European Commission

A technical analysis on decarbonisation scenarios - constraints, economic implications and policies

Technical Study on the Macroeconomics of Energy and Climate Policies

Prepared by

Eva Alexandri, Cambridge Econometrics
Kostas Fragkiadakis, E3-Modelling
Panagiotis Fragkos, E3-Modelling
Richard Lewney, Cambridge Econometrics
Leonidas Paroussos, E3-Modelling
Hector Pollitt, Cambridge Econometrics

Contact:

Richard Lewney
Cambridge Econometrics Ltd,

Covent Garden
Cambridge, UK
CB1 2HT

Rue Belliard 15-17

1040 Brussels

richard.lewney@camecon.com

Tel: +44 1223 533100

This study was ordered and paid for by the European Commission, Directorate-General for Energy, Contract no. ENER/A4/2015-436/SER/S12.716128.

Table of Contents

Executive Summary

This report applies two macro-sectoral global models that have been designed for energy-economy-environment analysis to identify potential constraints on EU decarbonisation, economic implications and broad policies that could address constraints and improve economic outcomes. The two models are E3ME[1] and GEM-E3-FIT[2], which have been applied and developed in the course of the project 'Study on the Macroeconomics of Energy and Climate Policies' (Contract no. ENERlA41201S-436/SER/S12.716128)[3] to improve their relevance and robustness for this kind of analysis.

Potential economic constraints on decarbonisation

Two main scenarios are developed to show the economic outcomes of two alternative futures for the global decarbonisation effort:

- a 'current policies' case ('REF')
- a case in which additional policies are introduced with the ambition of limiting global warming to 2° above pre-industrial levels ('2DEG')

The two cases are developed as global scenarios in both models, so that all countries are implementing carbon mitigation policies in 2DEG.

Substantial decarbonisation is achieved in the EU in the REF scenario: a reduction in CO2 emissions of about one third between 2020 and 2050. A much faster rate is achieved in 2DEG: a reduction of 70-75% over 2020-50. Compared with 1990 levels, CO2 emissions are reduced by about 80%. Consistent with previous economic impact analysis, the difference in the headline economic indicators between REF and 2DEG is small. In E3ME the EU28 GDP (and employment) impacts are slightly positive, while in GEM-E3-FIT the GDP impact is slightly negative (the employment impact is slightly positive). In the rest of the world, CO2 emissions continue to rise under REF but are cut by 50-55% over 2020-50 under 2DEG. The GDP impact of 2DEG in both models is slightly worse for the rest of the world than for the EU28, reflecting the fact that the EU28 is a net fossil fuel importer, but this is in the context of much faster underlying GDP growth in the rest of the world (in both REF and 2DEG).

Increased debt levels

A more ambitious decarbonisation path entails a higher rate of investment, reflecting

- the substitution of capital for energy (greater energy efficiency)
- the substitution of capital-intensive renewable technologies for fossil-fuel intensive technologies in power generation
- the substitution of electric appliances for fossil-fuel-based appliances in final energy use
- potentially, the early scrapping of fossil-fuel based equipment

The analysis examines whether the higher rate of investment is likely to encounter economy-wide constraints. Cumulative investment is 2-3% higher in 2050 in the

[1] See www.e3me.com.

[2] Developed originally as GEM-E3 (see http://e3modelling.gr/images/files/ModelManuals/GEM-E3_manual_2015.pdf) and extended to incorporate a treatment of finance and technical progress.

[3] See https://ec.europa.eu/energy/en/data-analysis/energy-modelling/macroeconomic-modelling.

2DEG scenario compared with REF, the increase in 2DEG being somewhat larger in E3ME than in GEM-E3-FIT. The models' measures of whole-economy (net) private indebtedness fall in REF and continue to fall in 2DEG but less rapidly. On this indicator, therefore, a macro constraint is not evident.

However, the increase in investment and debt is not spread evenly across the economy, but is focused on the sectors in which decarbonisation is strongest, notably in power generation. The scale of investment in power generation is higher in 2DEG and especially in the last decade, with the result that the estimated debt carried by the electricity industry rises sharply as a ratio to its gross operating surplus. Although the analysis suggests that the larger scale of debt can be serviced, it raises the question as to whether financial investors will require a higher return on investment in the face of this risk.

A sensitivity test was carried out to assess the effects of a higher rate of return required in power generation. The main consequence was a substantial impact on the levelised cost of electricity which is felt particularly in the more capital-intensive renewable technologies, compared with the less capital-intensive fossil-fuel technologies. These costs are passed on to electricity users who face substantial increases in bills, with consequent negative impacts on consumer spending and trade competitiveness.

A sensitivity test was also carried out to assess the effects of a greater perceived *country* risk for countries that suffer continued heavy central government indebtedness and weak growth. In the test, a renewed widening of long-term interest rate differentials compared with the eurozone average was assumed for selected countries. GDP in these countries is reduced as a result of lower investment. Higher interest rates affect the choice of technology in power generation, penalising the more capital-intensive renewable technologies. Lower investment curbs the rate of improvement in energy efficiency. Both of these effects raise carbon emissions. However, the net impact on carbon emissions is also influenced by lower overall economic activity (reflected in lower GDP) which acts to reduce energy use.

Capacity and skill constraints

Another key issue is whether the attempt to drive up investment will run up against capacity constraints, triggering higher inflation and/or a marked deterioration in the balance of payments. The 2DEG scenario has higher employment than the REF case, and so the unemployment rate is correspondingly lower, but at macroeconomic level the difference is not large and so the impact of a tighter labour market on wage inflation is small. This reflects the fact that the main economic impacts of 2DEG compared with REF are structural, shifting demand and activity between sectors (from fossil-fuel dependent sectors to suppliers of investment goods).

However, this is not the end of the physical constraints story, because resources released by a declining sector are not perfect substitutes for those required by an expanding sector. The potential for mismatch is mitigated by the long period allowed for the transition, but not necessarily eliminated. The analysis examines the potential for a labour constraint. Examining the issue first from a *sectoral* perspective, the models project a decline in the fossil-fuel dependent sectors in the REF case, and a stronger decline in the 2DEG case. Since these industries tend to be geographically concentrated (for reasons of geology or the dominance of large plants exploiting economies of scale), the trends highlight the issue of impact on particular communities and the challenge to replace the lost jobs and retrain workers. The job losses in these sectors in REF and 2DEG are larger than the reduction in the workforce that can be expected due to retirement of workers as they age over the decades.

Compared with REF, 2DEG implies more jobs in construction and architectural and engineering services reflecting the additional demand associated with higher investment, and the same is true for some building materials. But these increases are in the context of a long-term decline in jobs in these sectors, as productivity growth outpaces output growth. The effect of 2DEG is to reduce the rate of decline in jobs in these sectors, rather than to produce large increases over time that might pose recruitment difficulties.

Examining the issue from an *occupational/skill* perspective, 2DEG strengthens somewhat the strong trends already in REF towards higher-level occupations and qualifications, but the difference between 2DEG and REF is modest compared with the underlying trend over time expected in both scenarios. There is a substantial skills challenge in prospect with substantial restructuring of jobs in favour of high-skill occupations. Although the proportion of workers educated to tertiary level is projected to increase, the number is not projected to keep pace with the number of jobs projected for this qualification level, and stronger decarbonisation is expected to add to that challenge. The scale of the additional demand associated with stronger decarbonisation is not large relative to the number of jobs already envisaged across the whole economy, but it comes on top of a prospective mismatch of labour supply and demand.

The impact is likely to be felt more strongly in very specific occupations in which 'greening' (new competences required to adapt to the growing demand for new technologies) is expected to occur. An analysis that focuses on the skills needs in the energy supply sectors (whether in the fossil fuel or renewables supply chain) confirms the same finding: decarbonisation increases the demand for workers with higher qualifications.

Increasing the EU content of decarbonisation technologies

The report also examines the macroeconomic impact of measures that would increase the EU share of the value chain associated with key technologies in the decarbonisation transition. With respect to *batteries*, decarbonisation will lead to a very substantial increase in EU demand which, on current conditions, would largely be supplied from the Far East. The analysis considered two scenarios under which the share of EU-based suppliers of the EU battery market is increased. In one, some form of regulation has the effect of raising the share taken by EU suppliers, but at the cost of higher prices for batteries for customers. The benefit, in terms of increased value added and jobs among battery producers in the EU, is less than the cost in terms of lost competitiveness for the producers of equipment (notably electric vehicles) that incorporate batteries as a key component. In the second scenario, EU producers are assumed to receive support for R&D that makes them competitive with foreign suppliers. The net benefits of this scenario depend on the losses associated with diversion of the support for R&D from other projects and on the extent to which the knowledge advantage gained from R&D can be prevented from spilling over quickly to foreign competitors: on the assumptions used in the scenario, the next effect on EU GDP was marginally negative.

With respect to the supply chain for *renewable power generation*, the analysis noted the much stronger competitive position currently of EU producers in the supply chain for wind turbines than for solar photovoltaic panels (which are now largely imported). The modelling again found that a policy that had the effect of requiring electricity generators to buy higher-cost European equipment had a marginally negative impact on GDP. If R&D support were redirected from other clean energy technologies to support EU solar PV production, the net impact would be negative because the returns to R&D in other clean energy technologies are higher than in solar PV.

Part I. Introduction

This report applies two macro-sectoral global models that have been designed for energy-economy-environment analysis to identify potential constraints on EU decarbonisation, economic implications and broad policies that could address constraints and improve economic outcomes. The two models are E3ME[4] and GEM-E3-FIT[5], which have been applied and developed in the course of the project 'Study on the Macroeconomics of Energy and Climate Policies' (Contract no. ENERlA41201S-436/SER/S12.716128)[6] to improve their relevance and robustness for this kind of analysis.

The structure of the document is as follows.

Part II presents an analysis of the potential constraints and economic implications for the EU of a scenario in which global carbon emissions are reduced in line with a target of limiting the increase in average global temperatures to 2 degrees Celsius above pre-industrial levels. The analysis compares a 2-degree scenario with a 'current policies' reference case (in which the EU projections are based on the EU Reference Scenario 2016[7] and the rest of the world projections are based on the IEA Current Policies scenario[8].

Part III examines a number of potential constraints on decarbonisation through the use of sensitivity scenarios. Part IV presents scenarios that examine the competitiveness of the EU supply chain for the production of key technologies required to facilitate the transition and supply-side policies intended to improve competitiveness.

Part V draws conclusions.

[4] See www.e3me.com.

[5] Developed originally as GEM-E3 (see http://e3modelling.gr/images/files/ModelManuals/GEM-E3_manual_2015.pdf) and extended to incorporate a treatment of finance and technical progress.

[6] See https://ec.europa.eu/energy/en/data-analysis/energy-modelling/macroeconomic-modelling.

[7] https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf.

[8] See https://www.iea.org/media/publications/weo/WEO2016Chapter1.pdf.

Part II. Potential constraints and economic implications of a 2-degree scenario

This section compares the economic outcomes in the EU of two alternative futures for the global decarbonisation effort:

- a 'current policies' case ('REF')
- a case in which additional policies are introduced with the ambition of limiting global warming to 2° above pre-industrial levels ('2DEG')

The aim is to identify economic impacts and potential constraints on bringing about a more ambitious rate of decarbonisation, to set the context for the further scenarios that explore these issues further in Part III and Part IV.

1.1 Definition of the reference (REF) and 2-degree (2DEG) scenarios

In each case, the scenarios are defined by the prospective trends in energy and emissions outcomes and the associated policies.

The REF case is defined as:

- for the EU, the *EU Reference Scenario 2016*[9]
- for the rest of the world, the IEA's 'current policies' scenario published in *World Energy Outlook 2016*[10]

The 2DEG case is defined as:

- for the EU, consistent with DG ENER's EUCO30 policy scenario[11]
- for the rest of the world, a combination of each country's NDC[12] and additional measures targeting decarbonisation in the key sectors of power generation, road transport, buildings and industry (phasing out the use of coal in power generation and oil in road transport, together with additional energy efficiency investments drawing on the IEA's 450 scenario[13])

2DEG (consistent with EUCO30 for the EU; consistent with NDCs for the rest of the world; extended to 2050 with more ambitious policies that produce outcomes consistent with a reasonable likelihood of limiting warming to 2 degrees)

1.2 Summary of key outcomes

Table II.1 summarises the high-level economic and CO2 emissions outcomes of the REF and 2DEG scenarios as represented in E3ME and GEM-E3-FIT. While the principles outlined above have been used to implement each scenario in the two models, no attempt has been made to constrain the model outcomes to match each other. Long-term GDP and employment growth in the REF scenario reflect the projected decline in the EU's working-age population projected to 2050[14].

---

[9] European Commission (2016), *EU Reference Scenario 2016 - Energy, transport and GHG emissions Trends to 2050*, available at https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf.

[10] International Energy Agency (2016), *World Energy Outlook 2016*, available at https://www.iea.org/newsroom/news/2016/november/world-energy-outlook-2016.html.

[11] See https://ec.europa.eu/energy/en/data-analysis/energy-modelling for the EUCO30 policy scenario.

[12] Available from http://www4.unfccc.int/ndcregistry/Pages/All.aspx.

[13] Published in IEA (2016) ibid.

[14] In GEM-E3-FIT the unemployment rates are taken from European Commission (2015) *The 2015 Ageing Report Economic and budgetary projections for the 28 EU Member States (2013-2060)*, European

Table II.1: Key EU28 outcomes for the REF and 2DEG scenarios

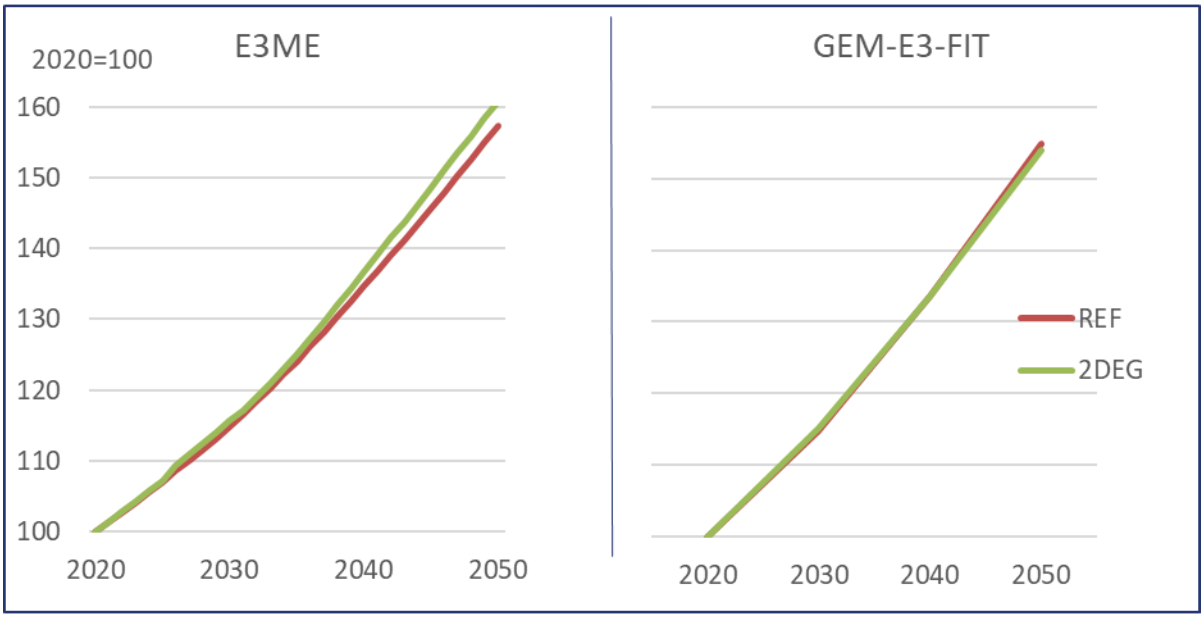
		2020	2030	2040	2050	2020-50
E3ME						
GDP	2020=100					%
REF		100.0	114.7	134.7	157.4	57.4
2DEG		100.0	115.7	136.8	160.8	60.8
Difference	%	0.0	0.8	1.6	2.2	
Unemployment rate	%					pp
REF		10.9	8.4	7.9	7.5	-3.4
2DEG		10.8	8.3	7.8	7.1	-3.7
Difference	pp	-0.1	-0.1	-0.1	-0.4	
CO2	mtCO2					%
REF		3109.5	2557.5	2193.7	2017.0	-35.1
2DEG		3045.0	2163.3	1356.4	911.6	-70.1
Difference	%	-2.1	-15.4	-38.2	-54.8	
	% reduction from 1990					
REF		-23.1%	-36.7%	-45.7%	-50.1%	
2DEG		-24.7%	-46.5%	-66.5%	-77.5%	
GEM-E3-FIT						
GDP	2020=100					%
REF		100.0	114.7	133.6	154.8	54.8
2DEG		100.0	115.1	133.6	154.0	54.0
Difference	%	0.0	0.3	0.0	-0.5	
Unemployment rate	%					
REF		9.2	7.7	6.6	6.6	-2.6
2DEG		9.1	7.4	6.7	6.5	-2.6
Difference	pp	0.0	-0.3	0.1	-0.1	
CO2	mtCO2					%
REF		3281.3	2844.3	2498.8	2175.5	-33.7
2DEG		3281.3	2509.6	1407.9	811.7	-75.3
Difference	%	0.0	-11.8	-43.7	-62.7	
	% reduction from 1990					

Economy 3/2015; in E3ME unemployment is an outcome of endogenous employment changes and labour supply changes.

