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Horizon 2020 Societal challenge 5:
Climate action, environment, resource efficiency and raw materials

COP21 RIPPLES

COP21: Results and Implications for Pathways and Policies for Low Emissions European Societies

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1. Changes with respect to the DoA

UEA model not used. Oxford gave inputs in Part A on TECH scenarios.

2. Dissemination and uptake

Within the project: all tasks in Work Package 3. Michael Grubb presentation in August/September
Outside the project:

3. Short Summary of results (<250 words)

The financial sector must play a key role in facilitating the transition towards the Paris Agreement goals. This analysis undertakes both quantitative and qualitative approaches in order to provide key recommendations to stakeholders and policymakers related to climate finance. The modeling analysis soft-links three different model types (TIAM-UCL, MEWA and ENGAGE) to consider investment requirement pathways and how the levels of investment are achieved through different financial instruments.

The TIAM-UCL modelling shows that strong climate ambition requires ramp-up of investments immediately. Another strong conclusion from the MEWA and ENGAGE models is that the economic impacts of decarbonisation are unevenly distributed between high-income and low-income regions, the latter of which are more reliant on fossil fuels out to 2050, and therefore financial mechanisms can play a significant role in rebalancing impacts with minimal cost. Therefore ending fossil fuel subsidies must be supported with other policies to direct inter-regional financial transfers to those regions which will lose out from such a transition.

The qualitative analysis suggests easing lending conditions for low-carbon investments, and relaxing macroprudential regulation could leverage more funds towards low-carbon assets. The Green World Bank and Green Fund modelling scenarios suggest that policies like this could lessen the economic burden on those who are most likely to lose out from undertaking climate mitigation. A mix of concessional financing approaches may be appropriate and more politically feasible.

Therefore one clear outcome is that public financial institutions (e.g. G20, World Bank) are correct to rethink their approaches towards concessional finance as these may be one way to achieve the rates of change required.

4. Evidence of accomplishment

This deliverable

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1 Introduction

The landmark 2015 Paris Agreement on climate change reaffirms the crucial role of finance in reaching climate policy goals (Art 2.1c: COP21, decision 1/CP.20; Boissinot et al., 2016). This deliverable is an overview of why finance is vital to the process of achieving the Paris Agreement goals and to provide greater insights into finance's role using both quantitative and qualitative approaches.

The financial sector is exposed to climate-related risks in terms of both physical impacts e.g. climate change damaging physical assets, and transition risks e.g. stranded fossil-fuel assets. Simultaneously, the achievement of decarbonisation in line with the Paris Agreement goals will require significant shifts in global finance towards low-carbon technologies and away from fossil fuel dependent energy systems. And current investment choices, whether or not in dirtier technologies will alter the future pathways over the coming decades towards the goals. Here we explore the climate finance requirements under different climate ambition levels and timings using scenarios from the COP21 RIPPLES project as well as exploring the importance that different types of financial instruments can have on the outcomes of achieving the same investment levels, especially between high- and low-income regions. We also qualify these analysis in the context of real-life issues surrounding the financial sector.

In Part A on the quantitative analysis, we firstly, in Section 2, provide background on the current levels of climate investment and finance as well what the literature suggests regarding future pathways. Then in Section 3 we describe the three models used in the quantitative analysis, the methodology undertaken and data utilised as well as a description of the scenarios which are then presented in the following results section. In Section 4 we present the results from undertaking the modelling analysis using several models to assess the COP21 RIPPLES decarbonisation pathways. Sections 4.1, 4.2 and 4.3 provide results for the TIAM-UCL, MEWA and ENGAGE models, respectively.

Part A provides an optimal worldview using modelling analysis that is somewhat removed from the realities of the real-world financial sector decision making and the political process. Therefore in Part B we look at why these pathways are not always followed and present a wider discussion on more qualitative aspects of climate finance to complement the quantitative analysis by understanding further the frictions and barriers as to why optimal pathways are not always selected. In particular these may related to the policy framework, market conditions and investor's practices and we then consider what incentives and policies are needed to overcome these barriers and align reality more towards optimal pathways. Section 5 is split into Section 5.1 on the financial instruments, Section 5.2 on barriers to low-carbon investments, and 5.3 on incentives and policies required.

Part A – Quantitative analysis of financial implications of decarbonisation

2 Financial requirements for current and ratcheted climate policy ambition

Here we provide details regarding the current landscape of climate finance at present day as well as the expected requirements for 2ºC and 1.5ºC scenarios from the literature available on such analysis. We focus on the period out to 2050 as this is the timeline used in COP21 RIPPLES. The definition of climate finance employed by the Climate Policy Initiative (CPI, 2015a) considers it to be capital flows directed towards low-carbon and climate-resilient development interventions with direct or indirect greenhouse gas mitigation or adaptation benefits. However, this definition tends to exclude private investments in energy efficiency, transport, adaptation and land-use.[1] Therefore there may be elements which will contribute to mitigation or adaptation that are omitted. In this analysis the models differ in terms of their ability to include all aspects and therefore models must be viewed individually rather than be directly comparable. There is further discussion of what can and cannot be considered in the model descriptions section.

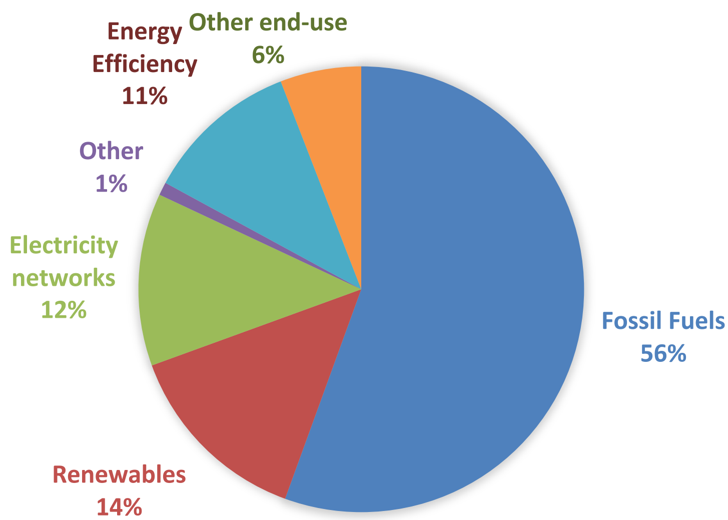
2.1 Current landscape

According to the World Energy Investment (IEA, 2019) total energy investment worldwide in 2018 was slightly over $1.8 trillion, an increase after declining for three previous years. The World Energy Outlook 2018 (IEA, 2018) states that the annual average energy supply investments over the period 2010-17 were $1.75 trillion (in $2017) which were split into fuels and power by 58% and 42%, respectively. Once end use and energy efficiency are included then total investments were $2.1 trillion and are split by type as shown in Figure 1.

However, IEA (2019) shows that for the last three years investment in the power sector has been larger than those in oil & gas, partly due to shifting costs of oil, but also showing the rising importance of electricity, whose demand growth in 2018 was nearly twice as fast as the growth for overall energy demand. Renewables accounted for around 17% of these electricity investments at annual average investments of $293 billion (IEA, 2018). China was the main destination for energy investment in 2017 with over one-fifth of total investment. The USA has, however, been a main driver of total energy investment since 2010 mostly through shale gas and the power sector (IEA, 2019).

[1] Private investments in supply-side energy technologies are included.

Figure 1 Annual Average Energy Investments by type 2010-17: source IEA (2018)



CPI (2018) estimates that global climate finance flows in 2015 and 2016 were around $472 billion and $455 billion, respectively. The fall in 2016 occurred due to falling renewables costs and, in some countries, fewer renewables capacity additions However, according to IEA (2019) adjusting for cost reductions sees renewable investment up by 55% since 2010. The CPI (2018) numbers for 2015 and 2016 include, for the first time, estimates on integration of electric vehicle sales. Early estimates expect climate finance to increase in 2017 to somewhere around $510-530 billion as this is not yet available.

The majority of global climate finance, averaged across 2015-16, was spent on mitigation, at around 94%, with the remainder on either adaptation, 5%, or dual benefits, 1%. In particular renewable energy generation is the largest share at 64% as well as sustainable transport, 20%, and energy efficiency, 6%. The split between private and public investment of the 2015-16 average total was 54% and 46%, respectively. Within private investment the largest actors are project developers, commercial Finance Institutions, corporate actors, and households. Whereas with public actors it is national and then multinational financial institutions.

Figure 3 shows that, in terms of destinations of climate finance, the largest region tracked by CPI (2018) is East Asia and Pacific at over a third of the total. Western Europe also attracts just under a quarter of all climate finance with another large region being America South Asia and Latin America & the Caribbean both receive about 5% and as a combined region Japan, Korea and Israel are 6%.

Figure 2 Global Climate Finance by public and private actors. Source CPI (2018)

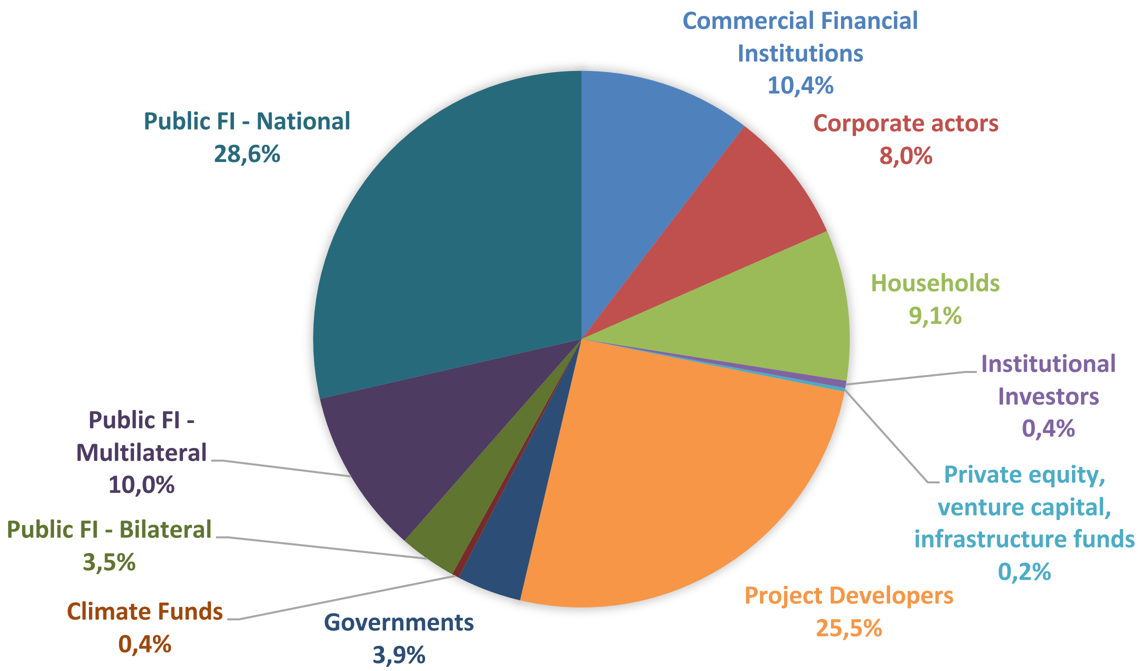
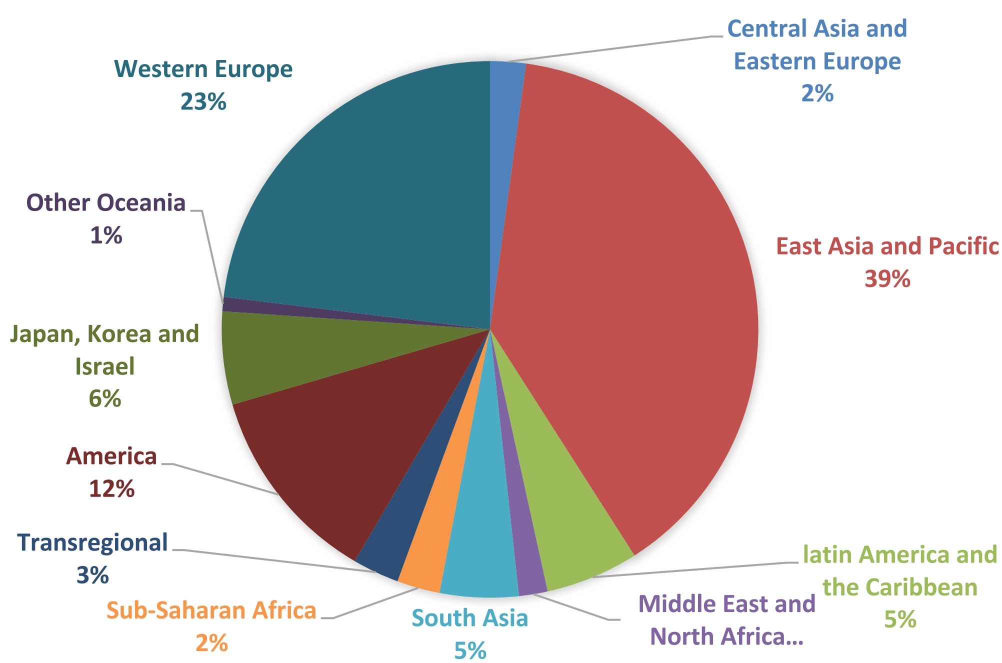


Figure 3 Global Climate Finance by region of destination. Source CPI (2018)



2.2 Future landscape

We now consider the future requirements for energy investments in order to meet the long-term Paris Agreement goals. IEA (2018) provide modelling analysis for three scenarios: New Policies, Current Policies and Sustainable Development. To achieve the Sustainable Development (SD) scenario cumulative investments, including end-use, over the period 2018-40 are required to be $68 trillion compared to $60 and $59 trillion in the New Polices and Current Policies scenarios. Here, we focus on the SD scenario as this is closest aligned to the 2^{o}C UN climate target.

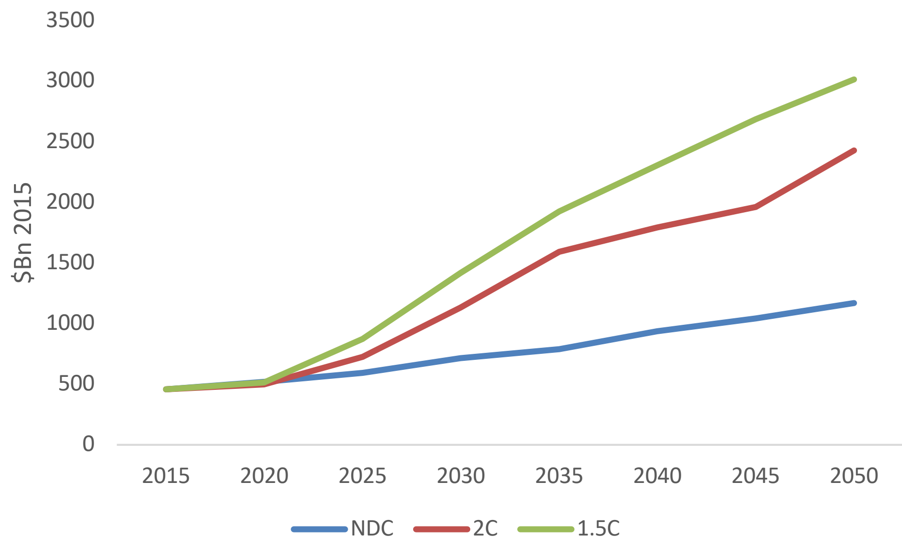
Annual average investments over the period 2018-25 are required to be $2.36 trillion of which $1.65 trillion are supply-side investments and in turn, $467 billion are invested in renewables. In the following years end-use efficiency and renewables become more important as in the period 2026-40 there is $3.26 trillion average annual total investment required, of which $1.85 trillion is supply-side investments and $663 billion is renewables. There are less average annual investments in the first period compared to the second period. While the SD scenario will require some short-term to direct the transition, it is facing constantly increasing energy demands due to population and economic activity.

McCollum et al (2018) provide a multi-model analysis of six different Integrated Assessment Models (IAMs) (the models are AIM, IMAGE, MESSAGE, POLES, REMIND, WITCH) and their investment requirements under scenarios of current polices, the Nationally Determined Contributions (NDCs), as well as meeting the 2^{o}C and 1.5^{o}C goals. In the NDC scenario, taking an average across the six models, total supply-side investment are $2.23 trillion a year from 2016 to 2050 of which only 35% ($784 billion a year) are low-carbon investments. To meet the 2^{o}C target, the annual average total supply side investments between 2016-2050, averaged across the six models, is $2.38 trillion a year of which 55% ($1.32 trillion a year) must be in low-carbon technologies. To meet the 1.5^{o}C target the levels of investment are even higher on average across the models at $2.59 trillion a year of which 65%, $1.65 trillion, must be supply-side climate finance. In their paper McCollum et al (2018) analysis they compare directly to an IEA and IRENA estimates, both of which are found to be at the lower end of the range of models in terms of average annual investments. Figure 4 shows the low-carbon investments averaged across the six models in the NDC, 2^{o}C and 1.5^{o}C scenarios. In 2050 there is a requirement for around three times the level of low-carbon investment to meet 1.5^{o}C compared to the NDC requirements.

In terms of share of GDP, there is not a significant rise under the different scenarios as these are just over 2% for Current Polices and NDC, rising to 2.5% and 2.8% for 2^{o}C and 1.5^{o}C

scenarios, respectively.[2] In the year 2050, the level of low-carbon finance, in the 2°C and 1.5°C scenarios, is more than 108% and 158% of the low-carbon investments in NDC scenario in that year.

Figure 4 Low-carbon (supply-side) investment requirements for decarbonisation scenarios (average across 6 IAM models)



Source: McCollum et al (2018)

However, it should be noted that there is significant range across model results in the McCollum et al (2018) study. For instance, the average annual total supply-side investments across the period 2016-2050 range from $1.54 to $3.46 trillion ($2015) in the 2°C scenario and $1.59 to $3.81 trillion ($2015) in the 1.5°C. And in the year 2050, specifically, the range is wider at $2.48 to $4.76 trillion ($2015) in the 2°C scenario and $2.77 to $4.99 trillion in the 1.5°C scenario.

Compared to the current levels of low-carbon investment it is clear that significantly more will be required on average over the coming three decades if the decarbonisation targets in the Paris Agreement are to be met. In particular, as decarbonisation targets increase in ambition there will be a greater requirement for, and faster deployment of, capital-intensive renewable energy as well as nuclear power, storage technologies and electricity transmission and distribution, and equally a quicker phase-out of fossil-based technologies.

[2] For more information on GDP across models and the assumptions made here, the reader should access the database which is provided by McCollum et al (2018)

3 Methodology to assess investment requirements and different financial approaches to fund deep decarbonisation

3.1 Overview

In this deliverable we attempt to contribute to the ongoing analysis regarding the scale and timing of climate finance requirements over the coming decades and also begin to understand the different methods of financing such levels of green investments. For instance, the McCollum et al (2018) study states that their analysis specifically addresses the question of “Where are the investment needs?” and not “Who pays for them?”. However, exploring how these investments are financed and who indeed pays for them are crucial questions. Here we attempt to answer this by soft-linking different modelling approaches which allows us to address the latter question to some extent while also undertaking the former. The MEWA model uses investment numbers from TIAM-UCL as an input for the financial policy scenarios and ENGAGE uses both the global emissions from TIAM-UCL and also the regional power-sector mix in 2050. The same scenarios are also used for each of the model analysis where possible. However, the models are not recalibrated to match each other in terms of input assumptions.

We address the first question of “where and how much” investment by using the TIAM-UCL global energy systems model which is described in detail in the next section. Transition pathways are used to derive consistent investment requirements disaggregated by technology and geography. Where possible, we distinguish between green and brown investments[3], as well as the overall system changes between different scenarios of decarbonisation ambition i.e. 2°C vs 1.5°C. First, we provide a central analysis for all the RIPPLES decarbonisation scenarios, as well as a number of extra scenarios. Secondly, in order to understand the role that cost reductions and technological change play in the investments, we undertake a comparison and sensitivity test of these assumptions within TIAM-UCL. Thirdly, there is an extra analysis regarding the assumptions around the hurdle rates employed in TIAM-UCL and in particular, about how these hurdle rates represent in some way the Weighted Average Cost of Capital (WACC), an important determinant of total investment requirements within the model, and the overall affect assumptions about this parameter has on regional investments[4]

We then begin to consider “who pays for them” by passing on the investment requirements from TIAM-UCL to be used as inputs in the DSGE model MEWA which is able to consider different finance instruments in detail. These financial instruments are used in MEWA to consider how different domestic and international financing options might be used and what the economic impacts of these different financing options are. The three financing scenarios

[3] Green and brown investments are defined in Section 3.3.1
[4] The concept of hurdle rates are explained further in Section 3.3.1

explored in the analysis are that either all investments are made domestically, or through direct transfers/grants (Green Fund), or through low-carbon loans (Green World Bank).

There is also a soft-linking between TIAM-UCL and ENGAGE whereby ENGAGE replicates the regional emission reduction pathway and electricity mix in 2050 from the corresponding TIAM-UCL scenario results. As a global Computable General Equilibrium (CGE) model, ENGAGE is able to consider the sectoral impacts of the decarbonisation scenarios. ENGAGE models 23 sectors in each of the 16 regions of the world. We also introduce capital transfers between regions to mimic the financial flows from MEWA. Thus, we assume different degrees of financial cooperation from high- and low-income economies. This cooperation enables developing economies to counterbalance the economic costs associated with a transition from an economy based on cheap fossil fuels to a one based on renewables.

Sections 3.2 provides a description of each of the models used in the analysis and details of the data each used when undertaking this study. Section 3.3 then details the overall scenarios and methodology for each modelling analysis as well as the linkages between the models.

3.2 Model descriptions

3.2.1 TIAM-UCL model

TIAM-UCL is the TIMES Integrated Assessment Model (TIAM) version developed at University College London. It is a global multiregional technology-rich bottom-up cost optimisation model. It is a whole system model that incorporates energy resource extraction through to conversion, infrastructure, and finally to sectoral end-use including renewables, other low-carbon and fossil-fuel technologies. The 16 geographic regions are linked through trade in crude oil, hard coal, pipeline gas, LNG, petroleum products (diesel, gasoline, naphtha, heavy fuel oil), biomass, and emission permits. On the resource side, a total of eleven conventional and unconventional oil resource categories, eight conventional and unconventional gas resource categories, and two coal resource categories are specified. Each of these categories is specified with an individual supply cost curve within each region.

Base-year energy-service demands are defined exogenously and are projected for the future using drivers such as GDP, population, household size, and sectoral outputs; in this study, the SSP2 socioeconomic pathway has been used. The base-year (2005) primary energy consumption, energy conversion, and final consumptions are calibrated to the latest IEA Energy Balance at sector and sub-sector levels. The power generation mix and end-use sector fuel consumption are in line with the past data (until 2015).

In addition to the global social discount rate of 3.5%, various hurdle rates are used for sector specific technologies. These hurdle rates may also vary across regions depending on the technology and reflect different types of barriers in technology choice capturing, for example, availability of capital, skilled labour, information, specific consumers' preference, etc. For a discussion of hurdle rates in energy system models see De Carolis et al (2017).

Lump sum investments are made for new energy infrastructure the year it is constructed. TIAM-UCL reports the repayment of these investments as 'annualized capital cost payments' – this is a stream of payments made each year, starting in the year of the investment and continuing through the economic lifetime of the technology. The technology-specific discount (hurdle) rates mean the present value of this stream of payments differs from the lump sum investment made in the first year (Loulou et al, 2016). This method represents the fact that energy infrastructure is generally financed with debt which is repaid over the lifetime of a project.

One limitation of TIAM-UCL, is that the model does not currently capture historical energy investments made before the model base-year. While there have been efforts made to align the model to historical power-sector, it was beyond the scope of the project to do so for historical investments and as such the investments in the base year, 2005, will represent investments made in that year only. Therefore the investment numbers in TIAM-UCL be likely be lower than historical numbers for the initial few periods as the lifetime.. However, the lack of historical investments does not make any difference when comparing across TIAM-UCL scenarios, as is undertaken in this here, but can make comparisons with historical or current numbers and other modelling studies more difficult.

Finally, TIAM-UCL also includes a climate module, which calculates changes in atmospheric greenhouse gas concentrations, radiative forcing and global temperature. We can constrain the climate module to limit temperature rise to a particular target such as 2°C. The module has been previously calibrated to represent a 60% chance of staying below the chosen target. This module is used in this study to achieve the various temperature targets.

3.2.2 MEWA model

MEWA (Materials, Energy, Waste, Agriculture) is a large-scale dynamic stochastic general equilibrium (DSGE) model. It combines the features of the DSGE modelling framework with a multi-sectoral, CGE-like, structure linking sectoral economic activities with energy, material use and GHG emissions. Similar to other general equilibrium models, MEWA assumes that all markets (goods, labour, capital, financial etc.) form a single economic system linked by price adjustments. Individual agents form expectations about the future evolution of the economy taking into account the optimal answers to possible disturbances from the model long-run equilibrium. These stochastic shocks may result from new policies or exogenous factors

dynamically propagating throughout the economy. Their occurrence affects the entire adjustment path of the model variables allowing the model to capture not only the ultimate impact of a given policy but also the adjustment over time. Government policy may either be anticipated by the agents or introduced unexpectedly. In the former case, households and companies will adjust their decisions even before the introduction of the policy (e.g. companies may expect decrease of the interest rates and postpone the low-carbon investments or treat the change of capital costs as a piece of novel information revealed to them in the subsequent periods).

The main types of agents in MEWA include:

- **Production firms** which produce homogenous goods on the sectoral level employing capital, energy, labour and materials (raw and components). The firms base their decisions on profit maximisation, taking into account operational and capital costs that are co-financed by financial sector (domestic or international) and may be subject to financial frictions, i.e. they must co-finance their investment to the certain threshold facing at the time costs of this external financing that dependents on the country and firm investments.
- **Households** which supply labour and receive wages and capital income (as they are owners of domestic enterprises). The households base their decisions on utility maximisation, with utility stemming from the consumption of market goods and home production performed internally by unemployed or inactive family members. Through bank deposits, they (indirectly) finance the investments of firms, and through taxation.
- **Government** which imposes taxes, purchases public goods, subsidizes private investments and undertakes infrastructure projects. The structure and level of both taxes and expenditures are exogenous (i.e. the government does not maximise social welfare with respect to shocks).

The world economy in the model has been divided into two symmetrical blocks described by the same set of equations. The blocks are interconnected by the international trade of goods and services on the sectoral level as well as financial flows between net exporters and importers of capital. This split is intended to reflect the differences between high-income and low-income countries with respect to their position in the international financial markets, and the availability and cost of capital (see Table 1). For the purpose of this modelling exercise, China has been classified as a high-income economy as it is expected to close the large part of the income gap to the OECD average by 2050, being at least an upper middle income country for over half of the remaining period. It also has an ample supply of domestic savings, does not face significant credit constraints and high cost of capital and already participates extensively in the development of capital intensive, zero-carbon technologies.

Table 1: Country groups in MEWA model

High-income	Low-income
Australia	Africa
Canada	Central and South America
China	Former Soviet Union
Eastern Europe	India
Japan	Middle-east
South Korea	Mexico
United Kingdom	Other Developing Asia
USA	
Western Europe	

In the context of this research, the key feature of the MEWA model is its capability to represent financial markets, including their imperfections (e.g. financial frictions). This allows us to discriminate between countries with “good” and “bad” access to international financial markets and because of that countries with the diversified ex-ante capability to undertake large scale low carbon investments. We associate this divide with the high-low income split within the model. Financial frictions interact with another type of real market imperfections, reflecting the delay in reallocation of production factors (capital, materials and labour) across the sectors, firms and markets. In particular the investment process is affected by the time required to replace existing capital with new technologies (time to build). The model input-output structure is estimated on the WIOD database (see Timmer et al. 2015). The MEWA version employed for this modelling exercise covers two regions (high-income countries and the low-income countries) in 2010-2050, with divergence between the policy scenarios modelled starting in 2020. The policy shocks are described in Section 3.3.2 and more details on the production structure, financial and real frictions in the MEWA model are included in Appendix on MEWA.

