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A macroeconomic perspective on climate change mitigation: Meeting the financing challenge

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Abstract

Transitioning to a low-carbon economy will require significant investment to transform energy systems, alter the built environment and adapt infrastructure. A strategy to finance this investment is needed if the limit of a 2°C increase in global mean temperatures is to be respected. Also, high-income countries have pledged to pay the "agreed full incremental costs" of climate-change mitigation by developing countries, which are not necessarily the same as incremental investment costs. Building on simulations using Integrated Assessment Models and historical evidence, this paper explores some of the issues posed by this dual financing challenge. We discuss the 'fiscal self-reliance' of the energy sector, finding that carbon pricing would generate sufficient fiscal revenues within each region to finance total investment in energy supply. Even when allowing for trade in emission permits, regional carbon fiscal revenues should still suffice to cover both their own investment in energy supply and permit purchases from abroad. We show that incremental energy-supply investment (and saving) needs are well within the range of past variation of aggregate investment, and argue that the challenge is rather to ensure that revenues from carbon pricing and other sources are complemented by investment in the appropriate sectors. But fairness and equity are likely to warrant transfers from advanced industrial countries to developing nations.

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Keywords: Macroeconomics, Climate Change, Integrated Assessment Models, Savings, Investments, Tax Revenues

1. Introduction

Integrated Assessment Models (IAMs) have proved to be crucially important tools to analyse the dynamic interactions between the economic, energy and climate systems. During the past two decades, since the first models attempting to link climate with the economic system (Nordhaus 1993; Nordhaus and Yang 1996), research using Integrated Assessment Models has made large steps forward and there is now a wide variety of different models routinely used to assess climate policies, as demonstrated by the increasingly numerous comparative exercises (Calvin et al. 2012; Clarke et al. 2009; Luderer et al. 2012).

The evolution of IAMs has mainly focused on the expansion and refinement of their energy and climate modules by the explicit representation of different sources of energy, greenhouse gases and technologies, the primary research objective being to identify the optimal future emissions trajectories and to understand how to shape energy systems in order to achieve them. This feature distinguishes them from the family of Computable General Equilibrium (CGE) models, very similar to IAMs in many aspects but more focused on the analysis of the economic system as a whole, even when the environment or climate are considered (Bovenberg and Goulder 1996). Given the great complexity of modelling energy and climate, most IAM designers have preferred to keep the economic modules relatively simple, conforming to the neoclassical Ramsey-type growth theory based on the intertemporal optimization of consumption (Acemoglu 2009; Ramsey 1928). Some other IAM designers have decided to avoid the welfare problem and focus instead on the minimisation of energy system costs, or to create a 'soft link' between cost-minimizing energy system models and welfare-maximizing macro models[1] (Bauer et al. 2008).

As a consequence, some of the wider macroeconomic implications of IAM simulations have yet to be properly explored and in the present paper we hope to contribute to the development of this research stream. More specifically, this work has two main objectives.

First, we offer a more detailed analysis of some of the macroeconomic variables that are already usually included in IAMs results. The most common – and typically the only – macroeconomic assessment of simulations in the literature concerns the *macroeconomic costs* of climate policies, calculated as the percentage loss of GDP or consumption with respect to business-as-usual scenarios. As argued by Carraro et al. (2012), there are other important pieces of economic information that can be extracted from simulations such as projected investment – in physical capital, energy capacity and R&D – and tax revenues.

This paper presents a macroeconomic analysis of the results from the models participating to the LIMITS project - Low climate IMpact scenarios and the Implications of required Tight emission control Strategies (Kriegler 2013; Tavoni 2013). A classification of LIMITS scenarios can be found in Table 1. In particular, we focus on two of the seven models participating in the LIMITS project: the WITCH model (Bosetti et al. 2007) and the REMIND model (Leimbach et al. 2010), which have a general equilibrium structure that allows the more detailed analysis of some of the macroeconomic variables involved in climate-change policies, and in particular that allows incremental investment costs and aggregate costs to be distinguished[2].

However, as discussed in section 2.1, the current state of the art of Integrated Assessment Modelling still does not allow a comprehensive analysis of the macroeconomic implications of climate-change policies. For this reason, we expand our discussion to include variables that are usually disregarded by the modelling literature. In particular, we study the implications for the finance of incremental energy-supply investment needs and payments to developing countries to cover their "full agreed costs" of climate-change mitigation. These are discussed in relation to global saving and investment flows and current account imbalances. Evidence from past increases in aggregate investment to support structural transformations is briefly reviewed.

These issues are particularly important when considering the radical transformation of the energy system needed to respect the 2°C limit to the global average temperature increase – as agreed in the Conference of the Parties to the UN Framework Convention on Climate Change in Copenhagen in 2009 (UNFCCC 2009). Transitioning to a low-carbon economy will require structural changes not only in the energy sectors but also in the economic system as a whole, as consumers, productive sectors and public authorities adapt to the new socio-economic and technological

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[1] For a more detailed classification of IAMs, see Elizabeth A. Stanton, Frank Ackerman, and Sivan Kartha, 'Inside the Integrated Assessment Models: Four Issues in Climate Economics', *Climate and Development,* 1/2 (2009), 166-84.
[2] See also Michael Jakob et al., 'Description of the Recipe Models', *RECIPE Background Paper,* (2009).

environment. However, we will show how the financial resources to be mobilised for the transition are by no means unprecedented and argue that climate change mitigation is feasible from an economic perspective, despite its expense.

The remainder of the paper is organized as follows. Section 2 offers a brief overview of the models' macroeconomic framework and presents a comparative analysis of the major macroeconomic variables across the different climate-policy scenarios, focusing in particular on GDP, aggregate and energy-supply investment, carbon tax revenues and international finance flows. Section 3 considers how big a challenge it will be to finance incremental investment needs and compensate developing countries for costs of climate-change mitigation. Section 4 concludes.

2. A macroeconomic analysis of LIMITS results

2.1 The macroeconomics of LIMITS models

The dynamics of Integrated Assessment Model simulations typically arise from some kind of optimization process, or simulation of some economic equilibrium: in some cases, this takes the form of a maximisation of a welfare function, in some others the objective is to minimise the costs of the energy systems; some of them use an intertemporal optimization method with forward-looking agents, while some others choose a recursive dynamic solution instead, where results are calculated for each time step without an explicit representation of agents' expectations. The two models WITCH and REMIND belong to the sub-class of IAMs that simulate future dynamics through the intertemporal maximization of a social welfare function either subject to some physical constraint – an exogenous target for temperature increase or atmospheric concentration of greenhouse gases – or in a cost-benefit framework taking account explicitly of the costs of climate change. Other models that share similar features include the RICE (Nordhaus and Yang 1996), the MERGE (Manne and Richels 1992) and the FUND (Tol 1997) models.[3]
In both WITCH and REMIND, the production of the single good – used for both consumption and investment purposes – takes place through a Constant Elasticity of Substitution (CES) technology, with physical capital, labour and energy services as input factors. The elasticity of substitution between inputs is chosen to be lower than one (Gerlagh and van der Zwaan 2004), implying that substitution between energy services and other inputs is difficult. The distribution of output among consumption, investment in physical capital and other energy expenditures is endogenously determined by a set of regional social planners with perfect foresight, who maximise the sum of intertemporal discounted regional utilities, which in turn are logarithmic functions of per capita consumption weighted by regional population (Bosetti et al. 2007; Leimbach et al. 2010). The theoretical structure of the models' economic modules therefore broadly follows the standard Ramsey-type growth framework, the main exceptions being the introduction of some features of endogenous growth theory in the WITCH model – especially regarding technical change in the energy sectors – and the representation of international trade in the case of REMIND.

These classes of IAMs are characterised by the highly aggregated nature of their economic modules. There is usually no distinction between the different economic agents – households, firms and government, let alone banks and monetary authorities – or different productive sectors, such as agriculture, industry and services. The

[3] Some of these models can also be used to endogenize the exogenous target by including projections of expected social welfare, including the expected net damages (in utility terms) from climate change, and choosing a target equalizing marginal expected welfare costs and benefits of climate-change mitigation. The discussion here focuses on their use without their climate-impact modules.

assumption of a single homogeneous economic sector simplifies and improves the tractability of the models but, on the other hand, does not allow an exhaustive analysis of economic interactions. This can be done using computable general equilibrium models (CGEs), such as those based on the GTAP input-output database (Narayanan et al. 2012), which are however generally used to examine more short-term policies.

Another distinctive feature of IAMs is the long-term perspective of their analysis, with simulations usually up to at least the end of the century. That is a reasonable choice given the temporal horizon of climate-change dynamics, though focusing on trends without considering economic fluctuations leaves IAMs with little to say about the relationship between emissions, policy settings and the shorter-term cycles of economic activity (Fischer and Springborn 2011; Heutel 2012).

Economic growth in these models is a result of two different factors: on one side, it reflects the accumulation of physical capital, which is endogenously determined through the welfare intertemporal optimization; on the other side, it is the outcome of the exogenous trends of the technical parameters describing the productivity of input factors. In most of them, the latter factor plays a predominant role; the economic dynamics of the models are mainly determined by the assumptions made about how labour productivity and energy efficiency evolve over time (Jakob et al. 2009).

[Figure 1 about here]

The first panel of Figure 1 shows GDP year-to-year growth rates across a selection of regions[4] in the business-as-usual scenario (Base), where no climate policy is implemented[5]. There is a large variation in annual growth rates in the short term (2020) – ranging from 2% in Europe to almost 14% in China – and then a gradual convergence towards a common long-run growth rate of around 1.5-2% by 2100. The only exception is the African region, where growth rates at the end of the century are still around 4%, although on a decreasing trend. Despite the convergence of growth rates, the large disparities in starting income levels and the different population dynamics across regions inhibit the long-run convergence of per capita income. The lower panel of Figure 1 indicates a divergence in individual income levels across regions, with North America and Europe clearly outdistancing all the other regions, and with Africa still lagging behind.

In all the other scenarios, a tax on carbon is implemented.

Figure 2 shows the dynamics of global carbon prices for both REMIND and WITCH across a range of scenarios[6]. In the Reference Policy (RefPol) and the Stringent Policy (StrPol) scenarios – where regions keep the same level of current commitments throughout the century without integrating their carbon markets – carbon prices are still very low in both models. Also, they differ across regions. In the rest of scenarios, the chosen climate policy is a global carbon tax on all Kyoto gases starting from 2025 onwards (2035 for RefPol2030-500). In these cases, carbon prices are endogenous to the model and determined through the optimisation process subject to some physical constraint.

[4] We use a geographical disaggregation based on 10 macro-regions: North America (NORTH_AM), European Economies (EUROPE), Pacific OECD (PAC_OECD), Reforming Economies (REF_ECON), China (CHINA+), India (INDIA+), Rest of Asian Economies (REST_ASIA), Africa (AFRICA), Middle Eastern Economies (MIDDLE_EAST), Latin America (LATIN_AM), plus a residual eleventh region, Rest of the World (REST_WORLD). For a more detailed discussion, see Massimo Tavoni, 'Policy Overview: Regional Effort for Climate Stabilization', *Climate Change Economics,* this issue (2013).
[5] We report only the results for WITCH. Results from REMIND are almost identical.
6 For the complete set of scenarios employed by the LIMITS projects, see Table 1.

For instance, Figure 2 shows the dynamics of carbon price for two scenarios in which the Reference Policy is applied until 2020, and then a carbon price is introduced so as to achieve a concentration target of 450 (RefPol-450) or 500 parts per million of CO_2 equivalent (RefPol-500) by 2100[7]. It can be seen how the two models exhibit different results, with WITCH having a higher carbon price than REMIND throughout the period. The difference is due to varying assumptions about the potential to decarbonize the supply side of the energy sector. WITCH assumes lower mitigation potential and limited substitutability between energy sources, and relies more on a reduction of energy demand, which given the complementarity between factors of production induces higher carbon prices. The two models span the range of carbon prices in the LIMITS multi-model exercise, thus providing a good coverage of different model characteristics.

