Ref. Ares(2019)2336347 - 02/04/2019

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 727114

MONROE - Modelling and evaluating the socio-economic impacts of research and innovation with the suite of macro- and regional-economic models

D.6.4.2 Key messages and recommendations for policy makers from the results

March 2019: Public

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Document Details

Authors	CE
Creation Date	21/03/2019
Date of Last Revision	31/03/2019
Version	V1
Description	

Version History

Version	**Updated By**	**Date**	**Changes / Comments**
V1	Stijn Van Hummelen, Panagiotis Fragkos, Olga Ivanova	31/03/2019	Draft for submitting

Project Involvement

Project Director	Olga Ivanova
Project Manager	Iason Diafas
WP Manager	Hector Pollitt
Project Leads	PBL

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Investing in research and innovation in the EU: potential socioeconomic impacts

HEADLINES

- Increasing spending on R&D could have considerable positive impacts on the EU's economy, although the impacts differs across countries and sectors.
- If R&D spending is increased by EU Member States to reach their national targets (by 2030), in combination with a gradual increase in the number of higher educated people in the workforce, this could lead to EU GDP increasing by 0.2%-0.8% in 2030 and 0.3%-2.5% in 2050, compared to business-as-usual.
- There are large benefits stemming from the simultaneous implementation of policies targeting innovation, education and the development of the required labour skills.
- R&I policies need to be considering in the context of the EU's GHG mitigation strategies. Investing in clean energy innovation could generate substantial benefits.
- Considering national and regional differences while designing R&D policies would lead to higher economic growth.

1 R&I policy in the European Union

Research and innovation (R&I) forms a key component of the EU's strategy for the European economy. Guided by the goals of the Innovation Union flagship initiative – the EU aims to turn Europe into a world-class science performer, revolutionize the way public and private sectors cooperate; and remove bottlenecks (like expensive patenting, market fragmentation, and skill shortages) that prevent the market development and upscaling of innovative ideas. EU countries are encouraged to invest 3% of their GDP in R&D by 2020 (1% public funding, 2% private-sector investment), with specific national targets for R&D considering country differences, socio-economic priorities and current situation. The Horizon 2020 programme (2014-2020) is designed to support transnational and multidisciplinary collaboration across the EU with public funds, while other initiatives, such as VentureEU, aim to boost capital investment in innovative start-up companies across Europe.

The central role R&I plays in EU policy is very likely to continue beyond 2020. In its proposal for the next Multiannual Financial Framework, the European Commission (EC) suggests upping investments in R&I by allocating EUR 100 billion over 2021-2027 to the Horizon Europe (building on the H2020 programme) and the Euratom Research and Training Programme. In addition, the EC proposes to mobilise around EUR 11 billion for financial instruments and budgetary guarantees under the InvestEU Fund, which is expected to mobilise EUR 200 billion of private investment to support R&I. The EU2050 strategy, the so-called mid-century strategy published in November 2018 by the EC and meant to cement the EU's long term goals, suggests that one of the deep social and economic priorities required in the EU to achieve a climate neutral Europe is to accelerate near-term research, innovation and entrepreneurship, boost the EU's industrial competitiveness through research and innovation, and invest in human capital in the next decade and beyond.

With this policy context in mind, it is crucial to improve our understanding of how R&I policy instruments affect firm productivity, economic growth and society. Policymakers can deploy a series of instruments to promote innovation, including direct investment in R&D and knowledge diffusion (e.g. open access to science), but also investments that facilitate innovation more indirectly: investing in human capital development (through education and training programmes), developing a regulatory and policy environment that stimulates the entry and exit of new businesses, promoting venture capital and access to finance so that businesses have access to low-cost and adequate funding. But what is their likely impact on growth and jobs?

The overall objective of the MONROE project is to assess how various R&I policy instruments - R&D spending in particular - could affect the European economy, at macro, regional and sectoral level, using some of Europe's most advanced macroeconomic models and a scenario-based approach. The policy scenarios for the analysis were designed with the objective of giving interested stakeholders a flavour of the policy levers the macroeconomic models can assess, as well as to illustrate what the likely direction of impacts will be across the EU Member States and different sectors if the different macroeconomic models are used

This project has received funding from the European Union's Horizon 2020 research and innovation programme
under grant agreement No 727114

to assess these policy levers. This policy brief presents a summary of the main scenario results and the resulting policy recommendations.