3.2.3 ENGAGE-UCL model

ENGAGE (ENvironmental Global Applied General Equilibrium) is a multi-region, multi-sector dynamic Computable General Equilibrium (CGE) model. ENGAGE is based on the GTAP-Power database and represents the global economy in 2011. It not only includes a detailed representation of different power technologies and energy related industries, but also represents other sectors of the economy, allowing in this way the assessment of the economy-wide impacts of energy related policies. ENGAGE models 23 economic activities and 16 regions. The regional aggregation in ENGAGE follows the regional representation in TIAM-

UCL, Thus, similar regional decarbonisation pathways produced by TIAM-UCL according to the different RIPPLES scenarios are modelled in ENGAGE. Moreover, regional energy mixes in ENGAGE are aligned according the energy system optimisation in TIAM-UCL. In a similar way, ENGAGE implements the same financing scenarios analysed by MEWA. Thus, ENGAGE assesses the overall economic impacts of energy, climate and financial policies across sectors and across regions.

In the Reference (REF) scenario described in Section 3.3.3, the GDP growth is calibrated to match the SSP2 pathway. In addition, the demand is driven by the SSP2 population growth and the economy structure changes according to the SSP2 OECD projections.

All decarbonization scenarios implemented in ENGAGE follow the same regional decarbonisation pathways produced by TIAM-UCL. A global carbon price in a future of global climate cooperation is the mechanism used to reduce regional emission per capita to match the TIAM-UCL emissions trajectories in all scenarios. A carbon price increases the cost of fossil fuels. Sectors using fossil fuels as an input in their production processes will search for least-cost alternatives to substitute fossil fuels. Thus, the decarbonisation modelling needs to be complemented by the development of renewable energy and the electrification of the economy which occur endogenously and are outputs of the modelling. Cost reductions in renewables technologies in ENGAGE follow TIAM-UCL assumptions. These are sector and country specific. The electrification of the economy is modelled in ENGAGE by gradually increasing the elasticity of substitution between electricity and other energy inputs, the extent of this increase is sector specific. Moreover, we also assume a gradual increase in the elasticity of substitution between electricity and other energy inputs in the household demand. All these changes are implemented alongside an autonomous improvement in energy efficiency. Damages from climate changes are not included in this version of ENGAGE and thus changes to economic activity only represent one part of the picture in showing the costs of mitigation.

3.3 Methodology and scenarios

3.3.1 Overview of COP21 RIPPLES narratives

The main scenarios analyzed in this report are based on the narratives developed in Deliverable 2.2 (D2.2) of the COP21 RIPPLES project. These narratives aim to answer the following two questions: (1) what are the advantages and disadvantages of increasing ambition in the short term? (2) What does it mean to pursue efforts to limit to the 1.5^{o}C goal?

The first two narratives (Current NDC and Enhanced NDC) are aimed at informing the review of the NDCs in 2020 and answering the first question. The third and fourth narratives (1.5C and

1.5HD) focus on moving towards 1.5^{o}C to make the long-term perspective inform the short-term action. The following are a summary of these four scenarios:

Current-NDC: Corresponding to the first narrative “From NDC ambition to Paris compatibility”, this scenario represents the implementation of NDCs until 2030 with little or no increased ambition pledged during the round of negotiations in 2020 but requiring an increased effort after 2030 to comply with the long-term goal of 2°C by the end of the century.

Enhanced-NDC: Sharing the same carbon budget for the period 2010-2050 as the NDC scenario, it corresponds to the second narrative “Increased 2030 ambition to Paris compatibility” representing an acceleration of climate action in the short-term before 2030. This implies a smoother emission path allowing for higher emissions after 2035 compared to the Current NDC scenario. In this case, the adoption of energy efficiency measures, more efficient capital, renewable energy deployment, and electrification of the economy are intensified before 2030.

1.5^{o}C (1.5C): With an emphasis on the long-term goal of 1.5° C by 2100 the carbon emissions for this scenario are much lower than the previous scenarios. This narrative is an attempt to explore how long-term efforts towards 1.5^{o}C can be achieved mostly driven through technology deployment. As such a technology variant (TECH) is applied to this scenario (and the other scenarios to understand implications).

High-Decoupling 1.5^{o}C (1.5HD): This scenario corresponds to the fourth narrative of D2.2: “Behaviour-driven transformation to 1.5C”, which is a combination of early action consisting in behavioural changes that allow for a reduced energy demand from the beginning along with low carbon technologies deployment.

There are also a number of other scenarios utilised in this deliverable. At times during the analysis we also focus on a 1.7^{o}C scenario as this is an attempt to bridge between the two groups of narratives 1 & 2 and narratives 3 & 4 across when using 3 separate models. A number of other scenario sensitivity variants are also described in the following sections.

3.3.2 Technology needs for driving investments

Firstly, we undertake a modelling analysis of the following COP21 RIPPLES scenarios using TIAM-UCL: Current NDC, Enhanced NDC, 1.5^{o}C, and High Decoupling 1.5^{o}C. These scenarios are all compared against a Reference NDC Baseline (REF) which assumes a continued level of emissions beyond 2030 with the same regional GHG per GDP/Capita from 2030 as an upper bound on emissions until the year 2100. Thus regional emissions change along with population

and GDP projections.[5] Analysis is also provided for a 1.7°C scenario, which is used to inform the MEWA and ENGAGE financial model shocks. All scenarios are listed in Table 2.

Table 2 Scenarios in TIAM-UCL

Name	**Before 2020**	**2020-30**	**2030-50**	**Demands**
REF	BASE	NDC	NDC	SSP2
Current-NDC	BASE	NDC	2C	SSP2
Enhanced-NDC	BASE	NDC+	2C	SSP2
1.5C	BASE	1.5C	1.5C	SSP2
1.5HD	BASE	1.5C	1.5C	SSP1
1.7C	BASE	1.7C	1.7C	SSP2

In the High Decoupling 1.5°C scenario (1.5HD), the model is driven with energy service demands that are lower than the other scenarios. While the SSP2 pathway depicts a scenario of 'middle of the road' socio-economic development, SSP1 characterises a future of green growth with high resource efficiency, sustainable production methods and investment in human development (Riahi et al 2017). In SSP2 the global population rises to peak at 9.5 billion people around 2070, then plateaus somewhat. In SSP1, the population is lower, peaking at 8.5 billion in 2055 and falling to 6.9 billion by 2100. The global GDP increases more quickly in SSP1, rising to $286 trillion by 2050, compared to $231 trillion in SSP2. These drivers affect the energy service demands differently in TIAM-UCL. For comparison, demands in the agricultural, residential and commercial sectors are approximately 10%, 15% and 16% lower in SSP1 than in SSP2 in 2050.

All model runs are fixed until 2020 to an unconstrained BASE run of TIAM-UCL with no climate constraints to represent the rough trajectory of global emissions between 2005 and 2020. The Current-NDC is then fixed to the REF baseline until 2030 and afterwards the model optimizes the path to achieve a 2°C temperature limit. Overshoot above the temperature limit is allowed in all model runs, meaning that the global temperature can go over 2°C somewhat during the model timeframe but must return to reach 2°C or lower in 2100.

Our analysis focuses on supply-side electricity, heat and upstream technologies i.e. the investment results presented in section 4.1 include primary resource extraction and processing, centralized conversion to electricity and heat, and energy storage, but not investments in

[5] See Winning et al (2019) for a detailed description of assumptions regarding inclusion of NDCs in TIAM-UCL and how they are modelled in the REF baseline scenario.

demand-side technologies (new trains, new fridges etc.). To examine the shift between investments in high and low-carbon technologies, we define technologies as 'Green' and 'Brown', as shown in Table 3.

Table 3 Technologies defined as Green and Brown

	Green	**Brown**
Upstream	Hydrogen production	Fossil fuel extraction and processing
	Uranium mining	Methane flaring and venting
	Biomass production and processing (including production of FT fuels)	Production of FT fuels from coal or biomass with coal
	Carbon sequestration	
Electricity & heat	Renewable electricity generation	Fossil fuel generation without CCS
	Biomass conversion (electricity generation and gasification)	
	Nuclear power	
	Fossil fuel energy with CCS	
	Energy storage	
	Carbon sequestration	
Heat	Heat with CCS	Heat without CCS

Secondly, we undertake a sensitivity analysis regarding renewables costs in order to show how important the input assumptions regarding renewable technology costs are to the model outputs. A weakness highlighted by CPI (2018) is "the use of outdated cost assumptions in cost-optimization models" and how these can affect the investment numbers. In particular, given that the current version of TIAM-UCL does not include endogenous technological change, we consider this exogenously by running versions of the Current NDC, Enhanced-NDC, 1.5C, 1.5HD and 1.7C scenarios with a set of lower capital costs for solar PV and wind generation. This is especially important for the scenario which is dependent on technology driven transformation towards reaching 1.5^{o}C. We name these lower cost scenarios "TECH" and compare them against both the baseline Reference (REF) scenario and against the original versions of these scenarios listed in Table 2. Figure 5 shows the key differences in the standard and TECH cost scenarios for Western Europe region as an example, noting that the technology costs vary between the model's regions. The capital costs of these technologies diverge in the TECH scenario from the standard assumptions between 2030 and 2050 (and are then constant up to 2100).

Figure 5 Solar PV, onshore wind, and offshore wind investment costs in the standard and TECH scenarios for Western Europe [$/kW]

Thirdly, we alter the Weighted Average Cost of Capital (WACC), which is an exogenous variable in the TIAM-UCL model used to capture the cost of capital. In fact a study by Egli et al. (2019) details the issues with assuming a uniform cost of capital within energy system models. As this was published late the timeline of the COP21 RIPPLES project, it does not play a fundamental role in framing our analysis, however, it is worth mentioning and it supports the WACC analysis in this Deliverable as well as our earlier work shown in WP3 Milestone 3.

Investment decisions are not only driven by technical characteristics and learning curves, but also by the related costs of financing. The financing costs (equity and debt) associated with the upfront cost of most renewable technologies, can dramatically affect the competitiveness of energy projects, depending upon the relative capital intensity, construction times, expected operating lifetimes of the asset and perceived investment risks. The WACC represents the discount rate that a company needs to apply to the stream of costs and income expected from

a project – the time profile of which may vary widely for different technologies. The higher the WACC, the more up-front investment costs will weigh, and the higher the corresponding 'levelised cost of energy' implied by the investment.

A WACC database covering most of the G20 countries has been collected at country or multi-country level (Ameli et al. 2017). Changes in the cost of capital in turn drive the investment needs and thus the energy mix in the TIAM-UCL model. Our WACC analysis focuses on the electricity sector of the model as only data which distinguished between green and brown electricity was available. TIAM-UCL encompasses more than 100 electricity generation technologies representing present and potential future technologies. Electricity can be provided by fossil fuel, nuclear, biomass thermal power plants and different renewable technologies: wind, solar, geothermal, hydro and tidal. The power plants producing CO_2 during generation (fossil fuel or biomass) can be retrofitted or newly built with carbon capture and sequestration at extra cost. Within the present version of the model, all electricity generating technologies (present and future) have a hurdle rate of 10% in all regions over the scenario timeline. Here, we introduce two other scenarios which utilise the data from the EU's Green-WIN project to consider the effects of altered technology-specific and regional WACCs on model outputs.[6]

A specific barrier represented in these hurdle rates is the availability and accessibility of finances to develop specific technology adoption in the pathway represented. We have access to present day (year 2017 computed WACC for different sectors. In these results, the power sector has been aggregated into two categories: "green & renewable" and "other" power sector. "Green and renewable" power comprises wind (off and on-shore), solar (PV and concentrated), hydropower, geothermal and tidal; the rest of the generating technologies will be within the "other power" sector, including nuclear, biomass and all CCS plants. (Note, these groupings differ slightly from the green and brown groupings listed in Table 3). The WACCs for the two types of electricity generation for each region are presented in Table 4.

Table 4 WACC across countries (percentage values, 2017)

WACC0	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JAP	MEA	MEX	ODA	SKO	UK	USA	WEU
Other	8.9	5.1	4.6	6.6	7.3	5.5	5.5	6.3	1.8	5.1	8.9	5.1	5.1	4.3	4.4	4.0
Green	11.8	6.1	5.4	6.6	9.2	5.8	5.8	8.2	2.4	6.8	11.8	6.8	6.8	4.4	5.1	4.2

The 2017 WACCs range from low 1.8% (Japan Other power) to a maximum of 11.8% (Mexico or Africa Green power), representing large regional variation. This accounts to a global figure

[6] The Horizon 2020 Green-WIN project deliverable which includes the database is available here https://green-win-cloud.org/index.php/s/RUEtfuWSNYCFcFr#pdfviewer

close to 5% for both sectors when weighted according to GDP (more precisely 5.4% and 4.6% for “green & renewable” and “other” respectively). This figure is relatively low compared to the 10% hurdle rates present in the original TIAM_UCL model.

For reconciliation with the original level of hurdle rate in TIAM_UCL, the 2017 WACCs (Table 4) are increased to achieve the globally GDP weighted value of 10% hurdle rates on the power sector. The new WACCs values are presented in Table 5. As with the original 2017 WACC, it is noticeable that the “green & renewable” technologies in all regions present a higher WACC than the other power sector. These are applied within the TIAM_UCL electricity sector to perform a first sensitivity test that is named “WACC1”. Compared to the original TIAM_UCL model, the global overall hurdle rate for power is identical, but the rates are regionally and technologically different.

Table 5 WACCs adjusted to be globally at 10% when weighted by GDP (percentage values)

WACC1	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JAP	MEA	MEX	ODA	SKO	UK	USA	WEU
Other	18	10	9	13	15	11	11	13	4	10	18	10	10	9	9	8
Green	23	12	11	13	18	12	12	16	5	13	23	13	13	9	10	8

A second sensitivity case has been conducted to analyse the effect of a differential in the WACC in favour of renewables between the two specific sectors (“green & renewable” and “other”). For this purpose, from the previous values (WACC1) a simple increase of 20% has been applied to each regional WACC for the “other” power sector and a reduction of 20% applied to the “green & renewable” WACCs. As seen in Table 6 below, the differential is now in favour of the “green & renewable” power sector in all the 16 regions in the model. This sensitivity test has been named WACC22. The hurdle rates in all the sensitivity tests are constant during the period represented (no variation over time). This WACC2 is to provide an example of a “what if” scenario of the implications and effects of changing policy towards low-carbon finance and is not based on any current specific policies or expectations.

Table 6 WACCs adjusted from the previous Table 5 to get lower WACC for “green & renewable” technologies in comparison to “other” power (respectively – and + 20% applied to Table 5 values, percentage values)

WACC2	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JAP	MEA	MEX	ODA	SKO	UK	USA	WEU
Other	21	12	11	16	17	13	13	15	4	12	21	12	12	10	10	9
Green	19	10	9	10	15	9	9	13	4	11	19	11	11	7	8	7

3.3.3 Introducing financial frictions

MEWA model takes as inputs the investment requirements, CO_2 emissions and final energy consumption for the NDC and 1.7°C TECH scenarios from TIAM-UCL.[7]

The modelling focuses on the role of the financial sector and financial frictions for the green transformation of the world economy. MEWA assumes that the cost of capital (in the steady state) in the industrialised economies (7%) is lower than the cost of capital in low-income economies (12%) which is a result of different time preferences of the relevant households and risk premiums in the banking sector. The required level of low-carbon investment rises for both the high- and low-income countries according to the information provided by the TIAM-UCL model.

To finance these efforts, firms must raise their demand for investment credit. This – ceteris paribus – pushes the interest rates upwards, impacting the overall investment costs, unless the additional financial assistance is being provided by domestic or international actors. This assistance may come into being as subsidies secured by the International Green Investment Fund provided by the high-income countries for the rest of the world, or materialise as the International Green Finance Mechanisms lowering the cost of capital and credit constraints for green investments undertaken in the developing economies.

In other words, MEWA takes into account the following financial scenarios:

1) **Reference scenario:** high- and low-income countries finance the investments in line with the TIAM-UCL REF from their own resources.
2) **Domestic finance scenario**: high- and low-income countries finance the low carbon investments in line with the TIAM-UCL 1.7°C TECH scenario from their own resources
3) **International Green Investment Fund (Green Fund) scenario**: the high-income countries subsidise 20% of the low-carbon investment costs in the low-income countries. In this scenario, the Green Fund is financed from general taxes, and the investments are in line with TIAM-UCL 1.7°C TECH scenario.
4) **International Green Finance Mechanisms (Green World Bank) scenario**: high-income countries provide cheap loans for low-carbon investments undertaken by low-income countries i.e. effective interest rates for the low-income countries are lowered and the availability of funds increases. The investments are in line with the TIAM-UCL 1.7°C TECH scenario.

[7] In order to simplify the analysis in the timeframe of the deliverable and focus on the effects of different financing mechanisms, just one representative scenario was undertaken on finance. The 1.7°C scenario was chosen as being somewhere towards 1.5°C and well-below 2°C that could be modelled using MEWA.

The macroeconomic outcomes of these alternatives are assessed and discussed below in section 4.2.

3.3.4 Economy wide and sectoral implications

Here the CGE model ENGAGE is employed to consider the wider multi-sectoral implications of the various scenarios detailed above on Sections 3.3.1 and 3.3.2. The model is soft-linked to TIAM-UCL in two ways. Firstly, emissions trajectories from the TIAM-UCL scenarios listed in Table 2 above are used as an input to constrain the emissions pathways in ENGAGE. Secondly, ENGAGE replicates the power sector mix from TIAM-UCL through the implementation of the same TECH cost reductions in renewable technologies. In addition, a fixed resource in renewable technologies is introduced to calibrate the path of renewable technologies to match TIAM-UCL. The fixed factor prevents abrupt changes in the power mix as the different power technologies are modelled as perfect substitutes and capital is perfectly mobile.

The above financing scenarios are implemented in ENGAGE in a similar fashion:

1) **Reference scenario:** This corresponds to the REF scenario, each country/region finances the transition with their own resources.
2) **Domestic finance scenario**: This corresponds to the 1.7°C TECH scenario, each country/region finances the transition with their own resources.
3) **International Green Investment Fund (Green Fund) scenario**: Based on the 1.7°C TECH scenario, high-income countries subsidise the difference in additional investment needs in low-income countries. The burden in high-income countries is distributed according to their share in the regional GDP.
4) **International Green Finance Mechanisms (Green World Bank) scenario**: Based on the 1.7°C TECH scenario, high-income countries provide cheap loans (9% interest rate) to finance the difference in additional investment needs in low-income countries.

We present ENGAGE results for the 1.7°C scenarios compared against the ENGAGE REF scenario. We attempt to replicate the three financing scenarios used in the MEWA analysis, described above, in order to provide a similar analysis using ENGAGE which captures the full decarbonisation of the economy (MEWA does not include emissions and only replicates investment trajectories) and gives a detailed representation of different power sector technologies and other economic sectors. However, ENGAGE does not include a detailed representation of the financial sector to the extent that MEWA does and therefore this analysis is aimed at provided an alternative model approach to the same financing options.

Figure 6: Capital transfers (billion USD)

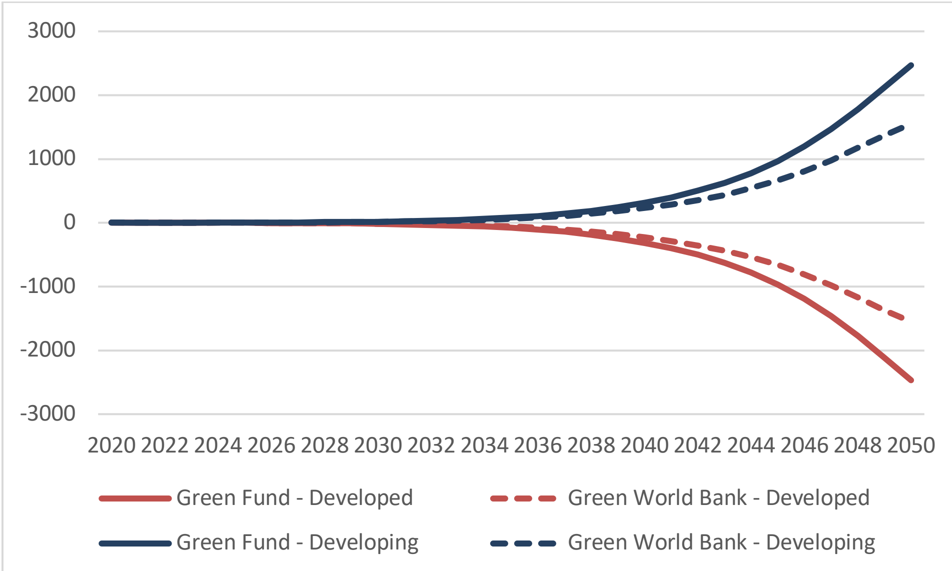


Figure 6 shows the capital transfers in the finance scenarios for ENGAGE. The capital transfers in the Green Fund scenario represent as an average 0.7% of the GDP in low-income countries during the period 2020-2050.

4 Results

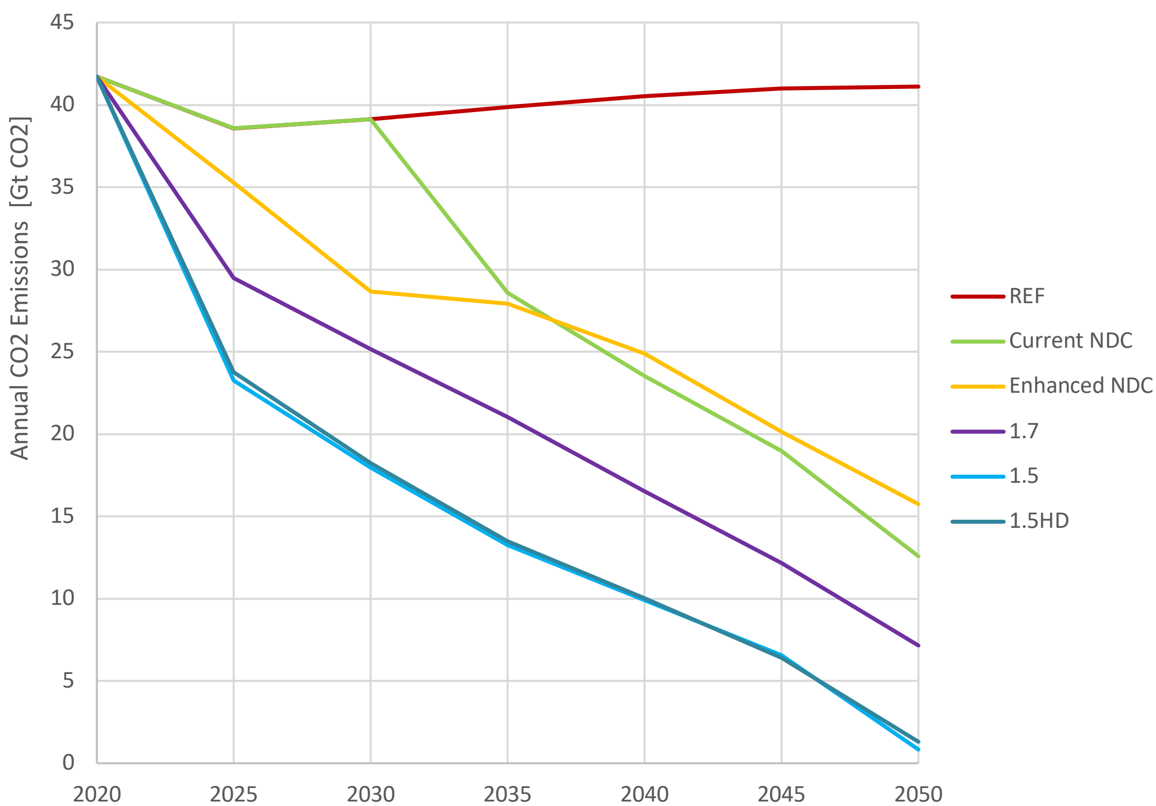
Various results for the RIPPLES scenarios described in Table 2 above are presented for TIAM-UCL, MEWA and ENGAGE. TIAM-UCL will focus on the energy system implications of these pathways, while the main financial findings will come from MEWA. These will include economic outputs and indicators such as employment, public and private consumption, imports/exports, capital and current accounts, all related to the various methods of financing the different pathways. ENGAGE then provides a wider sectoral analysis of the main RIPPLES scenarios and the finance scenarios for 1.7°C TECH. ENGAGE is able to model the costs of decarbonisation whereas the MEWA does not include emissions and as such only models the investments from decarbonisation and their impact on the economy rather than the entire decarbonisation. This difference amongst various others (database, model structure) explains the difference between results for MEWA and ENGAGE.

4.1 Implications for the energy system

4.1.1 Emissions and energy

Global emissions pathways for the scenarios are presented in Figure 7. The Current-NDC and Enhanced-NDC scenarios have a similar trajectory from 2035 along the optimal path to achieve 2°C by 2100.[8] The sharpest declines in CO_2 emissions are for both of the 1.5°C scenarios which reach almost zero by 2050. The 1.5C and 1.5HD scenarios are required to reduce CO_2 emissions dramatically and both follow a fairly similar path out towards 2050: they reduce on average by 13% to 14% % per year respectively between 2030 and 2050. The 1.7°C scenario reduces around 6% per year over the 2030 to 2050 period reaching 83% lower than 2020 levels by 2050, and reaches net zero CO_2 in approximately 2065. The emissions trajectories for the EU are presented in the Appendix (Figure A1). The EU reaches net zero CO_2 emissions sooner than the world as a whole; the soonest in the 1.5C scenarios between 2045 and 2050.

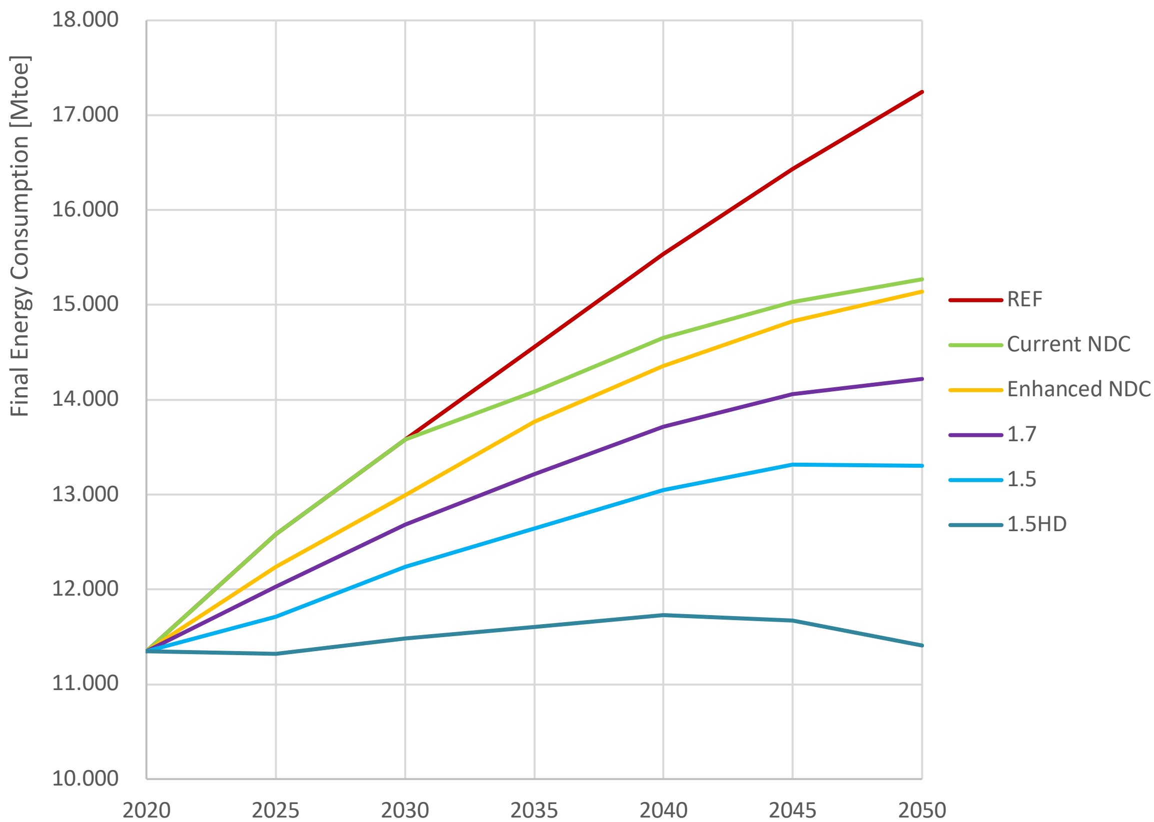
Figure 7 Global CO_2 emissions pathways by scenario



[8] Model results are only shown to 2050 to be consistent with focus of COP21 RIPPLES project and as the other models in this analysis only run to 2050.