[Figure 2 about here]

2.2 Aggregate investment and its composition

Climate policies in IAMs are usually evaluated according to their *macroeconomic costs*, measured as the amount of Gross Domestic Product that is lost with respect to the business-as-usual scenario because of the implementation of the climate policy, or as the loss according to the objective function chosen (e.g. expected discounted consumption per capita). Despite being a key variable, GDP loss is insufficient to describe the more complex economic dynamics involving investment, tax revenues, public and private expenditure, trade flows, current account balances, and so on. In the following sections, some of these variables are reintroduced in the discussion, while not disregarding the importance of GDP loss.

This section focuses on investment. Being mainly designed to study energy systems, many IAMs do not model economies' aggregate investment in a sophisticated way. This is probably due to the fact that, for the sake of simplicity, economic growth is generally assumed to take place as a result of exogenous trends in input factor productivities and aggregate output or capital. Even energy investment has not been investigated thoroughly in the IAMs literature and has only relatively recently attracted the interest of researchers (Carraro et al. 2012; IEA 2011; McCollum et al. 2013; Riahi et al. 2012).

However, there have been a number of estimates of the incremental aggregate investment needed. For instance, the survey by Olbrisch et al. (2011) reports estimates of additional yearly investment to be employed by 2030 to keep the rise in global temperatures below 2°C. They range from a minimum of about $400 billion per year to more than $1200 billion. According to WEF (2013), the investment required to respond adequately to the climate challenge is around $700 billion per year, from now until 2030, while UNEP (2011) estimates that the investment needed to green the economic system (and not only to stabilise temperatures) ranges from $1000 to $2600 billion. Kennedy and Corfee-Morlot (2012) focus on global investment needs in infrastructure. Based on OECD and IEA modelling, they suggest that the incremental global infrastructure costs of moving from a business-as-usual scenario to a low-carbon scenario in the near term (2015-2020) are likely to be between US$ 0 and US$ 400 billion per year (with savings in some sectors, due to reduced transportation and consumption of fossil fuel and increased fuel efficiency, but increases in others, including renewable power generation and buildings). The range of sectors for which investment is projected and the extent of macroeconomic adjustment envisaged differ across studies.

7 Temporary overshoot of targets is allowed.

[Figure 3 about here]

Figure 3 reports the difference with respect to the business-as-usual scenario (Base) of cumulative investment in the period 2010-2050 in various LIMITS low-carbon scenarios. Values are discounted using a 5% constant rate. For simplicity, only three scenarios are reported, but the rest of the scenarios show the same key features. Total aggregate investment is divided into investment flowing into the energy sectors to provide energy-supply capacity[8] and all the other 'non-energy' investment devoted to the accumulation of physical capital. Investment for energy efficiency improvements (e.g. in buildings and transport) and investment in energy-related R&D are not included[9]. The results differ across the two models. In the REMIND model, climate policies give rise to an increase in energy-supply investment and to a simultaneous decrease in other investment. In scenarios RefPol-450 and RefPol-500, the former effect prevails over the latter, thus leading to an increase of the total aggregate investment brought about by climate policy. In RefPol, changes with respect to the business-as-usual scenario are much smaller and approximately net each other out, leading to a minimal decrease in aggregate investment. In the WITCH model, by contrast, both energy-supply and other investment decrease when a carbon price is applied, with non-energy-supply investment falling slightly more than energy-supply investment in all scenarios. The net effect of climate policies on total aggregate investment is thus unambiguously negative.

The discrepancies between the models are mainly due to different assumptions regarding the reaction of the economy to an increase in the price of carbon. A higher carbon price will have two main economic consequences. On one side, it will provide incentives to switch to less polluting energy sources, for which investment costs are higher than for fossil fuels (McCollum et al. 2013), thus leading to an increase in total supply-side energy investment; on the other side, an increase in carbon prices will depress the demand for energy, as well as overall economic activity, and consequently tend to reduce investment in energy capacity. The prevalence of one of these effects over the other will determine the direction of the overall change in energy-supply investment with respect to the reference scenario with no climate policy. As noted above, the two models span the range of the LIMITS multi-model ensemble, with REMIND being more optimistic than WITCH about the long-term potential of low-carbon energy-supply resources and costs. The results reported in Figure 3 show accordingly that WITCH scenarios are characterised by a strong reduction in energy demand – which leads to a decrease in total energy-supply investment – whereas in REMIND the decarbonisation effect prevails.

Investment in other non-energy sectors exhibits the same trend across models, as it decreases with respect to the Base scenario both in WITCH and in REMIND. That happens because higher energy costs provide incentives to

[8] In this paper we focus on 'energy-supply investment', which include investment in: electricity generation and supply, including electricity storage and transmission & distribution; extraction and conversion of fossil fuels; production of hydrogen; production of liquid fuels; heat generation facilities; CO2 transport and storage; other types of energy conversion facilities. Energy-supply investment coverage slightly differs between the two models: REMIND does not report investment for biomass production and fossil fuel extraction, while WITCH does not report investment for biomass production, electricity transmission & distribution, fossil liquids production, and biofuels production.

[9] Investment for energy efficiency improvements and investment in energy-related R&D are not included in the standard WITCH and REMIND runs, and therefore are not considered in this paper. For an analysis of demand-side investments in LIMITS, see: David Mccollum et al., 'Energy Investments under Climate Policy: A Comparison of Global Models', *Climate Change Economics,* this issue (2013). See also the chapters dedicated to energy efficiency of: Iea, 'World Energy Outlook 2012', (Paris: OECD/IEA, 2012).

substitute other input factors (capital and labour) for energy. Given that the models employ a production function with an elasticity of substitution lower than one, the process causes a reduction in marginal productivity and a drop in investment in physical capital (Carraro et al. 2012). An important caveat is that changes in investment in other sectors as a result of decarbonisation policies are not considered explicitly. Nor are the investments required to increase energy efficiency in other sectors analysed. Also, the composition of gross investment will differ in practice, as different – lower carbon – technologies are embodied in new capital.

2.3 Carbon tax revenues

In every LIMITS scenario except the business-as-usual one, a price on carbon is implemented as the policy instrument designed to bring about emission reductions. A carbon price entails fiscal flows, usually from the private sector (especially firms in energy-intensive industries) to the government. A steadily rising price on carbon is likely to have strong effects on the rest of the economy and the behaviour of economic agents through relative price effects and the income effects on those taxed, influencing the composition of consumption, investment and trade (Goulder 1995; MacKenzie and Ohndorf 2012). But in practice it will also affect the economy through the effects generated by the use of tax revenues. Unfortunately, the high degree of aggregation of economic systems typical of IAMs does not allow a detailed investigation of fiscal effects, as no clear distinction is made between taxpayers and tax receivers. Usually, it is simply assumed that tax revenues are entirely recycled back into the economy by means of lump-sum transfers to households.

[Figure 4 about here]

Carbon tax revenues are equal to the price of carbon multiplied by the quantity of emissions of Kyoto gases. On one side, the increasing trend in carbon prices drives revenues up; on the other side, the decrease in polluting emissions that takes place in most of the scenarios erodes the tax base. It is not straightforward to anticipate which one of the two effects will prevail.

Figure 4 shows the trajectory of revenues from carbon taxation as a percentage of global GDP. In the WITCH model, the trajectories in the policy baselines RefPol and StrPol slowly increase and then stabilise around 1-2% of GDP. In the RefPol-450 and RefPol-500 scenarios, tax revenues increase much more, peaking at around 12% and 6% around the middle of the century. They then decrease to around 8% and 5% by 2100. The REMIND model shows similar trends in RefPol and StrPol, although values are lower and below 1% by the end of the period, but its results are clearly different from WITCH for the RefPol-450 and RefPol-500 scenarios. After a steep increase before 2030, tax revenues drop quite quickly and reach approximately 3% of GDP by 2050. They eventually become negative by the end of the century, reflecting the fact that subsidies have to be paid to 'negative emissions' producers[10]. The RefPol-450 scenario, which is more stringent than RefPol-500 since the radiative forcing target is lower, delivers the highest tax revenues in WITCH and is the scenario implying highest subsidies in REMIND. The strong difference between the two models is motivated by the different dynamics of carbon prices – shown in Figure 2 – on one side, and by the paths of optimal emissions on the other, as in REMIND emissions become negative by the end of the century.

[10] By 'negative emissions,' we mean the permanent removal of greenhouse gases from the atmosphere through carbon capture and storage (CCS) technology.

The figures for carbon tax revenues seem ambitious considering that the revenues from the entire set of environmentally related taxes in 2004 were approximately equal to 1% in North America, 2.6% in the EU15 and 1.8% on average across all OECD countries; the OECD average rate had fallen a little by 2008, to around 1.7% (OECD 2008). Nevertheless, general government revenues in 2010 accounted for approximately 36% of GDP in advanced industrial economies and 27% in emerging and developing countries (IMF 2012). A reform of fiscal policies could therefore lead with relatively small effort to carbon tax revenues similar to the ones depicted in Figure 4. It is also important to remember that the large carbon revenue figures are obtained in the case of climate policies that achieve the 2°C target with sufficiently high probability. These are thus very ambitious and stringent climate scenarios, in which every tonne of CO_2 has to be removed extremely quickly from both the energy and land-use systems, imposing radical changes in the way we consume and produce energy.

[Figure 5 about here]

Figure 5 presents the dynamics of the global 'energy fiscal surplus' – that is, the difference between investment flowing to the energy sectors to augment supply and revenues from carbon taxes levied on those sectors, both expressed as shares of Gross Domestic Product. The goal is to assess the capacity of economies to find the cash flows necessary to finance the energy-supply investment they require by raising carbon revenues. Values below the x-axis line are characterised by having carbon tax revenues lower than investment in energy supply; values above the axis indicate that carbon tax revenues are larger than the optimal energy-supply investment in the same scenario. In other words, the position on the plane offers a rough idea of the 'fiscal self-reliance' of the energy sector (although the diagram does not take into account the investment required for enhanced energy efficiency in the economy).

Until 2020, the absence of a global carbon tax makes the energy system fiscally dependent on the rest of the economy in all the scenarios, implying that the regional carbon prices applied in the short term are not sufficient to cover the necessary energy-supply investments and that the sector needs to find other sources of finance. This applies to the whole 2010-50 period presented in Figure 5 in the case of the RefPol scenario, and in the StrPol scenario according to REMIND (WITCH values for StrPol scenario become slightly positive from 2040 onwards). On the other hand, the RefPol-450 and RefPol-500 scenarios, in which an optimally determined global carbon price is implemented from 2025, show very strong fiscal self-reliance of the energy system, meaning that the needed energy-supply investment can be financed through the carbon-tax revenues without resorting to other sources. This is particularly true in the WITCH model, which shows an energy fiscal surplus of almost 12% by the middle of the century in the most stringent scenario RefPol-450. REMIND values are lower and on a declining trend (and eventually become negative once again towards the end of the century because of negative emissions).

2.4 Fiscal self-reliance of energy sectors in an international perspective

Figure 6 expands the analysis on fiscal self-reliance of the energy sector through a regional disaggregation of the domestic 'energy fiscal surplus'. For each region, we report the results for both models (REMIND values on the left with solid markers and WITCH on the right with dashed markers) and for two representative scenarios, RefPol and RefPol-450.

The results for RefPol, a scenario in which only governments' current commitments are implemented in the future, show 'energy fiscal deficits' across all regions, with the notable exception of Europe, meaning that the revenues raised through the introduction of a carbon price are not sufficient to finance the necessary investment in increasing energy supply. Some other source of finance would have to be found in order to do that. In particular, according to WITCH, the deficit appears to be very large in the Middle East region (-9%) and, to a lesser extent, in the Reforming Economies (-4%).

