic income programme. All the policy scenarios, including the *PNIEC* without social policies, project unemployment rates below the baseline. However, these remain substantially high in *PNIEC* and *PNIEC + BI*.

The Gini coefficient is presented in panel 5 b.[18] The *PNIEC* follows the same increasing trend as the baseline, with growing income inequalities that are reflected in an increase of around 36 to 38 in the Gini coefficient between 2020 and 2050. Both social policies result in a notable reduction in income inequality. The introduction of a *BI* policy has a large and sudden impact during the five years in which the transfer programme is introduced. This initial income distribution is followed by a slow but persistent increasing trend of the Gini coefficient after 2025.

The introduction of *WTR* leads to a persistent and accelerating decrease in income inequality. After a modest initial increase in the Gini after 2020, *WTR* projects a sharp decrease in the Gini coeffi-

[18] The Gini of the current study is based on the 13 different heterogeneous agent-groups in our model: low, middle and high-skill workers who are either employed, unemployed, inactive or retired, and capitalists (rentiers). The calculation includes both work, benefits and financial earnings from bonds and equity holdings.



(a) Total unemployment rate.

(b) Gini coefficient.

Fig. 5. Unemployment rate and income inequality. Comparison – from 2010 to 2050 – of the unemployment rate (left) and the Gini coefficient (right) under the baseline (black)and the three scenarios: *PNIEC* (blue), *PNIEC + Basic Income* (green), and *PNIEC + Working Time Reduction* (red). The dotted red lines plot the observed values of unemployment rates and the Gini coefficient until 2018 and 2015, respectively. The shaded areas around the lines indicate one standard deviation confidence intervals.

cient to 32 in 2050. The acceleration of income distribution under *WTR*, particularly after 2040, is due to the effects of low unemployment rates over labour force participation and wages. Falling unemployment rates increase the number of inactive workers that join the labour force. In turn, the increase in overall employment rates and relative scarcity of workers increases hourly wages which further contributes to improve income distribution.

These simulated scenarios suggest that the beneficial social effects of the energy policies advocated by the official Italian plan (MiSE-MATTM-MIT, 2020, p. 4-5) and other proponents of green growth are not automatic. Direct social policies are hence desirable to combine environmental targets with more social justice. In fact, our *PNIEC* scenario is characterized by a small reduction in unemployment rates, with respect to the baseline, and increasing income inequality. Job creation and social inclusion are explicitly mentioned as objectives or desirable consequences of the energy transition promoted by the official national plan. Still, it is not clear how these should be achieved. In our projected *PNIEC* scenario not even a very significant expansion in renewable energy investments is enough to outpace the impact that increasing labour productivity has on unemployment, labour force participation and, consequently, aggregate demand. Importantly, despite the massive effort to transform energy production and efficiency, the energy sector constitutes only a small fraction of total national output (about 5% in 2010). The addition of the two social policies illustrates how the joint achievement of social and environmental goals may be either complementary or substitutable. Even though both *BI* and *WTR* improve income distribution, they do so through different channels. The former directly transfers income to low-skill-low-income households and expands aggregate demand while the latter increases employment, though reducing individual yearly earnings. Consequently, as *BI* boosts production and CO_2 emissions, *WTR* reduces total energy consumption and emissions due to its moderating effect on aggregate demand.

4.3. The impacts of innovation

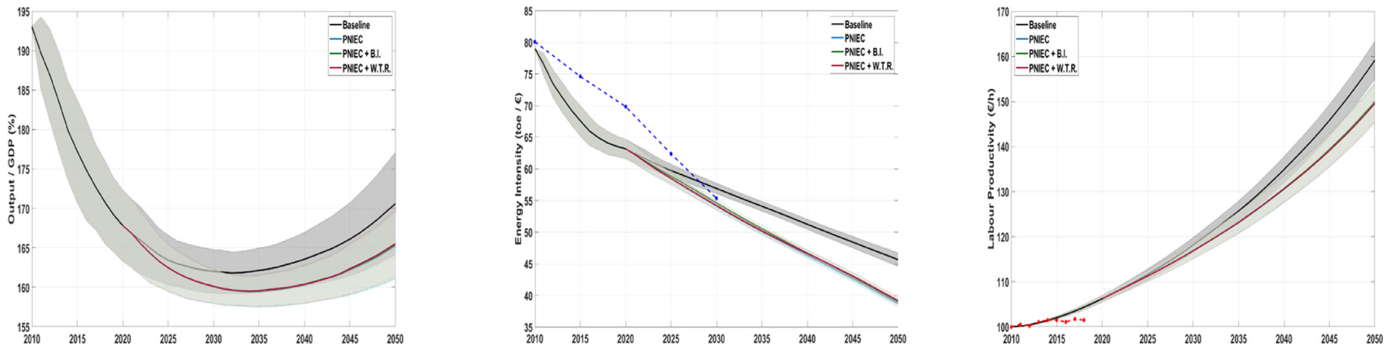
This section briefly presents the three main aggregate technological indicators in the model. Fig. 6 plots the simulated values for the output-to-GDP ratio (6 a), energy efficiency (6 b) and the labour productivity index which is normalized to 100 in 2010 (6 c). The three Panels depict negligible differences between the three policy scenarios although they differ from the baseline.