Overall final energy consumption in the model scenarios are provided in Figure 8 and show the wide range of energy consumption depending on the level of decarbonisation. As the stringency of decarbonisation increases, there is more energy demand reduction due to the price response from the elastic demand function in TIAM-UCL. The Current and Enhanced-NDC scenarios end up with approximately 11% to 12% lower final energy demand compared against the REF scenario in 2050. The 1.7C and 1.5C scenarios have even more reduced energy consumption, reaching levels 18% and 23% lower than the REF in 2050. This scenario is 34% lower than the REF in 2050. The 1.5C and 1.5HD scenarios reach the same level of decarbonisation but with different demand assumptions. The lowered demands in 1.5HD have the effect of lowering the final energy consumption by 79,442 PJ (approximately 14%) in 2050 compared to the SSP2 1.5°C scenario.

Figure 8 Global final energy consumption by scenario



As shown in the Appendix (Figure A2), in the decarbonisation scenarios, electricity consumption increases in all sectors except Upstream where less fossil fuel extraction and processing is required. In absolute the terms, the largest growth is in the residential sector, while in relative terms it is in the transport sector. In the appendix we also show final energy consumption by fuel for each scenario in 2030 and 2050 (Figure A3). In this period, the use of fossil fuels in the

end-use sectors falls most steeply in the 1.5C scenario, but we note in this case they still represent 51% of the final energy consumption in 2050 (falling to 30% by 2100).[9]

Global Electricity generation in 2030 and 2050 are shown below in Figure 9, broken down by technology. While there is an increase in electricity generation over these twenty in all scenarios, the increase is most pronounced for the 1.5C scenario, which is 53% higher than the REF in 2050. The electricity generation in the 1.5HD scenario in that same year is lower (to below that in the 1.7C case) owing to the lower overall demand requirements from the 1.5HD scenario.

In the REF and Current-NDC scenarios in 2030, just over 50% of the electricity is generated by low-carbon ('green') technologies (defined according to the McCollum et al. (2018) analysis, see Table 3. For the Enhanced-NDC and 1.7C scenarios, the share of green technologies is 64% and 75%, while for the deepest decarbonisations of 1.5C and 1.5HD the share of green electricity in 2030 is 88% and 86% respectively. This shows that there is large range of low-carbon electricity levels depending on the decarbonisation target, which will likely have implications for finance flows and requirements even in the short term to 2030 (See Section 4.1.2).

By 2050, the shares of low-carbon electricity generation are considerably larger again. While it is only 68% in the REF, all other scenarios have over 90% low-carbon generation by 2050 and there is not much difference between them. The majority of the extra electricity increase in the decarbonisation scenarios comes from solar PV which accounts for 40% of total generation in the Enhanced-NDC and 1.5C scenarios in 2050. By 2050, coal generation is completely phased out in all scenarios, while gas (a little with CCS) still plays a small role providing 3-7% of the generation and bio-CCS provides 15-22%. The share of electricity provided by nuclear is relatively stable over this period at 11-14% and the share provided by hydropower in fact decreases slightly. Offshore wind plays almost no role in these scenarios before 2050 due to its high capital cost.[10] The biggest changes between 2030 and 2050 are seen in Current-NDC, as only limited mitigation action is taken in the 2020s.

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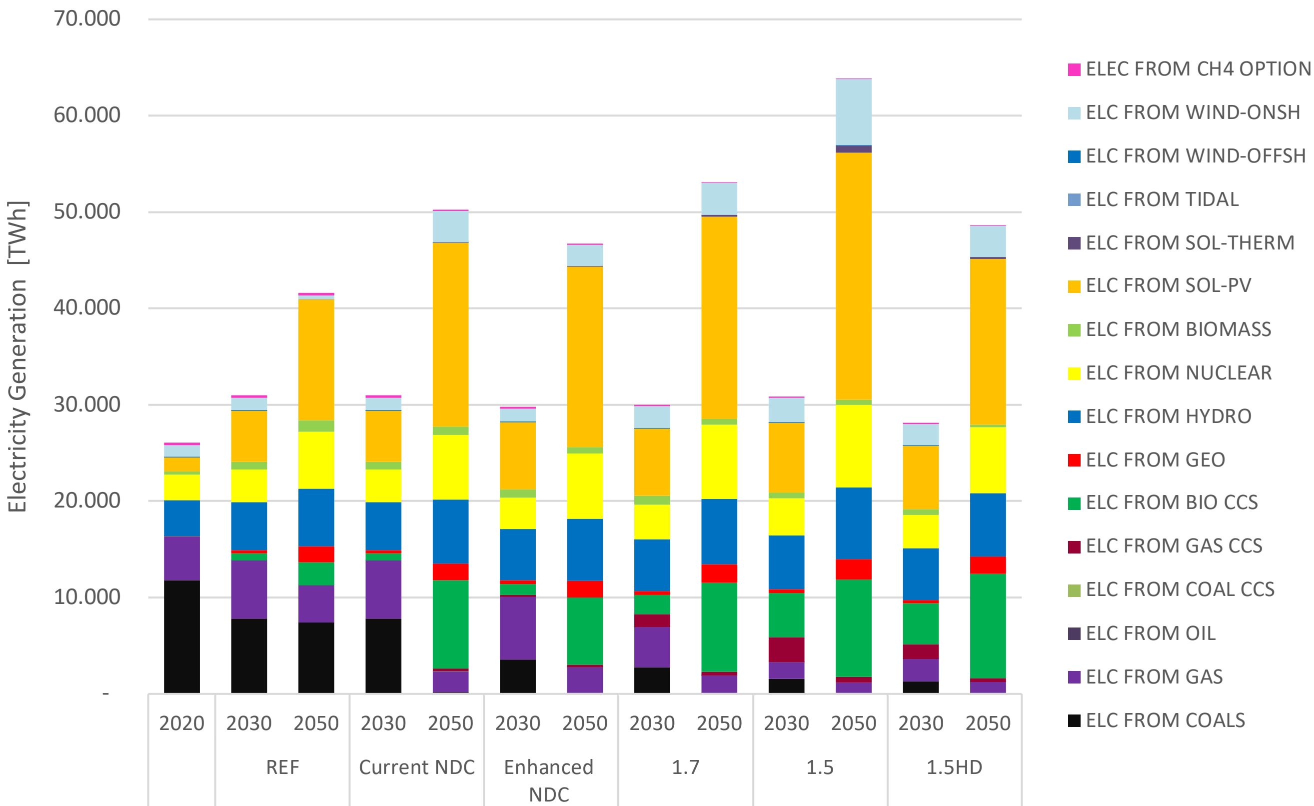
[9] This includes heat generation carbon capture and storage but not electricity. The majority of fossil fuels are used in the hard-to-decarbonise sectors industry and transport.

[10] However, recent trends in UK offshore wind auctions show that costs are reducing faster than expected, with lowest cost coming in at £40 per MWh, and these cost reductions will play a significant role over the coming decades.

Figure 9 Electricity generation by fuel for 2030 and 2050 by scenario



4.1.2 Investments

As described in 4.1.2, TIAM-UCL reports annualised capital cost payments for energy infrastructure throughout its economic lifetime. These represent the repayment of the lump sum investments made when the technology is constructed. In this section we present investment costs up to 2050. In each period, the investment costs are the sum of the annual payments being made for the capacity that is live in that period. They therefore take into account the capital costs of the technologies at the time they were built (see Figure 5), the technology-specific hurdle rates and the technologies' lifetimes.

In the REF scenario, there is no increased decarbonisation target post-2030 but continued investments are required to meet the rising demands for energy. In this case, the total supply-side annual investments for energy (electricity, heat and upstream) increase from $1.2 trillion in 2030 to around just over $2 trillion in 2050. As shown in Figure 10, in general the deeper decarbonisation scenarios have higher investment costs. The 1.5C scenario has the largest investment requirements, reaching almost $4.5 trillion per year in 2050, while in the 1.7C scenario they reach $3.4 trillion per year. The Current and Enhanced-NDC scenarios have

lower investments than the deeper decarbonisation scenarios, the former being fixed to the REF until 2030 and the latter only 9% higher than the REF in 2030.

Additional insights can be drawn from this scenario set. The high decoupling 1.5°C scenario reaches annual investments of just over $3 trillion in 2050, showing that a high decoupling of demand may substantially lower the investment requirements for ambitious decarbonisation pathways. Although it must be noted that the investments required to achieve this decoupling of demand are not endogenous to the model and therefore are not taken into account in the analysis. Interestingly, the pathway for 1.5HD and 1.7C cross just after 2035. Obviously these scenarios differ in both their decarbonisation targets and demands, but it shows that in 15 years' time, even a 1.7°C world will require increased investments slightly larger than a 1.5°C world where energy demands are reduced. The Enhanced NDC scenario has slightly higher annual investment costs than the Current NDC case up to approximately 2030 but then lower costs up to 2050, indicating that higher investments in the coming decade could bring savings in the longer term.

In the REF scenario, the percentage of investments that are considered green is fairly stable across the thirty year period at around 55-60% of total supply-side energy investments. However, the percentage of green investments increases in all of the decarbonisation scenarios, and the difference between them is most prominent in the near-term (Figure 11). Already, even by 2025, the 1.5C and 1.5HD scenarios reach almost 70% of investment being low-carbon and continue to increase to over 90% by 2050. For the Current and Enhanced-NDC scenarios, the percentage of green investment stays below 70% until after 2035. The 1.7C scenario still requires substantial initial green investments and also reaches of 90% green investments by 2050.

Figure 10 Total global annual energy investments (trillion $2005)

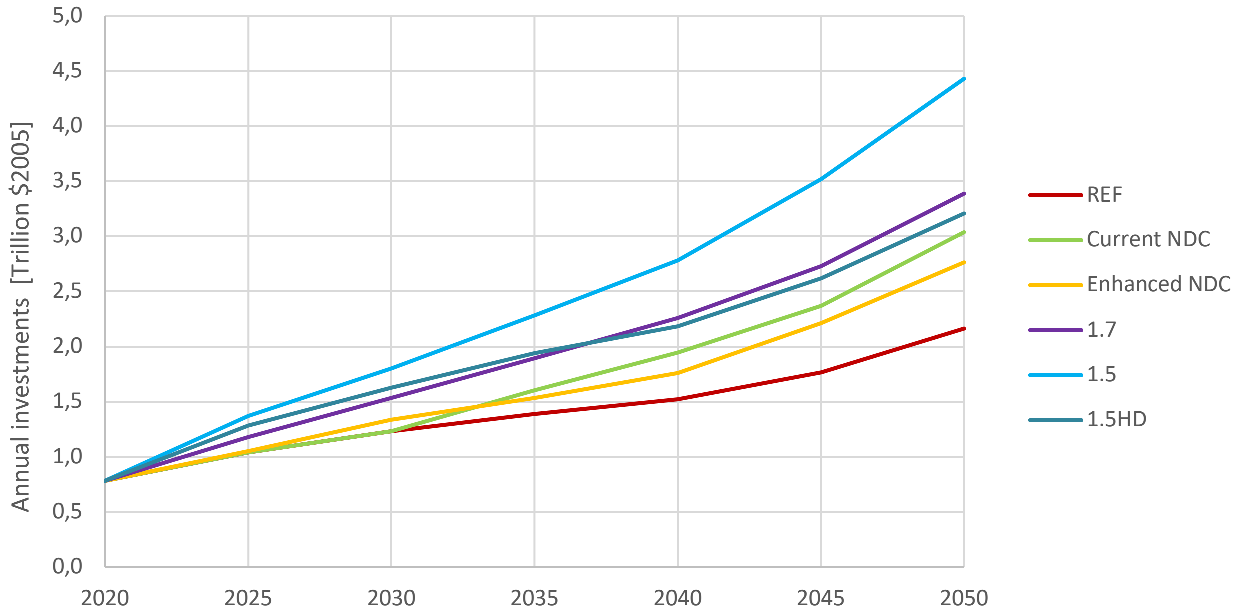
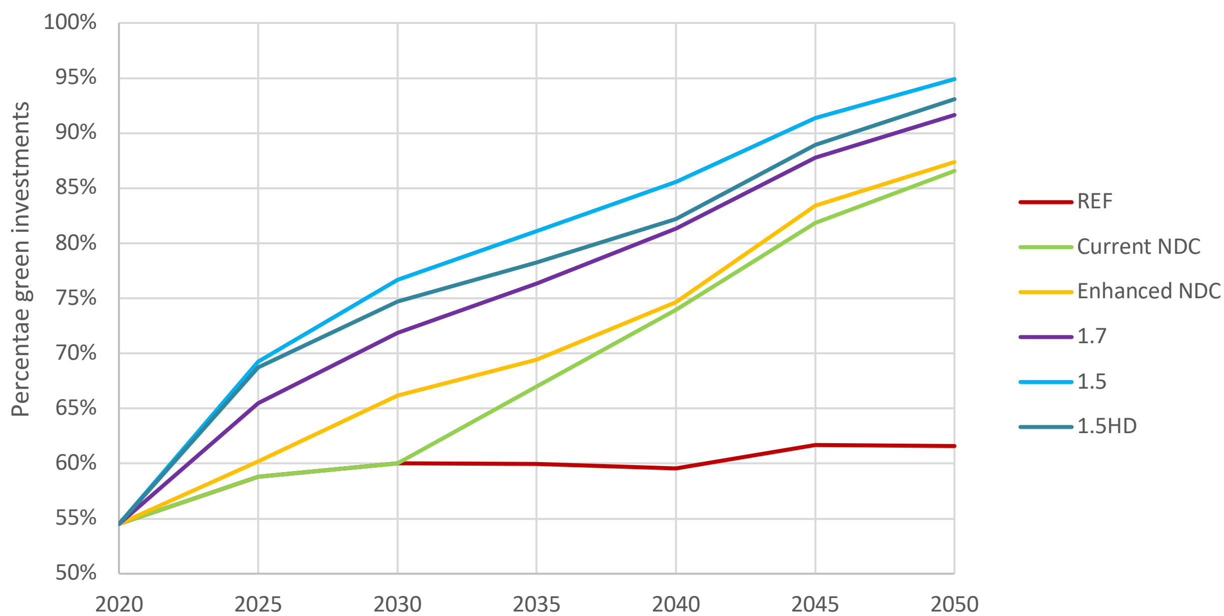


Figure 11 Annual global green energy investments, as percentage of total energy investments



In the appendix (Figure A4), we show the global electricity generation investments by technology for each scenario. Notably, in the deep decarbonisation scenarios, investments in electricity from fossil fuels fall rapidly. By 2050 in 1.5C and 1.7C respectively, investments in fossil fuel electricity without CCS falls to 4% and 7% of global electricity investments, and fossil

fuel electricity with CCS represents just 2% and 1%.[11] Across the decarbonisation scenarios, low carbon electricity (which includes renewables, nuclear and any fuel with CCS), represents 70-80% of global electricity investments in 2030 and over 90% in 2050. Investments for electricity from PV, wind, hydro and nuclear are similarly steady across the scenarios from 2020 to 2050, albeit with faster uptakes for deeper decarbonisation. The strongest difference in the investments in bioenergy with CCS: in Current-NDC and Enhanced-NDC, there is a sharp increase around 2040, while in the 1.5C and 1.7C scenarios, investment is focussed on this technology directly from 2020. Given that this technology does not yet exist at scale then the necessity to divert investment in this direction immediately or otherwise to focus on more expensive technologies and/or behavioural change becomes essential.

For Europe, the starting percentage of green investment in 2020, shown in Figure 12, is higher than the global level at approximately 76%, as opposed to 54% globally. With a stronger signal than in the global picture, in Europe the percentage of green energy investments rises to 95-97% by 2050 all scenarios. This happens even in the REF case, due to the ambitious NDC targets reaching to 2050 in this region of an 80% reduction in GHGs by 2050 from 1990 levels (see Appendix for corresponding EU emissions pathways). In Europe, a large portion of electricity investments are focussed on bioenergy with CCS in run-up to the middle of the century: Bio-CCS power accounts for 39% of annual electricity investments in the REF case in 2050 due to the achievement of the NDCs and continued ambition, and up to approximately 25% in the stronger decarbonisation scenarios where the energy transition starts earlier.

[11] While surprising that there are still investments in unabated fossil fuel power generation in 2050, it would be necessary to undertake sensitivity analysis around the role that negative emissions technologies play in creating the possibility of such investments.

Figure 12 Annual green energy investments for Europe

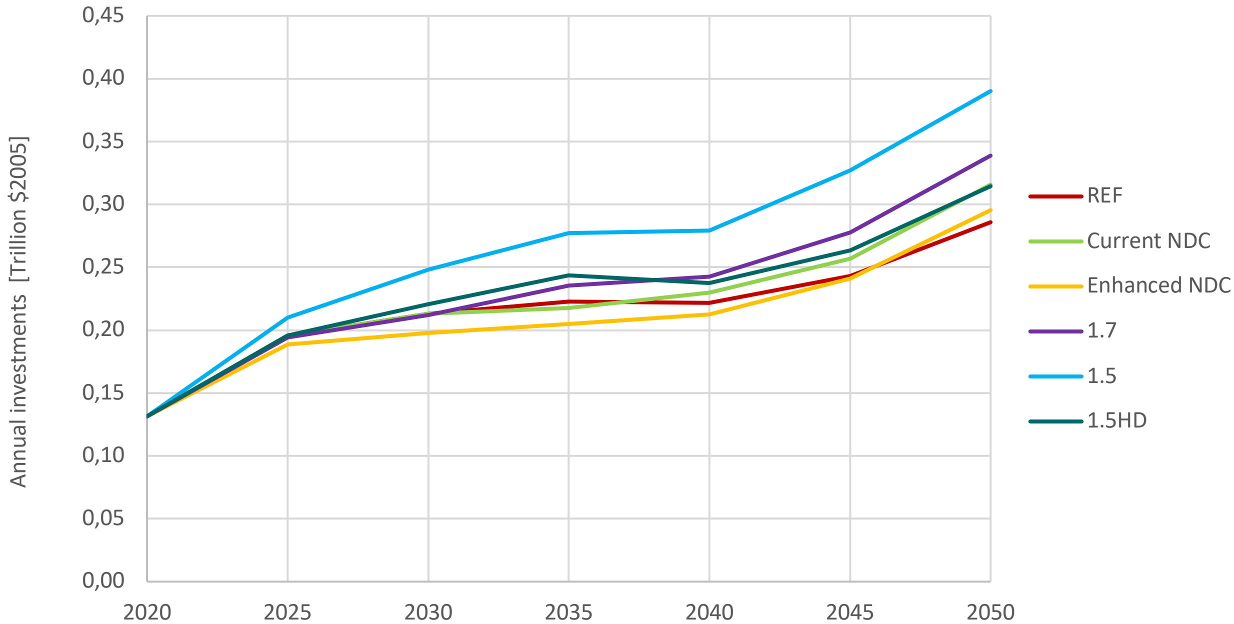
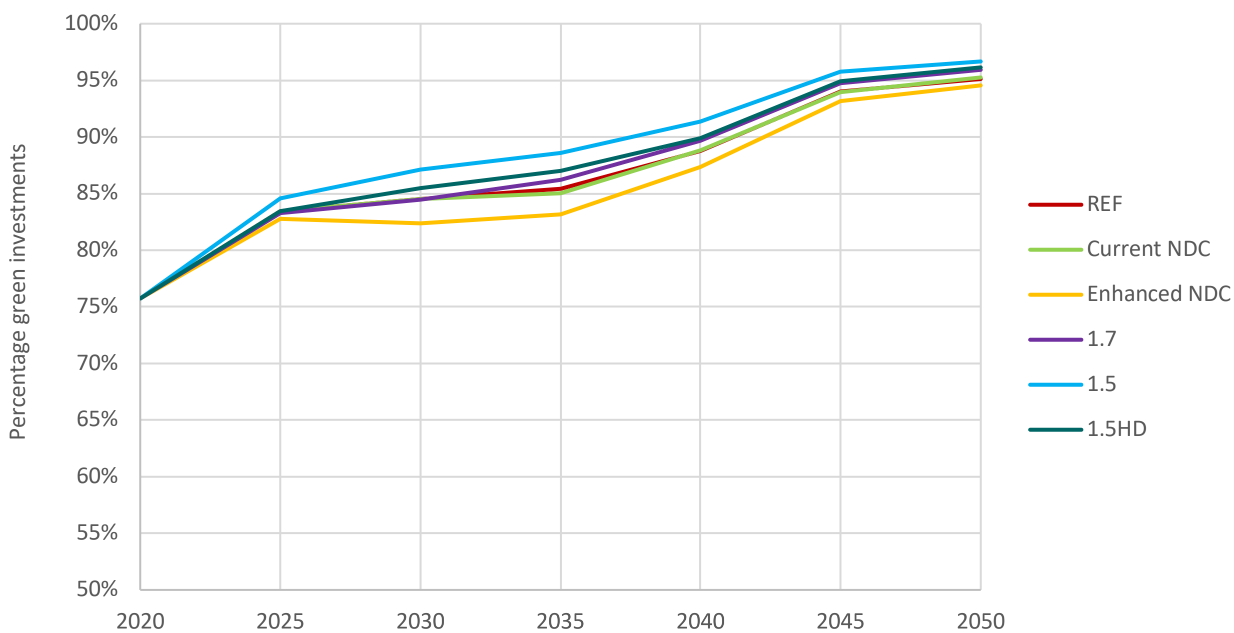


Figure 13 Annual green energy investments as percentage of total energy investments for Europe



4.1.3 Renewable costs sensitivity

As described in section 3.3.1, a set of sensitivity tests were performed on the effect of lowered costs for renewable generation technologies to exogenously simulate accelerated technology learning. This section focusses on the effect of these lowered costs in the Current-NDC, 1.7C and 1.5C scenarios. (The equivalent figures for the other scenarios are shown in the Appendix Figures A5, A6, A7).

In the TECH scenarios, the costs of green electricity technologies are lowered compared to the standard costs (see Figure 5). By 2050, the costs of solar, onshore wind and offshore wind are 36%, 61% and 71% lower than in the standard case. The lowered costs increasingly incentivise the use of these technologies over other renewable options and non-renewable fuels, and result in increased levels of electrification in all scenarios. As shown in Figure 14, total electricity generation increases more steeply in scenarios of deeper decarbonisation, and even more steeply when the renewable technology costs are lowered. The level of electrification is most sensitive to the technology costs in the 1.7C scenario, where in 2050 the global electricity generation is up to approximately 30% higher than in the standard cost scenario. As shown in Figure 15a, this is largely due to stronger electrification of transport, followed by industry. In the transport sector, electricity replaces oil, gas, biofuels and hydrogen. Industry is electrified to a lesser extent, with electricity partially displacing gas up to around 2080, and coal and heat from 2050 onwards. The lowered technology costs also lead to stronger electrification of these sectors in the 1.5C scenario. In the less stringent scenario of Current-NDC the lower technology costs lead to similar electrification in the transport sector but not industry.

The mix of technologies in the electricity generation portfolio also changes with the technology costs. Figure 15b shows the mix of electricity generation types for the two cases of technology costs in the 1.7C scenario. With the lower technology costs, the installed capacity of onshore wind is notably increased, and offshore wind is rolled out rapidly around the middle of the century. These partially displace other low carbon electricity options, most importantly nuclear, biomass and hydro, as well as natural gas, while solar PV capacity is also slightly reduced. Similar effects are seen in the 1.5C and Current NDC scenarios. The high availability of low-cost low carbon electricity in the middle and second half of the century has an effect on the technology choices of the model even before 2050, due to its perfect foresight feature. In the TECH scenarios, it is cost-optimal to reduce the role of more expensive mitigation technologies such as gas-CCS and bioenergy-CCS generation in the 2020-2050 period and instead use these later in the century.

Due to these changes in the energy mix, in each of the TECH scenarios, the emissions intensity of electricity and global CO_2 emissions are slightly higher in the medium term compared to their equivalent scenarios with standard technology costs. This is slightly counter-intuitive given lower renewable costs, and is related to the model using a forward looking perfect foresight

assumption knowing that future technologies will allow greater deployment of low-carbon technologies in later model periods. Global emissions of the TECH scenarios fall below those of the standard cost scenarios around 2050 in the 1.7C case and between 2035 and 2040 in the 1.5C case (Figure 16). In the 1.5C scenario, the lower TECH costs make very little difference to the global emissions from 2070 onwards, because the model has little choice about the technologies to deploy due to the stringency of the temperature target. The emissions are less sensitive to the lowered technology costs when the decarbonisation target is more ambitious.

The changes in the renewable technology costs and energy mix also impact the total annual electricity investments and the green share of the investments (Figure 17). In the TECH scenarios, the lower technology costs lead to lower total electricity investments, but this effect is partially offset by the increase in total electricity consumption. Between 2020 and 2050, the annual average electricity investment costs are 10%, 9% and 10% lower than the standard cost case for the Current-NDC, 1.7C and 1.5C scenarios respectively. Note, the investment costs for the standard and TECH cases diverge further after 2050, as the investment costs in each period take into the account the capital costs of any electricity generation capacity built up to that point. In all three scenarios with lowered technology costs, the share of green energy investments is lower in the medium term but rises to within 1% of the standard case by 2050, and is then higher in the second half of the century.