In contrast, the introduction of a global carbon tax on polluting emissions capable of achieving a radiative forcing of 2.8W/m^2 by the end of the century and a high chance (>70%) of staying below the 2°C ceiling – as contemplated by RefPol450 – seems to ensure domestic energy fiscal self-reliance in all the regions. In 2030, carbon tax revenues are able not only to finance all energy-supply investment, but a surplus is available to be used for other non-energy-supply-related purposes. The results reflect a certain consistency across models, with developing regions exhibiting much higher domestic fiscal surpluses than high-income ones. However, REMIND values tend to be lower than WITCH ones, in some cases by as much as 10%. This discrepancy increases in following decades because of the different dynamics of carbon tax revenues (increasing in WITCH, declining in REMIND).

The large differences between the RefPol and RefPol-450 scenarios in both models are mainly due to the much higher tax revenues rather than to the change in energy-supply investment requirements with respect to the business-as-usual scenario, underlining the fundamentally different nature of moderate climate-mitigation scenarios compared with the 2°C ones.

[Figure 6 about here]

One other crucial factor has to be introduced into the analysis when considering the issue of energy-supply investment financing: international financial flows. In the LIMITS project, international flows are limited to the ones that originate from the trade of emission permits, which takes place in two scenarios, RefPol-450-PC and RefPol-450-EE. Both of them are very similar to RefPol-450 but a burden-sharing mechanism is implemented in the allocation of permits: 'per capita convergence' in RefPol-450-PC, in which per capita emissions rights gradually converge to a common value across all regions by 2050; and 'equal effort' in RefPol-450-EE, which applies an equalization of mitigation costs across all regions (Kriegler 2013; Tavoni 2013). Trade in emissions permits generates international flows of funds. In practice, carbon pricing and other climate-change policies are likely to affect other elements of international capital flows as well (see, for example, Figure 13 and the discussion in Section 3), but it is useful to examine the permit-trade-related flows to draw some conclusions about their likely adequacy to finance energy-supply investment.

In Figure 7, the 2030 'energy fiscal surpluses' after allowing for emissions-permit trading are presented, calculated as the sum of tax revenues and international flows less the investment in energy supply. In RefPol-450, where no trade of permits takes place, the surplus is by definition equal to the surplus in the no-permit-trade case. As before, the REMIND values are reported on the left, using solid markers, and WITCH values on the right, with dashed markers.

In RefPol-450-PC, every region has a fiscally self-reliant energy sector. Despite the fact that emission-trading financial flows are negative in many regions – China, Europe, Latin America, Middle East, North America and Reforming Economies (plus Pacific OECD for WITCH) – the outflow is not sufficient to offset entirely the high revenues coming from carbon taxation, thus leaving their energy sectors with a fiscal surplus. The results are similar across the two models in some regions, but less so in others: the WITCH results for Africa, India and Latin America have much higher surpluses than does REMIND (in the African case, the discrepancy is more than 25%). In the RefPol-450-EE scenario, all regions are still fiscally self-reliant in their energy sectors, with the exception of Europe, which exhibits a small energy fiscal deficit. In contrast, Africa, Middle East and Reforming Economies show very strong energy fiscal surpluses.

Looking at the geographical disaggregation, the African continent enjoys a strong energy fiscal surplus in every scenario considered, especially in the ones that allow the trade of emission permits. Some differences are however visible between the models: for REMIND, the fiscal surplus is maximised in the RefPol-450-EE scenario, while according to WITCH RefPol-450-PC is the one delivering the highest surplus (up to 41%). But the two models agree in considering the equal-mitigation-costs scenario highly beneficial for the Middle Eastern region and the Reforming Economies. This is due to the fact that, in most of the scenarios without trade, these two regions – being producers of fossil fuels – incur costs significantly higher than the rest of the world. The equalisation of mitigation costs across all regions is therefore highly beneficial for them (Tavoni et al. 2013). The advanced industrial economies show both very low values of energy fiscal surplus/deficit and small differences across scenarios, meaning that international flows are not very relevant for their energy-sector fiscal self-reliance, while results are mixed for emerging economies such as China, India and Latin America[11].

[Figure 7 about here]

2.5 Macroeconomic costs and investment

After the brief perspective on what the LIMITS results entail for energy-supply and total investment and tax revenues offered above, this section discusses the link between these macroeconomic variables and the broader macroeconomic cost of climate policies, measured as the percentage deviation of GDP in the climate-policy scenario from the business-as-usual GDP. Figure 8 plots the scenarios in a plane where the macroeconomic cost is on the y-axis and the x-axis represents the percentage variation with respect to the Base scenario of aggregate investment in the economy. All values are cumulated over the 2010-50 period using a 5% constant discount rate. The WITCH model shows an almost linear trend: as the carbon price increases and climate policy becomes more stringent, aggregate investment decreases and the loss in GDP increases. This is due both to a decrease in energy-supply investment triggered by a reduction of energy demand and to a drop of investment in physical capital caused by the lower marginal productivity of capital, which produces a decline in the level of output. Some scenario clustering is visible from the graph: the Base scenario is at the origin of the axes, as it is the reference case; RefPol and StrPol start to show both macroeconomic costs and reduced investment; all the scenarios with a 3.2 W/m^2 radiative forcing target come next, with a reduction in investment of approximately 5% with respect to the Base and a loss of GDP of 2% over the 2010-50 period; finally, the scenarios with a radiative forcing target of 2.8 W/m^2 involve a decrease of investment of around 8% and a GDP loss of around 4%.

[Figure 8 about here]

REMIND results are quite different. There is no clear sign of a negative effect of climate policies on aggregate investment; in all the scenarios, investment is between -0.5% and 0.5% compared with the Base. The loss in GDP associated with climate policies is therefore the result of a transfer of investment resources from more productive to

[11] A more detailed analysis of the REMIND results is presented in Tino Aboumahboub et al., 'On the Regional Distribution of Climate Mitigation Costs: The Impact of Delayed Cooperative Action', *Climate Change Economics,* forthcoming (2013).

less productive sectors: even if the total amount of investment increases, the drop in aggregate productivity due to the redirection of resources towards the less productive low-carbon energy technologies is strong enough to produce a reduction in GDP with respect to the business-as-usual scenario.

Figure 9 offers a similar analysis but using just the share of investment that flows into the energy sectors to augment supply. In the WITCH model, the trend is similar to the one in Figure 8 but with a larger variation on the x-axis. Energy-supply investment decreases as the climate policy becomes more stringent and can reach a level 30% below the business-as-usual case. The results from REMIND go in the opposite direction: as the carbon price increases, energy-supply investment becomes larger and larger (up to 40% above the reference case in some scenarios). The discrepancy is due to the differences in how the two models represent the reaction of energy demand to an increase in carbon prices. While in REMIND a surge in investment in renewable energy capacity – more expensive than traditional fossil fuels – takes place, in WITCH a reduction in the demand for energy dominates, which leads to a net decrease in energy-supply investment.

[Figure 9 about here]

3. How big a challenge will it be to finance incremental investment needs and 'agreed full incremental costs' of climate-change mitigation?

The previous section of this paper considered the implications of various LIMITS scenarios for incremental investment costs, in energy system supply and across economies as a whole, and GDP costs. The exercise gives an idea of the financing needs generated and an indication of the scope for carbon pricing and permit trading to satisfy those needs. This section broadens the discussion of financing needs by putting them in the context of past variations in investment rates and considering briefly the prospects for financing incremental investment through domestic saving, international capital flows, environmental taxes and explicit 'climate finance.' Given the UNFCCC principle that incremental costs incurred by developing countries are to be treated differently from those incurred by advanced industrial countries, the focus is on the former.

3.1 Incremental investment needs compared with past variations in investment rates

Incremental aggregate investment needs in the 2010-2050 period (Figure 10) are not large compared with past variations in aggregate investment/GDP ratios (Figure 11). The models here suggest that investment rates are likely to increase in the short run under business as usual as well as in the various climate-change mitigation scenarios; comparing mitigation scenarios with the base case, incremental investment needs are small. Indeed, according to the WITCH simulations, incremental investment needs may be negative, largely thanks to reduced energy intensity[12]. This reduction is induced in part by substitutions away from energy in production and consumption in response to higher prices and in part by technological progress. In the REMIND runs, incremental investment at the global level reaches a maximum of just under 1.3 percentage points, although for some regions the maximum is larger. For

[12] Improvements in energy efficiency require investment too, including in energy R&D, which we do not consider here. For an analysis of R&D investments in WITCH, see: Giacomo Marangoni and Massimo Tavoni, 'The Clean Energy R&D Strategy to 2°C', ibid.

example, in both Africa and Reforming Economies, required incremental investment exceeds 3 percentage points of GDP in several periods.

[Figure 10 about here]

The models considered here do not capture all the incremental investment needs of the transition to a low-carbon economy, as they concentrate on the necessary changes in energy supply and the consequent general equilibrium changes in aggregate investment. They do not take account of the need for countries to invest to adapt to climate change; the costs of so doing could easily be of a similar magnitude to the costs of mitigation (Narain et al. 2011). Nor is incremental investment to reduce the demand for energy systematically considered, although this is likely to have to be substantial. For example, incremental investment needs in the transportation and buildings sectors are not fully modelled, although they are likely to be large (Kennedy and Corfee-Morlot 2012). McKinsey & Company (2009) estimated that additional investment in energy supply by 2026-30 to keep below the 2°C ceiling would amount to only about one fifth of the total incremental investment needed, with transport (e.g. electric car production) and buildings (e.g. higher standards of insulation) accounting for over 60%. Work for the UNFCCC also suggested only about one fifth of the total incremental investment needed would be in energy supply once allowance is made for reduced investment in the fossil-fuel sector; the IEA (2009) projected the fraction would be even lower (see Table 1 and its discussion in Olbrisch et al. 2011). The ADAM project's estimates of the investment needed to bring about a transition to a low-carbon economy in Europe suggested that over four times as much extra investment would be required for buildings than for energy supply (Hulme et al. 2009). The estimates of incremental investment needs also show considerable variation across regions, while the differences in the REMIND and WITCH results draw attention to the substantial uncertainty about such projections.

Nevertheless, the estimates are consistent with the view that the costs of staying below the 2°C ceiling, which include the consumption costs incurred if and when investment crowds out consumption, need not be prohibitive – if policy is implemented cost effectively and is not delayed. As the models allow for the substitution of capital for energy in response to the higher relative price of energy, a larger share of non-energy-supply investment is implicitly devoted to more energy-efficient technologies even though this process is not modelled separately from other (general equilibrium) changes in non-energy-supply investment. The REMIND and WITCH results are broadly in line with several studies that have considered aggregate mitigation costs, such as Stern et al. (2006), the RECIPE project (Edenhofer et al. 2009) and the ADAM project (Knopf and Edenhofer 2012). The estimates are less optimistic than some of the 'bottom-up' estimates in the literature, such as those in McKinsey & Company (2009) and Chapter 9 of Stern et al. (2006), even though the latter two explicitly include changes in investment in a broader range of sectors. The estimates reflect a more optimistic outlook than do a number of other aggregate studies, however, such as those compared in the EMF22 modelling exercise[13].

Figure 11 shows how investment ratios for various regions have varied since 1980 (IMF 2012). The standard deviations of these time series (Table 2) vary from just over 1% to over 5%, showing that significant variations in the level of investment – in most cases, well above the incremental investment needs computed for scenarios in the REMIND runs – have been successfully financed in the recent past. Investment ratios have tended to be

[13] See the 2009 special issue of Energy Economics, in particular Leon Clarke et al., 'International Climate Policy Architectures: Overview of the Emf 22 International Scenarios', *Energy Economics,* 31, Supplement 2/0 (2009), S64-S81.

considerably higher for many emerging-market economies than for high-income countries. India and China in particular have demonstrated how changes in broad economic policy – deregulation and integration into the global economy – can generate large increases in aggregate investment rates.[14] Specific exogenous shocks to economies, such as the increase in demand for Australian coal and minerals (Bishop and Cassidy 2012), have also been known to stimulate aggregate investment rates. Pioneering efforts to measure and model broader 'green investment' flows show that green investment has been a major impetus behind total energy-supply investment in recent years across countries and China has accounted for a large part of the increase in green investment (Eyraud et al. 2011)[15]. Thus, where and when increases in investment are required for climate-change mitigation, the pace of the necessary increases is by no means unprecedented. This stands in contrast to the speed of global reductions in annual greenhouse gas emissions that will ultimately be required to stay below the 2°C ceiling, which is without precedent.