The output-to-GDP ratio measures the amount of intermediate goods needed to produce a unit of GDP. It falls together with the technical coefficients of the input-output matrix and thus roughly expresses the amount of materials and intermediate inputs required to produce a certain level of GDP. The energy intensity measured in 6 b is calculated as the ratio between final energy consumption and GDP. Hence, as the output-to-GDP ratio, it is a measure of efficiency in production and should also decrease together with the technical coefficients of the industries that supply energy products.[19] The final technological indicator in 6 c measures the amount of output produced by a single worker in one hour.

To properly understand the three graphs in Fig. 6 in light of the endogenous process of technological change described in section 3.1 they should be interpreted together. The identical trend followed by the three policy scenarios is explained by their common energy policies. In comparison to the baseline, the introduction of the carbon tax, the gradual switch from coal and liquid to gas in electricity generation and from other energy products to electricity due to the electrification policy all increase the cost of energy as an intermediate input. Our three energy policies thus make it more likely that industries will adopt intermediate goods-saving and labour-augmenting technologies (*b*.) than its labour-saving and intermediate goods-augmenting counterpart (*a*.). These additional costs explain why our three policy scenarios project lower, more efficient, output-to-GDP and energy intensity indexes while under performing in terms of labour productivity with respect to the baseline.

Nonetheless, despite the incentives for energy efficiency, we see an inflection in the trend of the output-to-GDP ratio after 2035

[19] That is, when all other industries that demand energy products adopt technologies that require less energy in its different forms such as electricity or oil to produce a unit of output. In more technical terms, the energy intensity index falls if the technical coefficients of one or more of the four energy-supplying industries – mining, fossil energy, gas and electricity generation – is reduced. Thus, the coefficients that ought to fall to decrease energy intensity are in the rows of the input-output matrix. However, the choice of technology is performed from the demand side, i.e. industries in the column of the matrix. Therefore, less energy-intensive technologies will be adopted if, and only if, they are less costly than other technologies available, as explained in section 3.1.



(a) Output-to-GDP ratio (b) Energy Intensity (c) Labour Productivity

Fig. 6. Technology indicators. Comparison – from 2010 to 2050 – of the total output-to-GDP ratio (left), energy intensity (centre) and labour productivity (right) under the baseline (black) and three scenarios: *PNIEC* (blue), *PNIEC + Basic Income* (green), and *PNIEC + Working Time Reduction* (red). The navy blue dotted line, until 2030, represents the values projected by the official *PNIEC* plan. The dotted red line plots observed values until 2018. The shaded areas around the lines indicate one standard deviation confidence intervals.