QUICK GUIDE

The **MONROE project** was implemented from January 2017 to March 2019 and has received funding The European Union's Horizon 2020 Framework Programme for Research and Innovation. Five different macroeconomic models were used for impact assessments:

- E3ME is a macro-econometric model of the world's economic and energy systems and the environment. E3ME is a global and dynamic simulation model estimated by econometric methods, complemented by bottom-up technology diffusion models of the power, transport, household heating and steel sectors. It is developed and operated by Cambridge Econometrics, a research consultancy.
- GEM-E3 is a global, multi-regional, multi-sectoral recursive dynamic computable general equilibrium (CGE) model which provides details on the macro-economy and its interaction with the environment and the energy system. It is developed and operated by E3Modelling, an Athens-based research consultancy.
- EU-EMS (European Economic Modelling System) is a spatial computable general equilibrium (SCGE) modelling system that includes the representation of 62 countries of the world, with a very detailed regional dimensionality for EU28 countries by including them as consisting of 276 NUTS2 regions. It was built as part of Horizon2020 MONROE project and operated by PBL - Netherlands Environmental Assessment Agency.
- PACE (Policy Analysis based on Computable Equilibrium) is a multi-sector, multi-region CGE model of global production, consumption, trade and energy use. It is developed and operated by ZEW – Leibniz Centre for European Economic Research, a research institute based in Mannheim.
- DSGE is dynamic stochastic equilibrium (DSGE) model that covers the whole world and has separate representation of Germany, France, Great Britain, United States, the rest of EU28 countries and the rest of the world. The model includes the representation of inter-national trade, migration and capital flows. The model is a fully endogenous growth model and includes one global R&D sector that produces technological knowledge. The model was built by Dr. Tom Holden within the framework of the MONROE project.

In a first step, the macroeconomic models were enhanced with new features (towards an improved representation of private and public R&D, knowledge spillovers, human capital and their impacts on economy) and a new multi-region DSGE model was developed. In a second step, the advanced versions of the macroeconomic models were used explore the potential socioeconomic impact of policy scenarios integrating specific innovation and human capital policy instruments.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

2 The potential socioeconomic impacts of R&I policy

The potential impacts of R&I policies are assessed through the design and analysis of policy scenarios; model projections of different policy mixes that are compared with a baseline scenario (assuming continuation of current trends and policies in R&I, education and energy) to get a quantitative indication of the outcomes of specific R&I policies and the level of policy ambition required to meet specific targets. A comprehensive set of policy scenarios were developed with the set of macroeconomic models, mainly focussing on macroeconomic, societal and industrial benefits from public and private R&D investment, human capital formation, open innovation, R&I in clean energy technologies, and regional policies.

As a starting point, a Central Policy Scenario was designed with common assumptions and baseline data to be implemented across the various macroeconomic models. This is to make sure the macroeconomic models are – to the extent possible – assessing the same thing. In addition to a Central Policy Scenario, each of the modelling teams designed additional scenarios in order to reflect the model's strengths and add further detail to the analysis.

In the following subsections, the results for the most relevant scenarios from a policymaking perspective are discussed.

2.1 Investing in R&D and human capital

In the **Central Policy Scenario**, it is assumed that by 2030 all EU28 countries will increase their R&I intensities to meet their specific national targets, by 2030 instead of by 2020. the share of workforce with a tertiary degree in all EU countries would increase by 0.1% per year above baseline levels reflecting a steady upgrade of human capital.

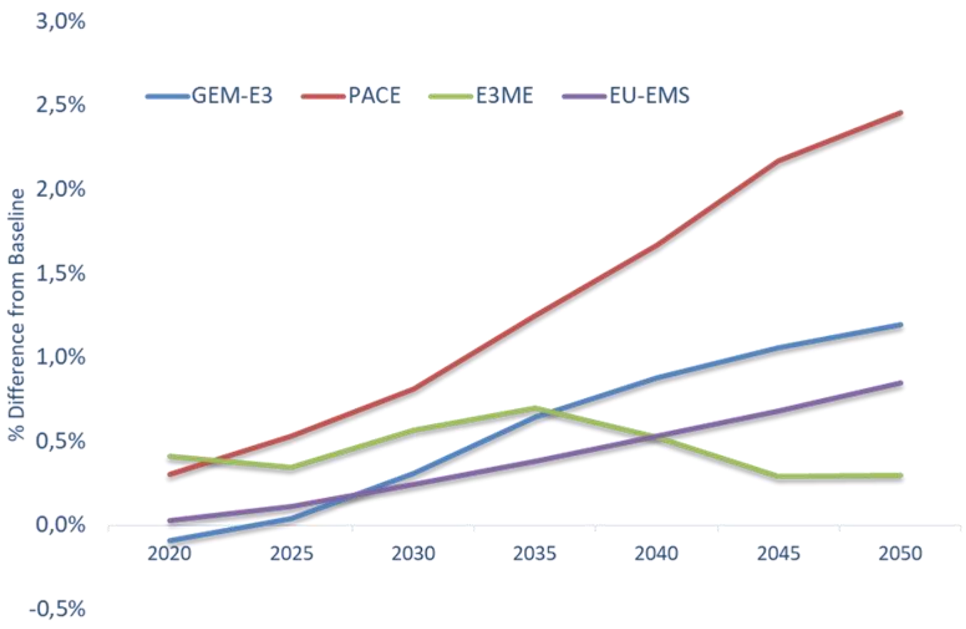
The advanced versions of E3ME, GEM-E3, PACE, EU-EMS and DSGE models with improved representation of public and private R&D, knowledge spillovers and human capital (Sections 3.1-3.5) were used to asses a Central Policy Scenario.