REF		-18.8%	-29.6%	-38.2%	-46.2%
2DEG	%	-18.8%	-37.9%	-65.2%	-79.9%

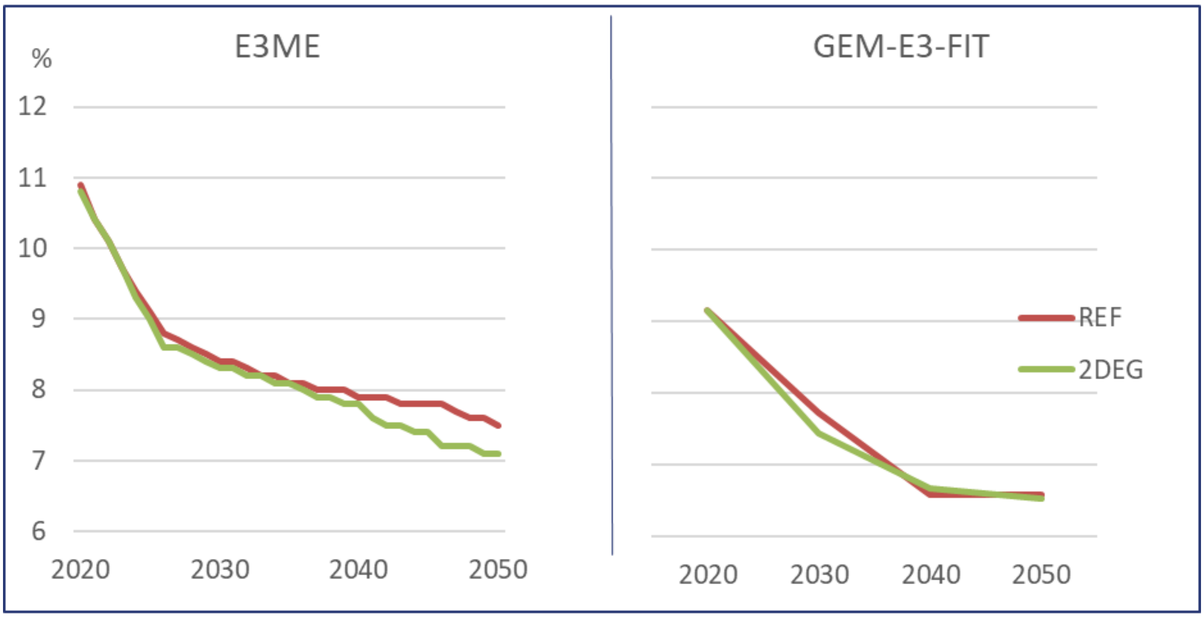
Note: CO2 is for emissions related to energy use only.
Source: E3ME and GEM-E3-FIT.

Figure II.1: GDP in the REF and 2DEG scenarios



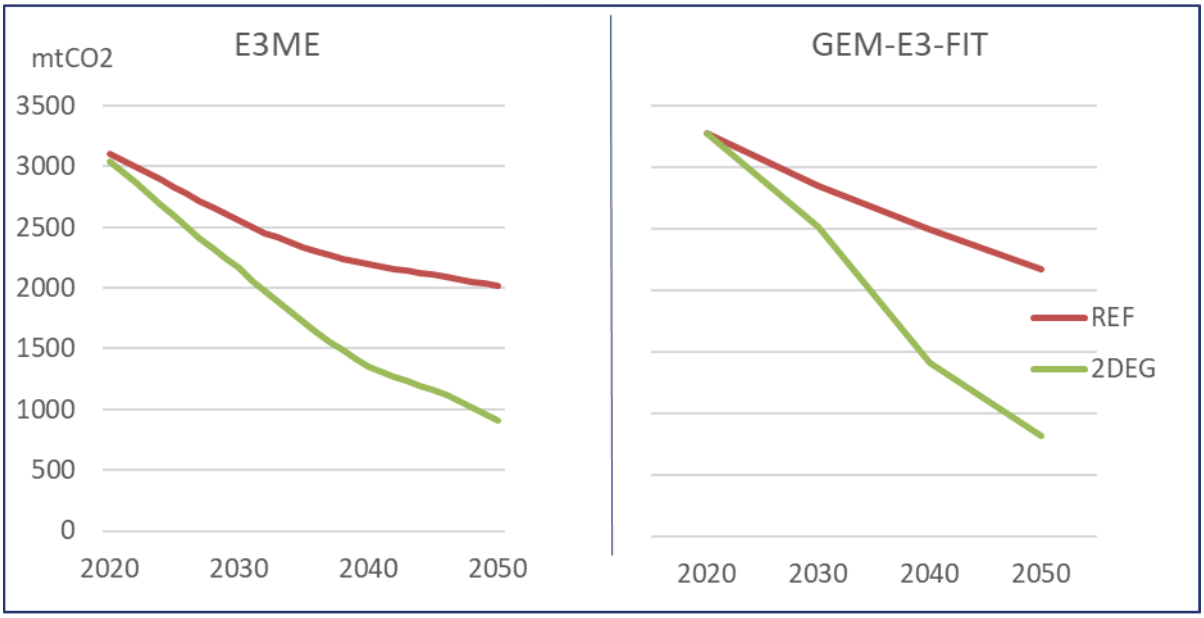
Source: E3ME and GEM-E3-FIT.

Figure II.2: Unemployment in the REF and 2DEG scenarios



Source: E3ME and GEM-E3-FIT.

Figure II.3: CO2 emissions in the REF and 2DEG scenarios



Note: CO2 is for emissions related to energy use only.
Source: E3ME and GEM-E3-FIT

Substantial decarbonisation is achieved in the REF scenario: a reduction in emissions of some 35%, between 2020 and 2050. A much faster rate is achieved in 2DEG: a reduction of 70-75% over 2020-50. Compared with 1990 levels, CO2 emissions are reduced by about 80%. Consistent with previous economic impact analysis, the difference in the headline economic indicators between REF and 2DEG is small. In E3ME the GDP (and employment) impacts are slightly positive, while in GEM-E3-FIT the GDP impact is slightly negative (the employment impact is slightly positive).

For comparison, the outcomes for global indicators, and for the rest of the world excluding the EU28, are shown in Table II.2. The proportionate CO2 reductions over 2020-50 in 2DEG are rather less than those for the EU28 in Table II.1, but the reductions in 2050 compared to REF are larger, because CO2 emissions under REF are projected to increase in the rest of the world over 2020-50 whereas in the EU28 they are projected to fall. The GDP impacts in the rest of the world compared to REF are small, particularly in the context of the large increase in GDP expected over 2020-50 in both REF and 2DEG. As for the EU28, E3ME's GDP impacts of 2DEG for the rest of the world are more positive than those given by GEM-E3-FIT, but the difference is small. For both models, the GDP impacts of 2DEG are a little worse than expected for the EU, reflecting among other things the fact that the EU is a net importer of fossil fuels.

Table II.2: Key global outcomes for the REF and 2DEG scenarios

				2020	2030	2040	2050	2020-50
E3ME								
	Global GDP							%
		REF		100.0	132.7	172.7	228.3	128.3
		2DEG		100.0	131.4	171.8	229.0	129.0
		Difference	%	0.0	-1.0	-0.6	0.3	
	Global CO2							%
		REF		35074.3	38998.5	42035.4	47276.7	34.8
		2DEG		32625.5	27902.1	20256.3	14699.7	-54.9
		Difference	%	-7.0	-28.5	-51.8	-68.9	
	RoW GDP							%
		REF		100.0	138.1	184.2	249.6	149.6
		2DEG		100.0	136.2	182.3	249.6	149.6
		Difference	%	0.0	-1.4	-1.0	0.0	
	RoW CO2							%
		REF		31964.8	36441.0	39841.8	45259.7	41.6
		2DEG		29580.9	25738.8	18899.9	13788.0	-53.4
		Difference	%	-7.5	-29.4	-52.6	-69.5	
GEM-E3-FIT								
	Global GDP							%
		REF		100.0	134.8	174.8	217.3	117.3
		2DEG		100.0	133.6	172.6	213.1	113.1
		Difference	%	0.0	-0.8	-1.2	-2.0	
	Global CO2							%
		REF		31840.8	35413.2	40032.3	45107.7	41.7
		2DEG		31840.8	27722.6	21682.6	14748.3	-53.7
		Difference	%	0.0	-21.7	-45.8	-67.3	
	RoW GDP							%
		REF		100.0	140.2	186.0	234.4	134.4
		2DEG		100.0	138.7	183.2	229.2	129.2
		Difference	%	0.0	-1.1	-1.5	-2.2	
	RoW CO2							%
		REF		28559.5	32568.9	37533.5	42932.2	50.3
		2DEG		28559.5	25213	20274.7	13936.6	-51.2
		Difference	%	0.0	-22.6	-46.0	-67.5	

Note: CO2 is for emissions related to energy use only.
Source: E3ME and GEM-E3-FIT.

1.3 Evidence of potential financial constraints

A more ambitious decarbonisation path entails a higher rate of investment, reflecting

- the substitution of capital for energy (greater energy efficiency)
- the substitution of capital-intensive renewable technologies for fossil-fuel intensive technologies in power generation
- the substitution of electric appliances for fossil-fuel-based appliances in final energy use
- potentially, the early scrapping of fossil-fuel based equipment

Conventionally the two traditions of macro-sectoral modelling out of which GEM-E3-FIT and E3ME have developed have focused on the availability of 'saving' (in the sense of income minus consumption) to 'finance' investment (to satisfy the national income identity). In the neoclassical tradition, the direction of causality operates so that the availability of saving is a constraint on investment: more investment in decarbonisation requires a reduction in investment elsewhere in the economy or a reduction in consumption, mediated by a rate of interest that brings the demand and supply of saving into balance. In the post-Keynesian tradition, the direction of causality operates so that higher investment raises income and saving (and, in an open economy, leads to a deterioration in the balance of payments current account and hence an inflow of foreign saving). Both models now have a more explicit treatment of finance, as distinct from 'saving', in which perceived risk is incorporated as an influence on lending and investment.

In a financial system in which the supply of money is endogenous, the supply of financial capital is not fixed in total but depends directly and indirectly on the willingness of banks to expand their balance sheets. A higher rate of investment is typically associated with a higher rate of debt accumulation by the sectors carrying out the investment, and the perceived sustainability of this greater debt burden poses a potential constraint on the willingness of financial investors to extend credit. A perception of greater risk will be reflected in an interest rate premium which will act to curb investment and favour less capital-intensive projects, both of which work against the decarbonisation pathway. However, data are not available on the interest rate faced by a borrowing sector, and banks do not work with a simple rule that the models can adopt. The modellers have followed different routes to address this. In GEM-E3-FIT a function relates debt sustainability and interest rates. In E3ME, the sectors for which a time-series econometric equation is estimated to determine investment (all sectors except power generation and household heating), have indebtedness as an explicit term (so that, in effect, the interest rate premium associated with indebtedness is modelled implicitly via its impact on investment). In power generation and household heating, interest rates are introduced as assumptions which can be varied across the alternative technologies (to allow for a higher rate for less mature technologies whose performance is not well-established): there is therefore no automatic link between indebtedness and interest rates for these two technologies, and any such link has to be imposed by assumption.

The results of the two models for the REF and 2DEG scenarios are shown in Table II.3. The results are broadly consistent across the two models. Cumulative investment is some 2% higher in 2050 in the 2DEG scenario compared with REF, the increase in 2DEG being somewhat larger in E3ME than in GEM-E3-FIT. The models' measures of whole-economy (net) private indebtedness reflect the investment trends (as expected, since the models assume that indebtedness is driven by investment). The debt ratio in any particular year depends upon the time profile of past investment, because debt is paid off over the term of the loan. Hence, an investment profile that is front-loaded would have a high debt ratio during the period of accelerated investment and a much-reduced debt ratio later after the debt is repaid. In REF there is a reduction in the ratio of debt to GDP over time (faster in GEM-E3-FIT than in E3ME, because E3ME's REF case has higher investment), and in 2DEG the speed of that reduction is slower (more so in E3ME, which has substantial investment in the last decade of the projection).

Table II.3: Key EU28 financial indicators for the REF and 2DEG scenarios

		2020	2030	2040	2050
E3ME					
Cumulative investment (2020 to year shown)	€2005bn				
REF		2969.3	35498.9	73919.5	119061.7
2DEG		2980.8	36178.7	74868.6	121633.5
Difference	%	0.4	1.7	1.3	2.8
Accumulated private debt	% of GDP				
REF		103.0	96.6	92.7	88.6
2DEG		103.0	97.9	95.5	93.0
Difference	pp	-0.1	1.3	2.8	4.4
GEM-E3-FIT					
Cumulative investment (2020 to year shown)	€2011bn				
REF		2354.5	27894.6	57594.0	92149.1
2DEG		2361.1	28435.4	58743.8	94007.0
Difference	%	0.3	1.9	2.0	2.0
Accumulated private debt	% of GDP				
REF		107.6	91.2	79.3	70.9
2DEG		107.6	91.8	79.7	71.5
Difference	pp	0.0	0.7	0.6	0.9

Note: Accumulated private debt is the sum of debt across industries and households.
Source: E3ME and GEM-E3-FIT.

The increase in investment and debt is not spread evenly across the economy, but is focused on the sectors in which decarbonisation is strongest, notably in power generation. The exact timing of investment in power generation depends on the net effect on electricity demand of greater energy efficiency on the one hand and electrification on the other. Table II.4 provides some sectoral detail for investment and debt, and the results for the electricity industry are of particular interest. In some years 2DEG has lower investment than REF, but overall the scale of investment is higher in 2DEG and especially in the last decade, with the result that the estimated debt carried by the electricity industry rises sharply as a ratio to its gross operating surplus. In other industries in E3ME the impact of accumulated debt introduces a cyclical effect: rapid accumulation of debt in 2DEG in the 2020s acts to hold back the growth of investment in the first half of the 2030s while debt is being paid off, after which investment picks up again.

Since the constraining effect of indebtedness on investment is already represented in the models in the manner described above, the results in Table II.3 show the outcome after taking that constraint into account. However, E3ME does not treat electricity industry investment in this way, because it is assumed that there will not be a shortfall in capacity to meet demand. Instead, investment is triggered as required to satisfy demand, and the costs of that investment are passed on in prices to consumers, spread over the lifetime of the assets. Although this ensures that the cost of higher investment is ultimately recouped in higher gross profits (out of which the cost of servicing debt can be met), it assumes that financial investors are willing to provide the finance despite the risks associated with lending to a more indebted sector. The sensitivity scenarios presented in Section 1.1 of Part III explore the importance of the indebtedness effect as a constraint.