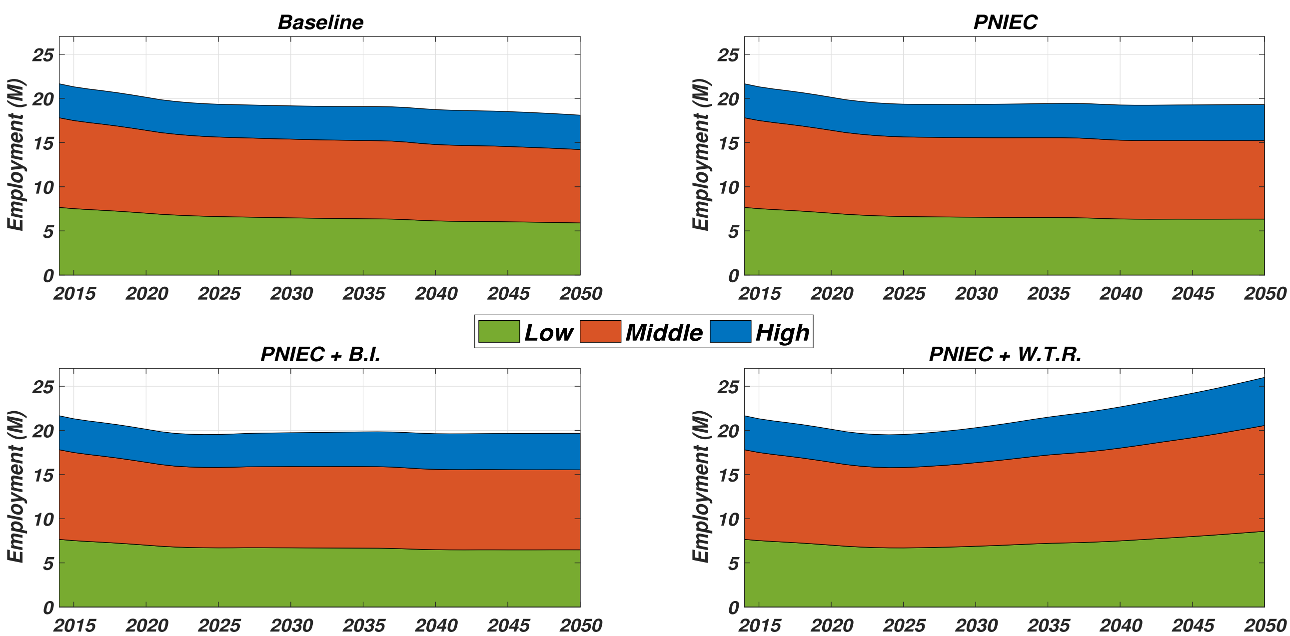


Fig. 7. Employment by skill. Millions of employed workers from 2010 to 2050 under the four scenarios: baseline (north-west), *PNIEC* (north-east), *PNIEC + BI* (south-west) and *PNIEC + WTR* (south-east). Employees are split between the three skills: low (green), middle (orange), and high (blue).

in graph 6 a. Note that this inflection occurs contemporaneously with the acceleration of the labour productivity index (6 c). The initial cost reduction in intermediate goods also increases the relative cost of labour, pushing innovation towards labour-saving technologies. However, the same inflection is not observed in energy intensity. Since it depends on the actual consumption of energy, measured in toe, energy intensity is also affected by the change in energy sources fostered by the policies simulated under the *PNIEC* scenario.

4.4. Disaggregated results

Some of the detailed results decomposing workers among three skills and production among industries are presented below. In order to keep the following figures as readable as possible we aggregate the 29 industries into seven macro-sectors.

The composition of total employment, by skill, in the simulated scenarios is presented in Fig. 7. The three skill levels are defined according to the maximum occupational attainment of the Italian working age population.[20] In the baseline, there is substantial job destruction with a loss of almost four million jobs between 2010 and 2050. Both the *PNIEC* and *PNIEC + BI* present similar trends, with a stronger decrease in the total number of employed individuals in the first ten simulated years. In spite of the very similar employment patterns in these two scenarios the number of employed workers is slightly larger with the basic income programme. There is also a relative decrease in the share of middle-skill employment during the first 10 simulated years in the four scenarios. This job polarization trend (Acemoglu and Autor, 2011; Goos et al., 2009) seems to be reversed once working time reduction is introduced in the bottom-right panel. Additionally, *WTR* leads to a sharp increase in total employment, from around 22 million in 2010 to almost 26 million in 2050, albeit each working fewer hours.

[20] Low-skill workers are those with lower secondary education or below, middle-skill workers those with secondary or post-secondary, non-tertiary education, and high-skill workers those with tertiary education.