Figure 14 (a),(b) and (c): Global electricity generation for standard and TECH assumptions for (a) Current-NDC, (b) 1.7C and (c) 1.5C scenarios

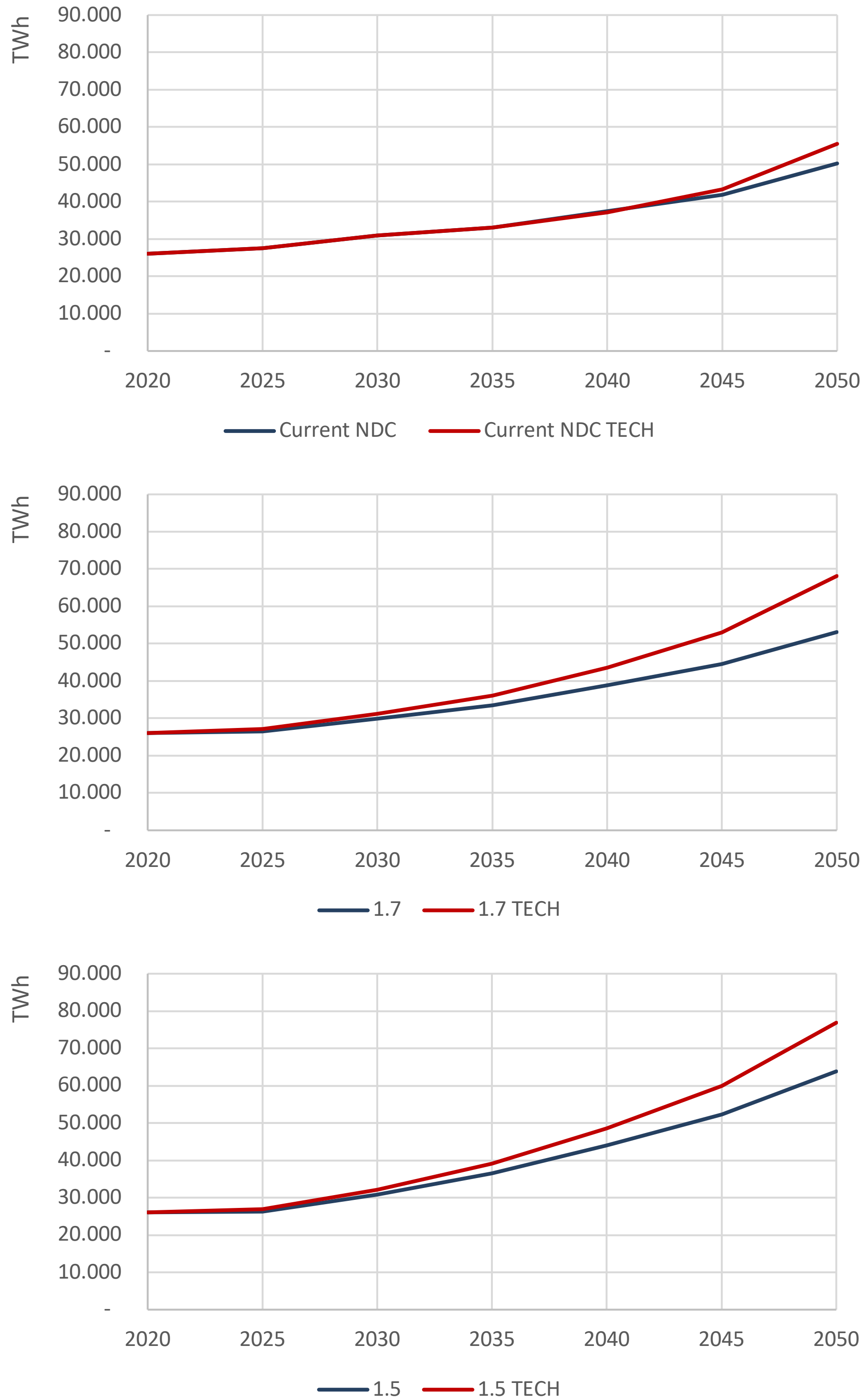


Figure 15 (a) and (b): (a) Electricity consumption by sector and (b) Installed electricity capacity by fuel for the 1.7C scenario for the standard technology cost assumptions and the lower TECH cost assumptions

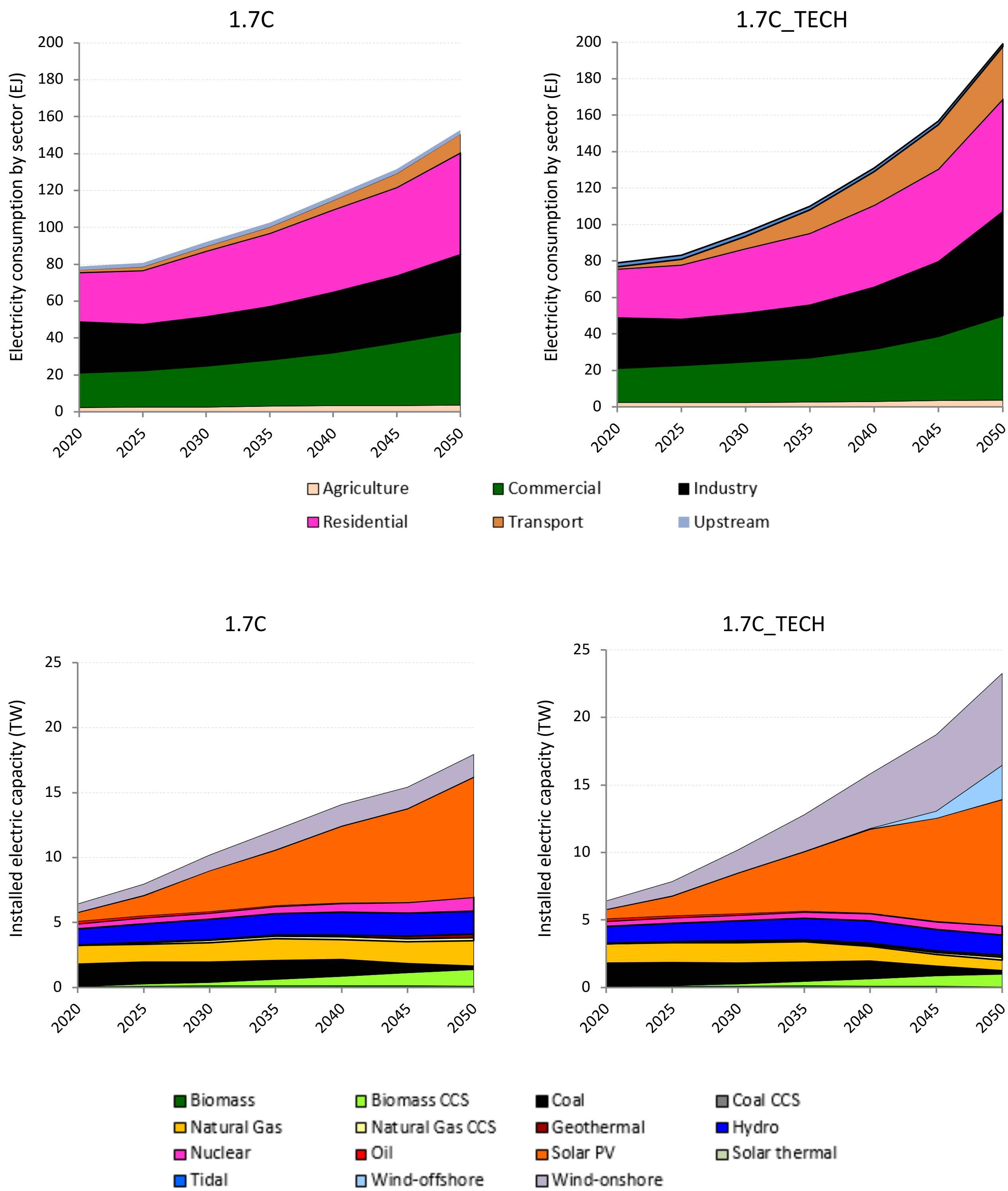


Figure 16 (a), (b) and (c): Global CO_2 emissions pathways for standard and TECH assumptions for (a) Current-NDC, (b) 1.7C and (c) 1.5C scenarios

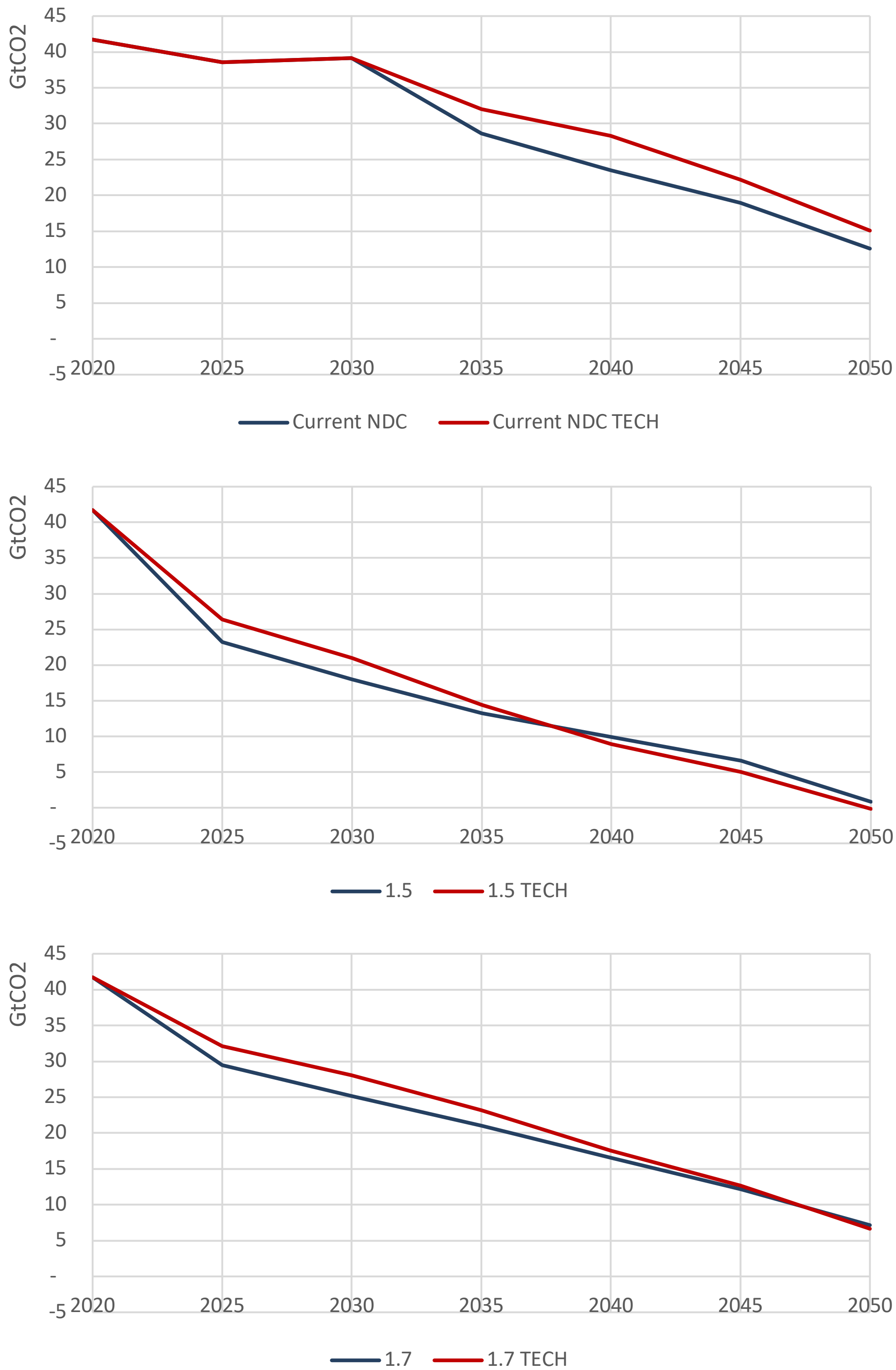
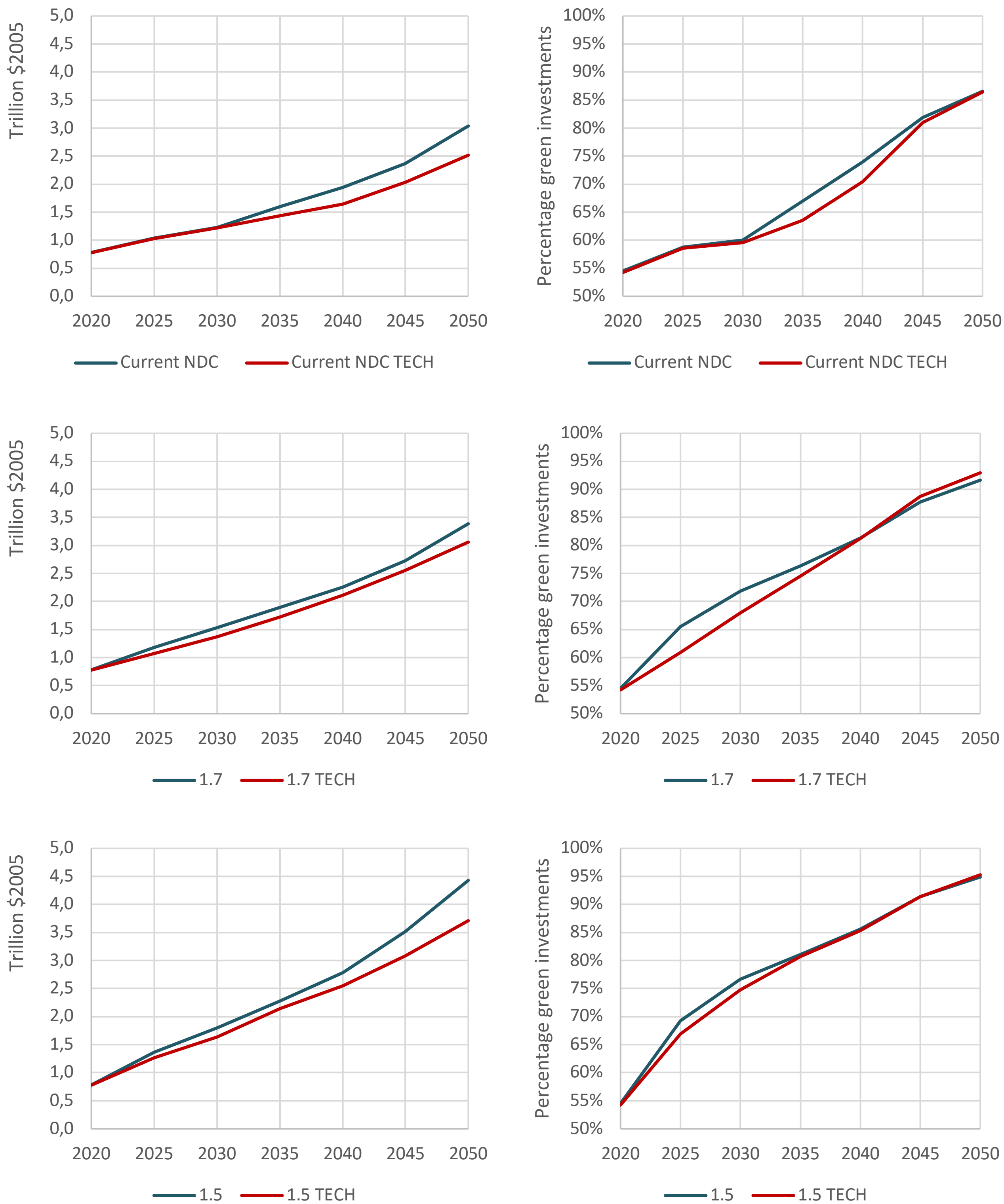


Figure 17 (a),(b) and (c): Total annual energy investments and Percentage green investments for (a) Current-NDC, (b) 1.7C and (c) 1.5C scenarios



4.1.4 Weighted Average Costs of Capital

As described in section 3.3.1, scenarios were constructed to examine the effect of varied hurdle rates on energy investments. These results are compared for the 1.7 TECH scenario, which has a1.7^{o}C global warming limit and the lowered technology costs (see 4.1.3). The 1.7 TECH scenario uses the standard 10% hurdle rate. In 1.7 WACC1 TECH, region-specific hurdle rates for green and other electricity technologies from the Green-WIN project were introduced and scaled by the regions' GDP to give a global average of 10% i.e. the global average hurdle rate on electricity technologies is 10%, as in the standard 1.7 TECH case, but there are variations between regions and technologies. In 1.7 WACC2 TECH, these hurdle rates were decreased by 20% for renewable technologies and increased by 20% for non-renewable technologies to test a scenario where finance availability is readjusted in favour of green technologies. Here we simply undertake a practical example/thought experiment to understand how altering the hurdle rates in TIAM-UCL may affect our results i.e. these are not based on any real-life policies. Specific mechanisms for this kind of readjustment are modelled by MEWA and discussed in section 6 of this report.

In the WACC1 sensitivity case, the regional differences and higher WACCs for green technologies (see Table 5) lead to a reduction in the electrification of the industry and residential sectors. Total global electricity generation is reduced in the WACC1 case (by 4% in 2050). Despite this, the higher costs for green technologies lead to an uplift in the global energy investment costs compared to the standard 1.7 TECH scenario. The global annual energy investments rise to 6% ($179 billion) above the standard case by 2050. Most of this extra cost ($176 billion) is accounted for by green electricity investments. Investments in green upstream technologies are also increased (by $7 billion in 2050), while investments in green heat are reduced (by $4 billion in 2050).

In the WACC2 case, when the hurdle rates are adjusted by ±20% in favour of green technologies, global electricity generation is increased compared to the WACC1 case (by 2% in 2050) as greater electrification can play a larger role in the strict decarbonisation required at lesser cost now, and the annual energy investments are reduced compared to the WACC1 case (by 3% by 2050). The cost reduction is accounted for by reduction in both green electricity and green heat investments. Investments in green upstream technologies are increased compared to the WACC1 case (by 11% in 2050) but are an order of magnitude smaller than electricity and heat in absolute terms.

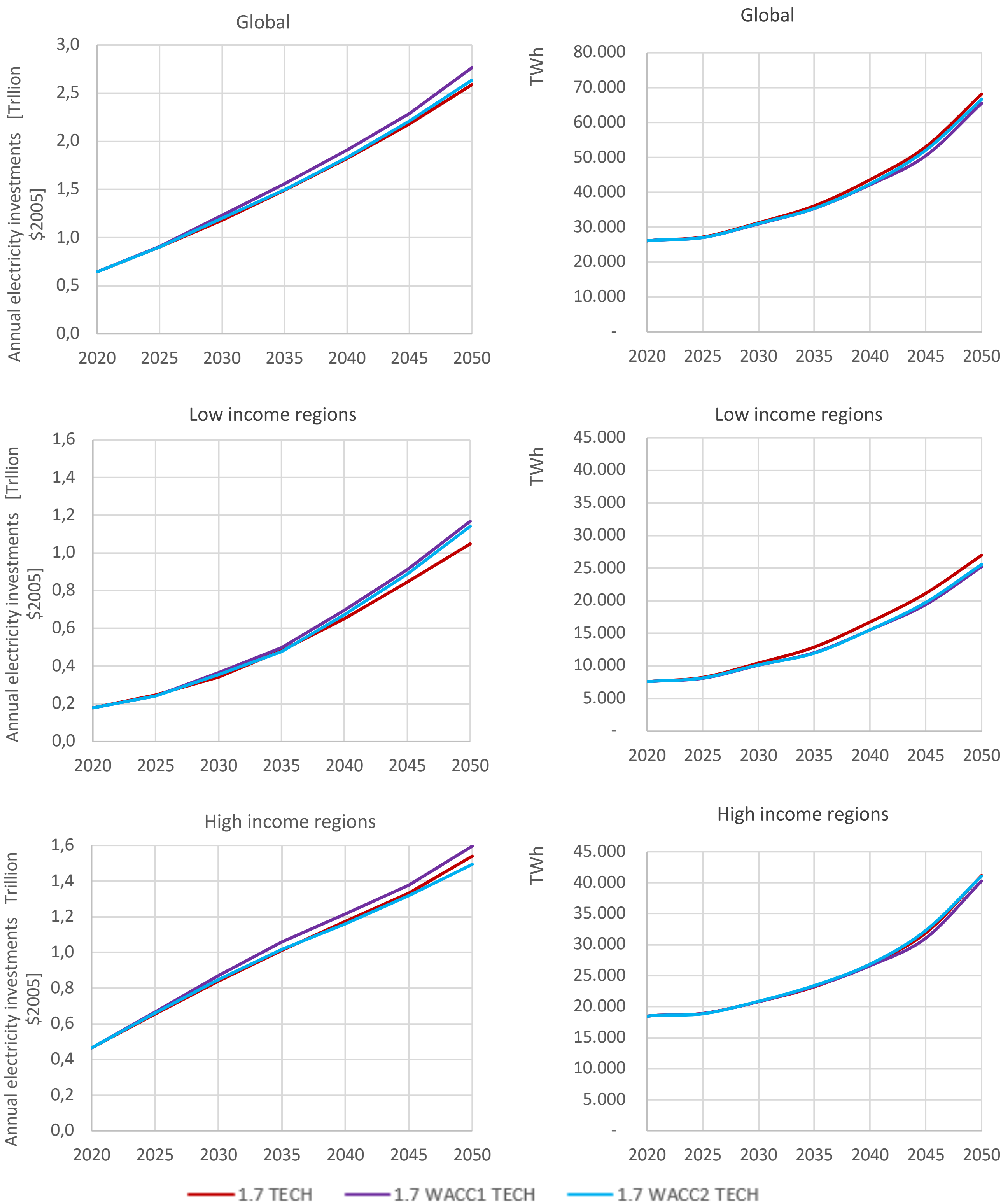
Apart from the level of electricity generation described above, the altered WACC values induce only minor changes in the fuel mix of the energy system designed by the TIAM. However, introducing the regional and technology-specific WACCs has an uneven impact on investment costs across the regions, showing the need for detailed examination of international climate

finance options, better data for individual regions and better representation of these in global scale models.

Figure 18 shows the total annual investments for the power sector up to 2050 for the global level, and high- and low-income regions separately, as defined by MEWA (see section 3.2.2 and note that China is included in the high-income group).

In the WACC1 case, the annual electricity investments are higher than in the baseline REF case in both high- and low-income regions (by 4% and 11% respectively by 2050). In the WACC2 case, where green technologies are favoured over other energy technologies, the annual electricity investments are lower than the WACC1 case in high-income regions (reduced by 6% in 2050) but only marginally reduced in low-income regions (reduced by 2% in 2050). This is because even under stringent climate targets, the low-income regions in the model as they have relatively lower costs of fossil generation compared to high-income regions and are therefore more dependent on traditional fossil fuel generation in the period 2020-2050. By 2050, 39% of final energy consumption is provided by electricity in the high-income regions, while it is only approximately 27% in low-income regions. Furthermore, the fuel mix of electricity generation in low-income regions remains more reliant on fossil fuels: by 2050, 6% of generation is still provided by fossil fuels, primarily gas, as opposed to 1% in high-income regions). Again, this demonstrates the importance of considering the current energy mix of different regions and the impact of this on the finance mechanisms needed to facilitate lowering the cost of the decarbonisation transition for low-income countries.

Figure 18 (a), (b) and (c): Total annual electricity investments by scenario for (a) global level, (b) low-income regions and (b) high-income regions

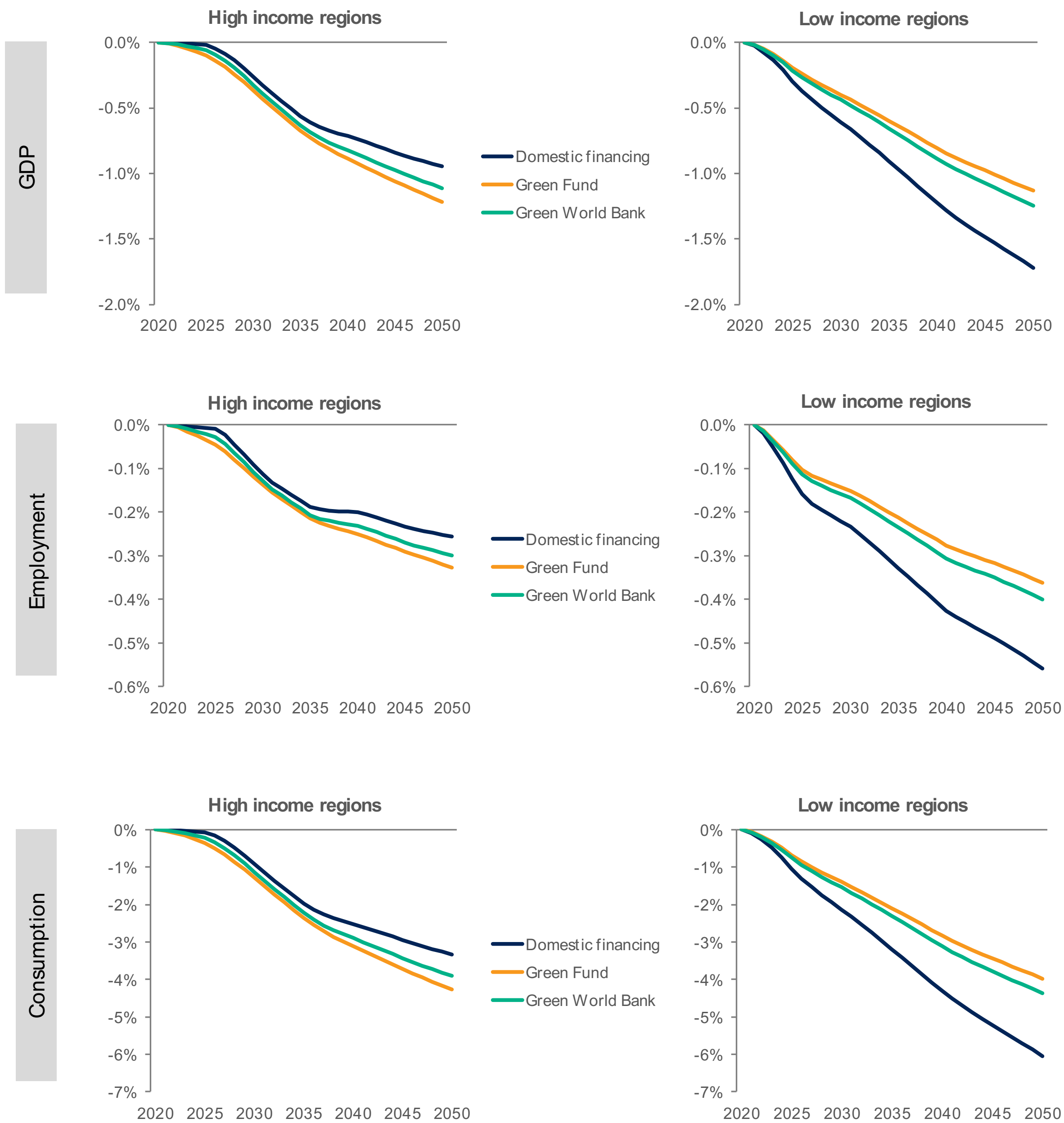


4.2 Financing the transition

4.2.1 Macroeconomic impacts

MEWA results indicate that the increased investment effort required to achieve the global low-carbon transition in line with the 1.7ºC TECH scenario provided by TIAM-UCL model will result in a moderate macroeconomic burden as shown in Figure 19 (i.e. decreases in the GDP, employment and consumption levels).

Figure 19 Deviation of GDP, employment and consumption from the Reference scenario in high and low-income country groups, 2020-2050



When no additional support is provided by the high-income countries to the low-income economies, the latter group sees larger growth slowdown than the former (-1.7% reduction of the GDP level in 2050 relative to the Reference scenario vs -0.9% in the high-income countries). It should be noted that there is still strong economic growth in all scenarios and that these values are comparatively low in the context of 30-year compound economic growth, effectively representing less than one year of average economic growth for each group of countries.

Both the Green Fund and the Green World Bank scenarios result in a near-equal distribution of the macroeconomic between the high and low-income countries on the level of 1.1% to 1.2% lower GDP in 2050. While the Green Fund scenario leads to a slightly better outcome for the low-income group, the Green World Bank achieves a similar result with a more limited impact on the high-income countries' GDP.

Similar observations apply to the employment and consumption indicators across all the considered scenarios. The main difference is the scale of the adjustment. By 2050, difference in employment compared to current NDC scenario is 3-4 lower than in the case of GDP (-0.26-0.3% in developed countries and -0.36-0.56% in developing countries), as the reallocation of workers between the economic sectors and activities as well as wage adjustment over the long term softens the impact of slower economic growth and rising unemployment. Most of the fall in employment, however, comes from the decreased labour supply due to either higher taxes or lower wages. Conversely, labour productivity and wages decrease slightly in all decarbonization scenarios: to achieve similar economic output without the GHG emissions, more inputs are required on the aggregate level.

Unlike employment levels, the consumption decreases by 3-6% (in the developed and developing block respectively), i.e. around x3.5 times more than GDP.. This is because the capital-intensive low-carbon transition requires the additional mobilisation of savings (that increase by 4-8% respectively), changing the composition of the aggregate economic activity in a way that benefits the banking sector and investment goods producers harming at the same time the rest of the economy and impacting the structure of expenditures on the macroeconomic level. A larger part of national income (and productive capacities) is devoted to investments and banking costs, at the expense of consumption. This perspective highlights the importance of implementation of the additional financing mechanisms for the distribution of the burden of transition between high- and low-income countries.