Table II.4: Key EU28 financial indicators by sector for the REF and 2DEG scenarios, E3ME

			2020	2030	2040	2050
E3ME						
Cumulative investment (2020 - year shown)		€2005bn				
REF	Electricity industry		76.4	749.1	1421.4	2079.1
	All other industries		2277.1	26954.8	55653.3	89284.4
	Households		615.8	7794.9	16844.8	27698.2
2DEG	Electricity industry		80.2	788.4	1516.9	2233.5
	All other industries		2284.7	27590.0	56465.1	91591.4
	Households		615.9	7800.3	16886.7	27808.6
		%				
Difference	Electricity industry		5.1	5.2	6.7	7.4
	All other industries		0.3	2.4	1.5	2.6
	Households		0.0	0.1	0.2	0.4
Accumulated private debt		% of income				
REF	Electricity industry		244.1	221.9	190.5	172.7
	All other industries		237.0	183.0	161.6	146.6
	Households		30.5	26.3	23.3	19.4
2DEG	Electricity industry		251.4	198.4	198.0	207.4
	All other industries		237.7	186.4	162.7	149.8
	Households		30.4	26.2	23.4	19.5
		pp				
Difference	Electricity industry		7.3	-23.0	2.2	34.7
	All other industries		0.8	3.4	1.1	3.2
	Households		0.0	-0.1	0.2	0.1

Note: Income is (current-price) gross operating surplus for industries and gross disposable income for households.
Source: E3ME

Table II.5: Key EU28 financial indicators by sector for the REF and 2DEG scenarios, GEM-E3-FIT

			2020	2030	2040	2050
GEM-E3-FIT						
Cumulative investment 2020 to year shown		€2005bn				
REF	Electricity industry		129.0	1196.2	2104.9	3185.2
	All other industries		2225.5	26698.4	55489.1	88963.9
	Households		157.0	1748.5	3487.9	5460.1
2DEG	Electricity industry		130.7	1240.9	2753.5	4326.9
	All other industries		2230.5	27194.5	55990.3	89680.1
	Households		157.0	2774.0	5444.7	9489.8
		%				
Difference	Electricity industry		1.3	3.7	30.8	35.8
	All other industries		0.2	-2.1	-2.8	-4.0
	Households		0.0	58.7	56.1	73.8
Accumulated private debt		% of income				
REF	Electricity industry		195.0	190.1	185.2	180.3
	All other industries		133.7	112.4	97.3	86.6
	Households		82.3	69.8	60.7	54.2
2DEG	Electricity industry		195.0	211.1	212.8	208.8
	All other industries		133.7	113.6	97.4	86.7
	Households		82.3	70.6	60.8	55.8
		pp				
Difference	Electricity industry		0.0	21.0	27.6	28.5
	All other industries		0.0	1.2	0.1	0.1
	Households		0.0	0.8	0.1	1.6

Note: Income is (current-price) gross operating surplus for industries and gross disposable income for households. Household investment includes only household expenditure related to energy efficiency improvements (e.g. insulation, advanced energy efficient equipment, retrofitting of buildings to increase thermal integrity).
Source: GEM-E3-FIT.

1.4 Evidence of potential physical capacity constraints

A key issue for assessing the economic impact of decarbonisation is whether the attempt to drive up investment will run up against capacity constraints. Table II.6 and Table II.7 show selected indicators of macroeconomic stress from the two models: the unemployment rate, inflation, and extra-EU imports (if domestic capacity is constrained, an increasing proportion of demand is likely to be satisfied by imports).

Table II.6: Key EU28 capacity indicators for the REG and 2DEG scenarios, E3ME

			2020	2030	2040	2050
E3ME						
REF	Unemployment rate	%	10.9	8.4	7.9	7.5
	Wage inflation	% pa	2.4	2.6	2.8	2.9
	Consumer price inflation	% pa	1.3	1.6	1.9	2.4
	Extra-EU imports	% of GDP (2005-priced)	15.9	16.4	16.8	17.2
2DEG	Unemployment rate	%	10.8	8.3	7.8	7.1
	Wage inflation	% pa	2.4	2.5	2.6	3.0
	Consumer price inflation	% pa	1.3	1.6	1.9	2.3
	Extra-EU imports	% of GDP (2005-priced)	15.8	16.3	16.4	16.8
Difference	Unemployment rate	pp	-0.1	-0.1	-0.1	-0.4
	Wage inflation	pp	0.0	0.0	-0.1	0.1
	Consumer price inflation	pp	0.0	0.0	0.0	0.0
	Extra-EU imports	pp	0.0	-0.2	-0.3	-0.4

Note: 'Wage inflation' is inflation in wages and salaries per job.
Source: E3ME.

Table II.7: Key EU28 capacity constraint indicators for the REF and 2DEG scenarios, GEM-E3-FIT

			2020	2030	2040	2050
GEM-E3-FIT						
REF	Unemployment rate	%	9.2	7.7	6.6	6.6
	Wage inflation	% pa	1.4	1.5	1.7	1.7
	Extra-EU imports	% of GDP (2005-priced)	16.4	17.6	18.7	19.7
2DEG	Unemployment rate	%	9.1	7.4	6.7	6.5
	Wage inflation	% pa	1.4	1.6	1.8	1.7
	Extra-EU imports	% of GDP (2005-priced)	16.4	17.6	18.4	19.7
Difference	Unemployment rate	pp	0.0	-0.3	0.1	-0.1
	Wage inflation	pp	0.0	0.1	0.1	0.0
	Extra-EU imports	pp	0.0	0.0	-0.2	0.0

Note: 'Wage inflation' is inflation in wages and salaries per job.
Source: GEM-E3-FIT.

The REF scenario has some reduction over time in the unemployment rate from its current high level, although the rate does not fall to a level that might be regarded as 'full employment'. Similarly, there is only a modest acceleration in wage and consumer price inflation. The 2DEG scenario has higher employment than the REF case, and so the unemployment rate shown in Table II.6 and Table II.7 is correspondingly lower, but at macroeconomic level the difference is not large and so the impact of a tighter labour market on wage inflation is small. This reflects the fact that the main economic impacts of 2DEG compared with REF are structural, shifting demand and activity between sectors (from fossil-fuel dependent sectors to suppliers of investment goods): this issue is explored further in Section 1.5 below.

Although E3ME's results have GDP in 2050 slightly higher in 2DEG compared with REF, the share of extra-EU imports in GDP is lower. Other things being equal, in E3ME the higher domestic spending associated with higher GDP would raise the import share, but the decarbonisation of energy use has a large impact on imports of oil and gas and this outweighs the effect of stronger investment demand on imports of machinery and equipment. The same substitution of machinery and equipment for oil is present in the GEM-E3-FIT results.

The conclusion is that, although a more ambitious rate of decarbonisation has important impacts at sectoral level, gains and losses by sector largely offset each other so that at macroeconomic level the effect is small. However, this is not the end of the physical constraints story, because resources released by a declining sector are not perfect substitutes for those required by an expanding sector. The potential for mismatch is mitigated by the long period allowed for the transition, but not necessarily eliminated. Section 1.5 investigates the evidence for possible mismatches in the labour market, where geographical, sectoral and skill specificities can hold back the redeployment of resources.

1.5 Evidence of potential skill constraints

Macro-sectoral modelling projects the number of jobs and the size of the labour force, allowing the potential constraint of broad labour demand and supply imbalances to be considered, as in Section 1.4. However, a more likely source of labour constraint in a scenario involving substantial *structural change* is at the industry and skill level. E3ME and GEM-E3-FIT model the shift from fossil-fuel dependent sectors to those related to electrification, renewable energy sources and energy efficiency equipment and installation, and project the change in the number of jobs in each industry. The number of jobs projected by the models under the REF and 2DEG scenarios are shown in Table II.8 and Table II.9.

The models differ somewhat in their definition of industries and so the levels are not directly comparable between the two tables. Both models project a decline in the fossil-fuel dependent sectors in the REF case, and a stronger decline in the 2DEG case.

In electricity, two offsetting trends are at work: increased demand for electricity due to substitution for fossil fuels in heat and transport, but a reduced demand for energy including electricity due to greater energy efficiency. In E3ME, although the demand for electricity is growing in both scenarios, it grows by less in 2DEG than in REF and so the result is fewer jobs in 2DEG than in REF; GEM-E3-FIT has a net increase because it has higher electricity demand in 2DEG than REF, reflecting stronger take-up of electric vehicles.

Table II.3 showed that cumulative investment is higher in 2DEG than in REF, consistent with substitution of capital (both for energy efficiency and for more capital-intensive power generation technologies) for fossil fuels. Both models project a decline in jobs in construction and architectural and engineering services over the long term in REF, as productivity outpaces output growth, but the decline is less in 2DEG reflecting the additional demand associated with higher investment. In the equipment and manufactured materials (building materials) industries, the projected long-term decline in REF is even stronger, reflecting slow output growth particularly in the production of materials. In E3ME, the additional demand associated with higher investment in 2DEG acts to slow the rate of decline in jobs. In GEM-E3-FIT there is a slight acceleration in the decline, reflecting the net effect of more jobs in building materials (as in E3ME) but a reduction in output and jobs in chemicals due to the impact on competitiveness of higher ETS allowance prices in 2DEG.

Table II.8: EU28 jobs by selected industry for the REF and 2DEG scenarios, E3ME

			2020	2030	2040	2050	2020-50
E3ME							
Jobs		'000					%
REF	Fossil-fuel extraction, processing and supply		806.4	695.0	672.3	656.2	-18.6
	Electricity		891.1	840.8	848.8	858.9	-3.6
	Equipment and manufactured materials		14218.6	13365.5	12302.0	11083.6	-22.0
	Construction, arch. and engineering services		18094.7	18822.6	17391.3	16409.5	-9.3
2DEG	Fossil-fuel extraction, processing and supply		789.4	628.8	557.4	533.6	-32.4
	Electricity		896.1	812.6	856.2	899.3	0.4
	Equipment and manufactured materials		14230.4	13429.3	12368.7	11382.7	-20.0
	Construction, arch. and engineering services		18110.8	19020.4	17384.8	16631.0	-8.2
		'000					pp
Difference	Fossil-fuel extraction, processing and supply		-16.9	-66.2	-114.8	-122.5	-13.8
	Electricity		5.0	-28.2	7.5	40.4	4.0
	Equipment and manufactured materials		11.8	63.8	66.6	299.0	2.0
	Construction, arch. and engineering services		16.1	197.8	-6.4	221.5	1.1

Note: Fossil-fuel extraction, processing and supply includes extraction of coal, oil & gas; petroleum refining; gas supply. Equipment and manufactured materials includes manufacture of chemicals (excl. pharmaceuticals), rubber and plastic products, mineral and metal products, machinery and equipment.
Source: E3ME.

Table II.9: EU28 jobs by selected industry for the REF and 2DEG scenarios, GEM-E3-FIT

			2020	2030	2040	2050	2020-50
GEM-E3-FIT							
Jobs		'000					%
REF	Fossil-fuel extraction, processing and supply		1181.8	986.0	806.9	703.3	-40.5
	Electricity		2730.0	3074.4	3381.2	3822.8	40.0
	Equipment and manufactured materials		11217.1	9497.1	8476.8	7565.7	-32.6
	Construction, arch. and engineering services		23938.0	23145.9	22636.0	21970.9	-8.2
2DEG	Fossil-fuel extraction, processing and supply		1183.2	901.1	550.3	380.0	-67.9
	Electricity		2736.4	3183.1	3922.7	4294.3	56.9
	Equipment and manufactured materials		11215.0	9453.4	8200.7	7251.5	-35.3
	Construction, arch. and engineering services		23966.9	24076.7	22593.0	22614.1	-5.6
		'000					pp
Difference	Fossil-fuel extraction, processing and supply		1.5	-85.0	-256.6	-323.3	-27.4
	Electricity		6.5	108.7	541.5	471.5	16.9
	Equipment and manufactured materials		-2.0	-43.7	-276.1	-314.2	-2.8
	Construction, arch. and engineering services		28.9	930.9	-43.0	643.2	2.6

Note: Fossil-fuel extraction, processing and supply includes extraction of coal, oil & gas; petroleum refining; gas supply and transport; manufacturing of coal and coke products. Equipment and manufactured materials includes manufacture of chemicals, rubber and plastic products, mineral products, machinery and equipment.
Source: GEM-E3-FIT.

Table II.10 draws out the implications for the structure of employment by selected occupations of the sectoral shifts projected by E3ME. In REF there are strong shifts towards information and communications occupations and towards science and engineering professionals (but away from the less qualified science and engineering associate professionals). There are large falls in jobs in ‘blue collar’ manufacturing occupations. The skilled manual occupations associated with the construction industry (building workers and related trades, not unskilled labourers) see little change in numbers. The 2DEG scenario is associated with higher overall employment, and so all the occupations shown in Table II.10 have more jobs than in REF, but the boost is stronger in skilled manual building workers and ICT occupations: the shift in industry structure seen in 2DEG favours sectors in which these occupations are more important (and growing in importance over time).

Table II.10: EU28 jobs by selected occupation for the REF and 2DEG scenarios, E3ME

			2020	2030	2040	2050	2020-50
E3ME							
Jobs	ISCO	'000					%
REF	21	Science & eng. profs.	6580.3	7175.6	7505.7	7486.2	13.8
	25	ICT professionals	3579.1	3844.8	4103.0	4118.7	15.1
	31	Science & eng. ass. profs.	7880.0	7902.9	7482.2	6890.4	-12.6
	35	IC technicians	1863.1	1898.4	1966.6	1997.5	7.2
	71	Bldng. wrkrs. excl electricians	8859.6	9271.8	9007.1	9276.4	4.7
	72	Metal, machinery workers	7980.1	6989.1	5680.9	4548.3	-43.0
	74	Elec & electronic workers	3331.0	3092.5	2634.6	2204.5	-33.8
	81	Stationary plant operators	5123.3	4866.9	4321.5	3782.3	-26.2
2DEG	21	Science & eng. profs.	6581.3	7181.8	7483.2	7518.5	14.2
	25	ICT professionals	3582.6	3866.6	4087.5	4187.4	16.9
	31	Science & eng. ass. profs.	7881.5	7907.2	7451.1	6906.5	-12.4
	35	IC technicians	1864.6	1908.6	1962.9	2022.9	8.5
	71	Bldng. wrkrs. excl electricians	8864.8	9337.8	8971.8	9396.9	6.0
	72	Metal, machinery workers	7981.7	7001.1	5672.3	4584.4	-42.6
	74	Elec & electronic workers	3332.2	3101.0	2619.8	2217.6	-33.4
	81	Stationary plant operators	5122.1	4860.0	4296.2	3793.2	-25.9
		'000					pp
Difference	21	Science & eng. profs.	1.0	6.2	-22.5	32.3	0.5
	25	ICT professionals	3.5	21.8	-15.5	68.7	1.8
	31	Science & eng. ass. profs.	1.5	4.3	-31.1	16.1	0.2
	35	IC technicians	1.5	10.2	-3.7	25.4	1.3
	71	Bldng. wrkrs. excl electricians	5.2	66.0	-35.3	120.5	1.3
	72	Metal, machinery workers	1.6	12.0	-8.6	36.1	0.4
	74	Elec & electronic workers	1.2	8.5	-14.8	13.1	0.4
	81	Stationary plant operators	-1.2	-6.9	-25.3	10.9	0.2

Note: ISCO numbers refer to the 2-digit ISCO classification of occupations (which has 41 entries in total).
Source: E3ME, drawing on Cedefop projections[15] for occupations by industry.

[15] See *Forecasting skill demand and supply*, project for Cedefop led by Cambridge Econometrics http://www.cedefop.europa.eu/en/events-and-projects/projects/forecasting-skill-demand-and-supply. The Cedefop projections cover the period to 2030; trends to 2050 have been extrapolated.

Table II.11 shows the implications for the level of qualifications of workers in the jobs projected in Table II.9 and Table II.10. It captures the sectoral shift in the economy over time, trends towards higher level occupations, and trends towards higher level qualifications in the occupations. The large shifts from low and medium to high (graduate) level qualifications in the REF scenario are clear. Again, because the 2DEG scenario is associated with higher overall employment, all the qualification levels shown in Table II.11 have more jobs than in REF, but the boost is stronger at the high level.

Table II.11: EU28 jobs by broad qualifications level for the REF and 2DEG scenarios, E3ME

			2020	2030	2040	2050	2020-50
E3ME							
Jobs	Qualifications level	'000					%
REF	Low		40876.7	33199.3	25464.2	19646.2	-51.9
	Medium		109345.7	104658.2	93564.7	81898.2	-25.1
	High		79127.9	94153.0	106648.2	118255.2	49.4
	Total		229350.3	232010.5	225677.1	219799.6	-4.2
2DEG	Low		40889.5	33272.5	25479.2	19800.1	-51.6
	Medium		109380.4	104856.6	93608.0	82449.9	-24.6
	High		79149.8	94308.7	106688.8	118943.7	50.3
	Total		229419.7	232437.8	225776.0	221193.7	-3.6
		'000					pp
Difference	Low		12.8	73.2	15.0	153.9	0.4
	Medium		34.7	198.4	43.3	551.7	0.5
	High		21.9	155.7	40.6	688.5	0.8
	Total		69.4	427.3	98.9	1394.1	0.6

Note: Low: up to and including lower secondary education; Medium: upper secondary and post-secondary non-tertiary education; High: tertiary education.
Source: E3ME, drawing on Cedefop (ibid) projections for qualifications by occupations by industry.