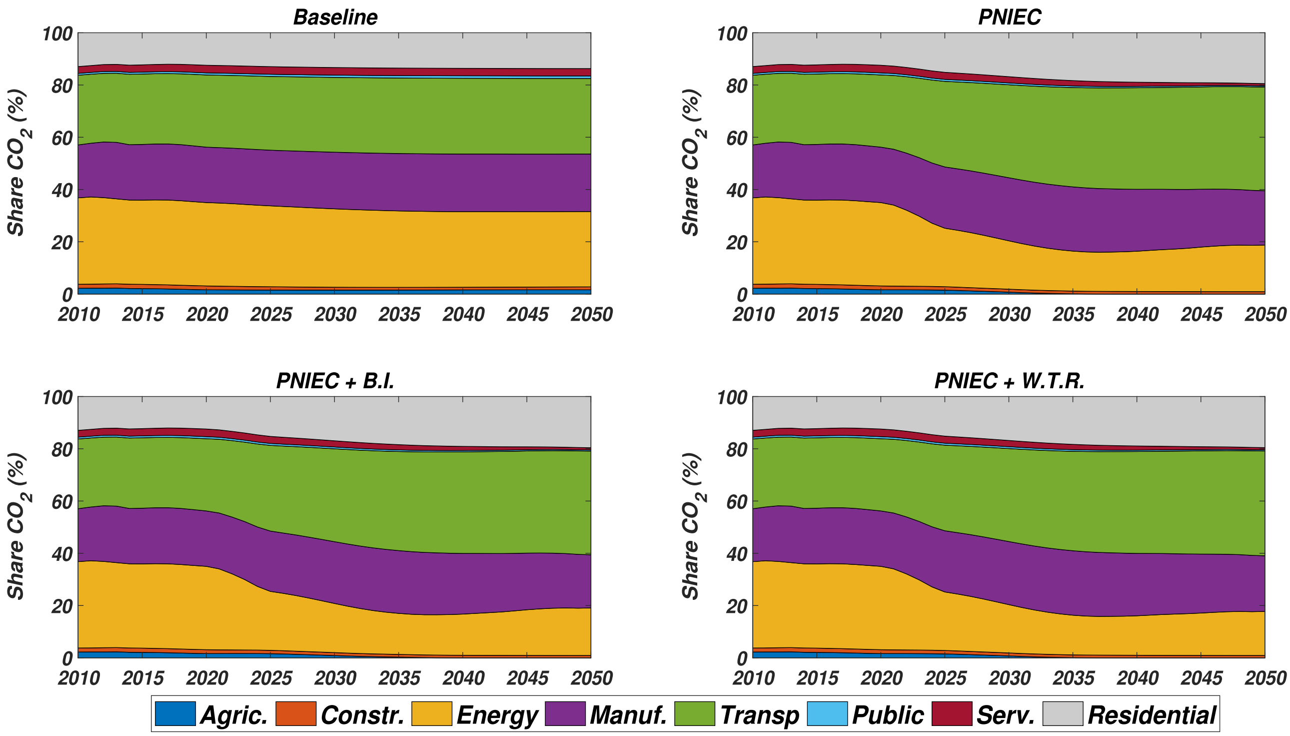


Fig. 8. *CO_2* **emission decomposition.** Total *CO_2* emissions from the seven macro-sectors and the residential sector (households), from 2010 to 2050, in the four scenarios: baseline (north-west), *PNIEC* (north-east), *PNIEC + BI* (south-west), and *PNIEC + WTR* (south-east).

The structural change promoted by the three policy-mix scenarios is more evident in Fig. 8 which presents the share of the seven macro-sectors plus the residential sector in total CO_2 emissions. The results of the environmental policies simulated to replicate the *PNIEC* in all three policy scenarios are evident in the relative reduction of the energy macro-sector in total CO2 emissions from 2020 onward, as well as in the lower CO_2 emissions from households and services due to higher energy efficiency. Nonetheless, Fig. 8 also denotes the limits of the planned environmental policies. The relative, although not absolute, increase in CO_2 emissions from manufacturing and transport industries represents the limits of current technological trends in substituting polluting energy products with electricity from renewable sources. These two macro-sectors include the largest use of solid and liquid fuels as well as natural gas. The change in intermediate-inputs and energy-saving technologies required to reach *PNIEC* goals is not enough to promote greater decarbonization of industrial processes and transportation which keep emitting significant quantities of CO_2 throughout the whole simulation period.

5. Conclusions

We developed a dynamic macrosimulation model applied to Italy to evaluate the short- and long-term socioeconomic consequences of its integrated national energy and climate plan. Although we calibrate the model to follow most of the trajectories reported in the plan (MiSE-MATTM-MIT, 2020), our approach does not take for granted the growth, employment and structural change projections used in bottom-up models. Instead, it allows for an endogenous determination of these key variables as a result of the simulated policies. Therefore, despite our efforts to replicate these energy policies and their respective goals, our methodology leads to significant differences in growth and employment.

Our results support two major conclusions. First, there is little evidence that these environmental policies associated with green growth will significantly boost job creation through economic growth. Investments in renewable energy sources and energy efficiency can, to some extent, create jobs and improve income distribution. However, such benefits are more than offset by the negative impacts on employment and distribution. Our results suggest the emergence of a reinforcing negative feedback loop. Incentives to green growth tend to increase labour productivity and thus reduce employment and increase the polarisation of wages within the labour market (between sectors where productivity growth is high and those where it is low). This process reduces consumer expenditure and aggregate demand leading to higher unemployment and lower wages. This downward spiral is limited by rising public spending and competitive advantages that tend to increase exports. However, this feedback loop limits the growth capacity of the economic system.