A robust outcome across the macroeconomic models is that increased investment in R&D and human capital would result in higher economic growth, with EU GDP increasing by 0.2%-0.8%

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

in 2030 and 0.3%-2.5% in 2050; this is triggered by the accumulation of knowledge stock leading to higher productivity growth. The GDP results are presents in Figure 1.

Figure 1: EU GDP changes in the Central Policy Scenario

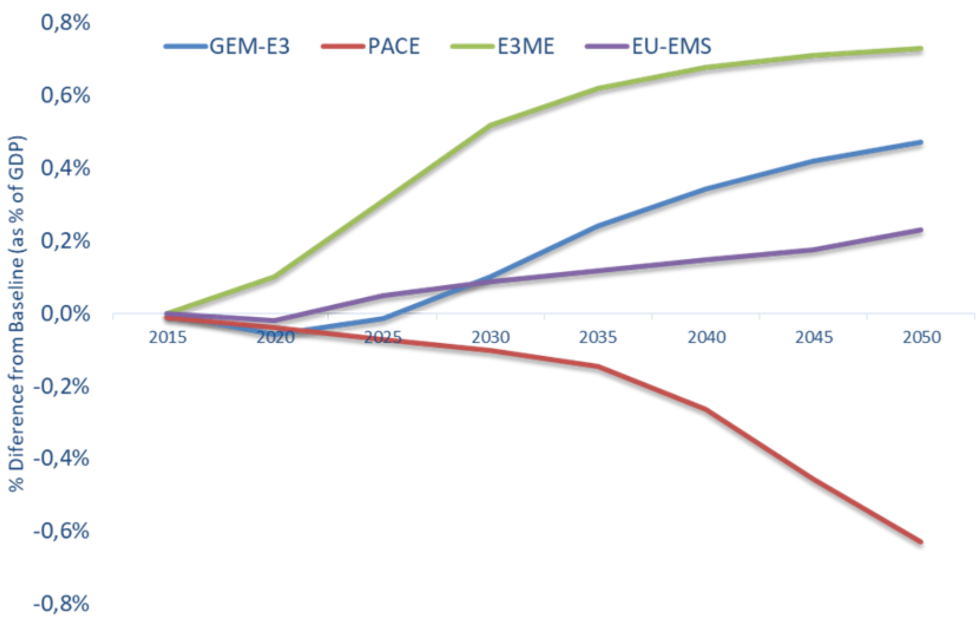


The main driver of the positive GDP impacts is an increased competitiveness of the EU and this is a consistent finding across the E3ME, GEM-E3 and EU-EMS models. Despite differences in results produced by the models due to different underlying methodologies or data sources, all models show that after 2025 higher productivity growth gives a boost to GDP growth and to the international competitiveness of EU economies with the EU balance of trade improving by 0.2%-0.7% of GDP in 2050. This is depicted in Figure 2. The innovation-induced productivity improvements in the Central Policy Scenario improve the international competitiveness of European firms leading to an improved balance of trade for the EU in the E3ME, GEM-E3 and EU-EMS models.[1]

[1] The improved EU balance of trade is induced by the modelling assumption of not-perfect substitutability of domestically produced and imported goods. When products are assumed to be close substitutes (i.e. trade elasticities are high), then by performing research (and cutting its production cost) a firm may significantly expand its market-share; this will not materialize when the firm's good is a poor substitute for its rivals. In PACE both exports and imports are projected to

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Figure 2: EU-28 Balance of trade in the Central Policy Scenario



At the sectoral level, the larger positive impacts are projected for the advanced manufacturing sectors which have a high R&D intensity and greatly benefit from knowledge spillovers. As highly traded sectors, they benefit the most from improved competitiveness as they can reap the benefits of better and lower-cost products within a global marketplace. Services sectors also benefit, although the effects are more indirect, resulting from a larger economy and higher levels of consumer expenditure.