The conclusion is that the 2DEG scenario increases sharply the job losses in fossil-fuel related industries, adding to the large losses already envisaged in the REF scenario. Since these industries tend to be geographically concentrated (for reasons of geology or the dominance of large plants exploiting economies of scale), the trends highlight the issue of impact on particular communities and the challenge to replace the lost jobs and retrain workers. The job losses in these sectors in REF and 2DEG are larger than the reduction in the workforce that can be expected due to retirement of workers as they age over the decades.

Strong trends towards higher-level occupations and qualifications are projected in REF, based on assumptions that reflect what has been seen over the past two decades. There is, of course, considerable uncertainty when it comes to particular occupations in which new kinds of automation could make it much more feasible to replace labour than in the past. Generally speaking, the trend towards higher-level qualifications is expected to be robust to this uncertainty, but some occupations that currently rank as medium-skill could be at risk.

These trends are strengthened further in 2DEG, but the difference between 2DEG and REF is modest compared with the underlying trend over time expected in both scenarios. There is a substantial skills challenge in prospect with substantial restructuring of jobs in favour of high-skill occupations; stronger decarbonisation is expected to add to that challenge. The scale of the additional demand associated with stronger decarbonisation is not large relative to the number of jobs already envisaged across the whole economy, but it comes on top of a prospective mismatch of labour supply and demand. The impact is likely to be felt more strongly in very specific occupations in which 'greening' (new competences required to adapt to the growing demand for new technologies) is expected to occur.

A complementary analysis of skills implications, focusing on the energy supply sectors, was undertaken using the jobs outcomes in the 2DEG case in GEM-E3-FIT and applying bottom-up information regarding sectoral skill requirements and labour intensities in each energy activity. Table II.12 shows estimates of the proportion of the labour force in energy supply sectors at each of three skill levels (adopting the broad classification of skills/qualifications used in Cedefop (2013)). The share of highly-qualified workers in each energy supply activity is generally higher than the average across all EU sectors, with the exception of coal mining.

Table II.12: Assessment of required qualification levels in energy supply sectors

	Low-qualified	Medium-qualified	High-qualified
Mining of coal and lignite (B05)	10%	75%	15%
Oil and gas extraction (B06+B09.1)	11%	47%	42%
Manufactured fossil fuels (C19)	11%	46%	43%
Electricity supply (D35.1)	8%	55%	37%
Transportation of gas (D35.2)	7%	60%	33%
RES sources (based on studies)	5%	50%	45%
Biomass supply	15%	55%	30%
Total EU workforce	*22%*	*48%*	*30%*

Sources: Cedefop (2013)[16], Behrens et al (2014)[17], Fragkos et al (2017)[18], Lehr (2011)[19], RenewableUK (2013)[20] and Herrero (2010)[21].

The employment structure of the renewable energy sector is not included in official statistics. Several job types related to renewable energy require a highly skilled workforce: industrial surveys in Germany (Lehr, 2011), Spain (Herrero, 2010) and

[16] Cedefop (2013), Skills Forecasts (retrieved from http://www.cedefop.europa.eu/EN/about-cedefop/projects/forecasting-skill-demand-and-supply/skills-forecasts.aspx).

[17] Behrens, A., Coulie, C., Genoese, F., Alessi, M., Wieczorkiewicz, J. and Egenhofer, C. (2014), 'Impact of the Decarbonisation of the Energy System on Employment in Europe', CEPS Special Report: NEUJobs project

[18] Fragkos P., L. Paroussos, P. Capros, S. Boeve, T. Sach (2017), Job creation related to Renewables, ASSET project.

[19] Lehr, U., Lutz, C., Khoroshun, O., Edler, D., O'Sulllivan, et al. (2011), Renewably employed! Short and long-term impacts of the expansion of renewable energy on the German labour market.

[20] RenewableUK and Energy & Utility Skills (2013), Working for a Green Britain & Northern Ireland 2013-23. Employment in the UK Wind and Marine Energy Industries, London/Shirley, September.

[21] Jiménez Herrero, L.M. and A. Leiva (2010), Empleo Verde en una Economía Sostenible, Madrid: Observatorio de la Sostenibilidad en España/Fundación Biodiversidad.

the UK (RenewableUK, 2013) indicate that high-skilled employees account for about 42-50% of the RES-related workforce.

Based on a detailed sectoral breakdown of energy supply jobs, Fragkos et al (2017) estimated the number of jobs in each energy activity in EU countries in the EU Reference and in a decarbonisation context in the period 2015-2050. By combining the GEM-E3-FIT employment results in all energy supply sectors with the qualification levels presented in Table II.12, a quantitative assessment of the implications of faster decarbonisation for skill requirements has been carried out.

Figure II.4 shows the implications of the REF and 2DEG scenarios for the shares of each level of qualifications of workers in the energy-related activities in the EU. It captures the sectoral shift in the energy system with increased electrification of final energy demand and substantial RES expansion substituting for fossil fuels. As RES activities are on average more labour intensive than fossil fuel activities[22], total EU employment in energy activities is projected to increase in the 2DEG scenario from REF levels with 150,000 additional jobs in 2050 (4.5% above REF). All qualification levels have more jobs in 2DEG than in REF, but the boost is stronger for high qualifications (+75 000 jobs in 2050). Low-skilled jobs are also projected to increase by about 3% above REF, driven by the expansion of low-skilled jobs in the production and collection of biomass feedstock (farmers); this more than counterbalances the reduction in low-skilled jobs in coal and lignite mining.

Figure II.4: EU28 jobs in energy supply sectors split by qualification level in REF and 2DEG scenarios (in '000s)

Source: Analysis based on GEM-E3-FIT jobs projections in REF and 2DEG.

The results confirm the finding from the E3ME analysis that the structural shift associated with faster decarbonisation will increase the demand for highly-skilled

[22] IEA (2017) World Energy Investment 2017, Fragkos et al (2017).

workers, adding to the underlying skills pressures expected to be experienced in the wider economy over the long term.

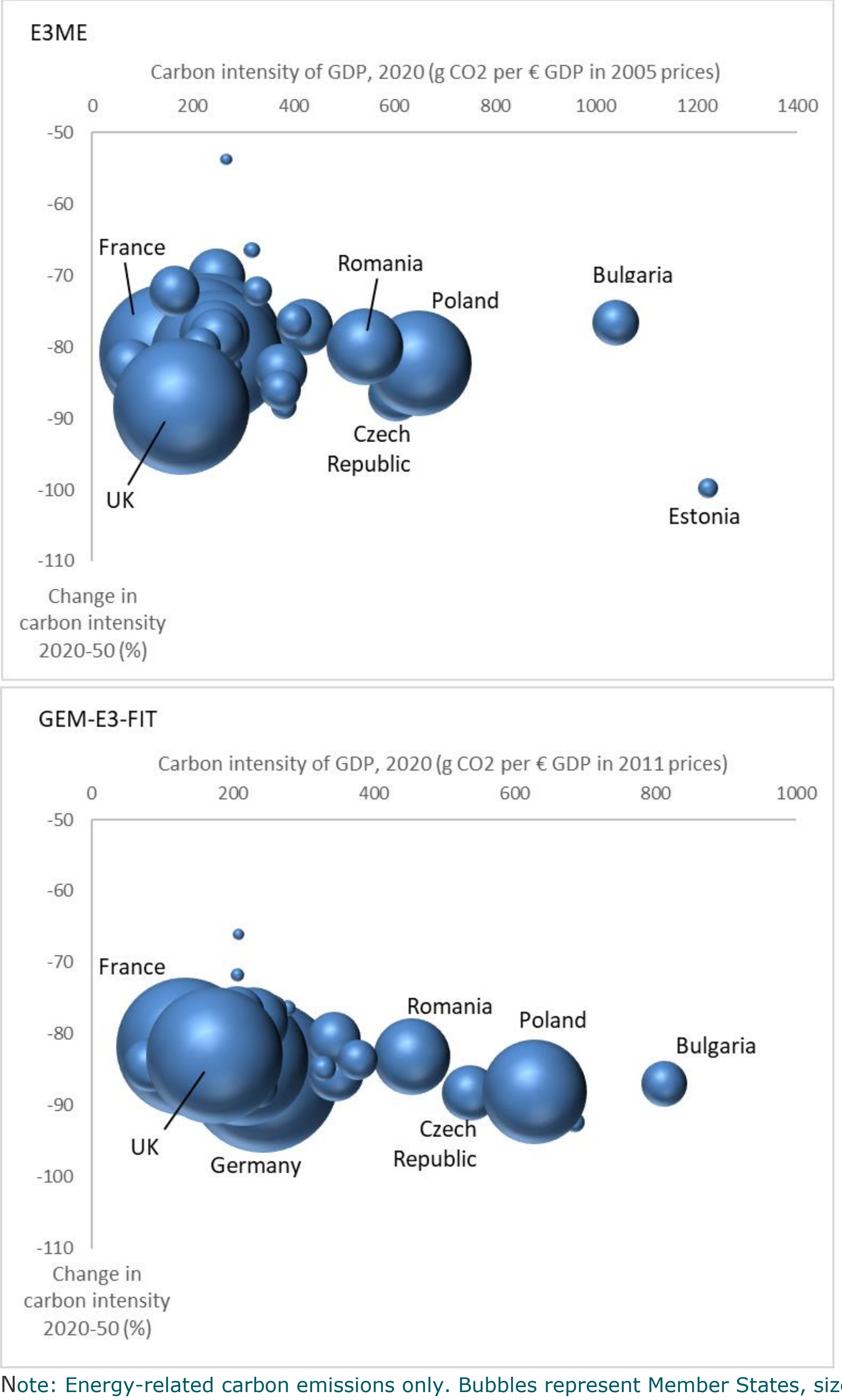
1.6 How decarbonisation progress is distributed across MS

Figure II.5 plots for each country:

- its carbon intensity of GDP in 2020
- the change in carbon intensity over 2020-50

for both E3ME and GEM-E3-FIT. The projected change in carbon intensity is used as an indicator of the scale of change in behaviour and technology envisaged, with implications for the demands placed upon consumers and businesses in those countries. Figure II.5 shows that there is a broad tendency in both models for the countries with the highest carbon intensity in 2020 (generally in eastern and southern Europe) to see the largest change to 2050, consistent with the principle of technological catch-up.

Figure II.5: Projections of the change in carbon intensity by Member State in the 2DEG scenario



Note: Energy-related carbon emissions only. Bubbles represent Member States, sized in proportion to population.
Source: E3ME and GEM-E3-FIT

1.7 Energy security outcomes

Table II.13 shows the outcomes in the two models for oil and gas imports as a share of GDP. The REF case assumes a recovery of the global oil price from its recent relatively low level; the 2DEG case incorporates the impact of lower demand on the global price. In the 2DEG case, this measure of vulnerability to the global oil price falls sharply: by some 25% (from 1.2% to 0.9% of GDP) in E3ME and by 58% (from 2.6% to 1.1%) in GEM-E3-FIT.

Table II.13: EU28 extra-EU oil and gas imports

		2020	2030	2040	2050	2020-50
Oil and gas imports, current prices	% of GDP					
E3ME						pp
REF		1.3	1.4	1.4	1.6	0.3
2DEG		1.2	1.1	1.0	0.9	-0.4
Difference	%	-0.1	-0.2	-0.4	-0.7	
GEM-E3_FIT						pp
REF		2.6	2.4	2.2	1.9	-0.7
2DEG		2.6	2.1	1.6	1.1	-1.5
Difference	%	0.0	-0.3	-0.6	-0.8	

Source: E3ME, GEM-E3-FIT.

Part III. Examining the implications and feasibility of EU decarbonisation

This section examines the possibility that certain constraints or risks could present obstacles to achieving decarbonisation in the EU.

1.1 Will financial constraints be a significant obstacle to delivering the 2DEG scenario, and how might this be addressed by policy?

In Section 1.3 of Part II it was noted that the higher rate of investment associated with faster decarbonisation could raise the perceived riskiness of loans and hence the interest rate faced by borrowers. The REF and 2DEG scenarios in the two models seek to incorporate this effect, but there is uncertainty as to how strong it is. In this section we carry out a set of sensitivity tests to explore the potential impact further.

B-RISK1: A higher interest rate premium for power generation investment

In the B-RISK1 scenario we begin with the 2DEG scenario and raise the interest rate (for all technologies) from 10% (the value used in REF and 2DEG) to 11.5% over 2020-25 and to 13% thereafter. The models assume that the power generation capacity required to meet electricity demand will still be built, but the higher interest rate can influence the choice of technology (favouring less capital-intensive technologies such as CCGT) and the higher cost of borrowing by the sector is assumed to be passed on to electricity consumers, reducing their disposable income available for other purchases.

There is a substantial impact on the levelised cost of electricity and on the price of electricity. Table III.1 shows the results for the levelised cost of electricity (LCOE) of selected technologies in Germany (selected for illustration purposes) and the impact on EU28 electricity prices. It can be seen that there is a much larger impact on LCOE of the more capital-intensive technologies compared with CCGT, and these costs are (by assumption) passed on to electricity users. The impact of higher consumer prices and higher costs faced by industry feeds through to consumer spending and trade performance and there is a consequent negative impact on GDP (larger in GEM-E3-FIT than in E3ME).

Table III.1: Impact of higher interest rate in B-RISK1 scenario on electricity costs and prices

	2020	2030	2040	2050
E3ME				
% diff from 2DEG				
Electricity industry				
EU28 consumer prices (households)	0.0	9.9	15.9	12.0
EU28 industry prices (business)	0.0	13.2	21.2	15.1
Levelised cost of electricity in Germany				
CCGT	0.0	0.0	2.0	3.6
Onshore wind	0.0	0.0	9.5	16.6
Solar PV	0.0	0.0	9.2	15.9
GDP	0.0	-0.2	-0.4	-0.3
GEM-E3-FIT				
% diff from 2DEG				
Electricity industry	0.0	14.2	14.7	15.7
Levelised cost of electricity in Germany				
Gas fired plants	0.0	3.4	3.0	2.8
Wind	0.0	19.2	19.0	18.8
Solar PV	0.0	16.7	16.6	16.5
GDP	0.0	-0.8	-0.7	-0.7

Note: Levelised cost of electricity excludes the price of ETS allowances.
Source: E3ME.

B-RISK2: The general impact of indebtedness on investment

The relationship between greater indebtedness, higher interest rates and hence lower investment is included in both the REF and 2DEG scenarios developed in both E3ME and GEM-E3-FIT. To see how much difference this makes, in the B-RISK2 scenario we begin with the 2DEG scenario and, in each of the two models, suppress the negative impact of greater indebtedness on investment.