[Figure 11 about here]

Incremental GDP costs, however, are likely to be larger and, in the REMIND scenarios with higher aggregate investment shares, incremental consumption costs are likely to be higher still. Figure 12 compares three different types of incremental costs for developing countries[16] over the next decade or two. It shows clearly that incremental investment costs can be a very misleading indicator of incremental GDP costs. The incremental GDP costs in 2020 are projected to be considerably more than implicitly acknowledged in international negotiations so far – around double the $100 billion per year agreed at Copenhagen for climate finance by 2020 from advanced industrial economies to developing countries (and these are supposed to cover adaptation costs as well as mitigation costs). By 2030, when polices are assumed to have kicked in more fully, the incremental costs are projected to be much higher still.

[Figure 12 about here]

3.2 Past sources of finance for incremental investment and development

Discussions about climate finance under the auspices of the UNFCCC have understandably concentrated on what contributions the advanced industrial economies should make to mitigation and adaptation costs in developing economies. But many countries are now also planning new 'green growth' strategies independently of the UN process. Also, it is unclear the extent to which climate finance from developed countries will be forthcoming for large middle-income developing countries. Hence it is useful to consider how difficult it might be for developing countries to finance their own low-carbon development strategies through other means, by looking at how past changes in investment rates have been financed. This has been the subject of much study at the aggregate level for developing countries. One caveat, however, is that the sectoral destination of investment has not been the focus of interest in the past, partly because it is difficult to link macroeconomic data on flows of saving from different sources with macroeconomic data on flows of investment to different destinations. Hence evidence about how past energy-supply

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[14] For example, reported Chinese investment increased by over seven percentage points of GDP between 1992 and 1993, while reported Indian investment rose by nearly 15 percentage points between 2001 and 2007.

15 They find that green investment is boosted by economic growth, a sound financial system conducive to low interest rates and high oil prices. They also find that some policy interventions, such as the introduction of 'feed-in tariffs' that require use of green energy, have a positive and significant impact on green investment but some others, such as support for biofuels, do not.

[16] The developing countries group includes: Africa, China, India, Latin America, Middle East, Reforming Economies, Rest of Asia and Rest of the World.

investment booms, let alone investment in improved energy efficiency, have been financed is not readily available on a comparable basis. A second caveat is that investment for the transition to a low-carbon economy is likely to be driven to a greater extent than in the past by the policy environment and expectations about government policies over the very long term, so historical evidence may have limited relevance.

Changes in national investment have tended to be correlated quite closely with changes in national saving rates in both developed and developing countries, as famously pointed out by Feldstein and Horioka (1980). That correlation persists, although there is some evidence that the correlation has declined over time (Apergis and Tsoumas 2009), which might indicate greater integration of capital markets around the world. Developing countries that have more developed domestic financial intermediation have tended to show a higher correlation between national saving and national investment than poorer countries with less developed financial intermediation, which suggests that emerging market economies are likely to use domestic funds to a greater extent to finance upward steps in investment rates as their domestic financial systems mature (a feature that is likely to be amplified if advanced industrial countries baulk at increasing steadily climate finance payments to middle-income developing countries). Eyraud et al. (2011) provide evidence that countries with sound domestic financial systems tend to have higher levels of green investment, suggesting that financial development facilitates finance for low-carbon infrastructure investment.

Although incremental investment has tended to be correlated with incremental domestic saving, this does not reflect a lack of cross-border capital flows. There was a rapid increase in financial inflows to developing countries between 2001 and 2007, driven by a decline in the global price of risk. Across countries, financial inflows tended to be larger, the higher the quality of the domestic institutional framework, the greater the access to international export markets and the more appropriate the macroeconomic policy for the country's circumstances (Luca and Spatafora 2012). Hence economic development appears to facilitate inward flows of finance. Both net capital inflows and domestic credit exerted a positive effect on investment.

[Figure 13 about here]

As Figure 13 shows, current account imbalances (the counterpart of net capital flows) have tended to be higher in recent years. Since the Asian financial crisis of the late 1990s, the net flow of capital has tended to be from emerging and developing economies to others (although India is a prominent exception). There has been a more mixed picture for advanced industrial economies (with the USA running a large deficit but much of northern Europe in surplus). Several emerging-market economies have been building up large stocks of foreign-currency-denominated official reserves, perhaps to help stabilise their currencies and to guard against sudden stops in inward capital flows in the future (Higgins and Klitgaard 2004), suggesting that it has not been difficult for these countries to raise finance for policy objectives, given their integration in global capital markets. But cross-border capital flows have tended to be a little less volatile than investment (Table 2), placing more of a burden on domestic saving to accommodate past investment fluctuations.

Combined with the results reported above for the WITCH and REMIND scenarios, this evidence suggests that incremental energy-supply investment needs in emerging-market developing countries as a whole could be relatively easily financed. The challenge will be greater in poorer countries with underdeveloped domestic financial intermediation, where past increases in investment have relied more heavily on inducing inward flows of foreign capital. Also, according to the REMIND scenarios, Africa in particular may have higher incremental investment needs and – if experience with aggregate investment is a guide – a lesser ability to finance these through increases in domestic saving. Much more problematic will be the financing by advanced industrial nations of the collective incremental full costs of climate-change mitigation, as agreed by the UNFCCC. The LIMITS results suggest that these costs are likely to be larger than incremental aggregate investment needs, not correlated with incremental investment needs and not necessarily incurred in the sectors in which most of the additional investment takes place.

[Table 2 about here]

3.3 The outlook for opportunities to exploit excess saving

Private saving rates in many advanced industrial countries are currently high by historical standards (if not in an international perspective), as financial intermediaries and households, particularly in the high-income countries, attempt to reduce their debts relative to income and corporate sectors build up financial assets faster than their investment in physical capital (Koo 2011; Zenghelis 2012). There appears to be an imbalance between what economic agents would plan to save if there were full employment and utilisation of capital assets and what they would currently plan to invest. This is reflected in low real interest rates around the world, especially for investment in financial instruments with low risk. The challenge to economic policy-makers is how to improve the prospects for investment returns, not how to increase aggregate saving rates. The current conjuncture is favourable for an increase in investment in the transition to a low-carbon global economy, either financed by governments or by suitably incentivised private capital flows, an argument elaborated in Bowen and Stern (2010) and Zenghelis (2012).

Over a period as long as the next fifty to one hundred years, the current conjuncture is less relevant. A few integrated assessment models place emphasis on the ability of mitigation investment to generate the saving necessary to finance it by boosting output (e.g. E3MG, developed by 4CMR at Cambridge University and Cambridge Econometrics[17]). However, the models considered in the LIMITS project in contrast assume full employment and capacity utilisation. Nevertheless, it seems unlikely that over a time interval of 100 years there would be no periods when it would be sensible for governments to act opportunistically (in the neutral sense of the word) to take advantage of periods of demand-deficient underemployment to accelerate the transition to low carbon. Recent experience suggests that macroeconomic management is far from having been perfected.

One reason why such periods of demand deficiency are likely to occur again (even if at unpredictable intervals) is that global imbalances in saving and investment rates – one of the main risk factors, according to many economists (Bernanke 2009; Eichengreen 2009; Portes 2009) – are likely to increase[18]. As Speller et al. (2011) argue, the build-up of global imbalances was one of the pre-conditions for the recent financial crisis, and the challenges for macroeconomic policy-makers will become more severe as large emerging market economies increasingly integrate into the global financial system. Speller et al. (2011) simulate capital flows and external balance sheets for the G20 nations over the next forty years, using a model based on demographic trends and assuming some degree of convergence in countries' GDP per capita. In their scenario, by 2050, the overall size of external balance sheets relative to GDP across the entire G20 increases from a ratio of around 1.3 to 2.2; non-G7 gross capital outflows increase to more than twice the size of G7 capital outflows; and global current account imbalances rise from around

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[17] See http://www.camecon.com/AnalysisTraining/suite_economic_models/E3MG.aspx.

[18] See also the dissenting view of Claudio Borio and Piti Disyatat, 'Global Imbalances and the Financial Crisis: Link or No Link?', *BIS Working Papers,* 346 (2011).

4% of world GDP to around 8% at their peak. These simulations do not rely on a presumption that emerging market economies will wish to continue to increase their foreign currency reserves as a ratio of GDP, a major factor over the past fifteen years or so. They strongly suggest that finding adequate domestic saving will not be a problem for the large emerging market developing economies and these economies will continue to seek more opportunities for investment abroad.

Pointing out that there are likely to be opportunities in periods of large surpluses of ex ante saving over ex ante investment to finance sharp increases in low-carbon investment does not establish that such financing will take place. First, actual saving may be reduced by falls in income, a Keynesian adjustment mechanism. There may not be enough agents in the 'excess ex ante saving' economies that are willing to run a financial deficit, given the desire to reduce leverage in the wake of financial crisis (Koo 2011). Second, saving may be channelled into domestic investment with lower returns than potential investment abroad, so that marginal returns to investment are not equated around the world. That would enable the finance of low-carbon investment in the countries where ex ante saving exceeds ex ante investment in the absence of mitigation measures but would be unhelpful for countries with prospective current account deficits (e.g. developing countries with improving governance and new investment opportunities in natural resource development) and/or large incremental investment requirements relative to GDP (e.g. Africa in the REMIND mitigation scenarios). This risk is a corollary of imperfect capital mobility, one possible explanation of the high correlation between national investment rates and saving rates.

This correlation is a puzzle, as pointed out by Feldstein and Horioka (1980) – "the mother of all puzzles" according to Obstfeld and Rogoff (2000). In a world of perfect capital mobility, wherever saving takes place, at the margin it should be used to finance investment wherever the marginal productivity of capital is highest. If the determinants of saving and investment are different, as predicted by the intertemporal theory of the current account, one would expect no correlation between investment and saving rates in large samples (Giannone and Lenza 2009). Yet, as Giannone and Lenza point out, "in the decades following the publication of Feldstein and Horioka results, capital mobility among OECD countries has kept on increasing while the correlation between saving and investment rates has only slightly decreased." They argue that some shocks can produce general equilibrium effects that could generate a correlation even when capital mobility is perfect, and other authors have also pointed out the possibility that investment and saving could be affected in the same direction by other variables – in other words, the Feldstein-Horioka empirical results suffer from omitted variable bias.

The fact that the correlation is a puzzle makes it difficult to know whether it will continue to hold in the future. If capital mobility were near perfect despite the Feldstein-Horioka puzzle, there would be no reason to presume that incremental investment for mitigation would be financed primarily from domestic sources in the absence of policy. But it seems likely that, if developing countries increase investment in the low-carbon transition, they will end up financing the investment primarily by increased domestic saving unless there are deliberate policy measures to stimulate capital inflows, official or otherwise. First, capital mobility is not near-perfect, especially when looking beyond the OECD, because of informational asymmetries, differences in legal systems, currency fluctuations and sovereign default risk (IMF 2010). New inward capital flows could be discouraged by the capital market frictions that preserve the home bias still observable in portfolio choices around the world. But these frictions will probably be reduced as financial globalisation proceeds. They are already low for many financial assets in the OECD. Second, the fear of expropriation where governance arrangements are distrusted is likely to act as a discouragement to additional private finance flows. Third, the moral hazard and risk of free riding with respect to future climate-change mitigation policies such as carbon pricing can discourage investment in low-carbon capital. While this is an issue that needs to be faced in all countries, it may be more serious for developing countries given their emphases on promoting near-term growth and on the financial implications of the historical responsibilities of rich countries for the current stock of greenhouse gases.

3.4 The outlook for environmental taxation

In the LIMITS scenarios, carbon tax revenues are projected to amount to between 0 and 6½ % of GDP, a similar order of magnitude to, or more than, the current level of *all* environmentally related taxes in the OECD as a whole according to the OECD, environmental taxes in the OECD amounted to around 2% on a weighted-average basis in 2011 and reached a maximum of around 4%, in Denmark).[19] A gradual increase in the relative size of such revenues is projected in most scenarios and models to around 2060/70. In REMIND RefPol-450 and RefPol-500, the decline of polluting emissions triggers a significant drop in revenues after reaching a peak, a challenge for fiscal policy-makers seeking stable sources of revenue.