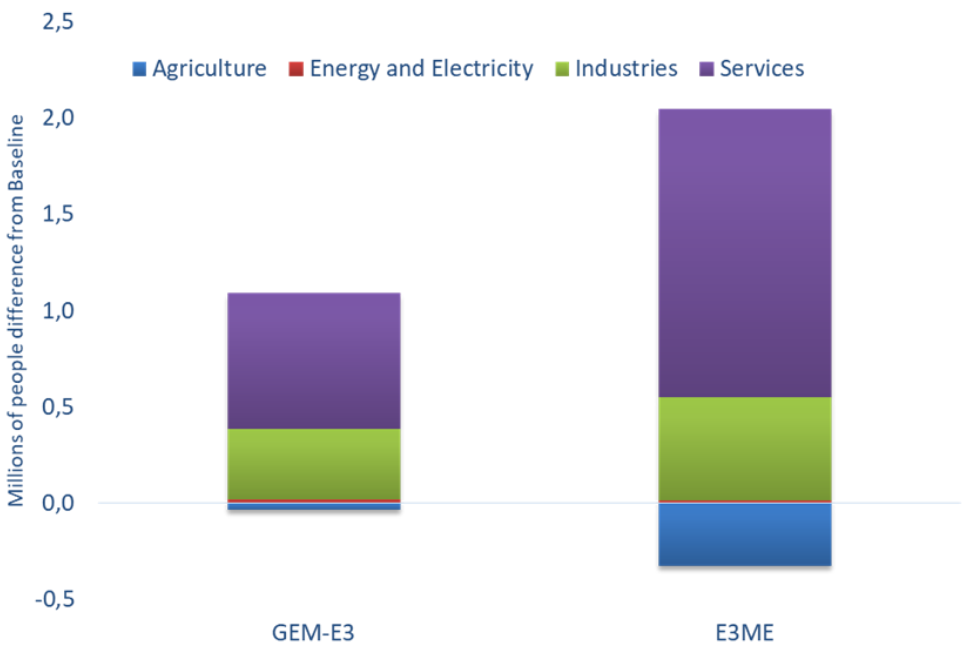
The positive GDP outcomes lead to higher employment, especially for highly-skilled workers triggered by increased expenditures in the R&D sector that primarily employs highly-skilled labour and by the larger supply of highly-skilled workforce. The impact in lower skill levels is slightly negative following trends of higher attendance in tertiary education. However, the impact is limited as the positive growth effects are cascade through supply chains to other sectors that do not necessarily require highly-skilled workforce. As a result of their high R&D intensity and high trade openness, the manufacturing sectors (especially those related

increase, but imports increase to a larger extent triggered by high GDP growth leading to increased demand for imported goods.

This project has received funding from the European Union's Horizon 2020 research and innovation programme
under grant agreement No 727114

to high-tech equipment manufacturing, transport equipment, electronics etc.) benefit the most from increased R&D investment, as they improve significantly their competitiveness in international markets and expand their exports to non-EU regions. Additional employment opportunities are created in the services sectors, which are often low paid and arise from multiplier (supply chain) effects in the macroeconomic models.

Figure 3: Sectoral Employment in the Central Policy Scenario in 2050, in GEM-E3 and E3ME



The results presented so far provide the picture for the EU-28 as a whole, but the variation of macroeconomic outcomes of R&I policies between EU Member States is significant. The most positively affected countries are the ones that:

- Can catch up fast with the technological frontier because of higher R&I investments.
- Invest large amounts in R&D to reach their ambitious national target
- Already have an extensive innovation base and can take full advantage of knowledge spillovers from R&D investment implemented in other countries.
- Can benefit from improved competitiveness due to their high trade openness

Some countries might register losses, as their relative competitiveness vis-à-vis other EU member states worsen.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

2.2 Clean energy innovation

Low-carbon transition pathways are widely explored in the EU to assess their impacts on the energy system, CO2 emissions and economic costs. In the ambitious GHG mitigation policy context in the EU, it is important to examine how investment in clean energy research and innovation (R&I) and human capital would affect the European economy.

2.2.1 The impact of ambitious RES targets

The computable general equilibrium (CGE) model PACE simulated a scenario which includes binding minimum shares of renewable energy sources in electricity generation. In the scenario, the EU targets to increase the renewable share in energy consumption up to 35% by 2030 were used and translated into electricity sector specific targets. In order to allow for this translation, the EUCO30 scenario of the European Commission was consulted.

The results show that for the EU28 aggregate such clean energy policies could raise the share of R&D expenditures within GDP by approximately 0.3 percentage points in 2030, compared to a scenario without RES targets. Absolute R&D expenditure levels increase by 7% in 2030 vis-à-vis a scenario without RES targets. Hence, strict and ambitious targets with respect to clean energy sources clearly stimulate R&D efforts in the EU economies. A deeper look into sector-specific findings reveals that in particular the engineering sector, which covers machinery and equipment, exhibits significant R&D increases. This, in turn, indicates that the enhanced R&D efforts are used to innovate with respect to clean energy sources.

As higher R&D investments raise productivity of a sector and the whole economy, GDP as well exhibits an increase, however to a small extent. Compared to a scenario without binding RES targets, GDP increases by 0.2% in 2030. If, however, the EU uses auctioning revenues from the EU emissions trading scheme to subsidize RES deployment (instead of paying these subsidies from the general public budget), GDP increases by 1.1% compared to the scenario without any RES targets. This is due to the freed resources from the public budget since subsidies are considered direct payments to the households. Using the EU ETS auction revenues to subsidize RES increases also R&D intensities, namely by 0.3 percentage points vis-à-vis the scenario without RES targets. Hence, the rise of GDP has two sources, the budgetary relief as well as an increase of R&D investments.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

2.2.2 The impact of research and innovation in clean technologies

> An advanced version of the computable general equilibrium (CGE) model GEM-E3 was used for detailed assessments of the macroeconomic and employment benefits generated by funding research and innovation in clean energy technologies, including solar PV, wind power, electric vehicles, Li-Ion batteries, CCS and biofuels.