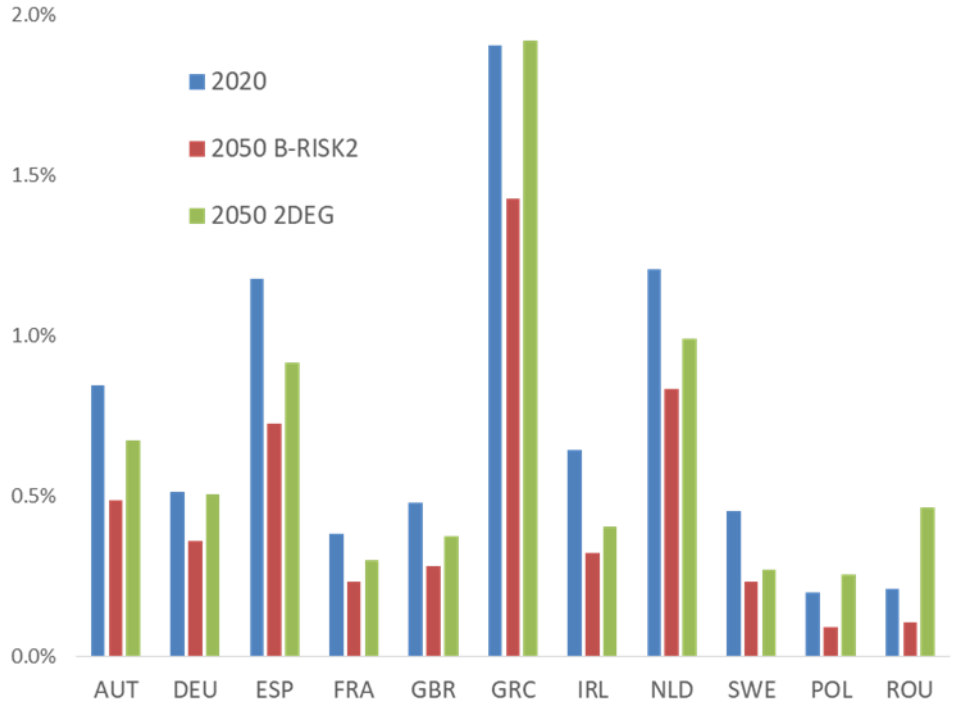
In E3ME, the level of debt is included explicitly as a term in the investment equations for all sectors except those for which there is a detailed treatment of the take-up of different technologies, which then drives investment (electricity and households). When this debt influence is turned off in the model, the difference between 2DEG and B-RISK2 for investment by the relevant sectors proved to be very small: 0.1% or less. This reflects the fact that, as a proportion of income, indebtedness for most sectors (outside of electricity) is declining over time in 2DEG (albeit at a slower rate than in REF), as shown in

In GEM-E3-FIT, the influence of indebtedness on investment is mediated via the impact of 'debt sustainability' on interest rates. Debt sustainability is defined as the ability of an agent to service uninterruptedly its debt and depends on the ratio of the net present value of its income to the net present value of its debt. Accelerated investment in the decarbonisation transition can cause debt to grow more rapidly than income, leading to a deterioration in debt sustainability; this in turn increases the interest rate faced by the borrower. In GEM-E3-FIT the interest rate applicable to household expenditures related to decarbonisation (e.g. building retrofits, purchases of electric cars and efficient energy appliances) based on the "Composite cost of borrowing indicator for households", developed by the European Central Bank (ECB[23]). This interest rate is decomposed into two elements: i) an EU-wide base interest rate that is set at 1.5%, and ii) a country-specific risk premium. The latter is calculated as the difference between the composite cost of borrowing for households and the EU-base interest rate and reflects national differences in the borrowing rates faced by households. Debt sustainability is proxied by the ratio of private debt to GDP and this determines the risk premium that the borrower faces. In most EU countries, private debt declines as a percentage of GDP in REF and so risk premiums are projected to be lower in 2050 than in 2020. The extra decarbonisation investment in 2DEG increases private indebtedness leading to higher risk premiums than in REF (Figure III.1 for selected EU countries), but the difference is small: an increase of between 0.1% and 0.3%. This reflects the fact that, as in E3ME, the ratio of debt to income in most sectors (outside of electricity) is declining over time in 2DEG (albeit at a slower rate than in REF).

To test the difference that greater indebtedness makes in 2DEG in GEM-E3-FIT, we construct an alternative scenario based on 2DEG but maintaining the risk premia faced by households at the REF levels. The macroeconomic impacts (the difference between these two scenarios) are positive but very small in most EU countries; they are larger in the countries in which the reduction in debt sustainability is greatest in 2DEG, for example Greece, Bulgaria, Romania, Latvia and Lithuania. At the EU level, decarbonisation-related loan payments of EU households are lower by about €11bn cumulatively over 2020-2050, resulting in cumulative GDP gains of €35bn over 2020-2050.

[23]Available here:
https://www.ecb.europa.eu/stats/financial_markets_and_interest_rates/bank_interest_rates/composite_cost_of_borrowing/html/index.en.html

Figure III.1: Risk premia for decarbonisation investment in B-RISK2 and 2DEG scenarios in selected EU countries



Source: GEM-E3-FIT.

B-RISK3: A higher interest rate premium for household heating

The B-RISK3 scenario repeats the sensitivity test in B-RISK1 but applies it to household investment in heating technologies. The interest rate (for all technologies) is raised from 10% (the value used in REF and 2DEG) to 11.5% over 2020-25 and to 13% thereafter. The models assume that heating equipment required to supply useful energy demand for residential heating (which does not vary across scenarios) will still be installed, but the higher interest rate influences the choice of technology (favouring less capital-intensive technologies such as gas boilers over more capital-intensive options such as heat pumps).

Table III.2 shows that in E3ME (the FTT:Heat submodel), higher interest rates do, indeed, shift investment decisions from more to less capital-intensive technologies, lowering spending on investment in heating. The impact varies across Member States, and selected results are shown in the table. The lowest impacts (not shown) are for Mediterranean countries (Greece, Cyprus, Malta) which have different characteristics for reasons of climate. While there are a variety of factors in the model that influence the choice of technology, a key one is the existing market share of technologies: uptake of a particular technology is less sensitive when its market share is very low (when cost incentives for uptake have to be very strong to increase market penetration) or very high (when cost disincentives would have to be strong to discourage uptake). The Netherlands begins the period with a high share of gas condensing boiler. In Finland and Sweden, the projection is influenced by the existing high share of district heating.

The GEM-E3-FIT results are very different, reflecting a different approach to modelling household behaviour. A bottom-up energy efficiency model linked to

GEM-E3-FIT has been used which assumes foresight behaviour in household investment for heating. The result is that investments in heating are brought forward to 2020 when the interest rate is still 10%. In 2030, when energy efficiency investment requirements are high, the effect of the 3 pp increase in the interest rate is to reduce EU household heating investment by 3%. After 2030 the investment in household heating is close to the 2DEG scenario as the impact on energy costs of the carbon tax in 2DEG renders most of the heating options still profitable (even with the increase of 3% in capital costs).

Table III.2: Impact of higher interest rate in B-RISK3 scenario on household heating investment

	2020	2030	2040	2050
Household heating investment				
% diff from 2DEG				
E3ME				
EU28	0.0	-0.4	-2.3	-4.4
Germany	0.0	-0.6	-4.1	-8.3
UK	0.0	-0.3	-2.1	-5.0
Netherlands	0.0	-0.2	-0.8	-0.9
Finland	0.0	-0.6	-1.4	-1.4
Sweden	0.0	-0.7	-1.6	-1.0
GEM-E3-FIT				
EU28	4.9	-3.2	-0.4	-0.3
Germany	7.1	-4.4	-0.3	0.2
UK	4.2	-2.6	-0.2	-1.1
Netherlands	5.4	-2.9	-1.6	-1.1
Finland	7.4	-3.0	0.0	-0.2
Sweden	4.2	-3.3	-0.6	-1.0

Source: E3ME and GEM-E3-FIT.

1.2 Will skill shortages be a significant obstacle to delivering the 2DEG scenario, and how might this be addressed by policy?

It was noted in Section 1.5 of Part II that the REF case already implies a substantial challenge in terms of restructuring of the labour market towards high skill jobs. Neither E3ME nor GEM-E3-FIT model the labour market process of skill matching at the detailed level reviewed in Part II and so they do not automatically capture the potential impact of lack of availability of skills to meet the additional demand posed by 2DEG.

To obtain a broad estimate of the scale of potential mismatch of skills we focus on the projected demand for workers with tertiary level qualifications and compare that with an estimate of projected supply.

Table II.11 presented projections for the change in employment by three broad skill levels. In both the REF and 2DEG scenarios, between 2020 and 2050 there is broadly a 50% decline in low-qualification jobs, a 25% decline in medium-qualification jobs and a 50% increase in high-qualification (tertiary education) jobs.

Table III.3 presents projections for the population aged 15-64[24] with tertiary education qualifications. Increases in participation in higher education have had the effect that the proportion of graduates is higher among younger people than in the rest of the population. The proportion of graduates in the young adult age cohort is likely to increase further (and it is assumed that the gap between males and females is closed). As the years pass they replace older cohorts who retire from the labour force. Consequently, the proportion of those with tertiary level qualifications rises over time. However, the EU28 population is aging, and the number aged 15-64 is expected to fall between 2020 and 2050. The scale of the projected fall depends on assumptions for fertility, mortality and migration. Eurostat's baseline population projections[25] have a 9.5% fall over the period; its 'lower migration' and 'lower fertility' sensitivity cases have falls of 13.2% and 15.6% respectively. Table III.3 uses World Bank projections, in which the fall over 2020-50 (14.4%) is towards the low end of the range presented by Eurostat, in order to test sensitivity to a lower supply of skilled workers.

Table III.3: EU28 population aged 15-64 with tertiary education qualifications

	2020	2030	2040	2050	2020-50
Proportions with tertiary education qualifications (aged 15-64)				%	pp
Total	29.2	35.6	40.1	42.3	13.0
Male	27.1	33.5	39.1	42.6	15.6
Female	31.5	37.8	41.0	41.9	10.4
Numbers with tertiary education qualifications (aged 15-64)				'000	%
Total	96057.8	111679.8	118315.6	118769.6	23.6
Male	44650.7	52995.0	58493.7	60792.5	36.2
Female	51407.1	58684.8	59821.8	57977.0	12.8
Population aged 15-64				'000	%
Total	328404.0	313476.0	295352.0	281081.6	-14.4
Male	165009.0	158116.0	149467.0	142649.0	-13.6
Female	163395.0	155360.0	145885.0	138432.6	-15.3

Note: Tertiary qualifications are defined as ISCED (2011) levels 5-8.
Source: Population projections: World Bank. Graduate projections: based on simple cohort model. Historical data for qualifications of population: Eurostat Population by sex, age and educational attainment level (lfsa_pgaed).

The resulting increase in the numbers aged 15-64 with tertiary qualifications over 2020-50 is 23.6%, about half of the percentage increase in jobs projected for this qualification level in Table II.11. Some of the gap could be closed by higher rates of participation of the population in the labour force, but even if all the additional workers aged 15-64 with tertiary education were in work there would still be a shortfall (of about 17 million workers).

[24] The age-band 15-64 is used for consistency with key data sources used. Some people work beyond the age of 64, and this is likely to increase with improved longevity, but this trend does not change the substantive conclusions from the analysis.

[25] Eurostat Population on 1st January by age, sex and type of projection [proj_15npms].

Our aim here is not to explore how that shortfall might be met, since it is a feature of both the REF and the 2DEG case. Rather, we are seeking to model the impact of the 2DEG case in a future in which there are already severe skills constraints. In the B-SKILLS scenario, we make explicit assumptions about the extent to which an inadequate supply of high-skilled labour affects the economy's capacity, as represented by the 'normal output' indicator in E3ME. This indicator is used together with the actual level of output in any given year to measure the extent of under-capacity, feeding in turn into the mechanisms by which firms and workers respond to such under-capacity: notably pressure on wages and prices and additional investment. The 'normal output' indicator is defined at the level of each industry in each Member State and so in principle the potential constraint could be targeted in detail, focusing, for example, on the industries that experience the largest boost to demand in the 2DEG case. However, since the hypothesised skills shortages are a feature of the underlying trend in the economy and not limited to the additional pressure brought about in the 2DEG case, in the B-SKILLS scenario we apply the constraint across all industries. Similarly, we do not make judgements as to which countries would face the most binding mismatches of labour demand and supply, but apply the constraint across all Member States.

The normal output indicator in E3ME is measured in terms of gross output in real terms. The steps taken to translate a potential shortfall in skilled labour into an impact on normal output were as follows:

- calculate the number of jobs at the high-skill level that could be filled by graduates over 2021-50, on the assumption that employment rates for graduates remain at the level projected for 2020;this 'shortfall' has the value of 0 by construction in 2020, rising to 20.4 million graduates in 2050 under the REF scenario and 21.1 million graduates under 2DEG
- assume that the shortfall is met by substituting medium- for high-qualification workers, and that the reduction in 'normal output' is proportional to the implied reduction in the wage bill (ratio of medium to high-qualification earnings[26] multiplied by the number of jobs in the shortfall) in each of REF and 2DEG

The macroeconomic results are shown in Table III.4

Table III.4: Key macroeconomic impacts in B-SKILLS scenario

	2020	2030	2040	2050
E3ME				
% diff from 2DEG				
GDP	0.00	0.00	-0.04	-0.12
Employment	0.00	0.00	0.00	-0.01
CPI	0.00	0.00	0.05	0.17

[26] The relative earnings data are based on OECD (2017) *Education at a glance 2017*, indicator A6, available at http://www.oecd-ilibrary.org/education/education-at-a-glance-2017/indicator-a6-what-are-the-earnings-advantages-from-education_eag-2017-12-en. The EU Member States included in the OECD analysis vary in the extent of advantage associated with higher qualifications: median values were used in the analysis here (a premium of 53% for high-level qualifications relative to medium-level qualifications). In practice, if graduates become relatively more scarce, the average earnings premium is likely to rise, but this effect has not been included in the analysis.

Profits	-0.01	-0.03	-0.23	-0.74

Source: E3ME.

It can be seen that the effects are negative (lower GDP, higher inflation, slightly lower employment, lower profitability) but not large in macroeconomic terms. The impact is mitigated by the assumption that substitution of medium for high-qualification workers is feasible and the additional investment undertaken by firms in response to capacity constraints.

1.3 Will perceived country-specific macro and policy risks that are associated with continued heavy central government indebtedness and weak growth in some countries be a significant obstacle to delivering the 2DEG scenario

A key objective of the overall project that this report contributes to has been to integrate macroeconomic conditions with the availability and cost of finance for investment, and in particular decarbonisation investment. Whereas in earlier scenarios we have considered the impact of a perceived greater risk for particular technologies or borrowers, here we focus on differences within the EU with respect to the country risk associated with the aftermath of the financial crisis and central government indebtedness. In an economy in which money creation is driven by commercial bank lending[27], perceptions of risk, including country macroeconomic risk, underpin the interest rates faced by borrowers.

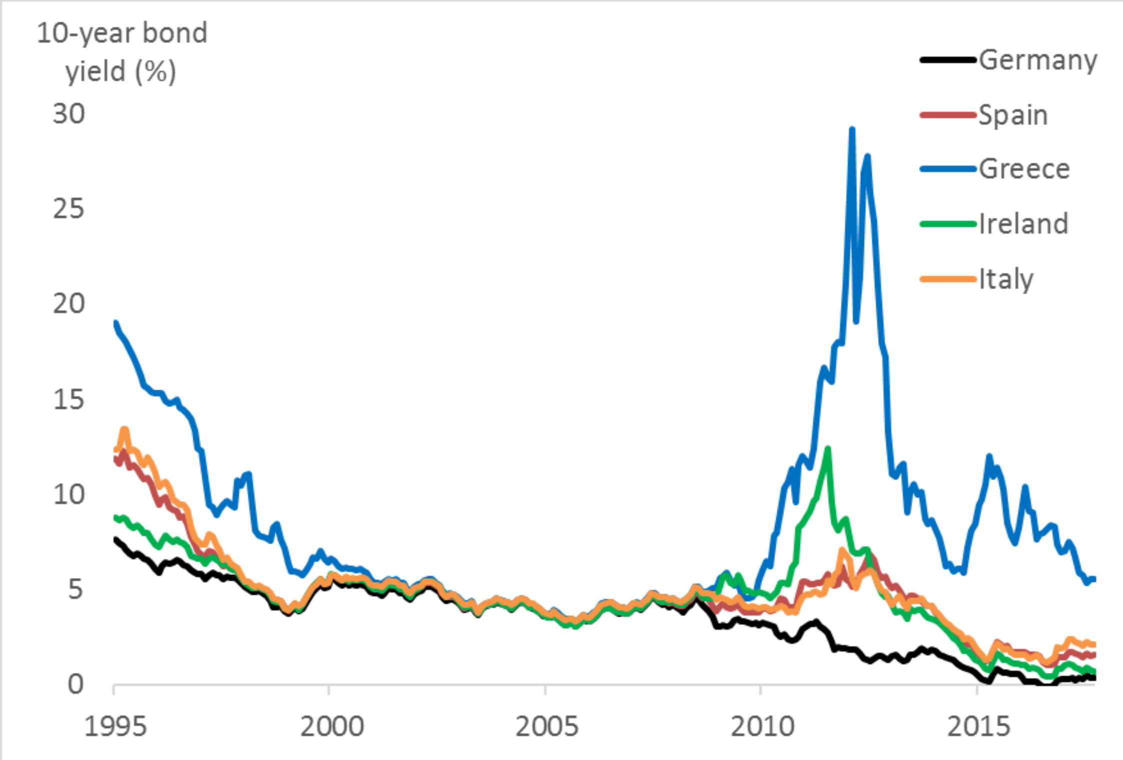
In this scenario it is assumed that selected countries suffer continued heavy central government indebtedness and weak growth and hence a high risk premium, while the euro area as a whole 'returns to normal' and so sees the policy interest rate, and long-term interest rates, rise. A higher interest rate acts as a disincentive to investment of any kind, and particularly penalises decarbonisation technologies, which are typically more capital-intensive than the carbon-based alternative.