To achieve this level of taxation will be a substantial challenge to all countries, given political resistance to increasing tax burdens as a proportion of GDP. There are also issues of enforceability and comprehensiveness, for example, with respect to carbon taxes on agricultural greenhouse-gas emissions, land-use change and deforestation and to taxes on other greenhouse-gas emissions that are more difficult than carbon dioxide to monitor. Even the attribution of CO_2 fluxes to certain activities, such as deforestation, is difficult and uncertain. But the projections illustrate the potential for offsetting reductions in tax rates elsewhere in the economy, shifting the burden from 'goods' such as employment to 'bads' such as environmental pollution, a shift advocated by the World Bank and others as part of fiscal reforms for developing countries (World Bank 2005). Such a shift has the potential to increase productivity by reducing fiscal disincentives to the efficient allocation of factors of production, a macroeconomic link rarely present in IAMs.

3.5 The outlook for international carbon finance flows

The emissions-permit-trading scenarios in the LIMITS portfolio can be regarded as a way of modelling climate-mitigation finance that makes explicit the choices made about the international incidence of mitigation costs. The particular equity principle being applied – 'per capita convergence' or 'equalisation of the cost burden' in LIMITS scenarios – can be implemented in the projections made by IAMs. Such scenarios can give a guide to the magnitude of transfers that climate finance arrangements would have to raise according to different ethical perspectives. In practice, financial mechanisms other than carbon quota trading are also available, such as multilateral funds, bilateral aid or new sources of revenue such as taxes on maritime and air-travel related emissions and other sources of externalities that are difficult to assign to individual countries (such as maritime congestion). Such mechanisms are discussed, for instance, in UN (2010). The economic issues involved are reviewed in Bowen (2011). Debate continues about what the Green Climate Fund, established by the UNFCCC in 2011 to support climate-change action in developing countries, should do (Gray and Tatrallyay 2012). The debate reflects the lack of consensus so far on how to interpret the undertakings on climate finance made in the UNFCCC and subsequently in the Copenhagen and Cancun UNFCCC meetings.

[19] Data are available from http://www2.oecd.org/ecoinst/queries/index.htm

Purely national carbon pricing schemes, such as domestic carbon taxation, can be thought of as a special case of permit distribution across countries in which the allocation of permits country by country exactly matches the pattern of residual emissions in the relevant mitigation scenario. There are several reasons why such schemes are unlikely to be universally appealing on the grounds of equity, for example, if a utilitarian ethical perspective is adopted or if arguments about historical responsibility are to the fore.

From the economist's perspective, it is useful to recall that the second fundamental theorem of welfare economics states that, under certain (rather restrictive) conditions, every Pareto-efficient allocation of resources can be achieved by a competitive market equilibrium. When the conditions hold, the problems of efficiency and distributional impacts across individuals can be separated (Varian 2009). If introducing emissions pricing to correct the inefficiency induced by the greenhouse-gas externality has adverse distributional consequences, these can be corrected by lump-sum transfers, set to ensure that at least someone is better off after the pricing is implemented, while no-one else is made worse off. As Bowen (2011) argues, in the context of climate-change mitigation, the point is not to rehearse the restrictiveness of the assumptions necessary for the theorem to hold but to emphasize that in this framework lump-sum transfers are necessary for the introduction of emissions pricing to be unambiguously welfare-enhancing. These are likely to entail net cross-border flows of transfers. Tying individual financial flows (for example, from specific revenue-raising instruments) to specific mitigation spending is not warranted by the general equity arguments – for example, the flows might be needed to compensate the poor in developing countries for higher fuel costs.[20] Also, there is no reason why cross-border revenues from a particular earmarked source should automatically equal the incremental costs borne period by period or in total – unless permit allocation is tweaked appropriately.

From the international negotiator's point of view, the key point is that developed countries agreed under the UNFCCC to pay the "agreed full incremental costs" of implementing mitigation measures in the developing countries. As yet, there is no agreement on how to define the full incremental costs. The LIMITS projections suggest that, if these payments are envisaged to be akin to the lump-sum transfers of economic textbooks, payments well above the $100 billion a year promised in Copenhagen are warranted and should not be tied to incremental energy-supply (or aggregate) investment, given that incremental investment is likely to be well below incremental consumption costs. However, the LIMITS projections show that there is considerable uncertainty, even given broadly similar modelling strategies, about the magnitude of net costs and the extent to which they are reflected in investment costs. Also, further analysis is needed of the incremental costs of investment in improving energy efficiency. Finally, the projections may not capture all the possible offsets to mitigation costs ('co-benefits') that might arise in well-designed 'green growth' policies.

The financial flows implied by permit trading under the 'per capita convergence' and 'equal costs' scenarios are large, but also varied across scenario, model and time horizon. Thus the basis chosen for determining the magnitude of cross-border payments is important. For some developing countries, especially in sub-Saharan Africa, there is a risk of inflicting a 'resource curse' if the flows of finance are large. Potential problems include appreciation of the recipient countries' exchange rates, the crowding out of employment-creating activities, especially outside the sectors transitioning to low-carbon technologies, rent-seeking and the undermining of fiscal discipline (the concept of a

[20] Of course, finance flows have to be conditional on there being a proper low-carbon transition plan in place. There are also other issues of governance that might justify earmarking at least some flows more closely to specific low-carbon expenditure by recipients.

‘resource curse’ is discussed in Collier (2010) among others). Adverse consequences are more likely if the flows of finance are volatile, a potential problem with a permit-trading-based regime if European experience with the EU Emissions Trading System is a guide. The issue is discussed further in Strand (2009), who argues that “the macroeconomic implications of such flows are manageable in the short run, but the larger revenues resulting from global emissions schemes could overwhelm this capacity and lead to a number of potential macroeconomic management problems.”

The results of the LIMITS scenario runs can be compared with those of Jakob et al. (2012), who use REMIND-R to explore potential finance flows in a range of scenarios and who also discuss the resource curse implications. In their projections, Africa and the ‘rest of Asia’ also do well out of ‘per capita convergence.’ The projected outcome across regions is more mixed across scenarios and models under ‘equal burden-sharing,’ although the Middle East is generally expected to benefit. Without inward flows of climate mitigation finance, the Middle East would be faced with the reverse of the resource curse. EBRD (2011) suggests that this would also be a problem for countries of the Former Soviet Union. Having structured their economies around high levels of revenues from the sale of fossil fuels internationally, they may suffer a sharp deterioration in their terms of trade. On top of that, they tend to have carbon-intensive economies themselves, so are likely to have abnormally large incremental investment requirements given the need to restructure production more widely.

3.6 The outlook for domestic financial intermediation

The ease of financing the transition to low-carbon energy systems depends not only on the scale of incremental investment and GDP costs but also on the effectiveness of financial intermediation between savers and investors. Financial intermediation has long been seen as an important factor in development generally (Hermes and Lensink 1996; Levine et al. 2000). In order for investment to take place in the sectors where it is most needed, countries have to have economic systems that allow socially profitable investment to be matched by finance. Even where incremental net investment is negative, the composition of gross investment flows will have to change, with some new investment carried out.

The effectiveness of domestic banking systems and financial markets in the particular case of facilitating the transition to a low-carbon economy will depend heavily on the long-run credibility of climate-change policies and, in a market economy, the pervasiveness and expected trajectory of carbon prices. The challenge is therefore greater than in the case of market-driven structural changes. From the perspective of individual potential investors, governments are subject to moral hazard from the possibility of free-riding on the actions of other governments and may set policies in a time-inconsistent manner (for example, threatening higher carbon prices but rescinding the threat after low-carbon investment has taken place). Governments also have to re-adjust policy settings in the light of evolving scientific and economic understanding of the science, economics and ethics of climate change.

Domestic financial intermediation is likely to support the transition to the low-carbon economy more effectively if there is some co-investment by the public sector to provide credibility about long-term strategy and if public agencies take on board the political risk associated with policy uncertainty (for example, by entering contracts conditional on the path of carbon prices over time) (Bowen 2011). Specialised banking intermediaries (‘Green Investment Banks’) may have a role to play in this regard[21]. Some hypothecation of (some) carbon revenues from carbon taxes or quota sales may help to raise the costs to future governments of reneging on climate-change plans (Brett and Keen 2000). Devolving operational decisions about policy settings to a specialised agency with a clear climate-change-mitigation mandate may provide institutional inertia to discourage moral hazard and improve monitoring by potential investors (analogous to granting central banks the power to set interest rates subject to an overall politically set monetary policy objective).

4. Conclusions

Transitioning to a low-carbon economy will require large macroeconomic adjustments to transform energy systems, improve energy efficiency, alter the built environment and adapt infrastructure. In particular, a financing strategy for the necessary investment is needed if the limit of a 2°C increase in global mean temperatures is to not to be exceeded. Also, rich countries have pledged to pay the “agreed full incremental costs” of climate-change mitigation by developing countries, which are not necessarily the same as incremental aggregate investment costs. Building on simulations using Integrated Assessment Models and on historical evidence, this paper has explored some of the issues posed by this dual financing challenge.

The first key conclusion is that the financing challenge is not insuperable, given the magnitude of the energy-supply investment flows needed. The simulations investigated here suggest that incremental energy-supply investment costs need not be high and indeed may be negative, because of reduced energy demand. The projections do not, however, take explicit account of the need for more investment in energy efficiency, which are likely to be larger than the incremental investment in energy supply, given the importance of reducing energy usage, in particular in buildings and transportation. Incremental GDP costs may also be modest, although higher than incremental investment costs (because of higher production costs, especially energy costs). Incremental costs could be lower still if related market failures and distortions are corrected at the same time (few of these distortions are usually modelled in IAMs), for example, if carbon tax revenues are used in part to reduce distortionary labour taxes and if spending on innovation is raised towards the socially optimal level. Further work is needed to assess whether this conclusion is robust when a wider range of mitigation actions (such as enhancing carbon sinks) and economic sectors are considered, and when investment in improved energy efficiency is explicitly modelled.

Second, appropriate carbon pricing would soon generate sufficient fiscal revenues within each region to finance total energy-supply investment, let alone the increment necessary (relative to current policies) to keep within the 2°C limit. Nor is the incremental amount of economy-wide investment needed likely to be prohibitive by virtue of its size alone (though further incremental investment will be needed for improved energy efficiency in sectors not treated in detail in the LIMITS scenarios, such as agriculture, transportation and the built environment). The main challenge rather is to ensure that the revenues are complemented by investment in the appropriate sectors. Emissions quota trading would put more of a burden on some regions but these regions’ fiscal revenues from carbon pricing should still generally suffice to cover both their own energy-supply investment and permit purchases from abroad.

[21] See Green Investment Bank Commission, 'Unlocking Investment to Deliver Britain's Low Carbon Future', (London: Green Investment Bank Commission, 2010).for a discussion of this issue in a UK context.

Third, historical experience suggests that incremental aggregate investment (and saving) needs are well within the range of past variation. Countries have tended to finance investment booms from domestic resources and could do so in future, too. Several emerging-market economies have experienced large increases of investment and domestic saving in a short space of time.

However, the question should be asked, why should developing countries be expected to rely on domestic saving? Under the UNFCCC, developed countries have agreed to pay the agreed full incremental costs of climate-change mitigation incurred by developing countries. However, the international community is still far from agreeing how to determine these costs. The LIMITS scenarios provide a further illustration that different definitions of costs have very different implications. If one takes estimates of full incremental GDP costs from the models considered here, the Copenhagen target of flows of $100 billion per year to developing countries by 2020 is too low and larger-still flows will be warranted as climate policies strengthen in subsequent decades

A second important question is the adequacy of financial intermediation, both across borders and within countries, to match saving with specific low-carbon investment needs. In the light of the continuing debate over precisely what the obligations of the advanced industrial nations are, and when nations should cease to be classified as 'developing,' today's developing countries would be well advised to consider how to improve domestic incentives to direct domestic funds, for investment and compensatory income support, to the appropriate sectors of their economies.