The policy scenarios are developed in the context of the Paris agreement on climate change and explore the macroeconomic, competitiveness and employment implications of using carbon revenues for public R&D in clean tech, private R&D in clean tech, human capital upgrade, and the above combined.

The scenarios aim to assess the interactions between energy system decarbonisation, the development of clean energy technologies and investment in clean energy R&D (public and private). All scenarios ensure public budget neutrality where government expenditures need always to be backed up by the generation of respective revenues. Model results thus show the impact of specific policies leading to a reallocation of resources and innovation-induced productivity growth, rather than just the impact of additional government spending on R&D or on tertiary education.

Energy system decarbonisation is driven by high carbon pricing in the GEM-E3 model and results in increased development of clean energy technologies that substitute for fossil fuel use in energy demand and supply sectors. In this context, the global clean energy market increases rapidly and is projected to amount to €36 trillion cumulatively over 2015-2050, with manufacturing of electric cars and batteries accounting for 44% of the market, followed by solar PV, wind turbines and biofuels.

Increased public and private investment in clean energy R&D (funded by carbon revenues) would lead to lower technology costs, improved productivity and GDP growth fuelled by innovation. The results of policy scenarios show an improvement in macroeconomic outcomes of policy packages assuming increased investment in clean energy R&D; GDP growth is induced by productivity improvements leading to cost reduction and increased competitiveness of EU companies in the international clean energy market.

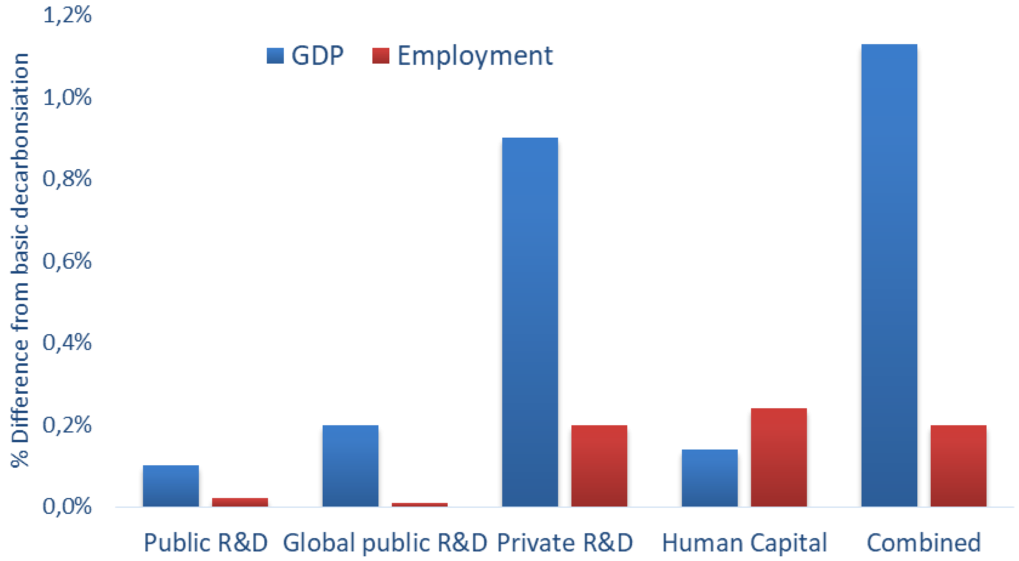
The public R&D scenario shows benefits to all countries as productivity improvements are diffused worldwide. The highest GDP gains are projected for large clean energy manufacturers, as they take advantage of increased global market and high export potential, i.e. Denmark and Germany (wind turbines), China (solar PV), Japan (batteries) and Brazil (biofuels). In case all countries use 10% of their carbon revenues to finance clean energy R&D, the cost reductions will be significant resulting in large GDP gains (0.2% at the global level in 2050).

The different nature of private R&D is reflected in alternative policy scenarios. Private R&D investment leads to improved productivity in the country and industry performing R&D, assuming limitations in knowledge diffusion to other countries which benefit indirectly through bilateral trade and knowledge spillovers. At the EU level, GDP gains are higher relative to public R&D (EU GDP increases by 0.9% in 2050), indicating the higher efficiency of corporate R&D, which is closer to industrial activities while public R&D commonly focuses on basic research and highly uncertain technologies with limited market value. Private R&D benefits more the countries with high clean energy manufacturing (Denmark, Spain, Germany) and those with a high innovation base ensuring high efficiency of increased clean energy R&D. Improved competitiveness and increased exports of clean energy equipment boost GDP growth. The impacts are smaller in magnitude in countries where the increased clean energy R&D does not suffice to reach the "threshold" for efficient R&I and thus they fail to benefit massively from clean energy innovation, while their relative competitiveness vis-à-vis other EU countries worsens.