We use differences in 10-year government bond yields across countries as a proxy for country risk.

Figure III.2 shows 10-year government bond yields over the past two decades (including a few years before the launch of the euro) for selected countries. The rapid convergence when countries joined the euro area (Greece joined in 2001) is clear. Similarly, the divergence during the financial crisis and its aftermath are also clear. Greece continues to stand apart, although its differential compared with Germany has narrowed over the past two years. Ireland's sharp turnaround is clear, the differentials for Italy and Spain have closed considerably since 2011, but a gap in the order of 1.0 - 2.0 pp with respect to Germany rates has persisted.

[27] See McLeay M, Radia A and Thomas, R (2014) 'Money creation in the modern economy', *Bank of England Quarterly Bulletin 2014Q1*, available at https://www.bankofengland.co.uk/-/media/boe/files/quarterly-bulletin/2014/money-creation-in-the-modern-economy

Figure III.2: 10-year sovereign bond yields in selected countries, 1995-2017



Source: ECB long-term interest rates for convergence purposes.

In the 2DEG scenario, the differentials between Member States with respect to long-term interest rates are small (of the order of 1-2 pp). In the B-DEBT scenario, these differentials are increased by 5 pp for Greece, 2 pp for Italy and 1.5 pp for Spain, broadly reflecting the differences shown in Figure III.2. The differences for key outcomes are shown in Table III.5.

Both in E3ME and in GEM-E3-FIT the impacts on GDP on the three countries reflect the scale of assumed interest rate differentials: Greece is worst affected, Italy and Spain less so. The impact comes about because of reductions in investment, with the countries ranked in the same order. The impact on carbon emissions reflects several effects. Higher interest rates affect the choice of technology in power generation, penalising the more capital-intensive renewable technologies. Lower investment curbs the rate of improvement in energy efficiency. Both of these effects raise carbon emissions. However, lower overall economic activity (reflected in lower GDP) reduces energy use and carbon emissions. E3ME shows that in the case of Greece and, to a lesser extent Spain, the GDP effect outweighs the other effects and carbon emissions are lower. In the case of Italy, the energy use effects are larger, and carbon emissions are higher. In GEM-E3-FIT the carbon intensity of each economy increases from the 2DEG scenario due to the lower investment in energy efficiency.

Table III.5: Key EU28 outcomes for the B-DEBT scenario

				2020	2030	2040	2050
E3ME							
	GDP		% diff from 2DEG				
		Greece		-0.5	-1.8	-1.9	-1.5
		Spain		-0.1	-0.4	-0.4	-0.3
		Italy		-0.1	-0.8	-0.4	-0.6
	Investment		% diff from 2DEG				
		Greece		-2.4	-9.3	-11.7	-10.7
		Spain		-0.3	-1.3	-1.5	-1.3
		Italy		-0.7	-3.9	-3.7	-4.1
	CO2		% diff from 2DEG				
		Greece		2.2	0.2	0.0	-1.4
		Spain		0.1	-0.1	-0.3	-0.3
		Italy		0.5	4.6	4.4	1.1
GEM-E3-FIT							
	GDP		% diff from 2DEG				
		Greece		-0.1	-0.7	-1.3	-1.9
		Spain		0.0	-0.3	-0.5	-0.7
		Italy		0.0	-0.4	-0.7	-1.1
	Investment		% diff from 2DEG				
		Greece		-2.0	-2.9	-3.5	-4.2
		Spain		-0.9	-1.3	-1.6	-2.0
		Italy		-1.4	-1.9	-2.2	-2.6
	CO2		% diff from 2DEG				
		Greece		0.0	-0.6	-1.1	-1.5
		Spain		0.0	-0.2	-0.4	-0.6
		Italy		0.0	-0.3	-0.6	-0.9

Source: E3ME and GEM-E3-FIT.

1.4 How might policy address the fall in global oil and gas prices?

The REF scenario assumes a recovery in the global oil price from its recent relatively low level. In 2DEG, the modelling allows the global oil price to fall in response to weaker global demand for fossil fuels. Consequently, there is a perverse signal (from the perspective of promoting decarbonisation) which can act to discourage energy efficiency or switching to non-fossil fuels.

In both E3ME and GEM-E3-FIT, by 2050 the global oil price is about 50% lower in 2DEG than in REF. In the B-OIL scenario, it is assumed that a tax is placed on oil and gas imports into the EU which offsets the price reduction between REF and 2DEG[28].

Table III.6 shows that restoring the oil and gas import prices to the levels in REF helps to curb the use of fossil fuels and the associated emissions, particularly in the sectors that primarily use petroleum products. There is a negative impact on GDP because in this scenario the revenue accruing to government from the tax has not been recycled, although of course it could be.

[28] The focus is only on oil and gas imports, and so there is an implied loss of competitiveness for EU energy users compared with the rest of the world.

Table III.6: EU28 CO2 emissions and macroeconomic indicators in the B-OIL scenario

	2020	2030	2040	2050
E3ME				
% diff from 2DEG				
CO2 emissions (energy-related)				
Power generation	0.0	0.1	0.2	0.2
Iron and steel	0.0	-0.1	-0.5	-0.4
Non-ferrous metals	0.0	-0.4	-0.3	-0.6
Chemicals	-0.1	-1.0	-1.0	-0.7
Non-metallic mineral products	-0.1	-0.6	-0.5	-0.3
Extraction of ores (non-energy)	0.0	-0.4	-0.8	-0.8
Food, drink and tobacco	0.0	-0.1	-0.2	-0.5
Textiles and clothing	0.0	-0.2	-0.8	-1.7
Paper and pulp	0.0	-0.2	-0.1	0.0
Construction	-0.2	-0.8	-1.1	-1.1
Rail transport	-0.1	-1.0	-1.4	-1.0
Road transport	-0.1	-1.4	-4.6	-6.4
Air transport	0.0	-1.8	-4.8	-8.1
All (including those not shown above)	-0.1	-0.6	-1.5	-2.3
GDP	0.0	-0.1	-0.2	-0.1
Employment	0.0	0.0	-0.1	0.1
GEM-E3-FIT				
% diff from 2DEG				
CO2 emissions (energy-related)				
Power generation	0.0	0.1	0.1	0.0
Energy-intensive industries	-0.1	-0.3	-0.7	-1.5
Land transport	-0.4	-1.6	-3.7	-7.3
Water transport	-0.5	-2.1	-4.1	-5.5
Air transport	-0.5	-2.3	-4.9	-7.8
All (including those not shown above)	-0.2	-0.8	-2.8	-5.0
GDP	0.0	-0.1	-0.2	-0.3
Employment	0.0	-0.2	-0.2	-0.3

Source: E3ME and GEM-E3-FIT.

Part IV. Supply chain competitiveness and policies

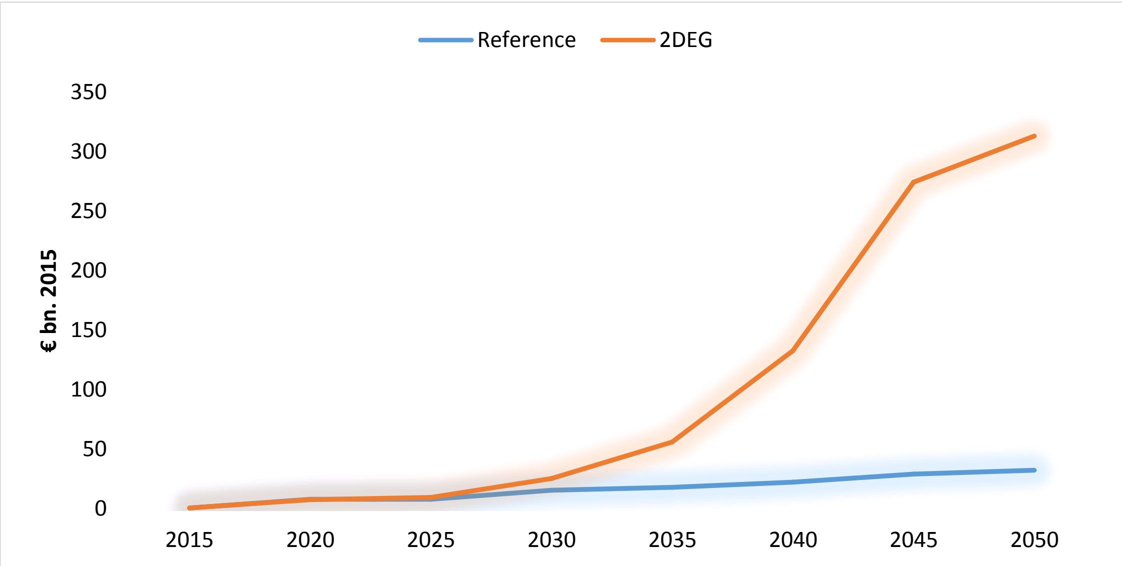
This section considers the macroeconomic impact of measures that would increase the EU share of the value chain associated with key technologies in the decarbonisation decarbonisation transition.

1.1 Summarising the projected evolution of the global market for clean energy technologies

The global market for clean energy technologies is highly competitive and fast growing driven by innovation dynamics, technological advancements and by energy and climate policies and regulations. In 2015 the size of the global market is estimated to be about €250bn and is dominated by the manufacture of solar PV panels and wind turbines.

In the 2DEG scenario, the global market for clean energy technologies is projected to amount to €43.6 trillion in cumulative terms over 2020-2050. The manufacture of electric cars represents the largest clean energy market, accounting for 44% of the global market, while the shares of wind and PV are 29% and 19% respectively. The EU is projected to account for about 18% of the global clean energy market, but has very small shares in the production of batteries and PV modules. EU manufacturers are projected to remain competitive in the global market for electric cars (27% share in global production) and wind turbines (20% share in global production). The size of the market for clean energy technologies (batteries, solar PV, wind and electric cars) depends greatly on climate, energy, environment and public R&D policies. Figure IV.1 shows the size of the global market for batteries for electric cars under REF policies and under 2DEG policies.

Figure IV.1: Global Market Size of Batteries for Electric Vehicles

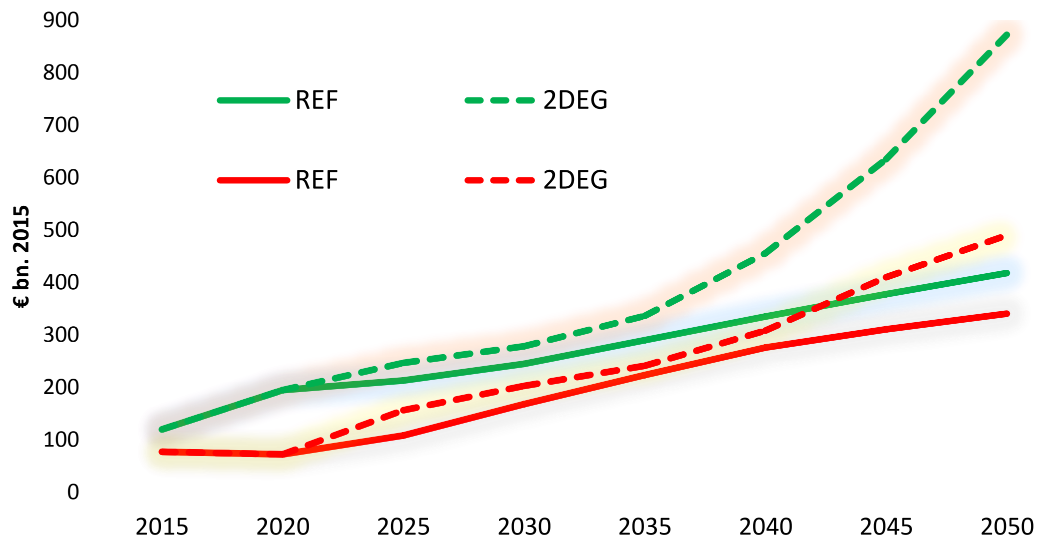


Source: GEM-E3-FIT

In the 2DEG scenario, the global battery market reaches almost €300bn in 2050 (the respective figure for electric vehicles is €1.8 trillion). In 2DEG, the average share of the EU in global battery production is projected to be 0.9% over 2020-2050 (i.e. EU electric vehicle manufacturers continue to outsource the manufacture of batteries and so a substantial part of the value added and employment associated with the production of electric cars is not located in Europe).

Figure IV.2 shows the size of the global market for solar PV and wind turbine equipment under REF policies and under 2DEG policies.

Figure IV.2: Global Market Size of Solar PV and Wind turbines in REF and 2DEG scenarios



Source: GEM-E3-FIT

In the 2DEG scenario, the global wind market reaches about €870bn in 2050, while the global PV market is projected to amount to €490bn in 2050. In REF, the global market for PV and wind turbine equipment increases by four times in the period 2015-50; the respective market increase in the 2DEG scenario is seven times. In 2DEG, the average share of the EU in global wind production over 2020-2050 is projected to amount to 20%, as EU manufacturers remain competitive in the global market and continue to provide wind turbines to meet expanding EU domestic demand. On the other hand, the EU outsources the vast majority of solar PV modules and EU-based PV manufacturing accounts for about 1.5% of the global market; thus a large part of the value added and employment associated with PV manufacturing is not located in Europe.

1.2 What would the impact on economic indicators be of an initiative that successfully established a competitive EU battery industry?

In the current study, we model policies designed to assure approximately a 100% share of the electric vehicles value chain for batteries being captured within the EU.

In 2015 it is estimated that the market for electric vehicle batteries is around €6bn, representing roughly 30% of the EV manufacturing market. Three countries and five companies account for 95% of global battery production[29][30]: Japan 56%, South

[29] Panasonic, BYD, Samsung, LG Chem, AESC (Nissan).

[30] The shares in global production are E3-Modelling calculations based on Kane, M. (2017), 'EV Battery Makers 2016: Panasonic And BYD Combine to Hold Majority of Market', https://insideevs.com/ev-battery-makers-2016-panasonic-and-byd-combine-to-hold-majority-of-market/, Cleantechnica (2016) and Transport and Environment (2016).

Korea 17% and China 25%. In the EU the largest electric car manufacturers, located in Germany, UK, Spain, Italy and France, outsource (import) 97% of their Li-on battery requirements (only 3% is produced within EU[31]). Recent announcements by car manufacturers and the EU[32] point towards an increase in in battery manufacture in the EU. Volkswagen, as part of its new 2025 Strategy, has outlined plans for a €10bn battery factory in Salzgitter in Germany; Samsung and LG Chem plan to invest in EV battery factories in Hungary and Poland respectively to exploit the rapidly growing EU demand; Ford, BMW and Tesla are also considering building battery factories in Europe. In October 2017, the European Commission launched[33] the European Battery Alliance with the target of developing battery manufacturing in the EU to compete with Asian and US manufacturers. Members of the EU industry and innovation community will drive this process, working in close partnership with the European Commission, the European Investment Bank and interested Member States, to establish a competitive manufacturing chain, capture sizeable markets and boost jobs, growth and investment across Europe.

Findings of a case study regarding the impacts of early EU climate action (Paroussos et al, 2017, *The influence of early action and spillover effects on the competitiveness impacts of climate and energy policies*[34]) indicate that there is modest potential for a first mover advantage for the EU driven by electric vehicle manufacturing and sales. The penetration of EU in the global electric car manufacturing market increases by 5 pp from Reference projections, while its share in global battery production increases by only 1% indicating that battery manufacturing is outsourced.

Battery production costs are today around 250 €/kWh (Figure IV.3). Costs have fallen substantially over the last decade (a 14% pa reduction between 2007 and 2016, from more than US$1,000 per kWh to around US$273 per kWh). The cost of battery packs needs to fall to “below US$150 per kWh in order for BEVs to become cost-competitive on par with internal combustion vehicles”, Björn & Nilsson (2015)[35].