Secondly, these findings convey the need to couple environmental policies with direct social interventions. Despite their positive effects on income distribution and employment rates, alternative social policies have their drawbacks that might hamper or slow down the achievement of environmental goals. The two social policy scenarios evaluated in the current study promote social equity through different channels. When environmental policies are accompanied by a basic income programme, the economy is able to temporarily increase GDP growth and marginally reduce unemployment rates. However, it does so at the expense of the development of clean energy sources and emission reductions due to greater aggregate demand. The basic income programme increases the government's deficit-to-GDP ratio which remains systematically above the 3% limit defined in the Maastricht Treaty. In contrast to basic income, the inclusion of working time reduction together with environmental policies actually improves the shares of renewable energy (Fig. 3) and limits the increase in final energy consumption while reducing the deficit-to-GDP ratio, particularly after 2030. This scenario matches environmental targets with social goals. It increases employment and labour force participation which, in turn, improves income distribution.

In other terms, we find a positive scale effect induced by working time reduction (Schor, 2005) that support the idea that social innovation can be extremely useful to enlarge the narrow path towards sustainability and, thus, the policy options to achieve this goal. However, under working time reduction, individual average income remains significantly below that of the other two scenarios. Hence, there are potential limits to such a substantial fall in working hours. Even though simulations indicate an overall improvement in unemployment rates and inequality, workers would have to accept lower income and consumption levels. This opens a debate on *who should pay* for working time reduction that goes beyond the scope of this paper.

Governments and European institutions are apparently recalling the green deal approach and taking into consideration the opportunity to address the post-COVID-19 recovery investments towards greening the economy (Euopean Commission, 2020). At the same time, structural social policies such as basic income and working time reduction are gaining momentum in the political debate as measures to mitigate the asymmetric impacts of the pandemic crisis on employment and distribution. Our contribution suggests that looking at the social and ecological crisis together allows for more effective and lasting solutions.

Declaration of Competing Interest

None.

CRediT authorship contribution statement

A. Cieplinski: Conceptualization, Data curation, Formal analysis, Methodology, Resources, Software, Visualization, Writing - original draft, Writing - review & editing. **S. D'Alessandro:** Conceptualization, Supervision, Writing - original draft, Writing - review & editing, Funding acquisition. **T. Distefano:** Conceptualization, Data curation, Formal analysis, Methodology, Resources, Software, Visualization, Writing - original draft, Writing - review & editing. **P. Guarnieri:** Conceptualization, Writing - original draft, Writing - review & editing.

Acknowledgements

We thank the participants of the conference "Capitalism, Conflict, and Cooperation: A Celebration of the Work of Samuel Bowles & Herbert Gintis" held at Columbia University and Luigi Giorgio, Francesco Marghella and Bill Mebane for valuable comments and suggestions. The authors acknowledge funding from the Greens|EFA Group at the European Parliament and from the LOCOMOTION project, within the European Union's Horizon 2020 research and innovation programme under grant agreement number 821105.

Appendix A. Data

The data sources employed to calibrate the model are summarized below.

- *Social and National Accounts*[21]: the Italian Institute of Statistics (ISTAT) provides data about the inter-industry intermediate and international trade, including information about the final demand, taxation, and value added (wages and profits). The data are consistent with the NACE (Rev. 2) classification[22] and available for the year 2010 and 2014 which we aggregate to build the input-output matrix for the 29 simulated industries.
- *Energy Accounts*[23]: the energy data come from two datasets. The ISTAT-PEFA reports the matrices of supply and demand of energy fluxes (in terajoules) by source for each NACE industry and for households, for the years 2014 and 2015. In particular, the demand for energy is split into two parts, a matrix (B) which supplies total use – including final use, losses, non-energy use, and for transformation – of energy, and a matrix (C) which reports the share of polluting energy that generates CO_2 emissions. We integrate these data with those from the EUROSTAT's energy balance to obtain final energy use and the actual amount of CO_2 emissions by source and industry, including the residential sector, from the Air Emission Account (AEA).[24]
- *Government Balance*[25]: ISTAT collects detailed information on public expenditure, debt and revenues from taxation.
- *Labour market data*: productivity, skill-specific wages and employment by industry, fixed capital stock and capital productivity and hours worked are obtained from the EU-KLEMS project database for Italy.[26]
- *Energy prices*: Energy commodity prices and electricity prices, per ktoe in real 2013 euros, are assumed exogenous and are derived from the official Italian *PNIEC* Report (MiSE-MATTM-MIT, 2020, p. 325).

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[21] The Italian input-output tables can be found here.
[22] The detailed classification is available here.
[23] Available here.
[24] A detailed description of the energy balance is found here while data on greenhouse gas emissions are available here.
[25] Available here.
[26] The data are available here.

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