In case that carbon revenues are used to promote high-skilled labour (engineers, IT, technicians, managers through labour cost subsidisation), the impact on employment is positive, especially for those that have attained tertiary education. As an increasing number of younger cohorts decides to attain tertiary education and delays entering the labour market, GDP impacts are slightly negative in the short term. However, in the longer-term, higher employment, increased labour productivity and household income boost GDP and private consumption.

Figure 4 shows the GDP and employment implications (at the EU level) simulating different ways to recycle 10% of carbon revenues in the decarbonisation context. It is clear that R&D has more positive impacts for GDP growth and limited impacts for employment, as R&D investment improves total factor productivity with only limited impacts on labour demand triggered by the improved competitiveness of industries. In contrast, if the policy focus lies on the creation of jobs, carbon revenues have to be directed towards subsidization of labour, especially highly-skilled labour (engineers, IT, technicians, managers) required for the low-carbon transition. Private R&D creates higher productivity and economic growth than public R&D with EU-based companies improving their competitiveness in international markets and increasing their clean energy exports.

Figure 4: GDP and Employment impacts of GEM-E3 scenarios in 2050



Source: GEM-E3 modelling runs

When the different measures are combined (public R&D, private R&D and skills) into one scenario, this leads to an even higher GDP growth as it is assumed that a larger part of carbon revenues are directed towards investment in (public and private) R&D and education. Both investment and consumption contribute to GDP growth, but the major driver is the increase in exports triggered by the improved EU competitiveness in international markets and the increased exports of clean energy products and equipment.

2.3 Regional innovation policies

The main regional economic policies of the EU, smart specialisation policies, have a focus on innovation. Smart specialisation strategies are shaped with the involvement of local stakeholders and aim to foster regional economic growth through economic specialisation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

They are built on the local regional context and its embeddedness in regional value chains based on information on the region's strengths.

The Spatial CGE model EU-EMS was used to assess a set of regional policy scenarios. The scenarios simulate changes in regional human capital and regional R&I expenditure (both private and public), in order to assess the potential impact of place-based economic policies on innovation and socioeconomic outcomes in the EU. The results from the policy scenarios identify the effectiveness of different policies from a place-based perspective and are therefore a crucial input to the smart specialisation policy making process.

Smart specialisation policies have been developed to combine the historical division in regional economic policy objectives between efficiency (i.e. maximizing economic growth) or spatial equity (i.e. balanced growth among regions). It signals a shift in regional economic policy from compensating for the possible adverse negative distributive effects of the macroeconomic growth policies and objectives towards place based regional economic policies as the main drivers of both regional economic equity and macroeconomic growth. Place-based policies are therefore taking a more central place in Europe where they are central in solving multiple policy objectives and bringing together different policies and different policy fields (Foray et al., 2018)[2]. These smart specialisation policies are nowadays required to receive several types of EU funding.

The Regional policy scenarios that have been evaluated with EU-EMS modelling system have been classified into the following three groups: (1) place-neutral (include macroeconomic scenario), (2) place-based (differentiating the scenario based on some regional characteristics) and (3) place-specific (includes data on EIT investments). The main idea behind the differentiation of economic policies between the regions is that it could take into account some specificities of the regional economies and hence improve the overall economic performance of the country and EU. Table 1 provides a general overview of the scenario design.

[2] Foray D., Kevin Morgan and Slavo Radosevic (2018), The role of smart specialisation in the EU research and innovation landscape, European Commission.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Table 1: Policies modelled in regional economic modelling EMS

Policy	Scenario
Place-neutral policies	A macroeconomic policy scenario that is common to all the models as our place-neutral policy scenario (hence the same policy changes apply to all regions within the same EU28 country)
Smart place-based policies for regions with common regional characteristics	This policy scenario is differentiated at the national level between the regions based on their characteristics that are supposed to be relevant for R&I policies (i.e. the level of human capital and the level of PPP adjusted GDP per capita) for all NUTS2 regions of the EU28.
Smart place-based policies targeted at specific regional characteristics.	Smart specialisation place-based policies are based on the importance of local stakeholders and not pre-imposed by statistics as the intention within smart specialisation strategies. We therefore use a scenario based on the expected funding for the coming seven years from the European Institute of Innovation and Technology (EIT). This scenario is region specific and regions that do not receive funding are therefore only indirectly affected by the EIT investments.

The results from the place neutral policy scenario demonstrates that, in general, policies targeted at adaptation of existing technologies may be more fruitful for lagging regions far away from the technological frontier, while fundamental research will push out the technological frontier itself thereby leading to the strongest growth in the technologically most advanced regions. This drives a large part of the observed results, where the countries with high ambitions of increasing their R&D expenditures have strong growth effects vis-à-vis countries like the UK and the Czech Republic with relative low ambitions and low present R&D expenditure levels. Countries like Germany with high ambitions and high present levels of R&D expenditures have a lower pay-off to R&D expenditure since they are already close to the technological frontier.