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Table 1 LIMITS Scenarios summary

Scenario	Description	Forcing level target (in 2100)	Before 2020	After 2020	Burden Sharing
Base	No Policy Baseline	/	No policy		/
RefPol	Weak Policy reference case	/	Weak policy		/
StrPol	Stringent Policy reference case	/	Strong policy		/
450	2.8 W/m2 benchmark case	2.8 W/m2	2.8 W/m2		/
500	3.2 W/ m2 benchmark case	3.2 W/m2	3.2 W/m2		/
RefPol-450	Weak policy until 2020 then cooperation to 2.8 W/m2	2.8 W/m2	Weak policy	Global GHG tax	/
StrPol-450	Stringent policy until 2020 then cooperation to 2.8 W/m2	2.8 W/m2	Strong policy	Global GHG tax	/
RefPol-500	Weak policy until 2020 then cooperation to 3.2 W/m2	3.2 W/m2	Weak policy	Global GHG tax	/
StrPol-500	Stringent policy until 2020 then cooperation to 3.2 W/m2	3.2 W/m2	Strong policy	Global GHG tax	/
RefPol2030-450	Weak policy until 2030 then cooperation to 3.2 W/m2	3.2 W/m2	Weak policy (before 2030)	GLobal GHG tax (after 2030)	/

RefPol-450-PC	Weak policy until 2020 then cooperation to 2.8 W/m^2 with C&C burden sharing	2.8 W/m^2	Weak policy	Global GHG tax	Contraction & Convergence
RefPol-450-EE	Weak policy until 2020 then cooperation to 2.8 W/m^2 with mitigation costs burden sharing	2.8 W/m^2	Weak policy	Global GHG tax	Equal mitigation costs

Table 2 Investment shares and current account balances (1980-2010) Source: IMF(2012)

	Investment share (%GDP)		Current account (%GDP)	
Country Group Name	Average	Stand. dev.	Average	Stand. dev.
World	22.87	0.93	/	/
Advanced economies	21.84	1.45	-0.43	0.43
Newly industrialized Asian economies	29.05	3.04	3.98	3.59
Emerging market and developing economies	26.15	1.97	-0.02	2.12
Central and eastern Europe	22.82	2.57	-3.29	2.21
Developing Asia	33.04	3.52	0.57	2.54
Latin America and the Caribbean	21.02	1.80	-1.55	1.70
Middle East and North Africa	24.47	2.00	3.58	7.39
Sub-Saharan Africa	19.09	2.08	-1.80	1.96
Brazil	18.23	2.00	-1.82	2.74
China	40.34	5.13	2.22	3.07
India	26.31	4.95	-1.24	1.08
European Union	21.08	1.39	-0.20	0.67
United States	19.30	1.65	-2.66	1.72

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Figure 1 Annual GDP growth rates (upper panel); Per capita GDP (lower panel) – Results from WITCH model

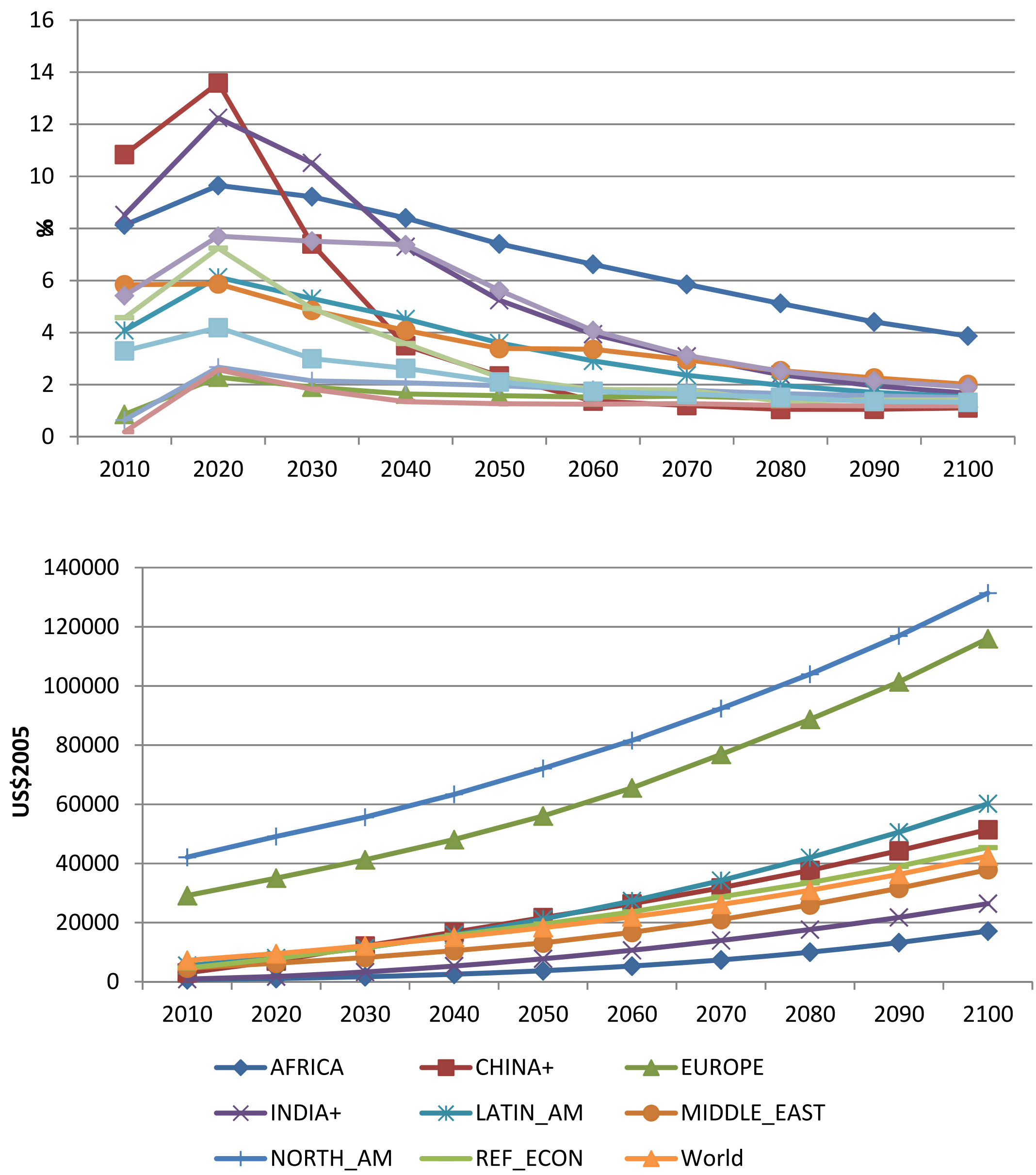


Figure 2 Carbon price dynamics

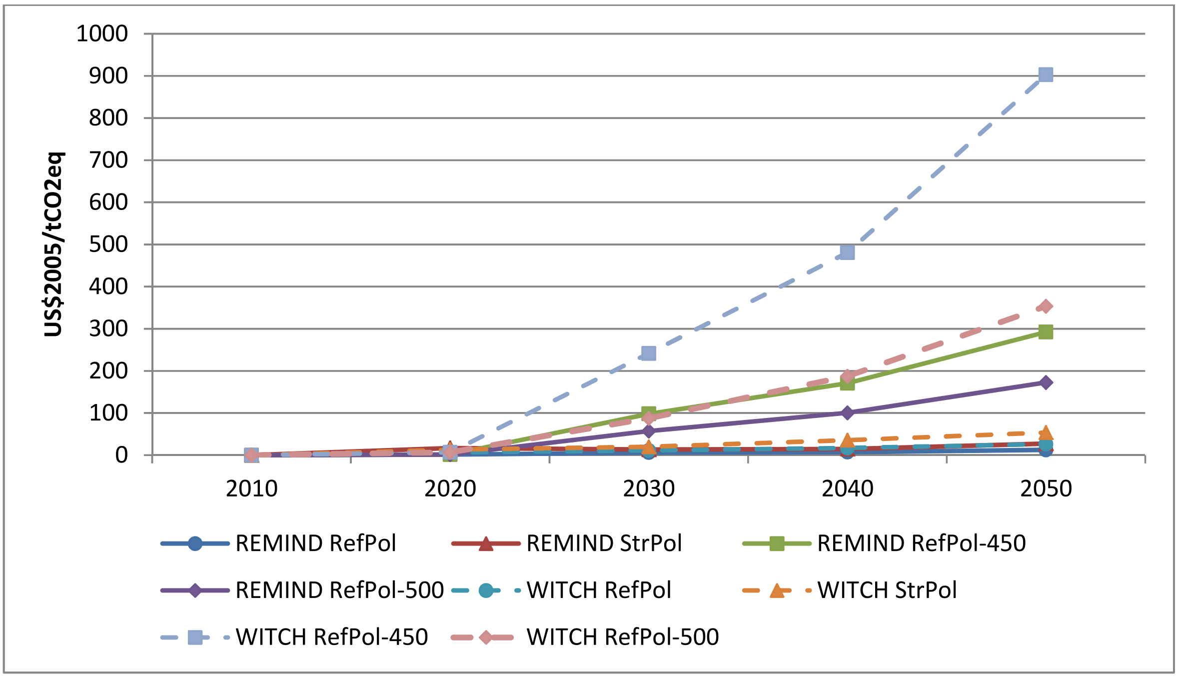


Figure 3 Cumulative investment 2010-50 (difference w.r.t. Base; 5% discount rate)

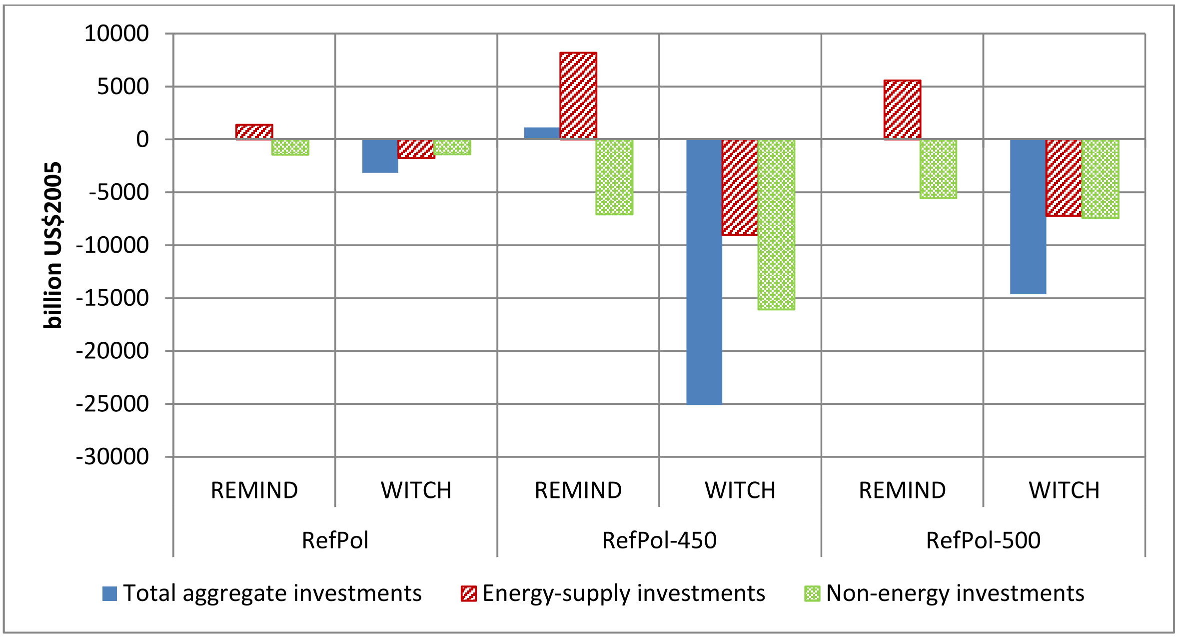


Figure 4 Carbon tax revenues (as share of GDP)