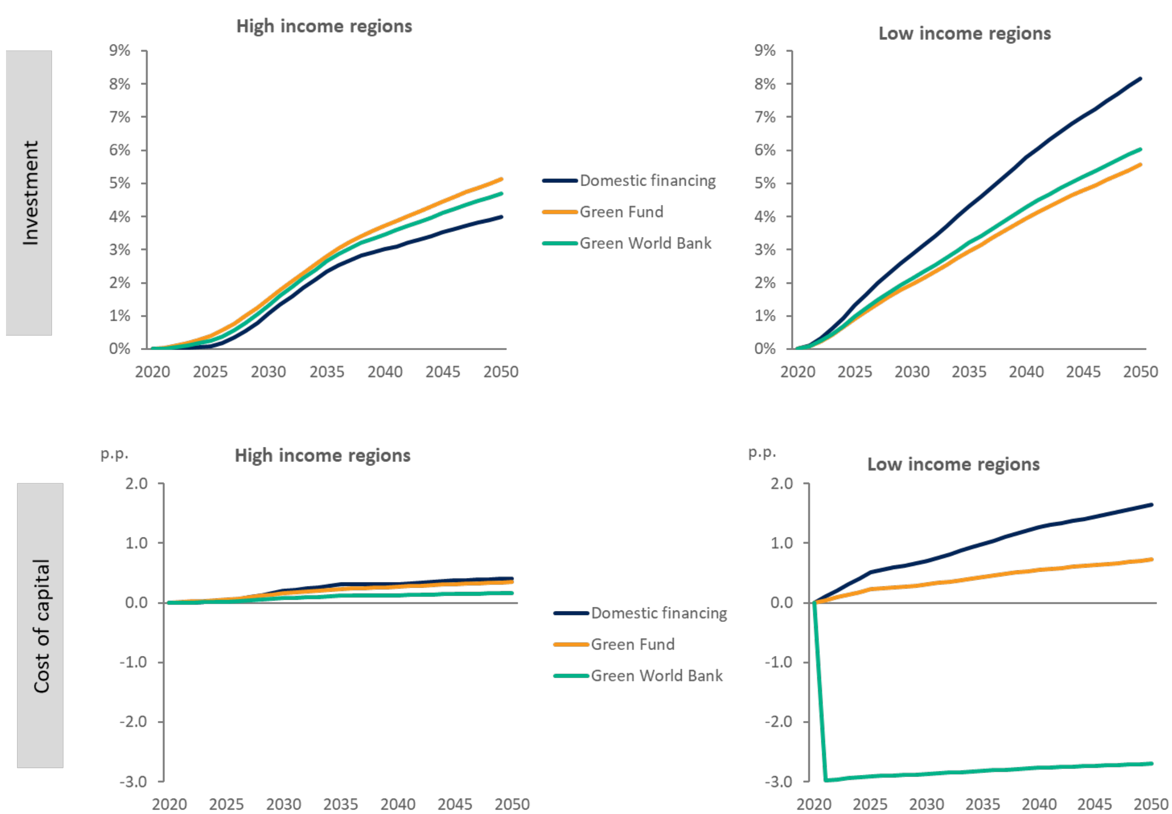
In the Domestic Financing scenario, the difference in consumption loss by 2050 is significant (-3.3% for high-income countries vs -6.0% for the low-income group). This imbalance decreases in the Green Fund scenario (-3.9% vs -4.4%) and is even reversed in the Green World Bank scenario (-4.3% vs -4.0%). In other words, the global financing mechanisms which decrease the high-income countries' consumption by 0.6 to 1% may at the same time lead to a

disproportionate improvement in the situation of citizens of the low-income country group (1.6-2.0% increase in consumption levels).

4.2.2 Investment and cost of capital

The increased investment effort on the level of individual companies translates to shifts in the macroeconomic aggregates. The scale of these changes depend not only on the sum of the additional overnight costs of investment borne by investors but also on the financing mechanisms, as these affect the costs of capital and its accessibility in both high and low-income countries. MEWA captures these effects by the financial frictions of the production firms accompanied by the differentiated access to the domestic and international savings. This allows us to capture how the different financing mechanisms across the scenarios affect the total macroeconomic demand for capital and its costs for investors. Note that the former is different than direct, overnight costs of low-carbon investments, due to the increased interest rates and cross-sector reallocation of investment flows induced by the transformation. For investments and interest rates, the deviation compared to the Reference scenario and the differences between the Domestic Funding and alternative scenarios are much more significant in low-income countries than in high-income ones (Figure 20).

Figure 20 Deviation of total investment and costs of capital from the Reference scenario in high- and low-income country groups, 2050



In all cases, increased investment effort leads to an increase in the cost of capital (WACC), as it must be financed either by domestic savings or taxation (Green Fund). The only exception is the Green World Bank scenario, which introduces lower-cost of credit for the low-income economies thanks to the discretionary shift in the international financial system granting them easier access to cheap capital by reducing the risk premium and credit constraints. However, this momentarily decreases the cost of capital in the low-income countries by 3 percentage points. Relative to this new lower-cost of credit system, costs of capital then increase up to 2050. We assume that this mechanism has little costs for savers in the high-income countries as it is primarily introduced via less strict requirements of the central banks in high-income regions (lower reserve rates), that allow them to finance increased demand for international money coming from the low-income countries without the need to increase the level of domestic savings. As the lending activity of the Green World Bank is not limited to the low-income economies, capital costs in the high-income group rise less than in the Domestic Financing scenario.

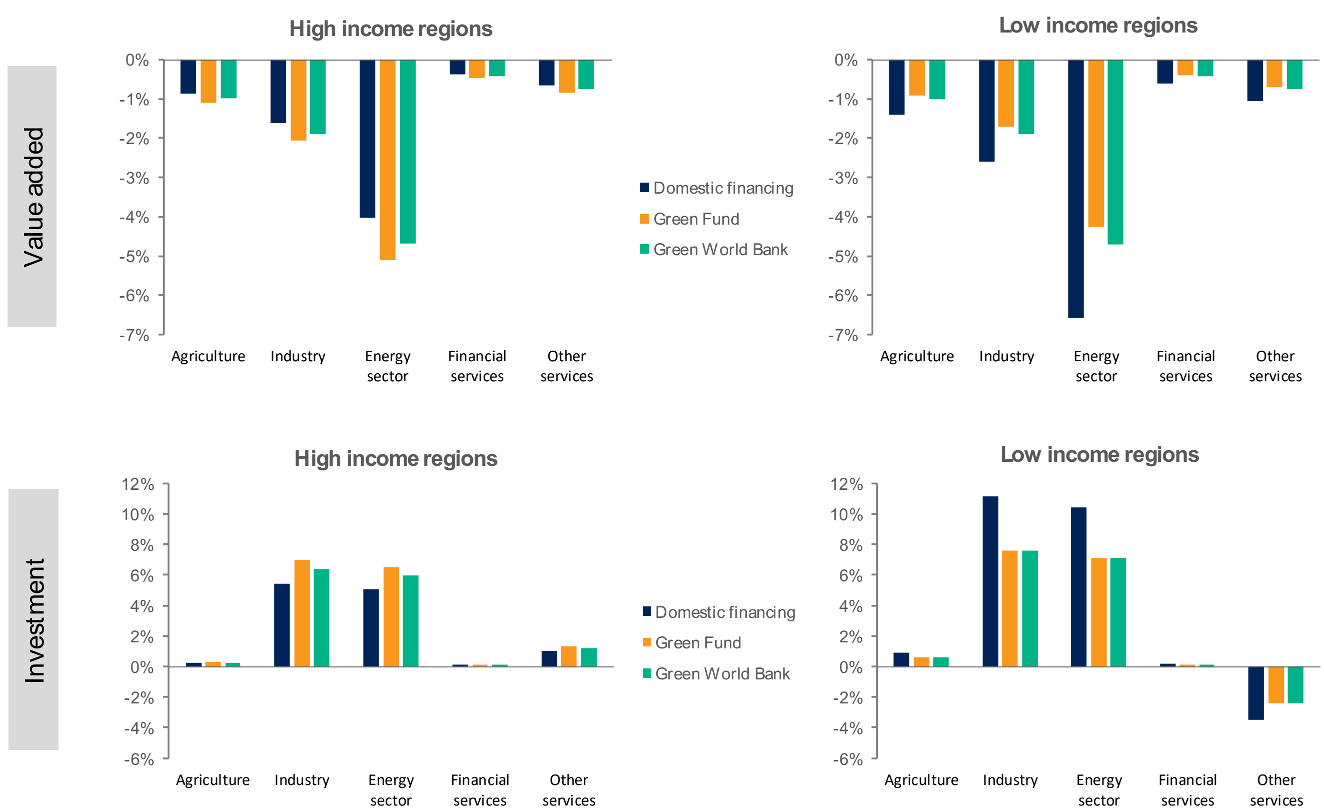
On the other hand, direct transfers financed through increased consumption taxation in high-income countries introduced in the Green Fund scenario lead to lower cost of capital compared to the Domestic Financing scenario in both high-income and low-income countries. This is explained by the different macroeconomic effects which dominate in each group of countries. In high-income countries, increased taxation required to finance the transfers within the Green Fund leads to the relative decrease in the economic activity, slightly decreasing the demand for capital, which in turn lowers its costs by approximately 0.06 p.p. compared to the Domestic Financing scenario. In low-income regions, the Green Fund affects mainly the supply of the capital, which also decreases its costs. The impact on WACC compared to the Domestic Financing scenario is more pronounced than in the high-income group, reaching -0.9 p.p.

4.2.3 Sectoral impacts

In all scenarios considered, sectors with the highest deviations of value added and investment from the reference scenario are energy and industry. This is due to the fact that most of the investment efforts considered in this analysis are concentrated in these sectors. In high-income countries the drop in value added in the power sector varies from -4.0 to -5.1% depending on the financing scenario, while in low-income countries it ranges from -4.3 to -6.6%. In the industry sector these numbers are three times smaller. The agriculture sector is affected to an even lesser extent, while the impact on both financial and non-financial services are negligible (with small scale positive effect in investment in high-income countries and a drop in low-income countries). In general, negative shocks are higher in low-income countries in all scenarios under consideration.

Shifting from domestic financing to alternative financing scenarios improves the sectoral outcomes for all the sectors in low-income countries to a greater extent than it worsens it in high-income countries. This may be observed particularly in the energy sector, where the difference between Green Fund and Green World Bank scenarios in comparison to Domestic Funding scenario amounts to more than 2 ppt. in avoided value added decrease, while for high-income countries the sectoral value added drop deepens by less than 1 ppt. Similar, albeit more moderate effect may also be observed in the industry sector. The scenario differences are evenly distributed across the sector since the financing schemes are implemented not on the sectoral level but rather on the level of the economies as a whole.

Figure 21 Deviation of sectoral value added and investment from the Reference scenario in high- and low-income country groups, 2020-2050



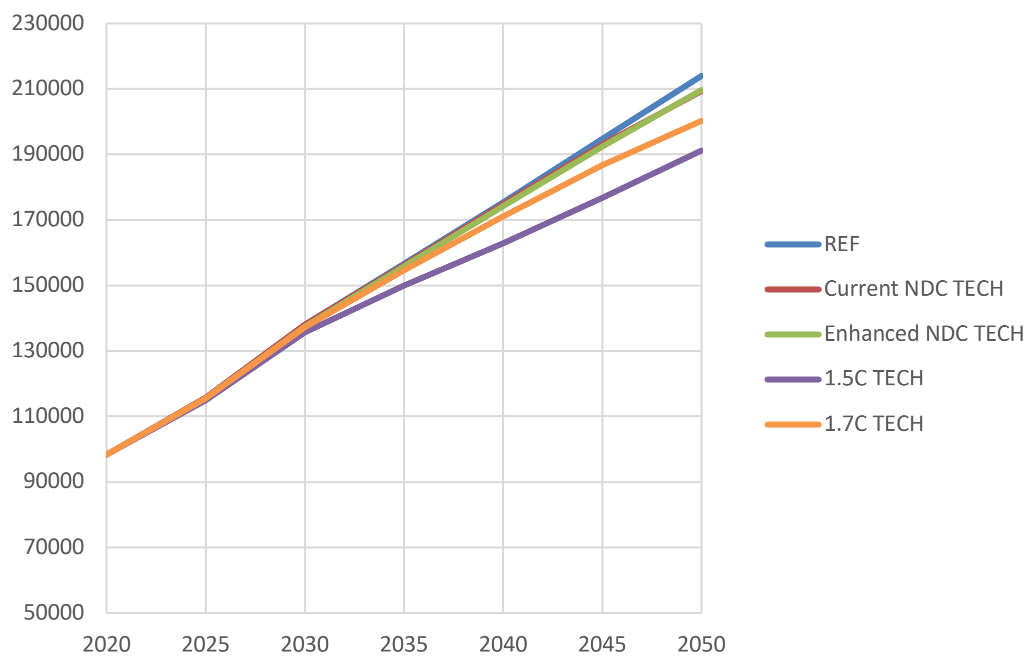
In all scenarios, there is no full crowding-out effect in high-income countries, while in low-income countries there is a negative impact on investment in non-financial services (2-4% drop depending on the scenario). Both direct transfers and provision of low-cost capital from high-income countries to low-income countries mitigate this effect.

4.3 Macroeconomic impacts

4.3.1 GDP results

Here we provide results in terms of GDP change against the ENGAGE REF scenario for the various scenarios run in ENGAGE (Figure 22). In the Current NDC TECH and Enhanced NDC TECH scenarios global GDP growth increases over the period 2020 to 2050. However, in 2050 the level of GDP in these scenarios is around 2% lower compared to the baseline REF showing the fairly minimal impacts of climate policy towards 2°C. When climate ambition is increased towards 1.5°C there are greater GDP impacts. While relatively small in 2030 these increase to around 6% and 10% in 2050 for 1.7C and 1.5C, respectively. In terms of annual average GDP growth rates, the world economy is expected to grow at a similar rate (~3.5%) during the 2011-2030 period under the different scenarios. However, during the 2031-2050 period, the growth rate in the Current NDC TECH and Enhanced NDC TECH scenarios are 0.1% lower than in REF (around 2.2% compared to 2.1%, respectively). Compared to REF, the annual average growth rate of the GDP declines by 0.3% in the 1.7C TECH scenario and by 0.5% in the 1.5C TECH scenario during the 2031-2050 period.

Figure 22: Global GDP (billion USD)



However, as the focus of the deliverable is on climate finance then we also provide GDP impacts on the three potential finance scenarios which are implemented in a similar fashion as to the MEWA analysis above. In particular, the following results in Figure 23 and Figure 24 show the aggregate GDP loss against the REF for the various finance scenarios for 1.7°C for

both high- and low-income regions. For the low-income regions both the Green Fund and Green World Bank scenarios reduce the negative impacts of the climate ambition to around 4% or 5% GDP loss against REF in 2050 compared to the instance where countries self-finance which results in a reduction of around 8%. Therefore financing options can play a significant role in limiting the impacts of nations which will find it difficult to finance their own transitions towards a low-carbon future.

For the high-income regions the opposite effect is in place as these regions provide the extra finance and as such see a negative impact as their capital is diverted away from domestic investment towards other regions. However, this finding is partly due to the nature of CGE models which assume crowding-out of investments. It is possible to imagine that with a proportional increase of domestic savings to compensate part of the capital diverted, the lower growth would be more moderate. Overall these results show that climate ambition towards 1.7°C, without any finance structures in place, would have a greater impact on the low-income regions, at around 8% lower than the REF, compared to the impact for high-income regions which is around 5% lower than REF. Given the principles of the Paris Agreement then it makes sense to share the mitigation burden in a fairer and more equitable manner using financial mechanisms.

Figure 23: GDP - High-income regions (billion USD)

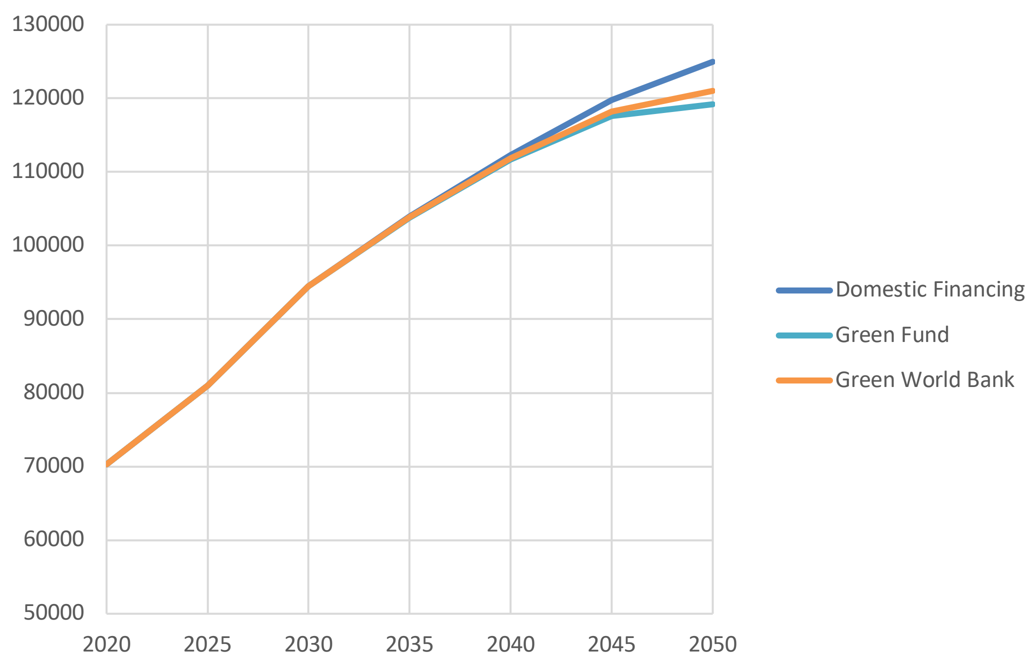
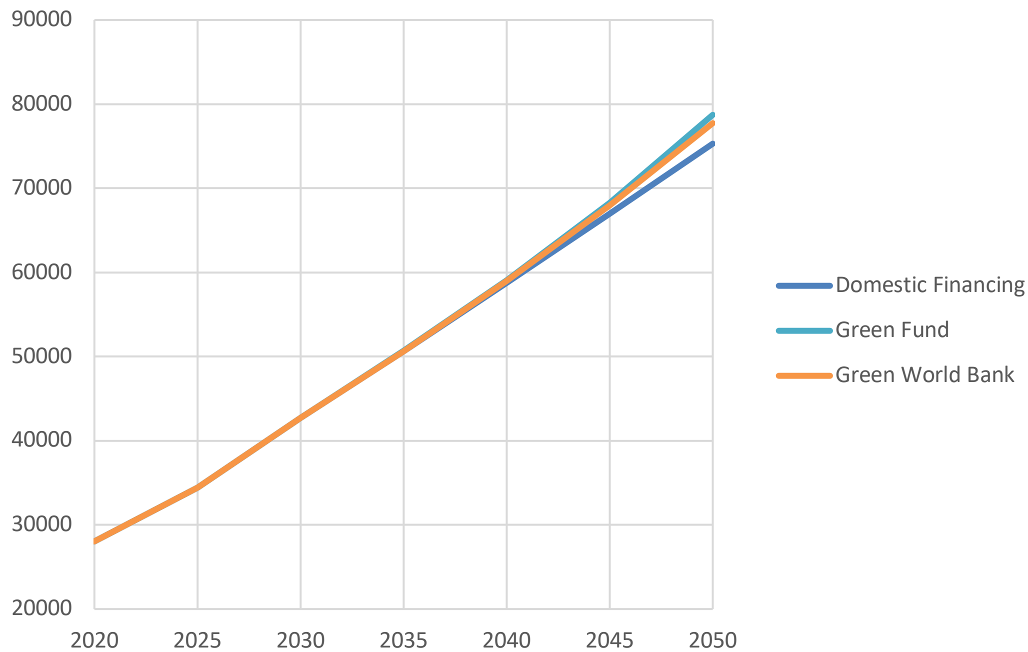


Figure 24: GDP - Low-income regions (billion USD)

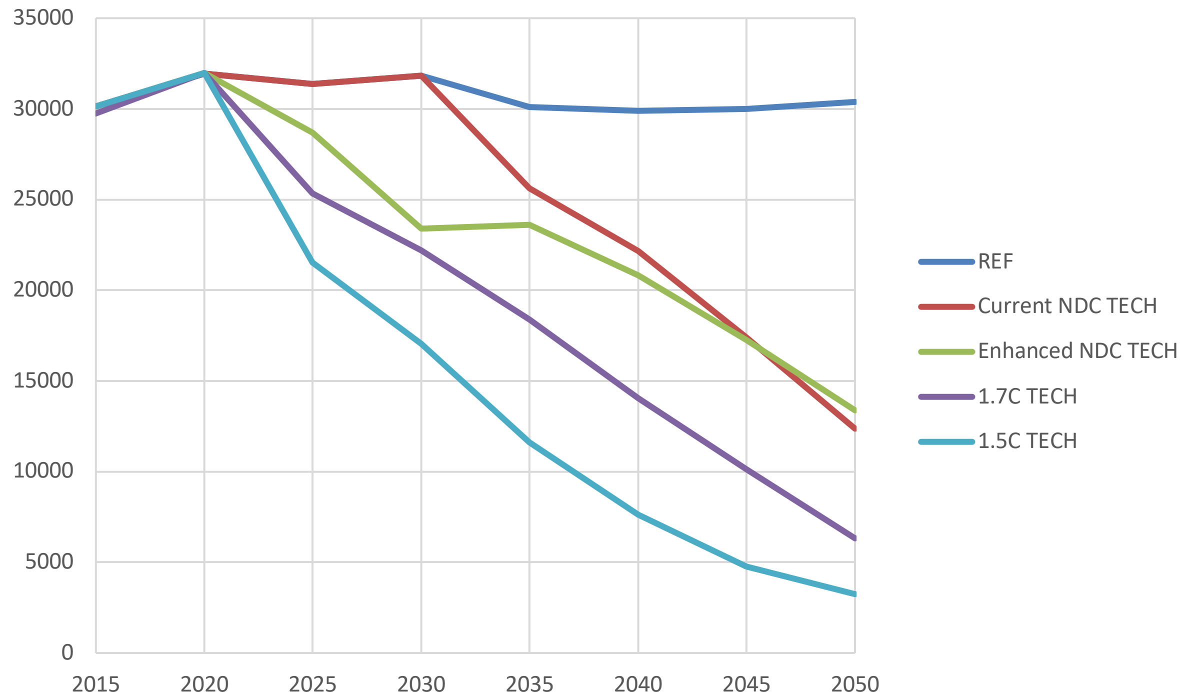


4.3.2 Emissions

Here we discuss the CO_2 emissions in the various RIPPLES scenarios for ENGAGE.[12] As can be seen from Figure 25 the ENGAGE emissions follow the same pathways as the TIAM-UCL model. The overall levels are different due to the fact that the ENGAGE coverage, as opposed to TIAM-UCL, only accounts for emissions from fossil fuel use and not for process emissions, plus there are also differences in base year calibration.

[12] We omit any discussion on emissions in relation to the finance scenarios as even across regions the emissions are all very similar.

Figure 25 Global CO_2 combustion emissions by scenario (Mt CO_2)



At the sectoral level, in 2030 the 1.5ºC scenario already sees a substantial drop in emissions across all sectors relative to the REF, ranging from 15% in transport to almost 70% in electricity, showing that the majority of short-term decarbonisation must occur in the latter sector. There is not much difference between the 2ºC and 1.7ºC emissions across all sectors in 2030. In 2050 agricultural, electricity and service sector emissions reduce by over 50% across all scenarios and so does industry although not by quite the same extent. There is a substantial difference across scenarios for emissions in the transport and fossil fuel extraction sectors in that those scenarios which go towards 1.5ºC have significantly larger reductions in emissions. (See Appendix - ENGAGE for sectoral emissions over time).

Figure 26 Global sectoral CO_2 emissions change % against REF in 2030 by scenario

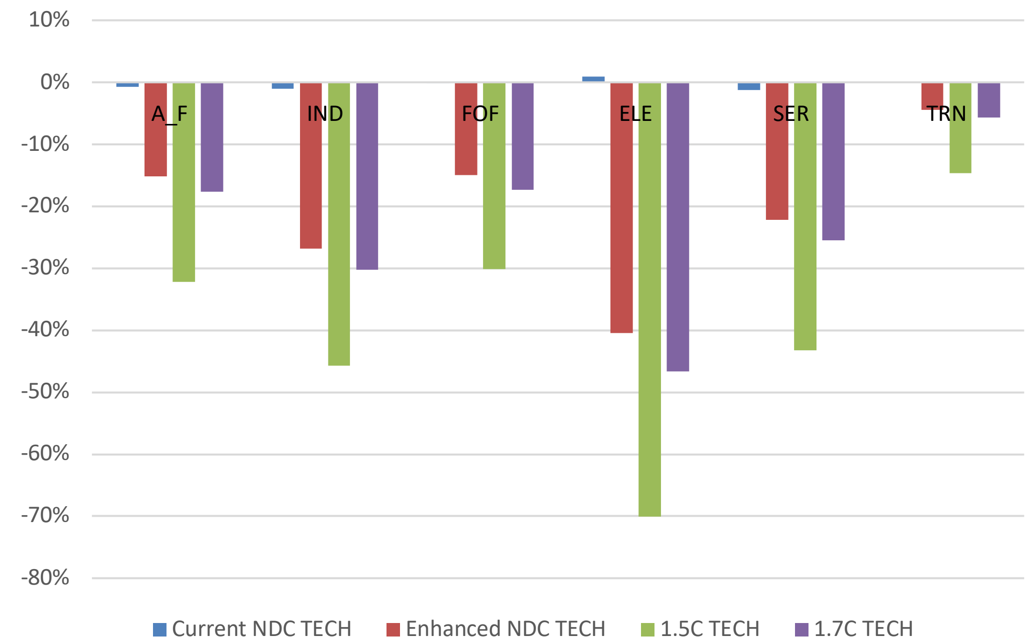
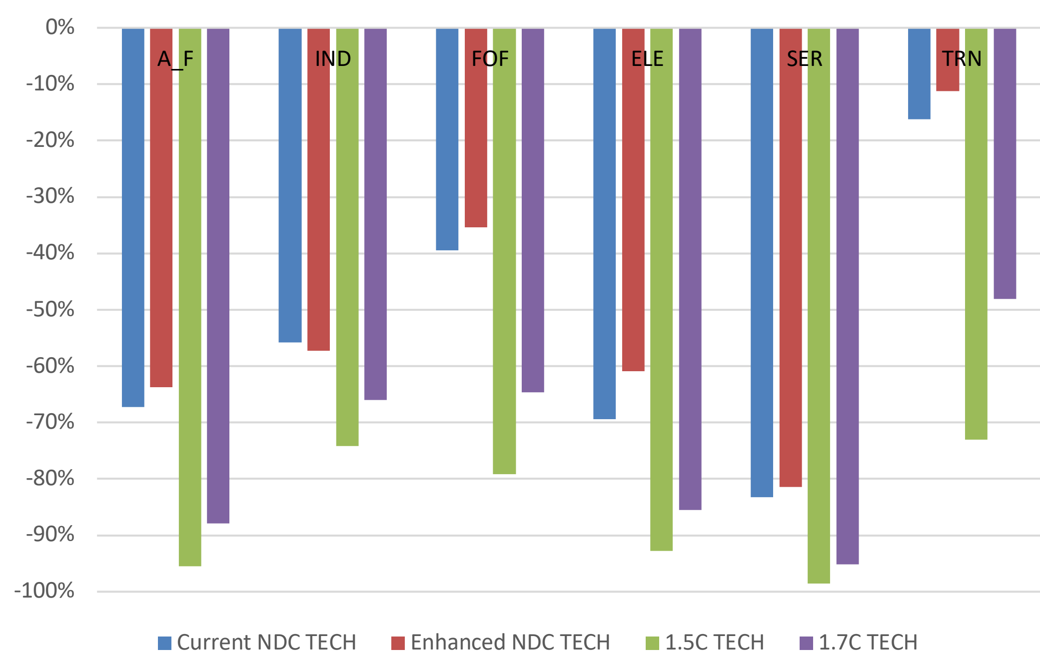
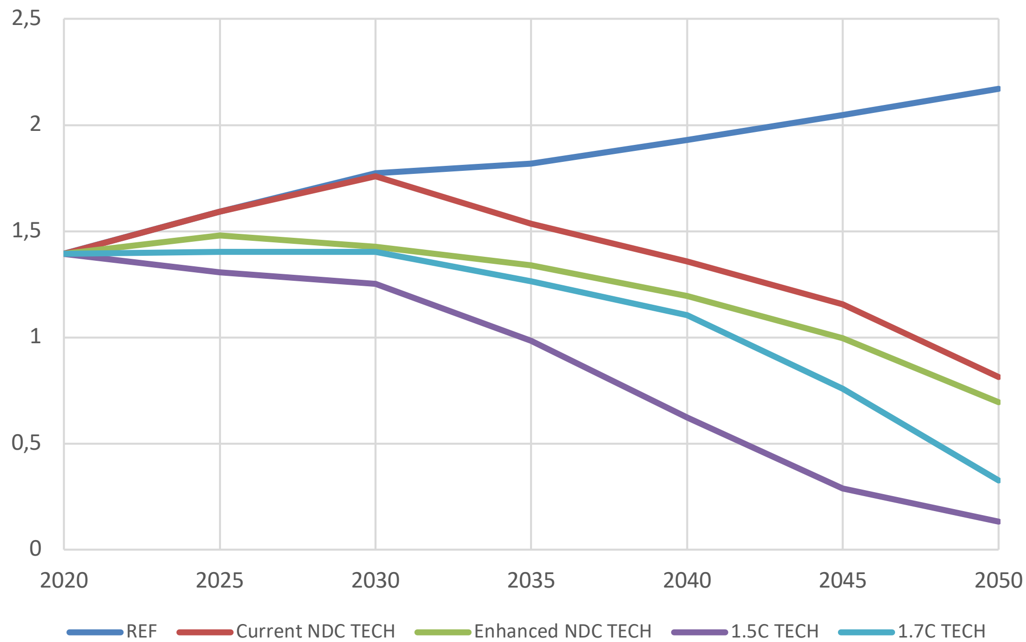


Figure 27 Global sectoral CO_2 emissions change % against REF in 2050 by scenario



Emissions from Households (as defined by the household sector in the GTAP dataset e.g. includes private transport demand etc.) are presented in Figure 28. It shows emissions relative to 2011 The results show a doubling of emissions in the REF by around 2043. However, all scenarios that are not fixed to the REF and therefore allow for emissions reductions from 2020 i.e. all except Current NDC, do not exceed a 1.5 times increase compared to 2011 levels and all begin to fall by the late 2020s. The changes in emissions from household purchases will come from substitution away from fossil fuel use towards substitutes e.g. electricity.