In other words, R&D investment policies have a significant effect on economic growth, but there are diminishing returns to investment when countries achieve higher levels of spending and approach the technological frontier. However, besides the macroeconomic growth objective, spatial distributional effects are an important part of regional economic policies; regional economic effects could lead to regional competitive effects that result in divergence on the regional level with even negative growth in some regions. Place-neutral regional policies therefore seem to be strong from the efficiency perspective, but weak from the equity perspective: they strengthen the economically stronger regions in the different countries partly at the expense of the economically weaker regions.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Smarter policy could be to regionally target policies to achieve a higher return on R&I investment. The analysis with EU-EMS suggests that a better targeting slightly increases the return to R&I policies and increases macroeconomic growth. However, this comes at the price of a higher backwash effect and more regions will be adversely affected by targeted policies. Targeted place-neutral policies are therefore ill-advised from the equity objective.

When policies are further tailored to the specific regional needs, the policies have a strong efficiency effect in those regions, causing an increase in economic growth. In this specific case these effects on economic growth may even be enhanced by smart co-financing rules on the R&I investment policies. The positive (spill over) effect off these policies on other regions are limited while the negative (backwash) effect on other regions stays significant. In other words, these specific policies do not contribute to higher equity.

All in all, the picture for regional R&I policies is mixed. Regional R&I policies clearly contribute to economic growth and the return to these policies can be enhanced by better targeting; there is a clear positive economic impact (in terms of higher GDP in 2050) of taking into account regional characteristics in creating the R&I related investment and policy packages. They seem therefore excellent policies from the efficiency objective. However, they also seem to generate a backwash effect in weaker regions and are thus not optimal from an equity perspective. The question whether proper smart specialisation policy targeting of R&I policies in weaker regions would outperform transfers as a policy to improve equity remains for future research.

3 Key policy recommendations

Investing in research and innovation pays off. A robust key outcome across the five macroeconomic models is that increased investment in R&D and human capital would result in higher economic growth, with EU GDP increasing by 0.2%-0.8% in 2030 and 0.3%-2.5% in 2050. This is triggered by accumulation of knowledge stock leading to higher productivity growth, reduced costs, resulting in a more competitive European economy.

There are, however, cross country differences leading to diverse outcomes as well as disparities between regions which can be addressed through policy packages that are tailored to specific needs of a country or region. The EU-EMS model simulations show that there is a clear positive economic impact (in terms of higher GDP) of taking into account the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

regional characteristics of human capital in creating the R&I policy and investment packages. In this respect, the scenarios assessed by the EU-EMS model show the overall importance of institutional quality and how policies addressing the institutional quality interact with other policies analysed since the institutional quality is important for other policies to be successful, and bad institutional quality may hamper economic development. Different policies may be targeted, combining the importance of overall governance structures and place-based policies to strengthen a region's embeddedness in (global) value chains as rules of the game.

Because of strong interactions between R&D investment, knowledge accumulation and human capital, there are large benefits stemming from the simultaneous implementation of policies targeting innovation, knowledge flows, education and the development of the required labour skills. Analysis undertaken with the E3ME model suggests that higher spending on R&D yields higher benefits when this is flanked with measures related to innovation, in particular those related to open innovation (leading to faster knowledge diffusion), education & skills training (leading through higher labour productivity and absorptive capacity) and competition policy (leading to faster innovation). These policies seem to have an endogenous effect on R&D (i.e. they trigger more R&D spending by the private sector) and hence the combination of measures yields higher positive outcomes than the sum of parts.

Research and innovation policy also needs to be considered carefully within the context of EU's climate mitigation goals and strategies. Simulations with the PACE model suggests that the introduction of GHG emissions reductions of 40% by 2030 and 80% by 2050 on top of an increase of R&D expenditures (Central Policy Scenario) could lead to negative economic outcomes if no further policy interventions are made. However, policy scenarios that assume additional policy interventions, such as higher RES targets triggering innovation within the clean energy sector or further investments in R&D could significantly alleviate the negative economic outcomes generated by very ambitious GHG emission reduction targets.

The GEM-E3 model simulations point to further large economic and employment benefits in case that policies targeting clean energy innovation are supplemented with policies aiming to boost highly-skilled labour (i.e. engineers, IT, technicians, managers) through

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

education and training. In the absence of such policies, decarbonisation of the EU energy system could lead to a potential mismatch between labour demand and supply for the specific skills which are greatly required for the low-carbon transition. Policies supporting the development of highly-skilled labour will mitigate this mismatch and increase the absorptive capacity of EU economies that can more easily benefit from increased investment in R&D and knowledge spillovers from other countries/regions.