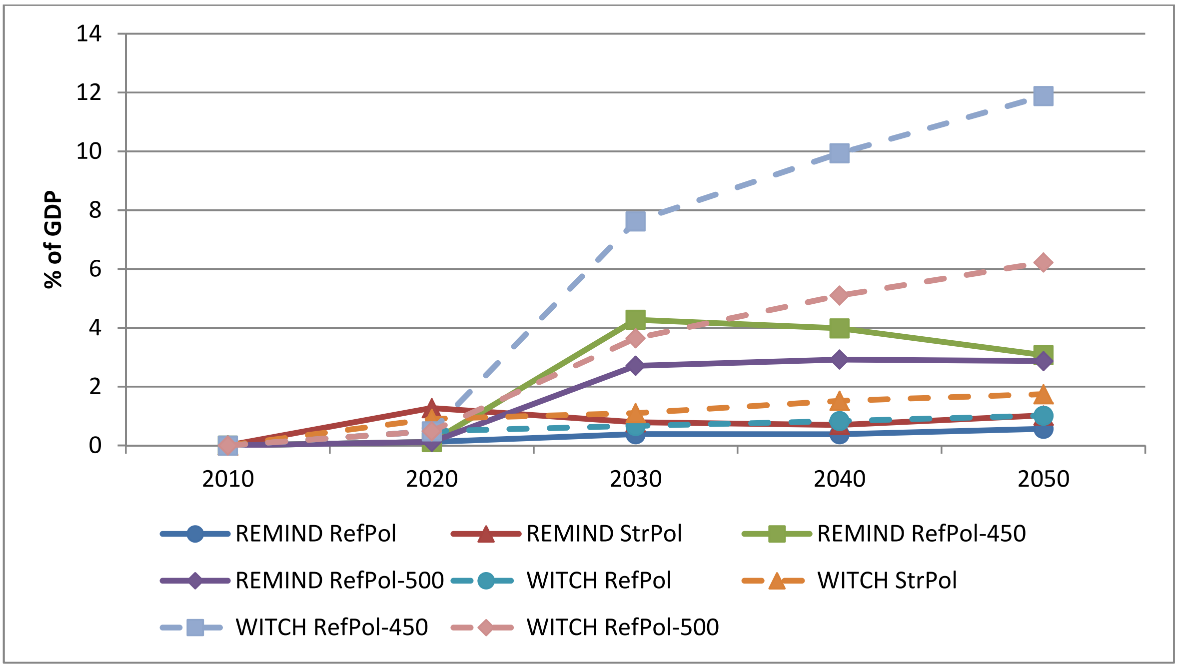


Figure 5 'Fiscal self-reliance' of energy-supply investment (as share of GDP)

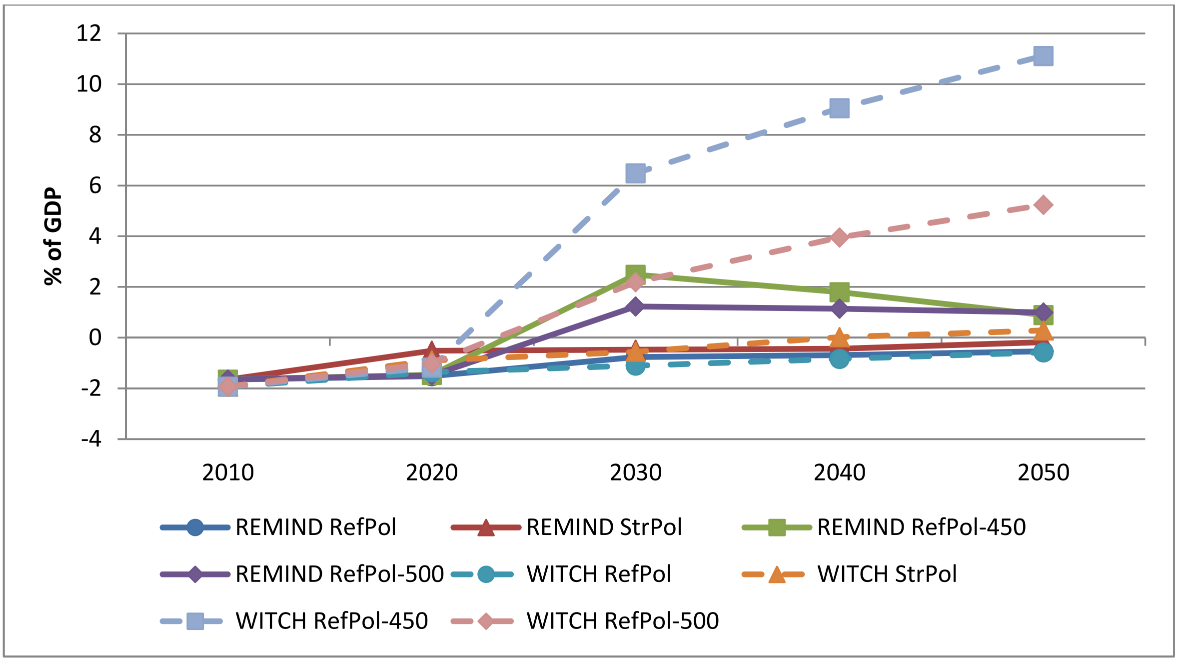
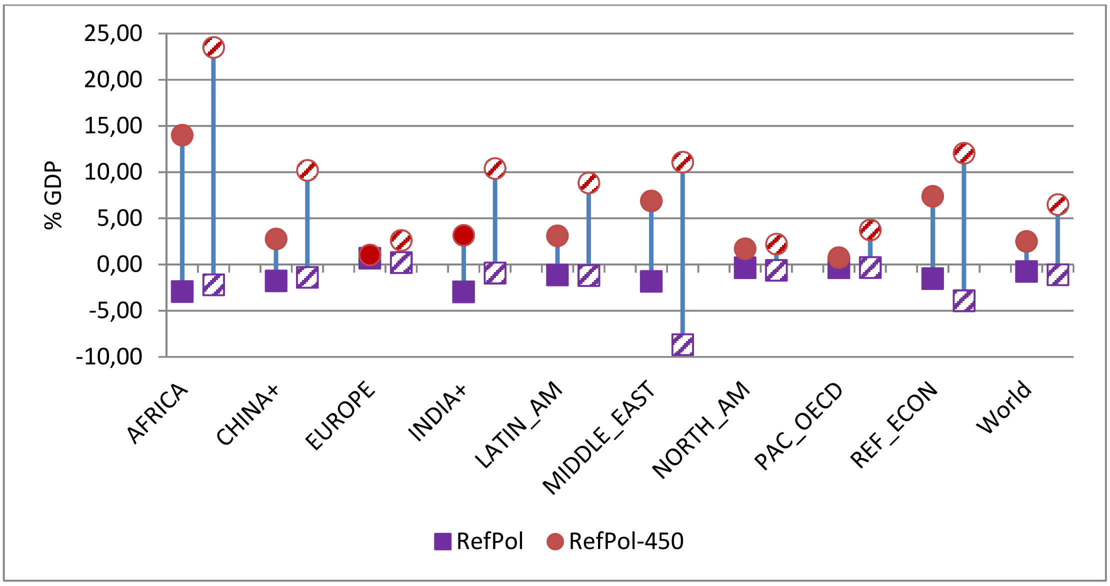


Figure 6 Regional domestic energy-supply 'fiscal self-reliance' for 2030 (REMIND: solid markers on the left; WITCH: dashed markers on the right)



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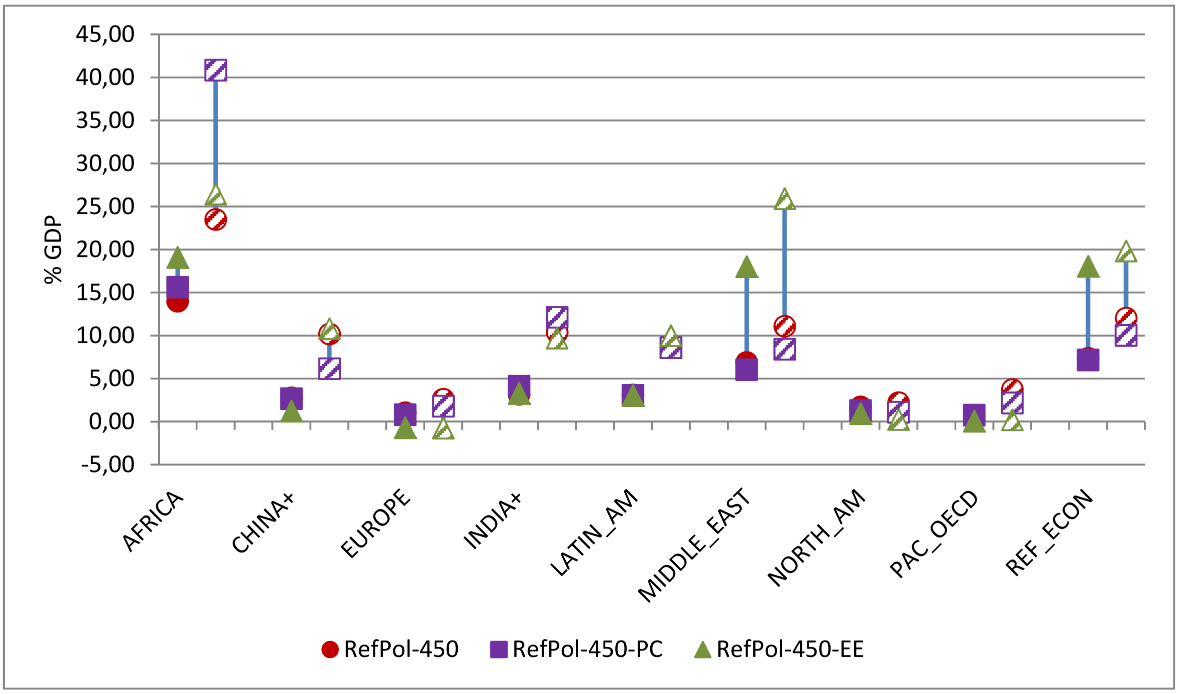

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on the right)

Figure 8 Aggregate investment and macroeconomic costs (cumulative values 2010-50; 5% discount rate)

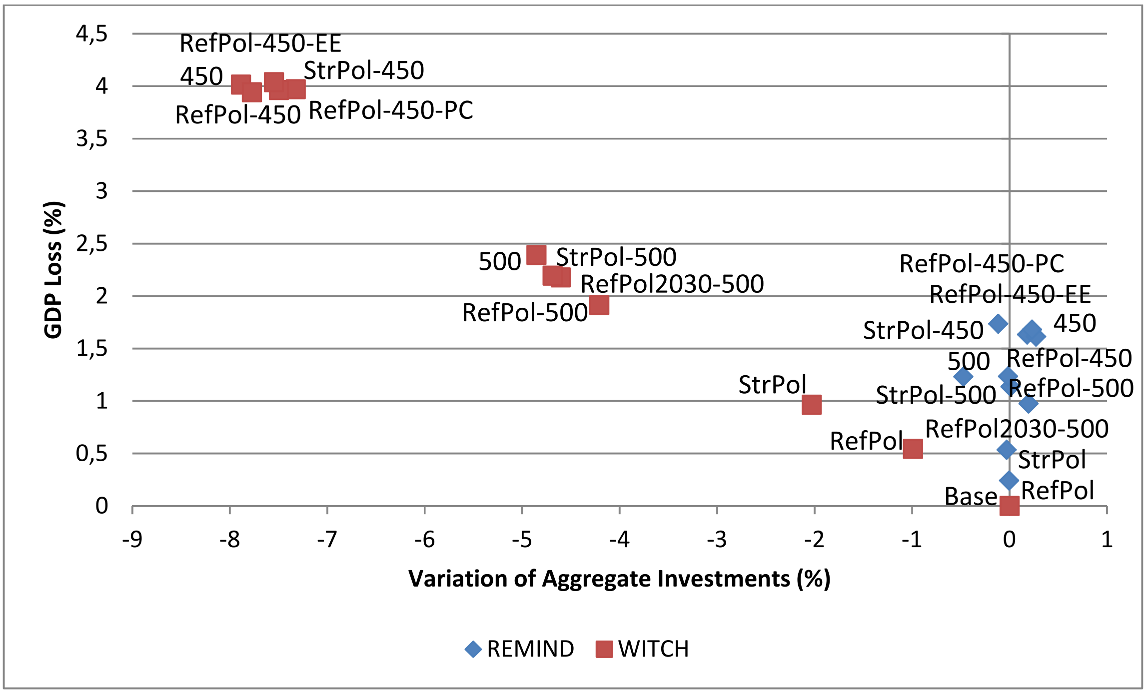


Figure 9 Energy-supply investment and macroeconomic costs (cumulative values 2010-50; 5% discount rate)