Figure 28 Household CO_2 emissions indexed to 2011



4.3.3 Sectoral production results

Here we provide more detail on sectoral production results at the global level and also for the various 1.7ºC finance scenarios.

Figure 29 provides production changes in monetary terms over time relative to the REF for the various economic sectors. Agricultural production does not alter much in any instance, between +0.6% and -0.8%, however, it does see a relative increase in the 2ºC scenarios from the increased efficiency assumptions. In the 1.7ºC scenario there is an increase in agricultural production from 2020 until around 2040 when it begins to reduce to about the same level as the REF in 2050. The 1.5ºC scenario sees a more from late 2030s the output is lower than that of the REF mostly due to crowding out of capital. In the higher climate ambition scenarios the

crowding-out effect is larger than in the lower ambition scenarios e.g. Current NDC and Enhanced NDC.

The largest difference between scenarios occurs for the Fossil fuels extraction and production sector which, as expected, reduces in all scenarios compared to the REF. Although these vary quite significantly as by 2050 these are around 15% lower than the REF in the two 2^{o}C instances while they are over 40% and 60% lower in the 1.7^{o}C and 1.5^{o}C scenarios, respectively. It should be stated that fossil production in the REF scenario is roughly flat throughout the model period.

Also, electricity production increases substantially as electrification plays a key role in decarbonisation in all instances in the near-term, and by 2050 the difference is between 35% and 49% higher, depending upon the level of climate ambition, than the REF where only continued NDC ambition is enacted.

Industrial sector production is higher than the REF for all scenarios, driven by an increase in efficiency, except the 1.5^{o}C scenario which sees a relative drop although around less than 1% lower. The Services sector sees a relative difference in production of +/- 1.5% by 2050 depending upon the level of climate ambition. Transport production is similar to Services in that all scenarios except the 1.5^{o}C instance provide a positive output impact compared to the REF although the scale is slightly larger. However, interestingly there is a larger negative impact in the 1.5C instance but that growth in production increases again beyond 2045 towards 2050. This is explained by a combination of a growing carbon price and the continuous increase in the elasticity of substitution between electricity and non-electric energy inputs, i.e. we expect that after 2045 the transport sector would shift towards a higher use of cheap electricity as fossil fuels prices are continuously increasing.

Figure 29 Percentage change in global sectoral production by scenario (Note the different y-axes)

When the various financing options are considered for the 1.7^{o}C TECH scenario then the impacts on production differ between high- and low-income regions. Production in the Agriculture sector by 2050 differ across all scenarios in the two regions. In the standard self-financing option there is a small positive impact on high-income regions and a slightly larger, though still less than 0.5%, negative impact on low-income regions. However, the financing options (Green Fund and Green World Bank) produce a negative impact in the high-income region and a larger positive impact in the low-income region. The Green World Bank option tends to dampen the impact as the low-income region still receives the benefit of cheaper finance but has to pay back the loan over time.

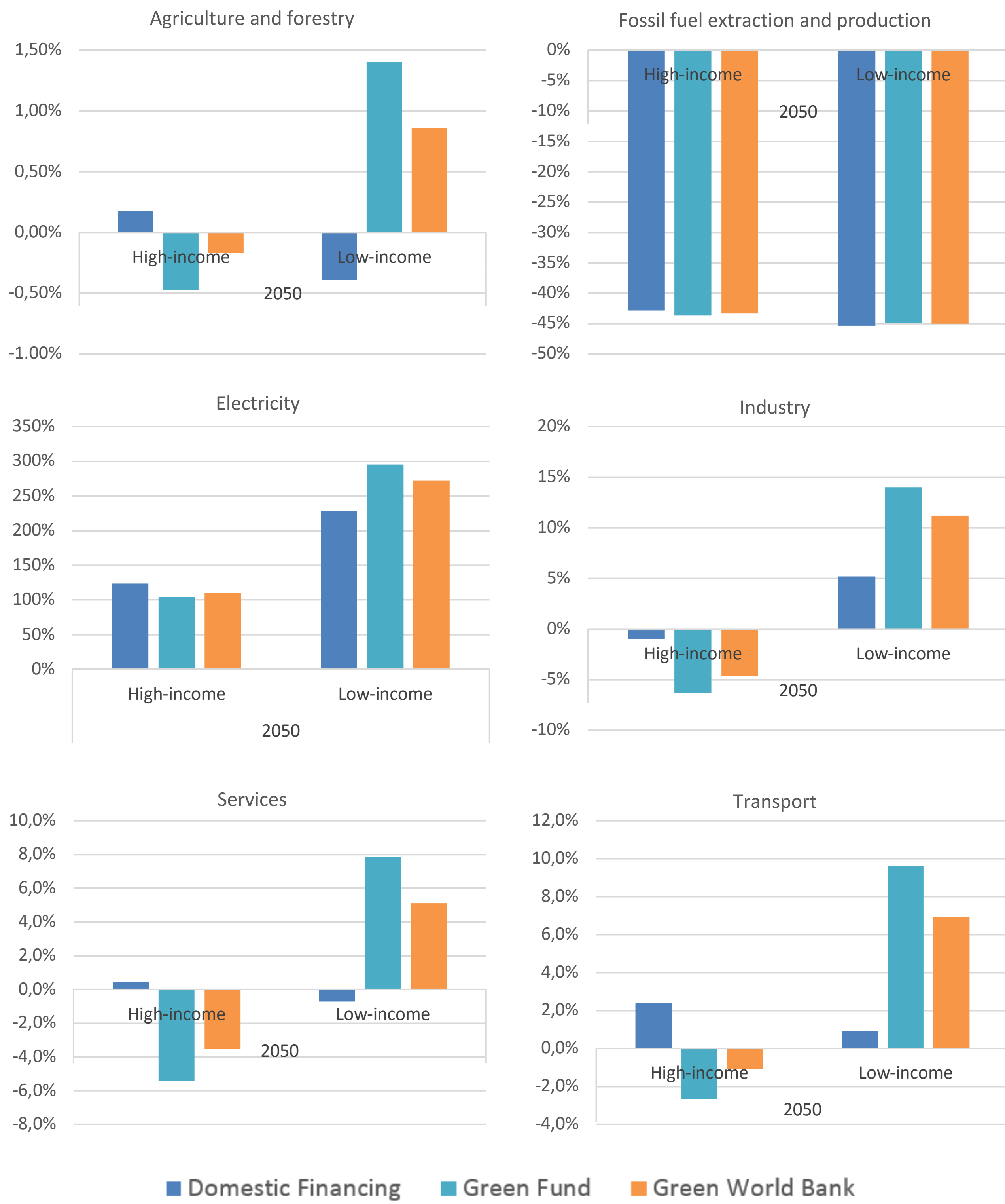
For the fossil fuel extraction and production sector there is a fairly uniform drop across all scenarios in 2050 in high- and low-income regions of over 40% relative to the REF. If taken alone within this sector then coal and gas declines by more than 80 percent, but Oil and P_C do not decline by so much because these sectors both contribute as well to produce other inputs as chemicals, plastics etc., that are essential for the production of other goods and services. Electricity production in 2050 for high-income regions increases relative to REF by over 100% for all 1.7^{o}C financing scenarios although the increase is not as much when through Green Fund or Green World Bank. For low-income regions the increase against the REF baseline is 229% for the self-financing 1.7^{o}C option and 296% and 272% higher than REF for the Green Fund and Green World Bank cases.

In the high-income region the Industrial production reduces slightly for all the financing scenarios, though more so for the ones where transfers are undertaken, 5% and 6% compared to 1% in the standard case. Industry production increases in all instances for the low-income region but by almost triple for green fund and double for the Green World Bank compared with the self-financing option.

Production in the Services sector changes by +0.5% and -0.7% in the high- and low-income regions respectively, relative to the REF, in the self-financing 1.7^{o}C TECH scenario. However, when Green Fund and Green World Bank scenarios are implemented the opposite impact is felt and the high-income region incurs a reduction of -5.4% (Green Fund) and -3.5% (Green World Bank) while the low-income region incurs an increase of 7.8% (Green Fund) and 5.1% (Green World Bank) in 2050 all against the relative REF.

The transport sector is positive in both regions in the self-financing standard option with the high-income region increase by more at around 2% relative to REF. However, the Green Fund reduces transport in the high-income region by about 2% and increases in the low-income region by almost 10% while the Green World Bank has a similar effect but dampened slightly in both regions.

Figure 30 Percentage change in sectoral production in high- and low-income regions in 2050 against REF baseline



Part B – Qualitative analysis of financial mechanisms for decarbonisation

5 The qualitative aspects on finance

This section provides details on the qualitative aspects of finance focusing on the main financial instruments currently employed by investors and public institutions, the main barriers to investment and potential policy solutions to overcome such barriers. Indeed, achieving Paris climate goals will strongly depend on the availability of financial flows to support defined decarbonisation pathways. To that end, attracting investors will require the implementation of appropriate policies to overcome specific barriers, create a favourable investment environment and ensure the effective use of public money to further leverage private investments.

5.1 Overview of the financial instruments, their assessment and landscape

5.1.1 Commercial rate finance vs concessional finance

The available studies that evaluate the annual landscape of climate finance flows at the global scale (e.g. CPI 2018, OECD 2018, UNFCCC 2018) assess the investments financed via instruments which fall into two main categories – concessional and commercial. Instruments that can be classified as concessional are grants and low-cost loans, whereas the project-level debt, equity and balance sheet financing are examples of capital instruments that are being operated on commercial terms.

Overview of the investments in the climate change mitigation and adaptation measures carried out in the period of 2013-2016 by CPI (2016a, 2018), shows that most of the investments were made with the expectation of earning commercial returns Table 7. Commercial rate finance channelled through the instruments such as balance sheet financing, project-level equity and market-rate debt increased from $255 billion in 2013 to almost $400 billion in 2016. Such increase in volumes was accompanied by the increase in the share of commercial financing in the total volume of climate finance from 75% in 2013 to exceed 85% in both 2015 and 2016. The majority of commercial rate climate finance was deployed as loans, which volume has almost tripled over the period of 4 years reaching $215 billion in 2016 i.e. almost 50% of all climate finance flows.

According to the CPI data (CPI 2016, 2018), the balance sheet financing (equity portion), remained the second most important financing vehicle, despite the volumes of investments made on companies' balance sheets decreased sharply in 2016 by almost $40 billion from 2015 reaching $142 billion. As mentioned earlier in the introduction, this trend mainly reflected the falling costs of renewables and the reduced investments in terms of renewable installed capacity (CPI 2018). Conversely, the significance of the other form of the equity investments –

the project equity has increased over the years (from $17 billion in 2013 invested as project equity to $36 billion in 2016).

Table 7 Global climate finance by instrument (USD billion) (CPI 2016, 2018)

Type of financing	Instrument	2013	2014	2015	2016
Commercial rate finance	Balance sheet financing	164	177	179	142
	Project-level equity	17	27	40	36
	Project-level market rate debt	74	125	190	215
Concessional finance	Grant	13	13	18	18
	Low-cost project debt	74	48	45	45
Total		*342*	*390*	*472*	*456*

The CPI's global climate finance landscapes (2016, 2018) show that the volume of financial flows deployed as concessional finance has decreased over the years from $87 billion in 2013 to $63 billion in 2016. The drop can be attributed to the decrease in the volume of investments channelled as low-cost project debt. Although in 2013 just above $74 billion of climate finance were invested as the low-cost project loans, already in 2015, the value of climate finance transferred as a concessional debt did not exceed $45 billion. At the same time, a much smaller share of climate finance has been disbursed through grants which value over the period of 2013-2016 remain relatively constant and did not exceed 5% of total climate finance flows.

5.1.2 Instruments used by public and private sector

Assessment of climate finance flows between 2013 and 2016 shows a clear shift away from the use of concessional instruments by public stakeholders, which in 2013 and 2014 accounted for approximately half of the climate finance flows (CPI 2016), towards the use of commercial rate finance. In 2015-2016 public investments amounted to 46% of total climate finance flows of which approximately 75% has been deployed through project-level market rate debt (CPI 2018). This correlates with a change in the investment strategy of the National Development Finance Institutions (DFIs) – in 2013 low-cost loans accounted for almost 70% of their financing, whereas in 2015 and 2016 for less than 30%. Bilateral DFIs were the other major source of the

low-cost loans – although the total volume of their commitments was over the years much smaller than that of National DFIs, more than two-thirds of their contributions were deployed as low-cost loans. The remainder of the climate finance flows driven by the Bilateral DFIs was invested through project-level market rate debt. Conversely, more than 80% of Multilateral DFIs' investments were financed with market-rate loans and only a minor share of the total as concessional (CPI 2018, MDBs 2018). Equity investments by public stakeholders across the analysed period accounted for only a small portion of the total – according to the data provided by the OECD in 2018, they did not exceed 6% of the total of bilateral and multilateral public climate finance (OECD 2018).

While DFIs predominantly disbursed their funds through loans (concessional and non-concessional), governmental entities and climate funds have used grants as one of the main investment vehicles – in 2014 approximately half of their respective commitments were financed through this instrument (CPI 2015a). It has been assessed that approximately 40% of almost all of climate finance flows reported by the EU Member States in 2016 has been channelled through grants, with some countries such as Netherlands and Sweden using them as a sole instrument (100% of climate finance in 2016 provided as grants) and other member states like France and Germany putting less emphasise on grants (6% and 38% respectively) and favouring other concessional non-grant instruments (Appelt and Dejgaard 2018).

Balance sheet financing has continuously been the most important instrument from the perspective of private sector stakeholders (CPI 2016a, 2016b, 2018). Corporate actors, as well as households, have invested almost all of their contributions using the balance sheets financing, similarly, more than 80% of financing provided by the project developers to address climate action relied on this instrument. The remainder of the share of the project developers' contributions has been channelled as project-level equity and project-level market-rate loans.

5.1.3 Matching the right instruments with the objectives

The preference of financial instruments reflects investors and institutions' objectives. DFIs using concessional instruments aim to facilitate the redirection of global financial flows towards low-carbon investments predominantly through the reduction of risks and incremental investment costs i.e. the difference between the cost of investment in the low-emission investments and these that would result from the business as usual development strategy (Gupta et al 2014). While the use of instruments that operate on commercial terms rather aims to spread the risks facilitating the more active engagement of the private sector stakeholders in the market.

On the other hand, public entities have used grants to reduce upfront costs, to promote early-stage technologies as well as to advance the process of capacity building and support investments in the projects that lack business models that would appeal to investors. This is

often the case with investments that enhance the resilience of the economy to the effects of climate change. Over the years, grants have remained the main source of adaptation finance, whilst in the majority of cases investments in mitigation have been channelled through non-concessional instruments. OECD estimates that more than 90% of adaptation project financed by MDBs and more than 60% of the projects financed through bilateral DFIs were financed through grants (OECD 2018a).

Private investments almost exclusively support mitigation projects, the majority of which targets renewable technologies, and are conducted through balance sheet finance and to a lesser extent through project-level equity. Such trend is in line with global patterns. Data provided by IEA (2019) shows that in 2018, 85% of investments in the power sector were financed on the balance sheets of companies. The same dataset also reveals growing importance of project finance as a financial vehicle for financing renewables and specifically the development of utility-scale renewable energy projects – between 2013 and 2016 the volume of investments financed through project financing increased by as much as 25% (IEA 2019).

5.1.4 Mobilisation of private funds

Currently, the CPI's global climate finance landscapes (CPI 2016a, 2018) do not capture financial instruments associated with de-risking interventions such as guarantees or insurances. This is because the addition of these values carries a risk of double counting against project investment costs. However, these uncaptured instruments potentially could have the highest leverage to mobilize private investments (Benn et al. 2017, CPI 2018), which have been estimated to represent at most 5% of the financial commitments.

Over the period of 2012-2015 Benn et al. (2017) estimate that guarantees provided by bilateral and multilateral providers mobilised the largest amount of financing (41%) and syndicated loans were responsible for the mobilisation of almost 30% of private finance. Almost 70% of the mobilised funds were invested in mitigation actions and specifically in the energy sector (Benn et al. 2017). Moreover, studies that closely monitor the state of public climate finance such as Benn et al. (2017) or MDBs (2016,2018) show that the volume of mobilized private climate finance systematically increases – in 2014 national, bilateral and multilateral providers mobilised as much as $5.1 billion and in 2015 already $7.2 billion. Furthermore, according to data provided by the MDBs, they have also recorded a 40% increase in mobilised private finance between 2015 and 2016 when it reached $15.6 billion (MDBs 2016, 2018).

5.2 Main barriers hampering low-carbon investments

This section presents an overview of the frictions and barriers hampering low-carbon investments, and thus it provides an explanation of why optimal pathways are not always selected.

A key factor in investment decision is the risk-adjusted return, a measure that estimates the return an investment will generate given the level of risk associated with it (Modigliani and Modigliani 1997). This measure is particularly crucial, as it enables investors to compare the potential performance of a high risk but high return investment with low risk but low return investment. Low-carbon investments entail a set of significant barriers, which often produce risk-adjusted returns below those produced by other, more traditional investments (Kaminker et al. 2013).

The main barriers to low-carbon investments are grouped into three categories to disentangle issues linked to (1) the climate policy framework, (2) market conditions (the financial system itself, respectively the impact of existing finance market structures), and (3) investors' practices. (the specific characteristics of investors operating in the financial system).

Barriers linked to the policy framework

Barriers linked to the policy framework mainly include the lack of policy certainty and stability, which increase investors' perceived risks surrounding low-carbon investment, along with the presence of fossil fuel subsidies.

Concerns about stability and clarity of policy instruments for low-carbon projects, and related rules and processes, are the main barrier to investment (Polzin et al. 2017; Kaminker et al. 2013). Hamilton (2009) points out that stable energy policy and regulatory framework is the critical element influencing where capital is deployed, as certain regulatory structures provide clarity on economic returns and investment timescales. A key example continues to be support mechanisms for renewable electricity, such as feed-in tariffs (FiT) which offer long-term contracts to renewable energy producers (usually 20-year), providing return predictability to investors. With generous guaranteed rates of return, the cost of these instruments may rapidly increase as technology costs decline. Without pre-defined adjustment mechanisms, political pressure to abruptly introduce (perhaps extensive) changes may rise. Such retroactive policy changes are likely to concern investors and impact their willingness to invest. A recent example is the case of Spain, where between 2010 to 2013 retrospective cuts on remuneration for solar PV, wind and concentrated solar power were introduced (EREF, 2013).

Low-carbon assets also suffer from current incentives that favour investment in incumbent technologies reliant on fossil fuel over renewables and energy-efficient technologies. The IMF

(2019) has estimated that globally subsidies to fossil fuel consumption[13] amounted to $4.7 trillion in 2015 and are projected at $5.2 trillion in 2017. In this way, incentives to fossil fuels create pricing distortions that work against low carbon technologies.

Barriers linked to market conditions

Barriers linked to the market conditions span from the shortage of historical data and indices for benchmarking investment, to the lack of pipeline of bankable projects together with their small size, and the lack of appropriate investment channels and tradable instruments.

The lack of high-quality data and standard reporting frameworks to allow appropriate due diligence and strategic planning process is a key barrier to low-carbon investment (Kaminker and Stewart 2012). Examples of such data include financial performance data, and data on market risks related to climate liabilities embedded in corporations' assets or investors' portfolios, like expected GHG emission reductions, carbon pricing implementation (e.g. scope and price level), exposure to other market (e.g. policy alterations) and climate (e.g. physical) risks. Although, growing efforts on climate risk disclosure (Carney 2015, TCFD 2017), data related to CO_2 intensity remain lacking. This shortage of objective information and historical data to assess low-carbon assets and associated risks seem to impede their further take up.

The lack of green indices for benchmarking investment is another factor hampering investment in low-carbon assets. Most investors' portfolios are invested largely or entirely in line with stock market indices, but as currently constituted, those indices are not aligned with climate targets. Major indices such as MSCI World, Stoxx 600 and S&P 500 are overexposed to fossil fuels industries and petrol/diesel cars, and underexposed to renewable energy and electric cars (Thomä et al. 2015a). By following the current indices, investors are mainly supporting sectors included in these indices, namely fossil fuels assets, and supporting scenarios targeting 4 or 5 Celsius degrees as the representation of low-carbon industries in the stock market is significantly lower than their current contribution.

Moreover, the lack of bankable projects pipeline together with their limited scalability given the small project size, may offer unattractive returns to investors. Few countries have defined clear climate roadmaps with associated project pipelines that are needed to attract investments. The small size of the projects also may make them less attractive to investors, as modest projects

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[13] Defined as fuel consumption times the gap between existing and efficient prices (i.e., prices warranted by supply costs, environmental costs, and revenue considerations), for 191 countries.

involve the same transaction and diligence costs as larger once as well as the attention of a limited pool of qualified staff. This is why investors tend to focus on larger projects. For instance, several studies suggest that minimum investment values for institutional investors is between $350 and $700 million (Nelson and Pierpont 2013).

Finally, there are also issues linked to the lack of investment channels to invest in low-carbon assets. Direct investment channels are relevant particularly for large investors because of the associated costs of retaining internal expertise. Indeed, the high fixed costs of maintaining an internal dedicated team imply that the direct investment portfolio must be of a certain size and/or the investor has a strong interest in low-carbon assets. Smaller investors tend to prefer indirect investment channels, transferring the selection and monitoring functions to a specialised manager. However, indirect channels come with high fees, as investment funds and external managers usually demand a 2% management fee plus a 10-15% performance fee, reducing final returns (Ameli et al 2019). Both direct and indirect investment strategies entail high transaction costs (e.g. investment appraisal and due diligence for direct investing, and high management and performance fees in indirect channels) that prevent investment in low-carbon assets.

Limited investment in low-carbon assets is exacerbated by the shortage of tradable financial instruments[14] matching investors' asset allocation. This is particularly critical when preferences and portfolio allocations of investors, are heavily concentrated around liquid instruments. Green bonds could be a promising liquid instrument to channel low-carbon investment, however they account for only a small share of the value of total bonds outstanding. At present, green bonds represent less than 0.5% of the global bond market (roughly $110 trillion), while considering the extended climate-aligned bond universe, it reached approximately 1% of the total bond market (Tissot 2018).

Barriers linked to investors' practices

Barriers linked to investors' practices relate to investors' management inexperience and track record, short investment time horizons and lack of clarity on fiduciary duty and stewardship with respect to environment, social and governance (ESG) issues.

A lack of investor capability, management experience and performance track record is widely recognised as a limiting factor to investment (Nelson and Pierpont 2013, Kaminker and Stewart

[14] Tradable (and liquid) financial instruments are assets that can be easily and quickly converted into cash with minimal impact to the price received.

2012). The relative novelty of such investments and the lack of data and operational comparisons make it a challenging sector for investors. Even where investors can see the benefits of low-carbon investment, they may not be able to accurately assess the risk profiles. Generally, smaller funds may lack knowledge and the resources to build an in-house specialised team on low-carbon assets, while other investors may feel that there are other, less risky types of infrastructure they can invest in making it not worthwhile to build the expertise needed to evaluate low-carbon projects.

Moreover, several studies suggest that current financial incentives are favoring short-termism rather long-term sustainable investing (Dupré and Chenet, 2012; Bernhardt et al., 2017; Naqvi et al., 2017). In practice, investment managers' performances are assessed frequently and short-term (usually annually or even quarterly) resulting in investment horizons ranging from less than 1 year to 5 years, which is quite short compared to the potential materialisation of significant climate-related financial risks. Investment portfolios' typical turnover of about 1-2 years (Bernhardt et al., 2017), and the horizon of financial analysis does not usually exceed 3-5 years (Dupré and Chenet, 2012; Naqvi et al., 2017), while most asset managers' incentives are based on an annual performance (Thomä et al., 2015b). Moreover, at the employee level, portfolio managers are explicitly or implicitly benchmarked on much shorter-term performance, quarterly, monthly or even weekly (Naqvi et al., 2017). Christophers (2019) also reports that investors are not worried about the implications of climate change as they do not expect physical risks of climate change will be widely and substantially evident on most of the companies they are investing in today.

A final aspect contributing to underinvestment in low-carbon assets is the lack of clarity on fiduciary duty and stewardship with respect to ESG issues. In most jurisdiction, rules do not exhaustively prescribe how investors should consider ESG factors in their investment decisions, and on the timeframes over which they define investment goals. In most cases, it is left to investors to determine the approach that will enable them to meet their legal obligations (PRI 2015). Recently, there has been significant efforts to promote ESG disclosure requirements for investors and in the use of soft law instruments such as stewardship codes that encourage investors to engage with the companies in which they are invested (PRI 2015). However, despite these progresses, many investors have yet to fully integrate ESG into their investment decision-making processes. PRI (2015) stated that "Failing to consider long-term investment value drivers – which include environmental, social and governance issues – in investment practice is a failure of fiduciary duty". In the face of such challenge, regulators, including the European Commission, have started to legislate on that issue to ensure sustainability considerations are integrated in the decision-making process (HLEG 2018).

Additional barriers impacting the risk-adjusted return of low-carbon assets are those associated with developing countries, including potential geopolitical, economic and financial market

development risks. Geopolitical risks, including corruption, political uncertainty and poor governance performance, derive from the actions of authorities exercising their legislative functions and discriminatory acts, while economic and financial risks derive from the broad macroeconomic operation of the economy, the development of the financial market and whether adequate standards for business conduct and transparency are in place. The perception of political, macroeconomic and financial risks is often very high in developing countries, and is a key factor preventing increased low-carbon investment by investors in such regions (Kaminker et al. 2013).

5.3 Incentives and policies needed

The low-carbon investment challenge encompasses several barriers linked to investors' instrument preferences, their lack of information, experience and track record, and their short-term horizon combined with weak incentives supporting low-carbon assets, lack of appropriate investment channels and long-term climate goals as well as existing incentives to fossil fuel investments. Therefore, attracting more investment towards low-carbon assets would require simultaneous policies targeting barriers linked to policy frameworks, market design and investors practices.

5.3.1 Policies

Clear and stable policy frameworks along with strong government commitments are necessary to catalyse low-carbon investment as uncertainty and expectations matter for returns on investments with long time horizons. A key element is the introduction of policy instruments that explicitly seek to incentivise low-carbon investment. Such instruments must adhere to "the three 'L's – Long, Loud and Legal" (Hamilton 2009). In the context of renewable electricity support instruments, for example, they must convey confidence to the investor that they will be in place for long enough for a return on the investment to be generated, they must target assets of a sufficient magnitude to attract institutional investors, and they must have a sufficient legal foundation to provide confidence that terms of an agreement or contract will not (or cannot) be changed once in place. To this end, governments could, for example, ensure that such instruments are sustainable in the long-run, and designed in such a way that adjustments in the face of uncertainty (e.g. rapidly decreasing technology costs) are possible, according to pre-defined and well publicised rules (e.g. degression mechanisms).

Similarly, government should encourage instruments and actions that would alter the balance of value and risk between low-carbon investments and their high-carbon equivalents, to make the former the more competitive option. This may be through action to reduce the cost of low-

carbon technologies and services, to increase the cost of high-carbon alternatives. Many researchers suggest that a mix of market-based instruments, including carbon prices, direct support mechanisms such as feed-in tariffs, capacity-based measures such as quotas and tradable green certificates, and fiscal measures such as tax incentives and rebates, is crucial to support low-carbon investment (Metcalf 2009, Fisher and Newell 2008, Haas et al. 2004, Hanson and John 2004). In parallel to implementing such incentives, removing fossil fuel subsidies is fundamental for correcting distortions in the risk-return profiles of low-carbon investments.