Furthermore, private R&D in clean energy creates higher economic growth relative to public R&D with EU-based companies improving their competitiveness in international markets and increasing their exports of clean energy products to non-EU regions. This indicates the higher efficiency of corporate R&D, which is closer to industrial activities while public R&D commonly focuses on basic research and highly uncertain technologies. Private R&D benefits more the countries with large clean energy manufacturing sectors (Denmark, Spain, Germany) and those with a high innovation base ensuring high efficiency of increased R&D and knowledge spillovers.

The DSGE model results are broadly in line with the results from the other macroeconomic models in the sense that the policy variables directly targeting human capital and R&D are effective in increasing economic output. The effects of the policy interventions are quite moderate on economic output in an interconnected world given scale effect considerations. The policy interventions applied in the Central Policy Scenario ensure that a greater proportion of world R&D occurs in the EU, which may be desirable to EU policy makers for political or security reasons. The results from the DSGE model further suggest that producing a permanent increase in productivity growth would require international agreement. Long run productivity growth may be enhanced by:

1. increasing the bargaining power of patent licensees (e.g. by making international patent law less favourable to the inventors and more favourable to those who wish to produce the invented products),
2. increasing the profitability of R&D intensive industries, by relaxing competition law.

Additionally, small increases in growth rates may be obtained by lengthening patent protection. This has the additional benefit of substantially dampening international medium frequency fluctuations. If this is not feasible, then substantial stabilisation gains could be

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

obtained through extending all existing patents during global recessions (i.e. not letting patents expire during a recession).

Without international agreement, a national policy maker can increase output by public R&D investment or lessening the costs of private human capital accumulation. However, whether the costs of this outweigh the benefits will depend crucially on how the extra government spending is funded, and on whether the policy maker has non-economic reasons for preferring that a greater share of world R&D happens within their country (e.g. national security). According to the DSGE model, reducing lump sum transfers is a powerful way of stimulating output while raising revenue, however we would not want to advance this as a policy conclusion as its welfare costs are likely to be high.

4 Related and future work

Macroeconomic models are useful tools to analyse the short and long-term impacts of policies supporting innovation and upgrade of human capital. However, they commonly fail to represent all the possible channels through which the various innovation policies impact economic growth and competitiveness. In this context, the objective of MONROE project has been to construct new and further develop already existing modelling tools to analyse how R&I and related policies affect the European economy, at macro, regional and sectoral level.

The comparative analysis of the policy simulation results from the five different macroeconomic models presented here creates new insights into the factors of success for R&I policies. The MONROE project thereby illustrates that a more precise representation of the principal complex channels through which innovation and education policies may impact economic growth is crucial for macroeconomic models. Consequently, the advanced macroeconomic models – now capturing more adequately both the short- and medium-term dynamics as well as long-term macroeconomic, industrial and competitiveness effects of relevant policies - can be applied for policy analysis in the fields of R&I, innovation and human capital policies to explore their linkages with broad economic and climate measures and other industrial and societal megatrends. Using the new advanced macroeconomic models for impacts assessment would facilitate better design of R&I related policies and programmes at the EU, national and regional level.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

However, the differences in projected outcomes from the Central Policy Scenario do show that differences in underlying model methodologies, different data sources and assumptions, and different representation of R&D and knowledge spillovers can lead to different assumptions can lead to different macroeconomic impacts of R&I boosting policies. It is therefore important that stakeholders try to understand the methodological differences between the models before coming to conclusions, and for modellers to help stakeholders to understand the differences by communicating transparently. To that purpose, the MONROE project has designed webpage with an online tool (forthcoming) where stakeholders and policy makers can access further information about the models and the scenario results.

The MONROE project has further shown that the advanced macroeconomic models have different strengths; one model may be better suited to address certain questions, while another model is better suited to address other questions:

- Given that R&D investment decisions are inherently dynamic and their effects are highly uncertain, the DSGE model is suitable for assessing the impact of R&D and innovation policies over time, as it assumes inter-temporal optimisation of economic agents.
- In order to address questions related to geographic concentration of innovative activities and spatial knowledge spillovers, the EU-EMS model has a comparative advantage, as it is the only one which models regional economies at the NUTS-2 level and spatial interactions between them explicitly.
- Due to its detailed treatment of energy sectors and environmental issues, GEM-E3 appears to be the most suitable model for assessing the impact of innovation in clean energy. It should also be noted that the E3ME model has a separate model of technology innovation (FTT) that was not developed in the MONROE project.
- For a more detailed modelling of different types of innovation measures, the large scale macroeconomic models E3ME, GEM-E3 and PACE can provide valuable insights thanks to their richness in accounting for specific channels of innovation through public and private R&D.

The MONROE project has offered a valuable opportunity to the modelling teams involved to enhance the capabilities of their macroeconomic models. Further work will focus on

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

improving the empirical validation of the models and the development of alternative and more refined scenarios. This will inform further methodological improvements in the way the macroeconomic models simulate product and process innovation.