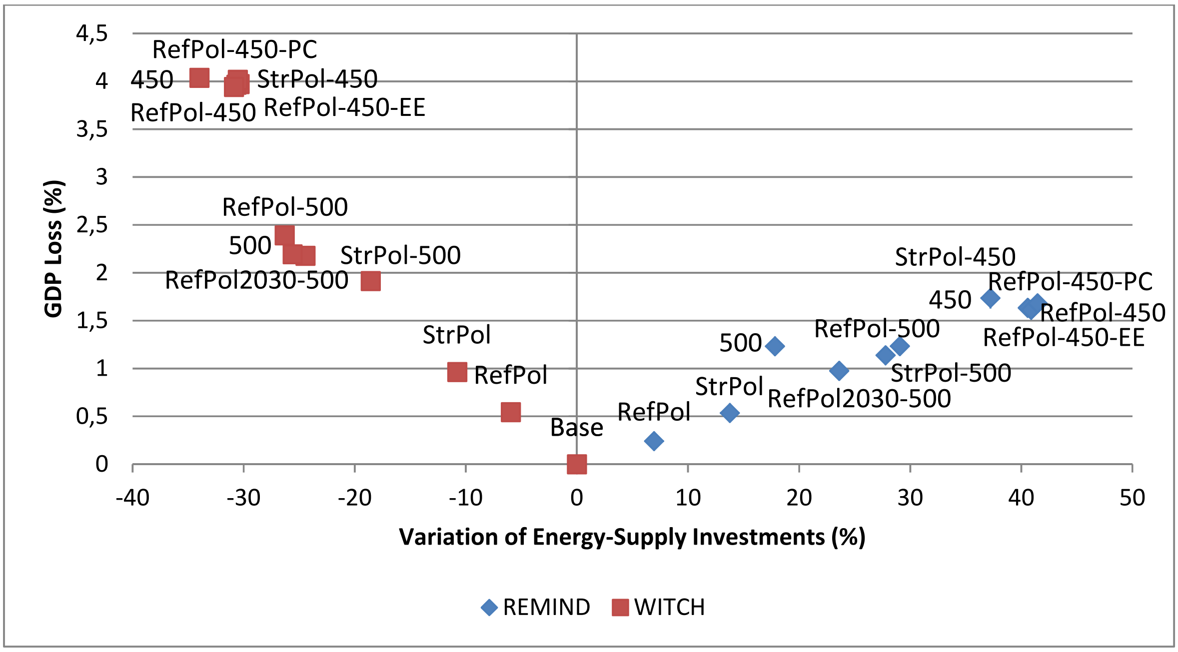


Figure 10 Incremental aggregate investment in RefPol-450 (2010-2050 values)

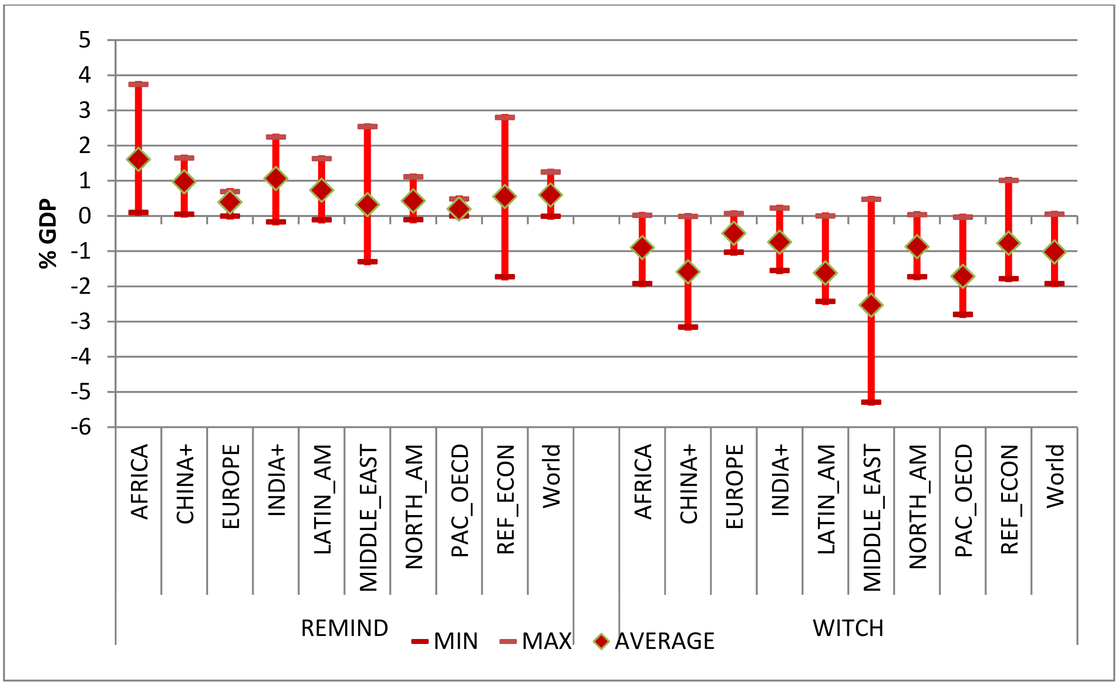
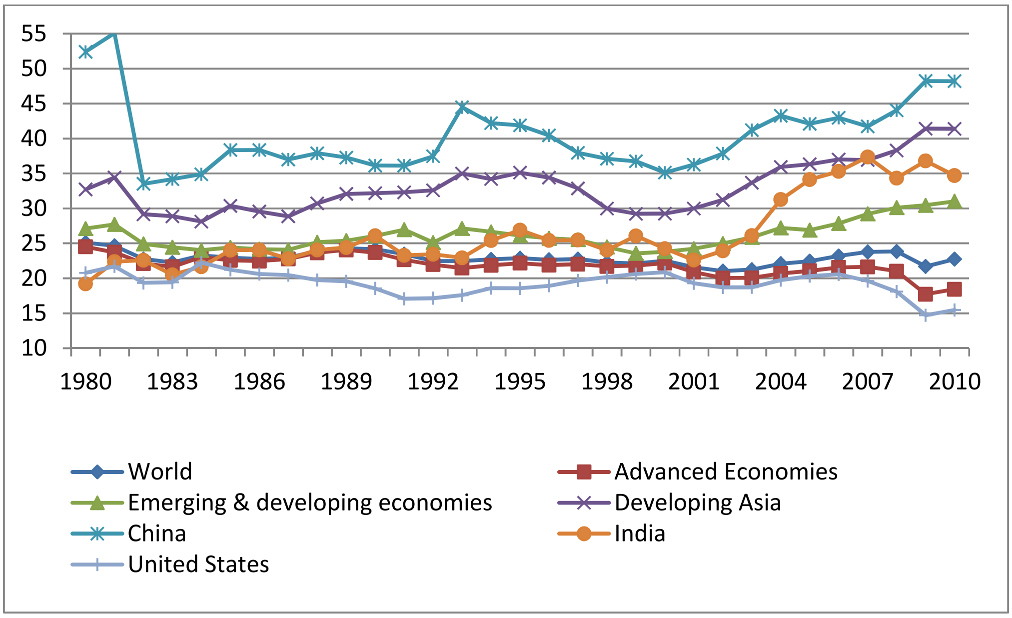


Figure 11 Gross aggregate investment as a proportion of GDP



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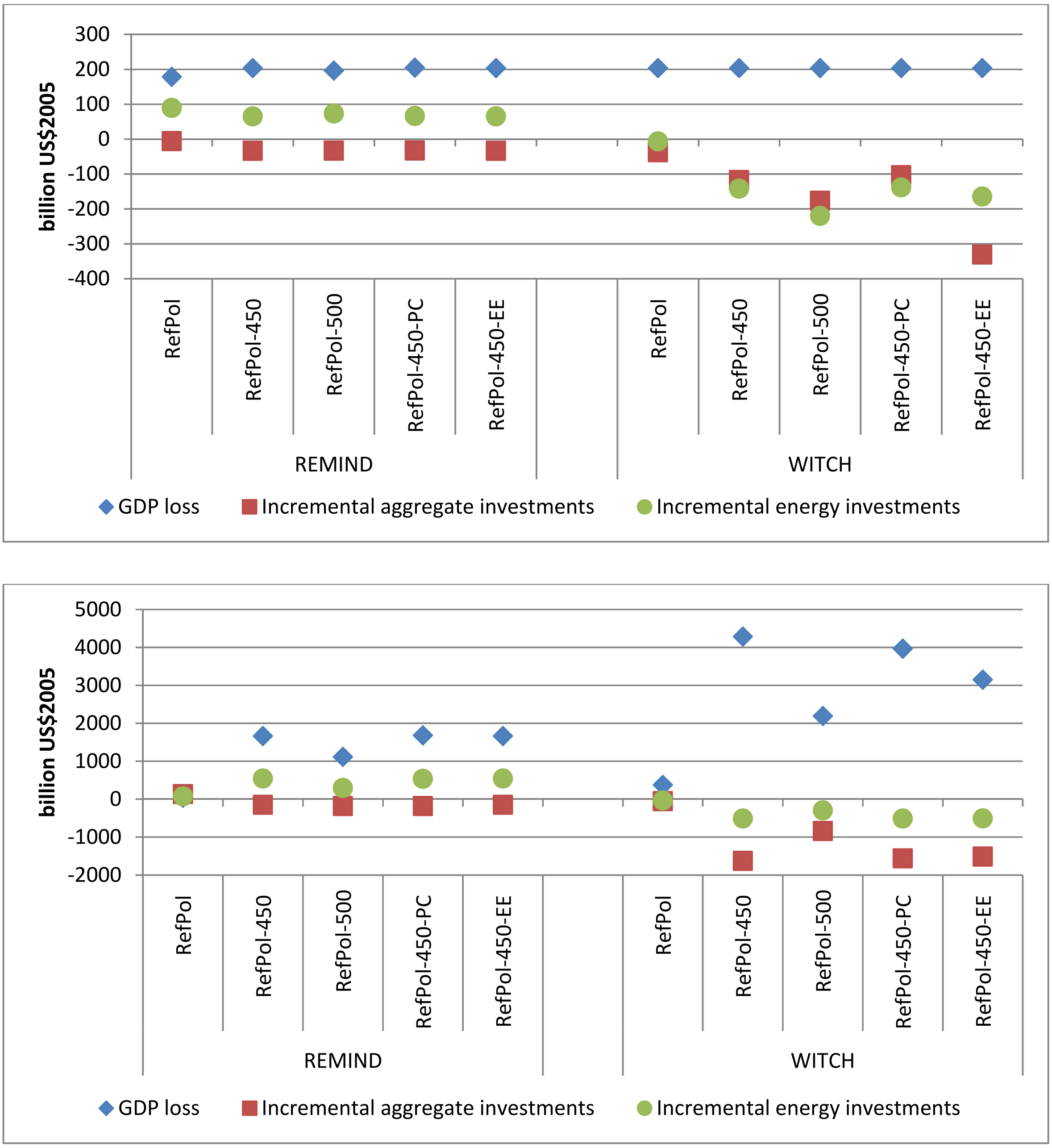

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