More recently, some scholars underlined the importance of monetary policies and central banks' reforms to enable a greater involvement of investors (Campiglio et all. 2018, Campiglio 2015). The banking system, by easing lending conditions for low-carbon investments, and relaxing macroprudential regulation, such as green differentiated reserve and specific capital requirements in favour of low carbon assets, could leverage more funds towards low-carbon assets.

Policy actions addressing market barriers should include the scale up of liquid financial instruments matching investors' expectations and the development of new green indices. Green bonds seem to be the most promising liquid instrument to channel low-carbon investment, representing a niche to be scaled up to attract more investment. Indeed, green bonds could be perceived as an appropriate way of 'piggybacking' low-carbon assets into the existing bond market structure familiar to investors. Another promising investment channel is through the use of green indices. Green indices would allow investors to increase their exposure to listed companies with superior environmental and governance performance compared to traditional ones. Investors can employ such indices for screening companies, for instance, to exclude certain activities from their portfolio, or to identify the best sustainability performance within industry groups (Baron 2014). Index investing is also the less complex and cheaper investment buy-and-hold portfolio strategy for long-term investment horizons, with minimal trading in the market (Bogle 2009). In this regard, pooling together small projects would further allow investors to reduce due diligence costs and invest at scale.

Finally, the promotion of clear and reliable data surrounding low-carbon investment performance and carbon footprint of potential investments, would help to improve market efficiency and investors' inexperience and track record. Such data would inform investors' decision-making process by supporting their due diligence procedures, their appropriate assessment of risk/return investment profiles and risk exposure from efforts to tackle CO_2 emissions. In this regard, policies requiring disclosure of relevant metrics, such as the latest policy initiatives designed also at European level (e.g. EU taxonomy of green sectors and assets, EU 2019) would allow investors to manage climate policy risk themselves.

Other policy interventions impacting investors' practices, are those related to short investment time horizons and surrounding ESG factors. Organizational reforms revising managers' incentives schemes along with the way climate risks are assessed would be critical to solve the time horizon discrepancy. For instance, linking executive compensation to meet climate-aligned corporate goals, would allow managers to set expectations for a strategy consistent with the 2°C target. Since remuneration structures are used to help deliver on the companies' objectives, this must be the starting point of engagement (Ameli et al. 2019).

Finally, policy initiatives should support efforts to make ESG disclosures mandatory and support standard practice. Experience shows that for companies above a certain size, ESG disclosure can be an important tool for identifying market risks and integrated performance, to eventually allow investors to make choices that better reflect environmental impacts (Baron 2014).

5.3.2 Mobilising private finance through the effective use of public resources

The previous section explored specific policies to overcome the main barriers to investment, while this section considers more closely the role of public sector and substantial processes of government-backed investments to mobilise more efficiently and effectively financial resources towards low-carbon projects.

The challenge of mobilising the private capital remains a strategic concern and one of the key objectives of public interventions, thus public financial institutions (e.g. G20, World Bank) begin to put more focus on rethinking the approach towards concessional finance (Cordella 2018, G20-IFA WG 2017). To date, Multilateral Development Banks (MDBs) have jointly endorsed investment guidelines (i.e. G20 Hamburg Principles) with provisions that aim to prioritize the actions that enable crowding-in of private capital and to reserve public financing for projects that are unable to secure funds otherwise. Notably, there is an increasing pressure for the public actors to predominantly focus on actions that enable risk mitigation and management that have a greater impact on crowding-in private finance than direct lending (Global Financial Governance 2018, OECD 2018c).

To this end, public sector entities such as the development finance institutions and climate funds (e.g. GCF, GEF) often rely on blended finance investment structures. Blended finance is understood as a structuring approach of the concessional instruments such as guarantees, design stage grants, insurance or technical assistance and the commercial instruments (debt and equity) with an aim to mobilize private investments. In such a set-up concessional instruments are deployed to enhance the creation of new climate markets by either reducing the risks associated with the investment or improving the risk-return profile (Convergence 2018). The structures are designed to address the lack of tailored instruments that can support the development of the markets that are of crucial importance to climate action and have the

potential to offer a business, however are yet to be targeted by private sector investors (International Finance Corporation 2015).

In 2018 the total number of blended finance transactions exceeded 300 closed transactions, of which approximately 32% were associated with climate action (Convergence 2018). This number is however likely to increase further in coming years, as blended finance is a solution promoted by both governments and other public institutions such as MDBs, which are developing relevant structures to support the associated operations and mainstream the concept. For example, World Bank's IDA has already established a blended finance unit and launched initiatives such as Private Sector Window, intended to mitigate the financial risks in high-impact sectors through the establishment of the Blended Finance Facility (International Finance Corporation 2019). Similarly, the EU has established Climate Change Windows, that are financed through the EU regional blending facilities and EIB's Global Energy Efficiency and Renewable Energy Fund. These initiatives helped to finance development investments through the combination of the EU grants and commercial instruments. It is estimated that between 2007-2013 more than €1 bn of EU grants supported roughly €25 bn investments and between 2014-2020 these values are expected to double (EC 2015).

The importance of blended finance structures also increased for climate funds. In 2017, the Green Climate Fund launched a "Mobilising Funds at Scale" campaign to catalyse private finance. It aimed to leverage $500 million with concessional instruments, however the received bids amounted to $43 bn (Convergence 2018), showing the current, untapped potential for a similar, wider scale interventions. Moreover, given that only 15 projects co-financed by Green Climate Fund and MDBs reached $4 bn by 2018 (Meltzer 2018), the predicted substantial increase in the number of organizations accredited to apply for GCF regular funding is likely to facilitate larger financial flows to be channelled through blended finance structures. As of April 2016, there were only 33 GEF accredited organisations (CPI 2016a) – this number has already almost doubled in 2 years reaching 59 entities and is expected to further increase from 2016 as 198 entities are undergoing accreditation (Meltzer 2018).

Part C – Conclusions

6 Conclusions and synthesis

6.1 Modelling

The quantitative part of this study used three soft-linked global models – an energy system model, a Dynamic Stochasic General Equilibrium model and a Computable General Equilibrium model - to examine the investments required for the decarbonisation of the energy system, and the ways in which the transition could be financed, particularly redirecting towards developing countries, as well as considering what the wider economic implications of these options.

Overall the TIAM-UCL model shows that climate ambition at a global level requires significant increased investments in low-carbon technologies to 2050 and in particular that increased ambition towards 1.5^{o}C requires significantly higher levels of investment that must start in the short-term. Therefore pursuing efforts towards 1.5^{o}C starting from 2020 will require around 46% higher energy supply-side investment requirements in 2030 compared to current policies and double by 2050. Even compared to an ambitious 2^{o}C pathway, achieving 1.5^{o}C still requires 60% higher total investments in 2050. However, behaviour driven transformation in achieving 1.5^{o}C, which reduces energy demand growth, reduces investment costs towards levels more similar to those of a 2^{o}C pathway without behavior change. Undertaking sensitivity around technology costs, and in particular falling renewables costs, does have the effect to reduce overall investment costs somewhat although these are offset by stimulating electrification.

When the weighted average cost of capital is differentiated between regions in the model using exploratory data and weighted in favour of low-carbon options then the results show how regions may be impacted differently. Introducing the regional and technology-specific WACCs has an uneven impact on investment costs across the regions, showing the need for detailed examination of international climate finance options, better data for individual regions and better representation of these in global scale models.

The model finds that as developing regions are more reliant on fossil-fuels out to 2050, so then switching financing from brown to green (i.e. increasing the cost of fossil fuel and lowering the cost of low-carbon) technologies can raise the investments required for developing regions. Therefore, in achieving the Paris Agreement goals, it is not only important that green technologies are supported relative to brown ones, but also that those regions which are dependent upon brown technologies, are also supported through improved financing options to reduce the welfare impact of moving away from this carbon–intensive future.

We then considered different options of financing the extra levels of investment requirements using the MEWA and ENGAGE models. The first option was standard domestic financing as is assumed in most modelling approaches but then also two other options are provided of a Green

Fund and a Green World Bank, the former of which is essentially a transfer and the latter a loan. These analysis showed that while there may be an economic cost to decarbonisation, that the burden of this economic cost can be made more equitable through providing finance to regions to reduce their costs.

The MEWA model was used to examine the macroeconomic impacts of different instruments available to finance the low-carbon transition. The results indicate that the increased investment effort required to achieve the global low-carbon transition, provided for the 1.7°C TECH scenario by TIAM-UCL, will result in a moderate macroeconomic burden (i.e. GDP decreased by 0.8%-1.5%, employment by 0.2%-0.5% and consumption levels by 3%-6% over 30 years).

The results indicate that the limited access to capital and high cost of capital are as important for the economic impacts as differences in income levels between developed and developing countries. Provision of low-cost access to capital for low-carbon investments not only benefits developing countries but also reduces the economic burden on the donor countries, especially if the Green World Bank is considered.

From the perspective of the recipient countries, the Green Fund scenario is the most preferable. This allows for slightly larger reduction of the transition costs than the Green World Bank scenario. On the other hand, the donor countries may prefer the Green World Bank option if its establishment allows them to limit the demand for additional savings on the domestic market. Differences with the Green Fund are small, which may indicate that mixed solutions combining the best features of both mechanisms may offer the most acceptable option for the worldwide low carbon transition delivering the best outcome for the relatively more and less industrialised parts of the world economy.

The ENGAGE model provides a multi-sector macroeconomic analysis on the decarbonisation in the RIPPLES scenarios and also replicates the financial options from MEWA using a CGE model. There is considerable GDP growth, even when full decarbonisation of the economy is taken into account, as 1.5°C still achieves an average annual growth between 2011 and 2050 of 2.6% compared to 2.9% in the REF (though the REF is without any climate damages).

The introduction of the Green Fund and Green World Bank scenarios in achieving 1.7°C result in a more significant financial burden compared to MEWA as the ENGAGE model includes more features of decarbonisation beyond simply the investment requirements needed to achieve the climate target. However, the overall effect is similar in terms of direction of effect, as the use of Green Fund (transfer) and Green World Bank (loans) leads to a reduction in economic growth on the low-income region that is around half compared to the reduction when they self-finance. Given the trade-off between development and environment for many low-income regions it is then essential that they are supported through global financial system to undertake the decarbonisation required but at least economic impact.

In terms of sectoral production, we see the fossil fuel sector decreases and the electricity sector increases due to the necessity to substitute between these as mass electrification occurs. Other sectors which rely on fossil fuels such as transport and industry do tend to expand sectoral output except in the 1.5^{o}C where crowding-out overwhelms any efficiency improvements assumed.

6.2 Qualitative analysis

The qualitative aspect of the deliverable provides details of financial instruments, the main barriers to investment and potential policy solutions to incentivise investment in decarbonisation. The majority of climate finance now flows as commercial investments; commercial loans represented almost 50% of all climate finance in 2016. Private investments almost exclusively support mitigation projects, the majority of which targets renewable technologies, and are conducted through balance sheet finance and project-level equity. In contrast, grants remain the main source of adaptation finance.

Barriers to investments stem from policy frameworks, market conditions and investors' practices. Uncertainty around relevant policies increase investors' perceived risks around low-carbon investment. A lack of green indices, high-quality data and standard reporting frameworks inhibit appropriate due diligence and strategic planning. Low carbon projects are often unattractive to investors due to their relatively small size and the high transaction cost of either direct or indirect investment strategies. Also, there is a shortage of tradable financial instruments matching investors' asset allocation. Barriers linked to investors' practices relate to investors' management inexperience and track record and short investment evaluation periods. There is a lack of clarity on fiduciary duty and stewardship with respect to the extent to which managers can and should account for environment, social and governance (ESG) issues. Finally, investments in developing countries are hindered by a perception of high geopolitical, economic and financial market development risks.

To overcome these barriers, stable long-term energy policy and regulatory frameworks for low-carbon technologies are vital. Policy instruments must be 'loud, long and legal' to engender confidence, and must be sustainable and adaptable in the long-term with transparent mechanisms. They should improve the balance of value and risk, for example by directly reducing costs or setting quotas. Fossil fuel subsidies must be removed. Monetary policy should be realigned to ease lending conditions for low-carbon investments. Liquid finance instruments should be scaled-up, such as green bonds, green indices should be developed, and small projects should be grouped together to lower transaction costs. The promotion of good data around low carbon assets, their financial and carbon performance and risks should be prioritised. At the firm level, investment managers' remunerations should be re-organised to be in line with more ambitious climate targets and publication of ESG performance should be

mandated. Over the past few years there has been a clear shift away from concessional financing. It could again play a larger role, particularly with the aim of mobilizing private finance. Blended finance instruments such as guarantees, design stage grants, insurance and technical assistance look promising.

6.3 Synthesis

There are a number of clear outcomes for policymakers from the analysis undertaken throughout this deliverable.

Achieving deep decarbonisation towards 1.5ºC requires radical changes in the financial sector. Current practice is not fit for purpose. Both quantitative changes e.g. how much is flowing, and qualitative changes e.g. structures, policies and incentives, are required in order to facilitate this level of investment. These must overcome the barriers outlined in Part B.

There are also complications which need to be given attention as across regions and markets there is not one-shoe-fits-all policy with regards to achieving investments consistent with the Paris Agreement. One country/region or technology cannot be directly compared to another in terms of risk and therefore improved data at national levels are essential for good practice. In improving market conditions, information is key, through green indices and low-carbon specific risk factor data. Restructuring managers' remuneration packages to reward decarbonisation internalises the need for such data, and along with making wide publication of ESG factors is expected to facilitate this improved data. These types of datasets could also benefit the types of modelling approaches undertaken in this deliverable.

Policies which reduce the cost of low-carbon solutions, or make high carbon relatively more expensive, must also take into account national/regional energy systems and development needs. Therefore ending fossil fuel subsidies, must be supported with other policies to direct interregional financial transfers to those regions which will lose out from undertaking such a transition.

Part B suggests easing lending conditions for low-carbon investments, and relaxing macroprudential regulation, such as green differentiated reserve and specific capital requirements in favour of low carbon assets, could leverage more funds towards low-carbon assets. The Green World Bank and Green Fund scenarios from Part A suggests that policies like this could lessen the economic burden on those who are most likely to lose out from undertaking climate ambition. A mix of concessional financing approaches may be appropriate if more politically feasible.

The main message is the need to ramp-up investment immediately, immediate action is crucial, but the trade-off is to do so with the least adverse impact on all parties.Therefore one other clear outcome is that public financial institutions (e.g. G20, World Bank) are correct to rethink

their approaches towards concessional finance as these may be one way to achieve the rates of change required.

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Appendix - TIAM-UCL

Figure A1: Europe CO_2 emissions pathways by scenario – See also Figure 7

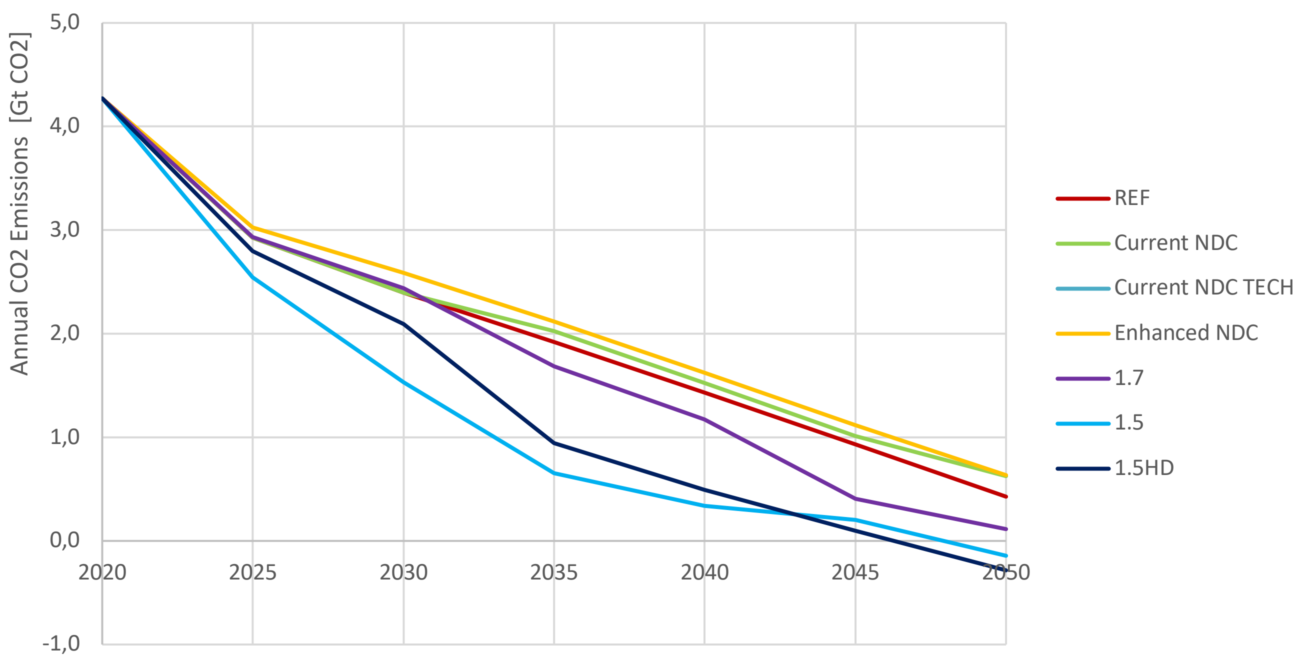


Figure A2: Global electricity consumption by sector for each scenario 2030 and 2050

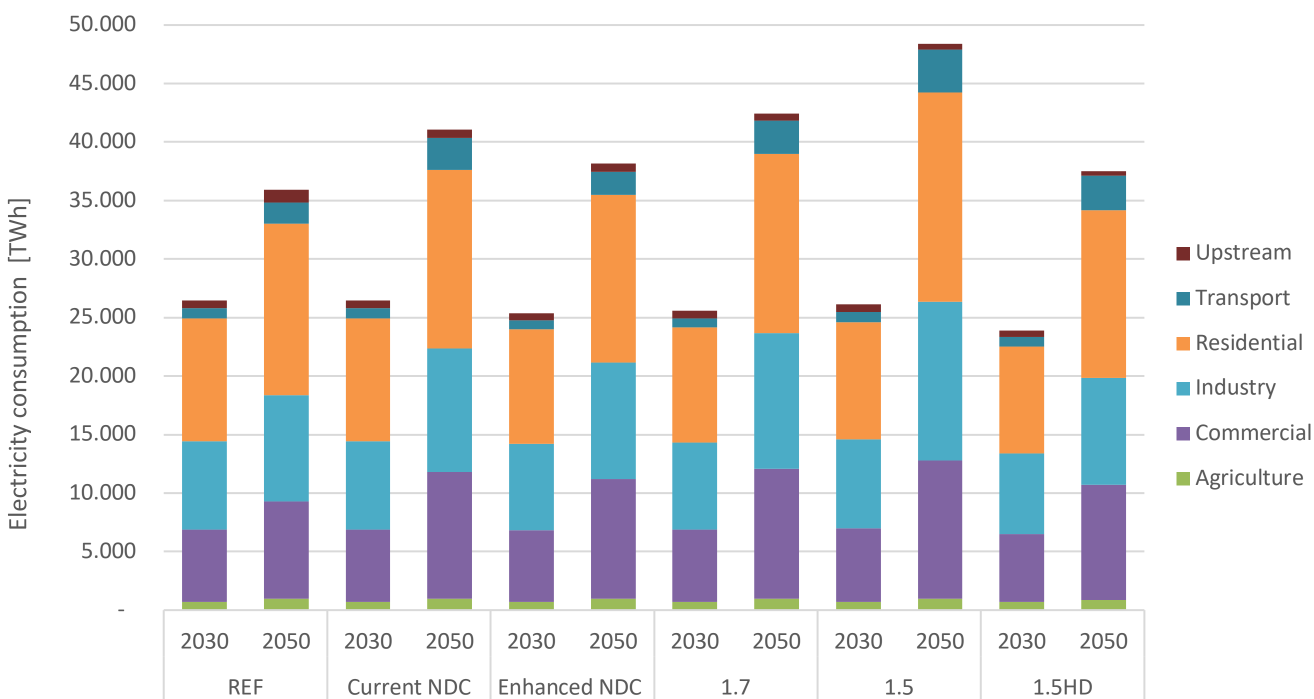


Figure A3 – Global final energy consumption by fuel for each scenario 2030 and 2050 – See also Figure 8

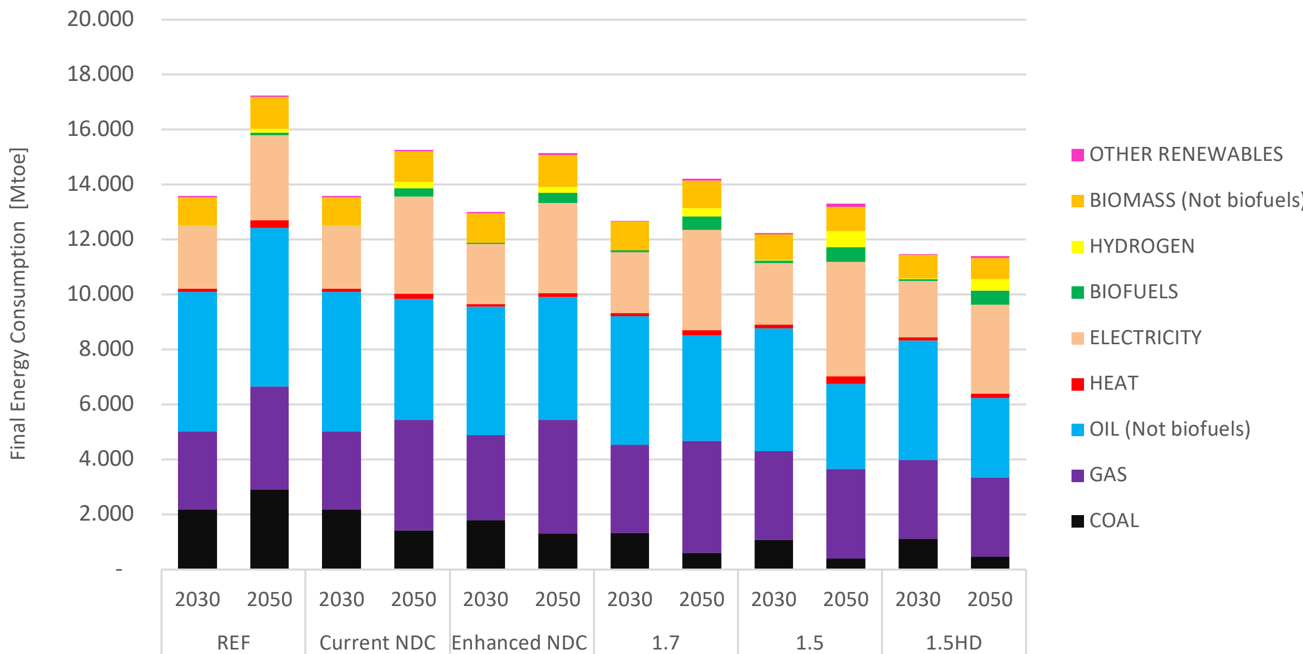


Figure A4 – Electricity investments by fuel

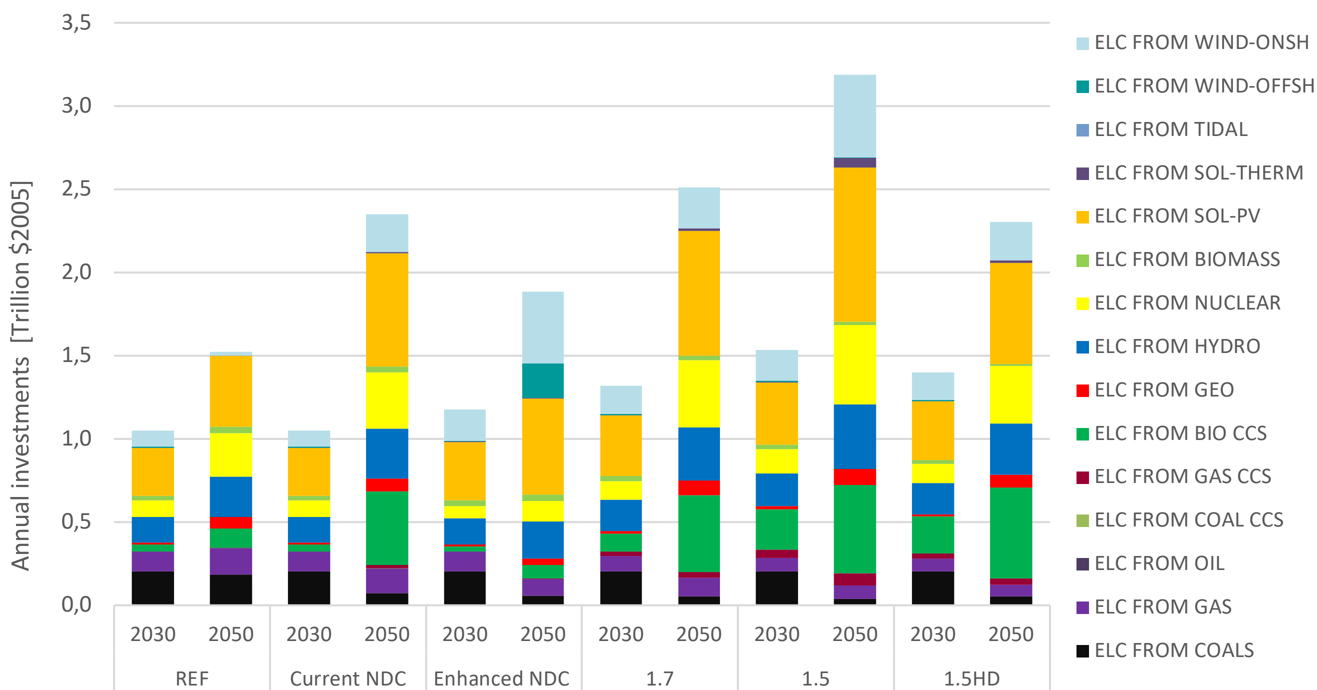
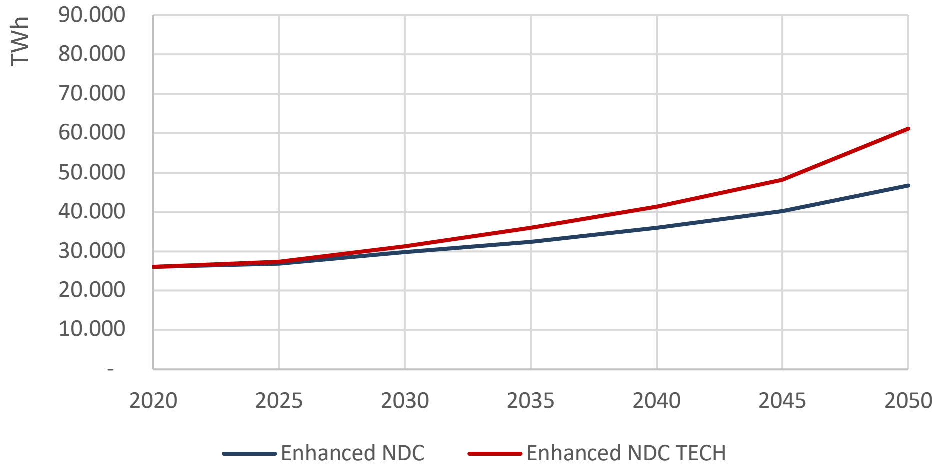


Figure A5 (a) and (b): Global electricity generation for standard and TECH assumptions for (a) Enhanced-NDC, (b) 1.5C HD scenarios - See also Figure 14