The key drivers for the steep cost reductions in battery manufacturing are:

i) economies of scale and learning by doing effects

   Global sales of electric vehicles and batteries have significantly expanded[36] and the associated learning rate is estimated to be 16-17%

ii) research and innovation

   “There are still R&D improvements to be made in, for example, anode and cathode materials, separator stability and thickness, and electrolyte

---

[31] Bloomberg New Energy Finance

[32] “Maros Sefcovic, European Commission vice-president in charge of energy, will host a summit on October 11 of executives from chemicals groups such BASF, carmakers including BMW and battery manufacturers to promote co-operation in the sector, with up to €2.2bn of EU funding available to support the plan”, Financial Times, 2017

[33] http://europa.eu/rapid/press-release_STATEMENT-17-3861_en.htm

[34] Available at https://ec.europa.eu/energy/en/studies/.

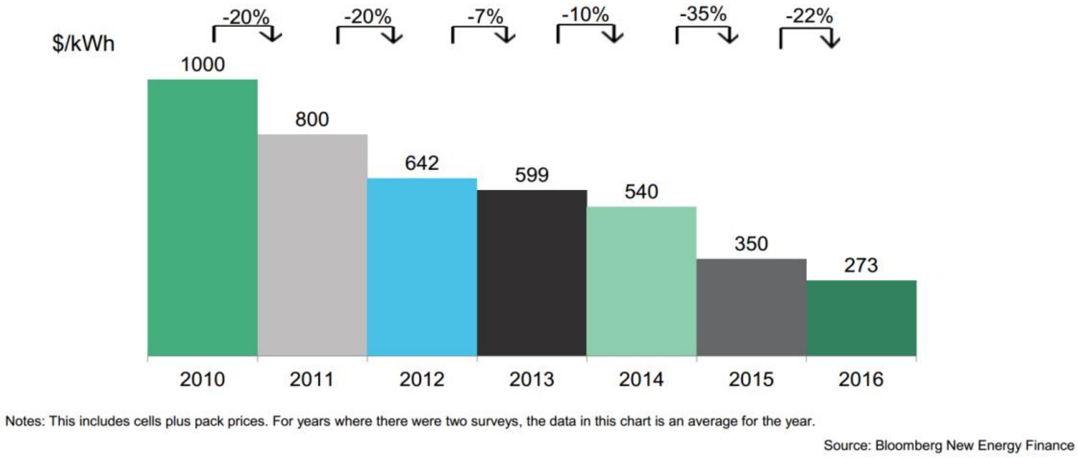
[35] Björn Nykvist, M. N. (2015), 'Rapidly falling costs of battery packs for electric vehicles', *Nature, Climate Change*.

[36] The IEA estimates that the global stock of electric and plug-in hybrid cars surpassed 2 million units in 2016, while electric car sales double each year over 2012-2016 (IEA, Global EV Outlook 2017)

composition. Among these factors, input material cost is among the most competitive battery pack costs and that these represent a more realistic long-term learning rate", Björn & Nilsson (2015).

Raw materials for batteries (like cobalt, graphite, silicon metal, lithium) are mainly produced by Congo, China, Russia, the US, India, Australia and Brazil. The EU's main trading partners for battery raw materials are Russia, China and Brazil.

Figure IV.3: Li-Ion battery price trends



Source: Extract from Curry (2017), "Lithium-ion Battery Costs and Market", Bloomberg New Energy Finance.[37]

Scenarios investigated

The GEM-E3-FIT model has been used to quantify the macroeconomic implications of a future in which the production of batteries for EU-manufactured electric vehicles are also manufactured in the EU rather than imported. To this end three core scenarios have been designed:

i) C-REG-BATTERY: A regulation-based scenario in which imports of batteries from non-EU countries are not allowed. In this scenario 100% of EU demand for batteries is produced in the EU irrespective of their cost compared with imports. Hence, in this scenario EU battery production is supported by regulations and standards and is not price competitive.

ii) C-R&D-BATTERY-ETS: An R&D based scenario in which part of the ETS auction revenues is directed to R&D for batteries until EU-produced batteries are competitive in international markets. This scenario is based on the suggestion of Lebedeva et al JRC (2016) that "*To become competitive in this time frame however, consolidated R&I action at a European level is required in the short term to secure Europe's strong industrial position in pack manufacturing in the future*".

[37] Curry, C. (2017), 'Lithium-ion Battery: Costs and Market', *Bloomberg New Energy Finance.*

iii) C-R&D-BATTERY-RES: An R&D based scenario in which EU-28 public R&D is redirected from other clean energy technologies to batteries until European production becomes competitive with leading battery manufacturers in international markets.

Results

C-REG-BATTERY

In this case GDP in 2050 is reduced by 0.19% compared with 2DEG. The learning and economies of scale effects are not sufficient to make battery production competitive, the production cost of electric vehicles increases and sales decrease compared with 2DEG. The EU is assumed to produce batteries at a price 30% higher than its main supplier in 2020[38], falling to 10% in 2050 due to economies of scale[39] induced by increased domestic battery production relative to the 2DEG scenario.

Table IV.1: Macroeconomic and employment implications of C-REG-BATTERY scenario

				2020	2030	2040	2050
GEM-E3-FIT							
	GDP		2020=100				
		REF		100.0	114.7	133.6	154.8
		2DEG		100.0	115.1	133.6	154.0
		C-REG-BATTERY		100.0	115.0	133.5	153.7
		Difference from 2DEG	%	0.0	-0.03	-0.10	-0.19
	Employment		millions				
		REF		219.0	216.4	212.9	208.4
		2DEG		219.1	217.0	212.7	208.6
		C-REG-BATTERY		219.1	217.0	212.6	208.4
		Difference from 2DEG	%	0.0	-0.01	-0.04	-0.06

Source: GEM-E3-FIT

The EU benefits from lower battery imports but the loss of EV sales is dominant in the EU's trade balance: in 2050 EU imports of batteries are reduced by €58bn, but exports of electric vehicles are reduced by €148bn.

Table IV.2: Trade implications of C-REG-BATTERY scenario

Absolute change from 2DEG (in €bn)	2025	2030	2040	2050
Exports of electric vehicles	-0.8	-8.1	-52.6	-148.7
Imports of batteries	-3.4	-7.6	-32.0	-58.3
Net benefit/loss for the EU	2.6	-0.4	-20.6	-90.4

[38] This is based on the assessment of lithium-ion manufacturing costs by country in "Benchmarks of Global Clean Energy Manufacturing", CEMAC, 2016 (Clean Energy Manufacturing Center).

[39] In the C-REG-BATTERY scenario, EU battery manufacturing is higher than in 2DEG, as battery imports from non-EU countries are not allowed. This triggers increased learning by doing and economies of scale effects which drive down the costs of EU-produced batteries.

% of EU GDP	0.01%	0.00%	-0.07%	-0.24%

Source: GEM-E3-FIT

In terms of employment, EU production of batteries increases the labour intensity of the economy. It is estimated that for each additional €1m of value of batteries produced in the EU, 3 full-time equivalent jobs are generated. If the income effect of the scenario is not taken into account (i.e. if the EU economy had the same GDP as in 2DEG) then employment would increase by 140,000 jobs in 2050. However lower sales and production of the EV industry drive GDP reductions and hence employment is 0.06% lower than 2DEG in 2050.

C-R&D-BATTERY-ETS

In this scenario it is assumed that the EU increases its public R&D expenditure so as to reduce the production costs of EU-manufactured batteries. As the relationship between R&D expenditure and total factor productivity improvements is uncertain, three variants have been developed. In the variants, the relationship between R&D expenditure and TFP improvements is varied (i.e. different learning rates used). Table IV.3 presents the main assumptions for the three variants.

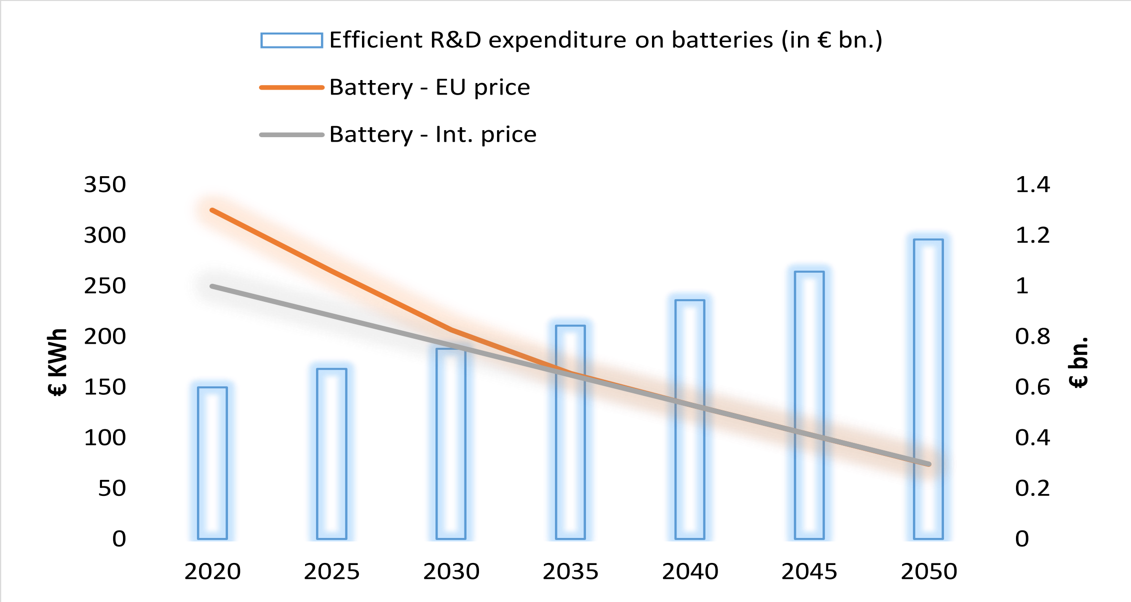
Table IV.3: Variants of the C-R&D-BATTERY-ETS scenario

Scenario Name	Cumulative R&D expenditure (2020-2050)	Average annual expendit ure	TFP improvement	Learning rate*
Efficient R&D	€26bn	€860m	3.5	24%
Unsuccessful R&D	€45bn	€1.5bn	2.8	16%
Ambitious R&D	€160bn	€5.3bn	4	16%

* Learning rates are taken from the upper and lower bounds available in literature. The R&D learning rate indicates the reduction in unit costs for each doubling of the cumulative R&D expenditure.
Source: GEM-E3-FIT.

In the efficient variant, R&D expenditure is calculated so that the EU produces batteries at a competitive price by 2035. In the unsuccessful R&D scenario, the learning rate is set at the lower bound and the EU only achieves competitive battery pricing in 2050. In the ambitious R&D variant, the EU achieves price parity in 2035 and produces batteries at a lower cost than its competitors thereafter. In the efficient scenario it has been estimated that €26bn would need to be spent on battery R&D over the 2020-2050 period (the resulting spending and price parity are presented in Figure IV.4).

Figure IV.4: R&D expenditure on batteries and prices of the efficient R&D scenario



Source: GEM-E3-FIT

In order to simulate a budget neutral policy, it is assumed that a part of ETS revenues is directed to R&D for batteries. A second variant regarding the financing of R&D expenditures is examined that assumes that public R&D is redirected from other clean energy technologies to batteries (this variant has been developed only for the R&D efficient scenario). It has been assumed that any patents on batteries that are generated in the EU do not spill over to non-EU countries in the first five years.

The net impact of the ETS-financed R&D variants on EU GDP and employment is slightly negative when compared with 2DEG but positive when compared to the C-REG-BATTERY scenario.

The C-R&D-BATTERY-RES scenario has a slight negative impact on EU GDP and employment relative to the ETS-financed R&D cases (other than the unsuccessful R&D case) , due to the reduction of R&D expenditures in other clean energy technologies.

Table IV.4: Macroeconomic and employment implications of Battery R&D scenarios

		2020	2030	2040	2050
GEM-E3-FIT					
GDP	2020=100				
REF		100.0	114.7	133.6	154.8
2DEG		100.0	115.1	133.6	154.0
C-R&D-BATTERY-RES		100.0	115.1	133.5	153.9
Efficient R&D -ETS		100.0	115.1	133.5	153.9
Unsuccessful R&D - ETS		100.0	115.1	133.5	153.8
Ambitious R&D - ETS		100.0	115.1	133.6	154.1
Difference from 2DEG	%				
C-R&D-BATTERY-RES		0.00	-0.02	-0.05	-0.05
Efficient R&D-ETS		0.00	-0.02	-0.05	-0.05
Unsuccessful R&D-ETS		0.00	-0.02	-0.07	-0.13

Ambitious R&D-ETS		0.00	-0.01	-0.02	0.03
Employment	millions				
REF		219.0	216.4	212.9	208.4
2DEG		219.1	217.0	212.7	208.6
C-R&D-BATTERY-RES		219.1	217.0	212.7	208.6
Efficient R&D -ETS		219.1	217.0	212.7	208.6
Unsuccessful R&D-ETS		219.1	217.0	212.6	208.5
Ambitious R&D-ETS		219.1	217.0	212.7	208.6
Difference from 2DEG	%				
C-R&D-BATTERY-RES		0.00	-0.01	-0.02	-0.01
Efficient R&D-ETS		0.00	-0.01	-0.02	-0.01
Unsuccessful R&D-ETS		0.00	-0.01	-0.03	-0.04
Ambitious R&D-ETS		0.00	-0.01	0.00	0.01

Source: GEM-E3-FIT

As other clean energy technologies, mainly solar PV and wind, have lower potential for cost reductions through learning, the reallocation of R&D funds to battery production offers higher multiplier effects. However, the time needed for the EU to achieve price parity (with its competitors) is crucial.

The GEM-E3 results (Table IV.5) show that in the short-term, the benefit from reduced battery imports is larger than the loss from lower exports of electric vehicles. In the long-term where the market of electric cars becomes larger, the losses from reduced exports of electric cars are not compensated by reduced battery imports. The proportion of the battery cost to the total cost of electric vehicles is projected to decline from 0.35 in 2020 to 0.20 in 2050 (as battery costs drop faster relative to the total cost of electric cars[40]).

Table IV.5: Trade implications of C-R&D-BATTERY scenario

Absolute change from 2DEG (in €bn)	2025	2030	2035	2040	2045	2050
C-R&D-BATTERY-RES						
Exports of electric vehicles	-0.5	-4.1	-10.8	-24.4	-57.3	-65.2
Imports of batteries	-3.4	-7.6	-14.9	-31.9	-55.5	-58.1
Net benefit for the EU	2.9	3.5	4.1	7.5	-1.8	-7.1
% of EU GDP	0.01%	0.01%	0.02%	0.02%	-0.01%	-0.02%
Unsuccessful R&D-ETS						
Exports of electric vehicles	-0.7	-6.7	-17.9	-41.1	-96.4	-108.0
Imports of batteries	-3.5	-7.4	-13.6	-28.0	-46.3	-46.0
Net benefit for the EU	2.8	0.7	-4.3	-13.1	-50.1	-62.0
% of EU GDP	0.01%	0.00%	-0.02%	-0.04%	-0.15%	-0.17%

[40] This means that (in terms of quantity) a larger reduction in battery imports is required to compensate lower exports of electric cars in 2050 compared to 2020.

Ambitious R&D-ETS						
Exports of electric vehicles	-0.6	-3.8	-8.6	-16.9	-31.1	-24.8
Imports of batteries	-3.4	-7.6	-14.9	-31.8	-55.4	-58.0
Net benefit for the EU	2.8	3.8	6.3	15.0	24.3	33.2
% of EU GDP	0.01%	0.02%	0.02%	0.05%	0.07%	0.09%

Source: GEM-E3-FIT

The development of a low cost battery manufacturing capability boosts domestic activity both through the production of batteries and through higher employment and the associated impact on household income.

Conclusions from the EU battery manufacturing scenarios

Currently the EU has a very small share in the battery value chain as most EU electric vehicle manufacturers outsource the production of batteries. In the 2DEG scenario, the EU share in global battery manufacturing is estimated to be 0.9% over 2020-2050 which means that through to 2050 EU manufacturers will still outsource the manufacturing of batteries. In order for the EU to become a competitive battery supplier, extensive public R&I is required to support private firms in the production of batteries (or alternatively incentives to private firms in the form of large tax exemptions/subsidies).

The economic impacts expected to arise from a policy that brings about the relocation of battery manufacture to the EU depends on whether it is achieved by regulations and standards that have the effect of requiring EU car producers to purchase higher-cost batteries from EU producers, or by R&D support that lowers the costs of EU producers to match those of non-EU competitors. Both cases bring benefits in the form of reduced imports of batteries and reduced dependence on non-EU manufacturers located in China, Japan and South Korea. However, in the regulation case, EU electric car producers face higher prices for batteries. The benefit, in terms of increased value added and jobs among battery producers in the EU, is less than the cost in terms of lost competitiveness for the producers of equipment (notably electric vehicles) that incorporate batteries as a key component. In the case in which EU producers are assumed to receive support for R&D that makes them competitive with foreign suppliers, the net benefits depend on the losses associated with diversion of the support for R&D from other clean energy projects and on the extent to which the knowledge advantage gained from R&D can be prevented from spilling over quickly to foreign competitors: on the assumptions used in the scenario, the effect on EU GDP was marginally negative.

Modelling Caveats

Two cases have not been examined:

i) A case that has not been examined is the acquisition by an EU firm of a battery manufacturer located outside of the EU. In this case jobs would be created outside the EU and profits remitted to the EU while manufacturing costs would be competitive.

ii) A case where the EU is a late mover on battery production until EVs get a price parity (i.e. the innovation to reduce battery costs is produced outside EU) and benefits from the spillover effects (i.e. succeeds in replicating the battery patents and establishing the battery industry without bearing the costs of the first mover).

1.3 What would the impact on economic indicators be of an initiative that successfully improved the competitiveness of EU producers in renewable supply chains such as solar or wind?

In this analysis we model a scenario in which a higher proportion of clean energy technologies (wind, solar PV) is produced in the EU.

The current global market size of the PV industry is c. €65bn and is dominated by China and Taiwan (accounting for 67% of the global solar PV production), while the share of European manufacturers has decreased from 26% in 2008 to a mere 5% in 2015 due to intense competition from low-cost modules produced in China and in other Asian countries (Paroussos et al (2017)). Germany accounts for the bulk of EU production, while small-scale PV panel production capacities are located in other countries, mainly in Poland, Italy and France. Modules are a commodity product with increased global trade and supply chains. Due to the relatively limited product differentiation in PV modules, the basis for competition between PV producers is the price. China has established a cost advantage over its competitors by taking advantage of low wages and economies of scale. The total PV manufacturing costs across nationally integrated supply chains show a price differential of about 20%[41] between Chinese and EU PV manufacturing.

In contrast to the PV industry, the EU holds the largest market share in the global wind turbine manufacturing (about 40% in 2015). EU manufacturers (located mainly in Germany, Denmark and Spain) continue to meet local EU demand and at the same time export wind turbines to non-EU economies. EU companies account for about 90% of global exports of wind equipment in 2015 indicating that transportation costs and non-EU competitors are not yet a significant barrier to EU wind manufacturers.

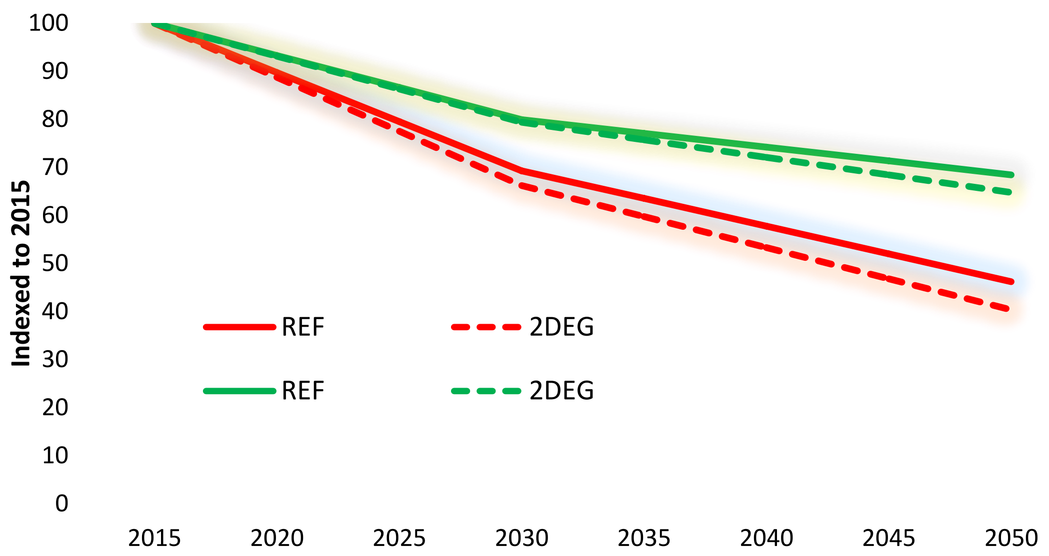
In recent years, the costs of solar PV modules and wind turbines have declined rapidly due to: (1) exploitation of economies of scale and learning by doing effects and (2) increased R&D expenditures. The cost reduction implies that in many countries wind and solar PV are already competitive[42] with conventional fossil fuel power plants, even without subsidies and other support schemes (like feed-in-tariffs).

The size of the market for clean energy technologies is driven both by the number of units sold and the unit costs. The large penetration of solar PV and wind technologies in the power system already in the REF scenario would drive their unit costs down close to their technical potential ("floor costs"); Hence the additional deployment of solar PV and wind in the 2DEG context leads to a relatively limited cost reduction by about 12% and 5% (Paroussos et al, 2017) respectively from the REF scenario in 2050 induced by accelerated learning by doing.

[41] CEMAC (2016) Clean Energy Manufacturing Analysis Centre, Benchmarks of Global Clean Energy Manufacturing

[42] McKinsey (2012), Solar Power: Darkest before Dawn

Figure IV.5: Evolution of investment costs of solar PV and onshore wind turbines in REF and in 2DEG scenarios (indexed to 2015)



Source: GEM-E3-FIT

Scenario investigated

The GEM-E3-FIT model has been used to quantify the macroeconomic implications of a future in which the production of solar PV modules and wind turbines are also manufactured in the EU rather than imported. To this end, three scenarios have been modelled.

i) C-REG-RENEW is a regulation-based scenario in which imports of solar PV and wind equipment from non-EU countries are not allowed. In this scenario 100% of EU demand for solar PV and wind is produced in the EU irrespective of their cost compared with imports. Hence, in this scenario EU PV production is supported by regulations and standards and is not price competitive

ii) C-R&D-RENEW-ETS: An R&D based scenario in which part of the ETS revenues is directed to R&D for solar PV until EU-produced PV are competitive with Chinese PV modules.

iii) C-R&D-RENEW-RES: An R&D based scenario in which EU-28 public R&D is redirected from electric cars and batteries to solar PV until EU-manufactured PV become competitive with Chinese-based production.

Results

C-REG-RENEW

In C-REG-RENEW, it is assumed that the EU sets regulations and standards which have the effect of reducing PV imports. The learning and economies of scale effects are not sufficient to make the EU solar PV production competitive with Chinese-based manufacturing, as labour costs account for about 12-15% of total PV manufacturing costs (CEMAC, 2016).

In the case where the EU produces domestically the PV and wind equipment required for decarbonisation of its energy system, the impact on its GDP is virtually zero. This reflects the fact that the cost reductions projected for PV modules to 2050 make them only a small burden on the EU trade balance (PV imports in the EU in 2050 are €13bn). Hence, if PV panels are produced in the EU, there is a benefit in terms of local production and employment and a cost in terms of higher electricity prices (0.1% higher than in 2DEG scenario) as a result of using PVs manufactured at higher costs relative to Chinese imports. The total net impact on employment is also very small.

The C-REG-RENEW scenario leads to increased EU manufacturing of wind and solar PV. The EU share in the cumulative global PV market more than doubles from 1.3% in the 2DEG scenario to 3.3% in the C-REG-RENEW scenario, while the EU share in global cumulative wind market increases from 20% in the 2DEG scenario to 21% in the C-REG-RENEW scenario.

Table IV.6: Macroeconomic and employment implications of C-REG-RENEW scenario

		2020	2030	2040	2050
GEM-E3-FIT					
GDP	2020=100				
REF		100.0	114.7	133.6	154.8
2DEG		100.0	115.1	133.6	154.0
C-REG-RENEW		100.0	115.1	133.6	154.0
Difference from 2 DEG	%	0.00	0.00	0.00	-0.01
Employment	millions				
REF		219.0	216.4	212.9	208.4
2DEG		219.1	217.0	212.7	208.6
C-REG-RENEW		219.1	217.0	212.7	208.6
Difference from 2 DEG	%	0.00	0.00	0.00	0.00

Source: GEM-E3-FIT

C-R&D-RENEW

In this scenario it is assumed that the EU increases its public R&D expenditure so as to reduce the production costs of EU-manufactured PV modules. In order to simulate a budget neutral policy, it is assumed that a part of ETS revenues is directed to R&D for solar PV. A second variant is examined that assumes that public R&D is redirected from other clean energy technologies to solar PV. In addition it has been assumed that any patents on solar PV that are generated in the EU do not spill over to non-EU countries in the first five years.

The net impact of the C-R&D-RENEW-ETS scenario on EU GDP and employment is slightly negative when compared to 2DEG but slightly positive when compared to the C-REG-RENEW scenario. In the C-R&D-RENEW scenario the EU GDP and employment decline from the regulation-based scenario, as the reallocation of R&D funds from other clean energy technologies to PV has negative economic impacts for the EU; This is due to the lower potential for cost reductions through learning by research for solar PV relative to other clean energy technologies such as electric cars and batteries, which offer higher multiplier effects.

Table IV.7: Macroeconomic and employment implications of C-R&D-RENEW-ETS and C-R&D-RENEW scenarios

		2020	2030	2040	2050
GEM-E3-FIT					
GDP	2020=100				
2DEG		100.0	115.1	133.6	154.0
C-R&D-RENEW-ETS		100.0	115.1	133.6	154.0
C-R&D-RENEW-RES		100.0	115.1	133.6	153.9
Difference from 2DEG %					
C-R&D-RENEW-ETS		0.00	0.00	0.00	-0.01
C-R&D-RENEW-RES		0.00	0.00	-0.01	-0.06
Employment	millions				
2DEG		219.1	217.0	212.7	208.6
C-R&D-RENEW-ETS		219.1	217.0	212.7	208.6
C-R&D-RENEW-RES		219.1	217.0	212.7	208.5
Difference from 2DEG %					
C-R&D-RENEW-ETS		0.00	0.00	0.00	0.00
C-R&D-RENEW-RES		0.00	0.00	0.00	-0.01

Part V. Conclusions

This report has used the E3ME and GEM-E3-FIT models to explore

- the implications of a more ambitious rate of decarbonisation (2DEG) than envisaged under current policies (REF)
- the potential impact of different kinds of constraints on the decarbonisation path
- the potential impact of measures to increase the EU share of the value chain associated with key technologies in the decarbonisation transition

The key findings are as follows.

Consistent with previous economic impact analysis, the difference in the headline economic indicators between REF and 2DEG is small. In E3ME both the GDP and employment impacts are slightly positive, while in GEM-E3-FIT the GDP impact is slightly negative and the employment impact is slightly positive.

A more ambitious decarbonisation path entails a higher rate of investment, reflecting

- the substitution of capital for energy (greater energy efficiency)
- the substitution of capital-intensive renewable technologies for fossil-fuel intensive technologies in power generation
- the substitution of electric appliances for fossil-fuel-based appliances in final energy use
- potentially, the early scrapping of fossil-fuel based equipment

The scale of investment increases over time already in the REF scenario, and is still higher in the 2DEG scenario. A question central to the analysis presented here is whether there could be financial, physical or skill constraints that might prevent the investment required to bring about the transition from being realised.

With regard to *financial constraints*, at a macro level the larger call on finance for investment in 2DEG comes in the context of a decline in the ratio of private sector debt to GDP over time in REF. The speed of that decline is less under 2DEG, but at this broad macro level the burden of indebtedness is not rising over time. However, the increase in investment and debt is not spread evenly across the economy, but is focused on the sectors in which decarbonisation is strongest, notably in power generation. In E3ME's results the scale of investment in electricity is higher in 2DEG and especially in the last decade, with the result that the estimated debt carried by the electricity industry rises sharply as a ratio to its gross operating surplus, suggesting that financial investors may require a higher risk premium in lending rates. E3ME assumes that the power generation capacity required to meet electricity demand will still be built, but the higher cost of borrowing by the sector is assumed to be passed on to electricity consumers. In a sensitivity test, in which a higher interest rate was required from the electricity sector, there is a much larger impact on the levelised cost of electricity of the more capital-intensive technologies compared with combined-cycle gas turbine technology, and these costs are (by assumption) passed on to electricity users, raising the electricity price to those users by about 10% in 2050.

Financial constraints may also apply with respect to differences in the risk premium across countries. In the 2DEG scenario, the differentials between Member States with respect to long-term interest rates are small. In a sensitivity test, these differentials were increased by 5 pp for Greece, 2 pp for Italy and 1.5 pp for Spain, broadly reflecting recent differences in government bond yields. As expected, the consequence is lower investment and GDP in these countries. The impact on their carbon emissions reflects several effects. Higher interest rates affect the choice of technology in power generation, penalising the more capital-intensive renewable technologies. Lower investment curbs the rate of improvement in energy efficiency. Both of these effects raise carbon emissions. However, lower overall economic activity (reflected in lower GDP) reduces energy use and carbon emissions. In the case of Greece and, to a lesser extent Spain, the GDP effect outweighs the other effects and carbon emissions are lower; in the case of Italy, the energy use effects are larger, and carbon emissions are higher.

With regard to *physical constraints*, again at a macro level the difference between REF and 2DEG is not large, in terms for example of GDP and labour demand, and so the impact of a tighter labour market on wage inflation is small. This reflects the fact that the main economic impacts of 2DEG compared with REF are structural, shifting demand and activity between sectors (from fossil-fuel dependent sectors to suppliers of investment goods).

Although a more ambitious rate of decarbonisation has important impacts at sectoral level, gains and losses by sector largely offset each other so that at macroeconomic level the effect is small. However, this is not the end of the physical constraints story, because resources released by a declining sector are not perfect substitutes for those required by an expanding sector. The potential for mismatch is mitigated by the long period allowed for the transition, but not necessarily eliminated.

The 2DEG scenario increases sharply the job losses in fossil-fuel related industries, adding to the large losses already envisaged in the REF scenario. Since these industries tend to be geographically concentrated (for reasons of geology or the dominance of large plants exploiting economies of scale), the trends highlight the issue of impact on particular communities and the challenge to replace the lost jobs and retrain workers. The job losses in these sectors in REF and 2DEG are larger than the reduction in the workforce that can be expected due to retirement of workers as they age over the decades.

With regard to potential *skill constraints*, the difference between 2DEG and REF is modest compared with the underlying trend over time expected in both scenarios. There is a substantial skills challenge in prospect with substantial restructuring of jobs in favour of high-skill occupations; stronger decarbonisation is expected to add to that challenge. The scale of the additional demand associated with stronger decarbonisation is not large relative to the number of jobs already envisaged across the whole economy, but it comes on top of a prospective mismatch of labour supply and demand. The impact is likely to be felt more strongly in very specific occupations in which 'greening' (new competences required to adapt to the growing demand for new technologies) is expected to occur.

With regard to the potential impact of measures to increase the EU share of the value chain associated with key technologies in the decarbonisation transition, analysis was made of

- a battery initiative (implemented either through restricting imports by means of regulation and standards or by supporting European R&D)
- an initiative to support European producers of solar PV and wind technologies

Currently the EU has a very small share in the battery value chain and so the scale of public R&D support to assure the production of competitively-priced batteries is likely to be substantial (or alternatively incentives to private firms in the form of large tax exemptions). In the modelling analysis it was assumed that R&D support was redirected from other kinds of clean energy R&D support (to assure budget neutrality). The relocation of battery manufacture to the EU brings benefits in the form of reduced imports of batteries and reduced dependence on non-EU manufacturers. In the case where the initiative is implemented by restricting imports, the consequence is higher production costs for the EU electric vehicles industry, and the loss of vehicle export revenues outweighs the reduction in the value of battery imports.

The modelling of the impact of support for European producers of solar PV and wind technologies also found that restricting imports, so imposing higher costs on electricity generators using these technologies (effectively transferring welfare from European electricity consumers to European producers of the technologies), had a marginally negative impact on GDP. If R&D support were redirected from other clean energy technologies to support EU solar PV production, the net impact would be negative because the returns to R&D in other clean energy technologies are higher than in solar PV.