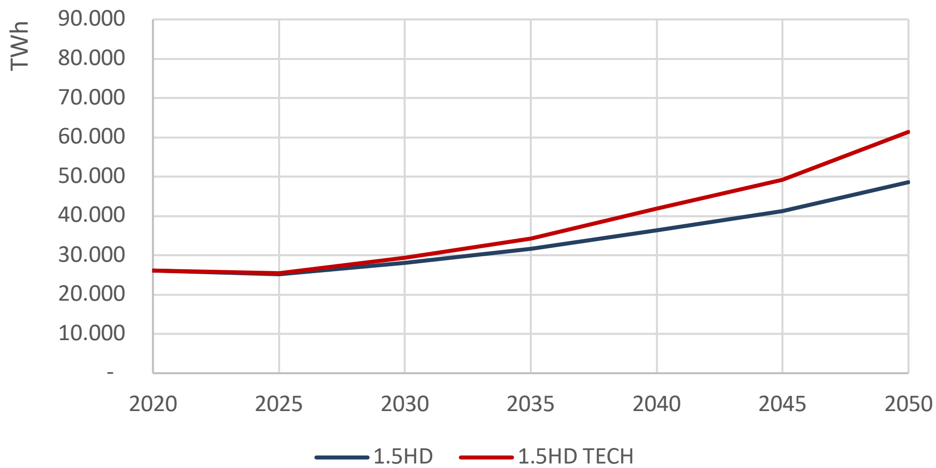
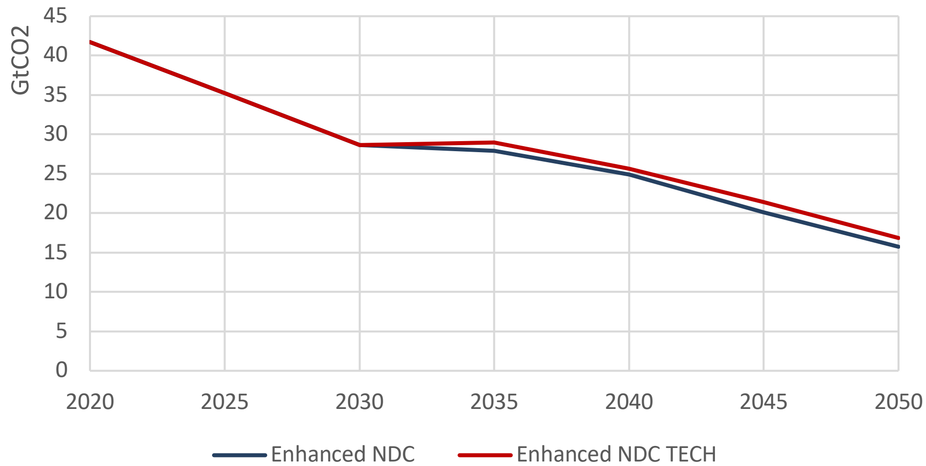


Figure A6 (a) and (b): Global CO_2 emissions pathways for standard and TECH assumptions for (a) Enhanced-NDC and (b) 1.5C HD scenarios - See also Figure 16



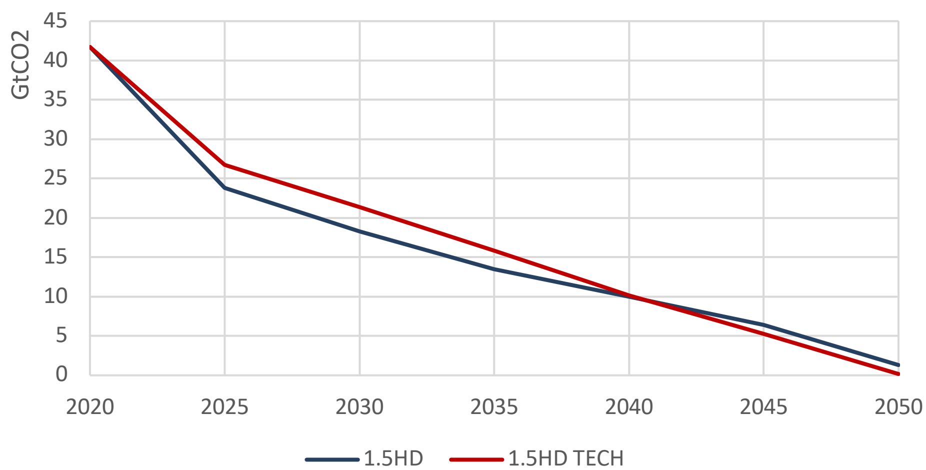
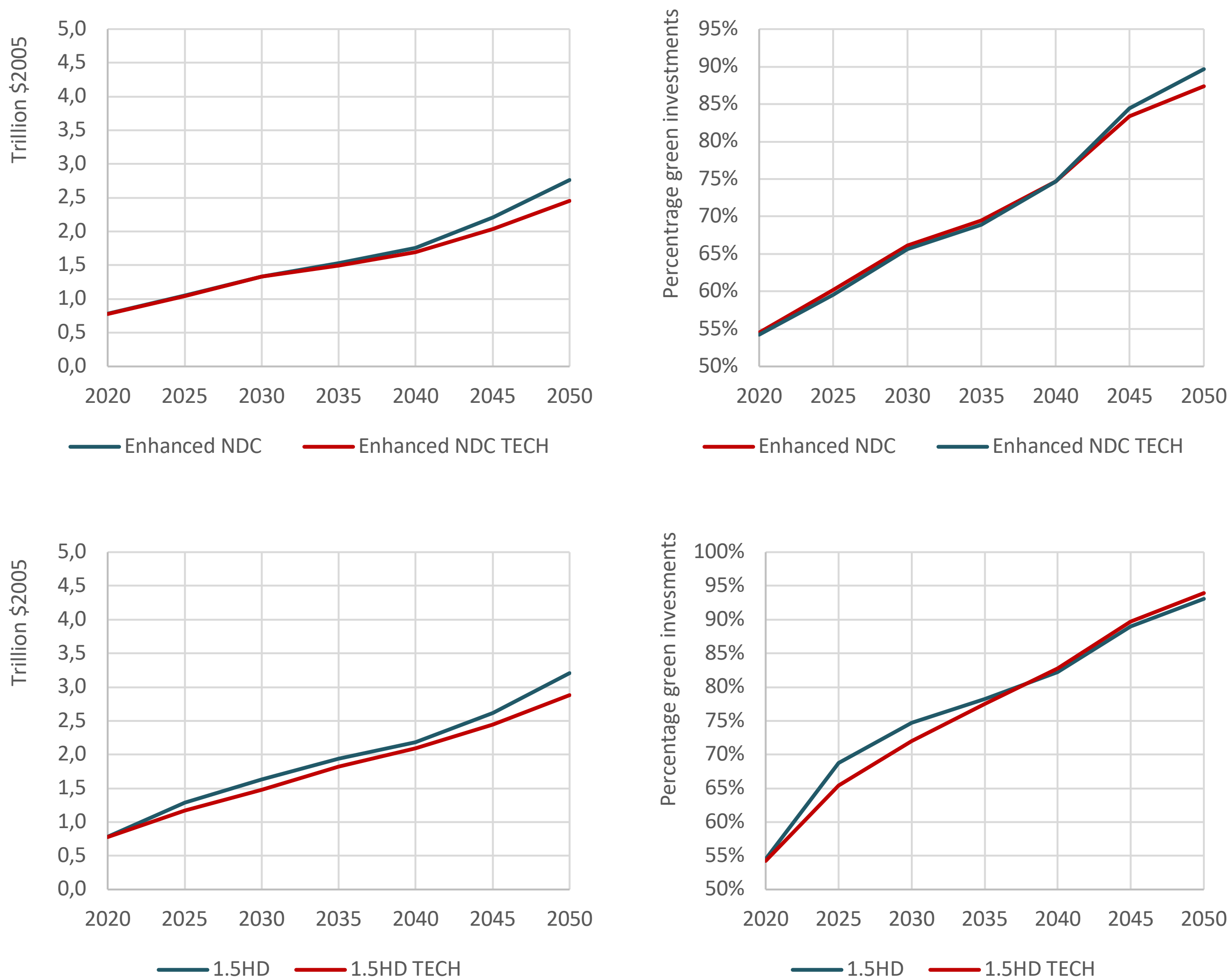
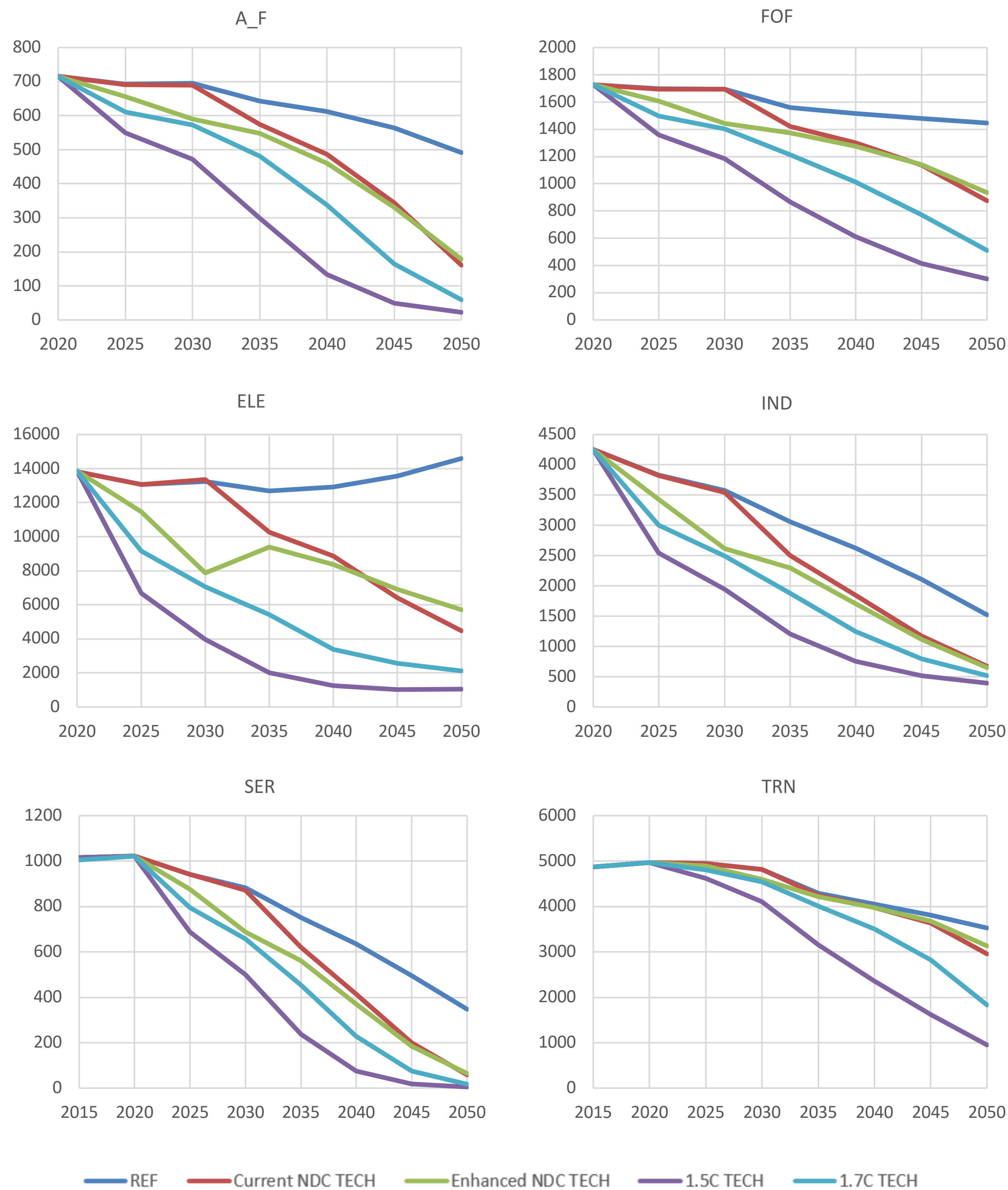


Figure A7 (a) and (b): Total annual energy investments and Percentage green investments for standard and TECH assumptions for (a) Enhanced-NDC, (b) 1.5HD scenarios – See also Figure 17



Appendix - ENGAGE

Figure A8 (a-f): Global CO_2 emissions by sector and scenario (Mt CO_2) (Note the different y axes)



Appendix - MEWA

Households

Both regions[15] represented in the model (high- and low-income) are populated by POP_t number of consumers (normalised in the steady state to 1) maximising the lifetime utility in the form:

$U_0 = E_0\left(\sum_{t=0}^{+\infty} \beta^t \ u(\widetilde{C_t})\right)$where β is a subjective discount factor, $u(\widetilde{C_t})$ belongs to the CRRA class and $\widetilde{C_t}$ is a consumption good composed of the market consumption C_t and home production of the household $H_t = \eta NE_t$. which is proportional to the fraction of household members that are unemployed or inactive ($POP_t = N_t + NE_t = N_t + UN_t + NA_t$). Households take into account the budget constraint in the form

$$(1+\tau_t^V)P_tC_t = (1-\tau_t^W)W_tN_t + T_t + \Pi_t + \Delta_t$$

Where τ_t^V and τ_t^W denote taxes on consumption and labour income ($W_t \ N_t$), Π_t are profits, T_t net transfers, and Δ_t change in deposits.

Production

Production in the model is divided into five sectors (banking and four "real economy" sectors: agriculture, industry, energy, non-financial services). In a given sector production is divided into subsequent stages combing (in a nested CES) four production inputs: capital and energy, labour and materials.

Formally, the production in a given sector Y_t^s is a nested CES compound (with vector of parameters Θ^M) of materials M_t^s: and compound of capital, labour and energy KLE_t^s:

$$Y_t^s = CES(KLE_t^s, M_t^s;\ \Theta^M; \eta^M)$$

[15] For the brevity we omit the country index "c"

Where

$$\text{KLE}_t^s = CES(KE_t^s, N_t^s.\Theta^N; \eta^N)$$

is a CES compound of labour N_t^s and synthetic good KE_t^s composed of capital and energy given by another CES function:

$$\text{KE}_t^s = CES(K_t^s, E_t^s.\Theta^K; \eta^K)$$

Material input M_t^s determined by the Leontief production function from sectoral goods $M_t^{s,r}$

$$\text{M}_t^{s,r} = \Theta_{s,r}^L M_t^s$$

Composed of domestic $M_t^{D,s,r}$ and imported $M_t^{F,s,r}$ sectoral goods in the following way

$$\text{M}_t^{s,r} = CES(M_t^{D,s,r}, M_t^{F,s,r}, \Theta^H; \eta^H)$$

with

$$CES(X, Y.\Theta^X, \eta^X) = \left[(\Theta^X)^{\frac{1}{\eta^X}}(X)^{\frac{\eta^X-1}{\eta^X}} + (1-\Theta^X)^{\frac{1}{\eta^X}}(Y)^{\frac{\eta^X-1}{\eta^X}}\right]^{\frac{\eta^X}{\eta^X-1}}$$

Firms

Firms maximise the expected discounted sum of profits defined as:

$\Pi_0^s = E_0(\sum_{t=0}^{+\infty} \Lambda_t \pi_t^s)$Where $\Lambda_{t+1} = \beta \frac{\lambda_{t+1}^C}{\lambda_t^C} \Lambda_t$ is the stochastic discount factor, mirroring the preferences of households, and λ_t^C is a Lagrange multiplier associated with households' budget constraint. Current cash flow is denoted by π_t^s and calculated in the following manner:

$$\pi_t^s = {P_t}^s {Y_t}^s - W_t^s N_t^s - IC_t^s - MC_t^s - FC_t^s,$$

where ${P_t}^s {Y_t}^s$ is the value of production, $W_t^s N_t^s$ is a labour cost (wage multiplied by labour input). $IC_t^s,\ MC_t^s\ and\ FC_t^s$ are investment, material and financial cost defined as:

$$IC_t^s = P_t^I (I_t^s + \frac{\varphi^{INV}}{2}(\frac{I_t^s}{K_{t-1}^s} - \delta^{K,i})^2),$$

where $P_t^I I_t^s$ is the price of actual investment supplemented by the convex adjustment costs resulting from the real investment frictions. MC_t^s is the total cost of purchasing the intermediate

inputs from all other sectors, and FC_t^s is the cost of financing the capital needs of the company e.g. repaying and servicing debt, and acquiring new financing.

Investment and financing frictions

Production capital K_t^s is accumulated in a time-to-built mechanism governed by the following equation:

$$K_t^s = (1 - \delta^s)K_{t-1}^s + IF_t^s$$

Where IF_t^i denotes investments finished in a given period expressed as a constant fraction ω^s of the stochastic investment process, with previous stage of development (ID^s)

$$I_t^s = (1 - \omega^s)ID_t^s + \omega^s IF_t^s$$

$$IF_t^s = \omega^s(IF_{t-1}^s + I_t^s)$$

$$ID_t^s = (1 - \omega^s)(ID_{t-1}^s + I_t^s)$$

with

$$KB_t^s = (1 - \delta^s)KB_{t-1}^s + IC_t^s$$

Reflecting the book value of the installed capital that also must obey the following equation:

$$KB_t^s \geq \gamma^L B_t^s$$

Where γ^L is a leverage ratio i.e. the maximum share of production capital that may be financed by a bank loan B_t^s. This ratio depends on a country grouping with stronger frictions present in the low-income countries.

Banking sector

The banking sector is divided into investment and commercial banking subsector. Loans from commercial banking are based on households deposits and reserves level governed by the rules of central bank, whereas investment banks supply loans B_t to firms with volume determined by the CES technology

$$\mathrm{B}_t = CES(B_t^H, B_t^F . \Theta^B; \eta^B)$$

with B_t^H.and B_t^F representing the loans in the commercial banking sector and international financing facility (Green World Bank) respectively. Interest rate R_t paid by firms maximizes the bank profit

$$\pi_t^B = \frac{B_t}{R_t} - B_t - (\frac{{B_t}^H}{R_t^H} - B_t^H) - (\frac{{B_t}^F}{R_t^F} - B_t^F)\text{-}$$

Where both domestic and foreign inter-banking interest rates R_t^H.and R_t^F take into account risk premiums that depend on the country and its level of ineptness relative to GDP e.g.:

$$\mathrm{RP}_t^F = \psi^B exp(B_t^F / GDP_t^H)$$

Higher risk premium translates to higher interest rates for the production sector.

Appendix - Modelling evaluation

There are a number of aspects worth discussing further regarding the above quantitative analysis and approaches. The above models all have inherently different structures and formulations and as such there are limitations of each. Given the partial equilibrium nature of the TIAM-UCL model then it is only possible to cover the areas which are modelled in detail such as electricity, heat and upstream sectors. Our analysis using TIAM-UCL therefore only considers the supply-side of the energy system and lacks investments in other parts of the economy. On the other hand the ENGAGE model, being a General Equilibrium Model, can include investments across all sectors of the economy, however, the lack of technological detail in the model, given its top-down economic sector rather than bottom-up technology focus, makes it difficult to consider how technological progress will happen in sectors and as such investments in new technologies are hard to represent in any detail. Therefore ENGAGE relies on substitution as its method of decarbonisation, towards pre-existing low-carbon technologies

such as electricity from renewables but is limited in its approach to other solutions e.g. hydrogen in steel making.

Another limitation of the approach used for ENGAGE in this analysis is the assumption of a global carbon price which assumes cooperation between regions leading to a very different outcome as opposed to regionally differentiated prices. It may be necessary as a transition period until a global carbon market could be put in place. Such a different assumption assumption could change the main findings or key messages but is unfortunately beyond the scope of the project.

Some limitations of the individual models highlight key areas for future work. In the TIAM-UCL modelling, accelerated cost reductions were assumed exogenously. This method omits key interlinkages and feedback effects and means the lower technology costs in future periods are accounted throughout the modelling period the due to the perfect foresight of the model. Exploring the role of technology learning in more depth, represented endogenously in the model, would be beneficial in future analysis. Some detail was lost during the steps of aggregating the WACC data into the TIAM-UCL regions and categorising technologies as green vs. brown and assigning the regions as high- and low-income. Further work could use more detailed regional WACC data and more refined categorisation of regions' economic development trends. Furthermore, opportunity to work with an expert team to develop a database of technology specific WACC values and implement these in TIAM would be highly beneficial.

We have attempted to overcome these limitations by soft-linking the models, however, this is only possible to a certain extent. In this deliverable we do not attempt to harmonise the model baselines/calibration as this undertaking is beyond the scope of this project. So in terms of soft-linking, there are outputs from one model used as inputs to another and scenarios are aligned, but the models themselves do not necessarily use the same data sources, base years. Therefore there will be inherent differences in the models results. However, suggested future work may be to undertake this in a more comprehensive manner using the same underlying data for each model.

There are other uncertainties worth mentioning. The TIAM-UCL results indicate the transition of the energy system required for various levels of climate change mitigation ambition, and the associated supply-side investment costs to achieve these different climate mitigation futures. These are the results of only one single model, and as such are highly dependent upon model-specific assumptions and various factors, therefore it is important to situate these results in the context of the wider literature.

In particular, here we compare the TIAM-UCL results with those from the model ensemble present by McCollum et al (2018).[16] For the set of scenarios run by the various IAMs in the McCollum study there are quite a range of investment trajectories as shown in Figure A9 below.

In the NDC set of runs the average investment across the six IAMs is $2.98 trillion in 2050, and in TIAM-UCL it is $2.63 trillion in REF in the same time period (the analogous run from TIAM-UCL). However, investment in AIM/CGE is $1.94 trillion in 2050, whereas REMIND-MAgPIE reaches double that level in 2050 at $4.04 trillion. The TIAM-UCL results for total energy supply-side investments are below the range of the models until the 2030s, and then continue within the lower end of the range.

In the 2^{o}C analysis in McCollum et al (2018) the average total supply-side investments across the six IAMs in 2050 is $3.31 trillion which is 11% higher than the average in the NDC runs. The Enhanced NDC scenario for TIAM-UCL follows a roughly similar path to both MESSAGE–GLOBIOM and WITCH from 2030 onwards and results in investments of $3.35 trillion in 2050. The percentage of green investments is high compared to most models except AIM/CGE and WITCH.

For the 1.5^{o}C analysis the rate of investment increases substantially faster in TIAM-UCL than compared to other models. The average across all models in McCollum et al (2018) is $3.66 trillion in 2050 whereas TIAM-UCL has reached over $5 trillion by then in the 1.5C scenario.

Therefore overall TIAM-UCL is within the range of most models. However, it would have benefited from calibration with these other models and sharing of further model assumptions, scenario alignments etc. which was not possible under the COP21 RIPPLES project.

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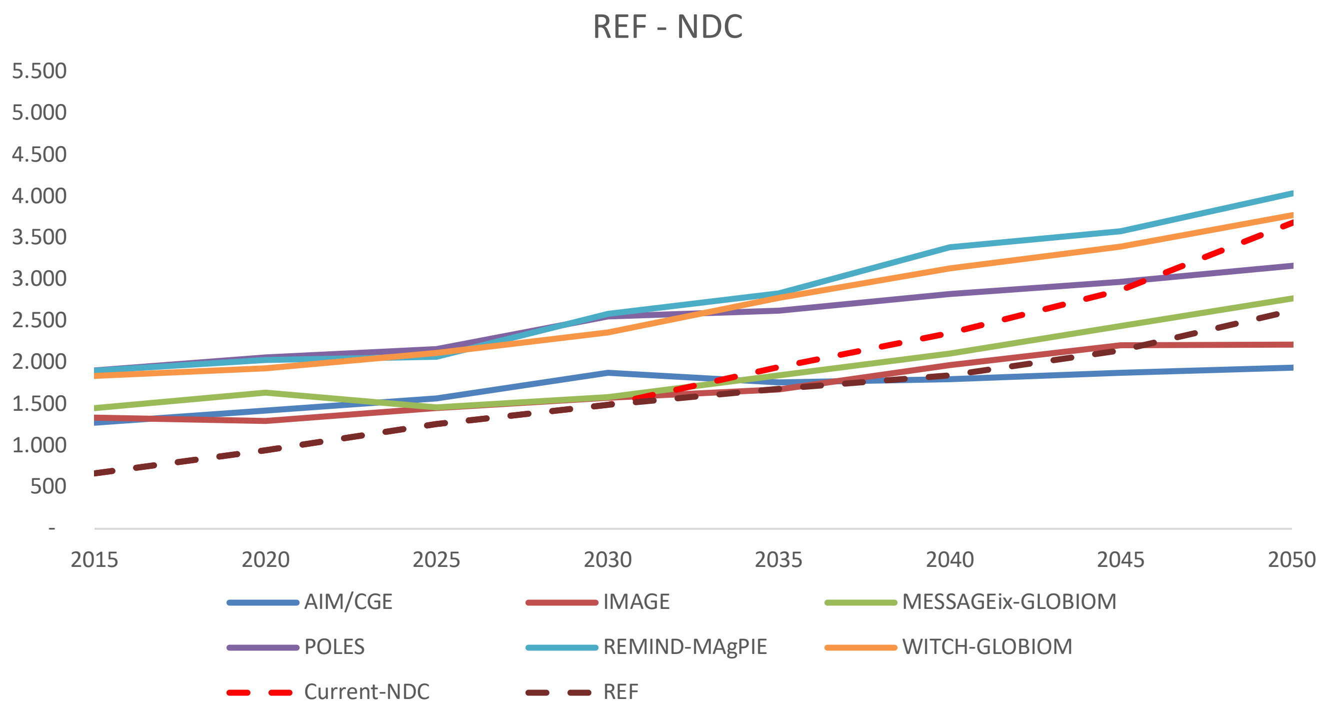
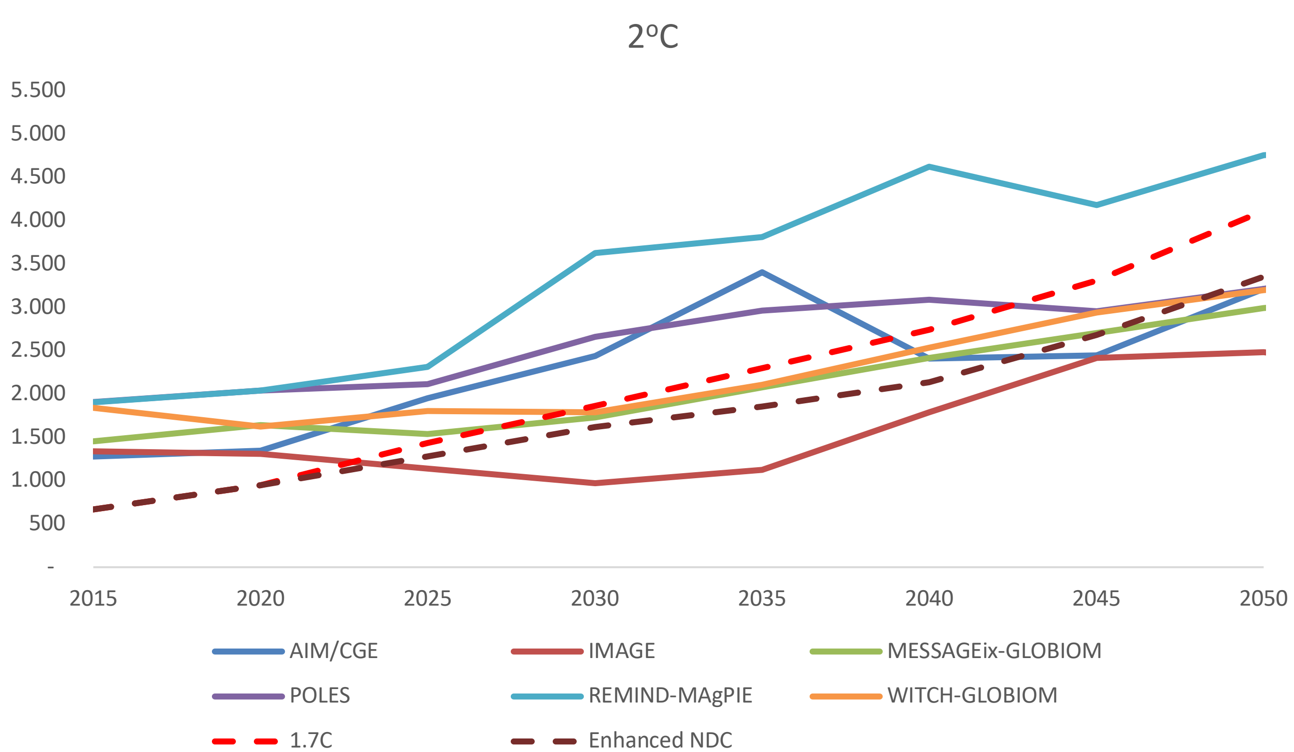
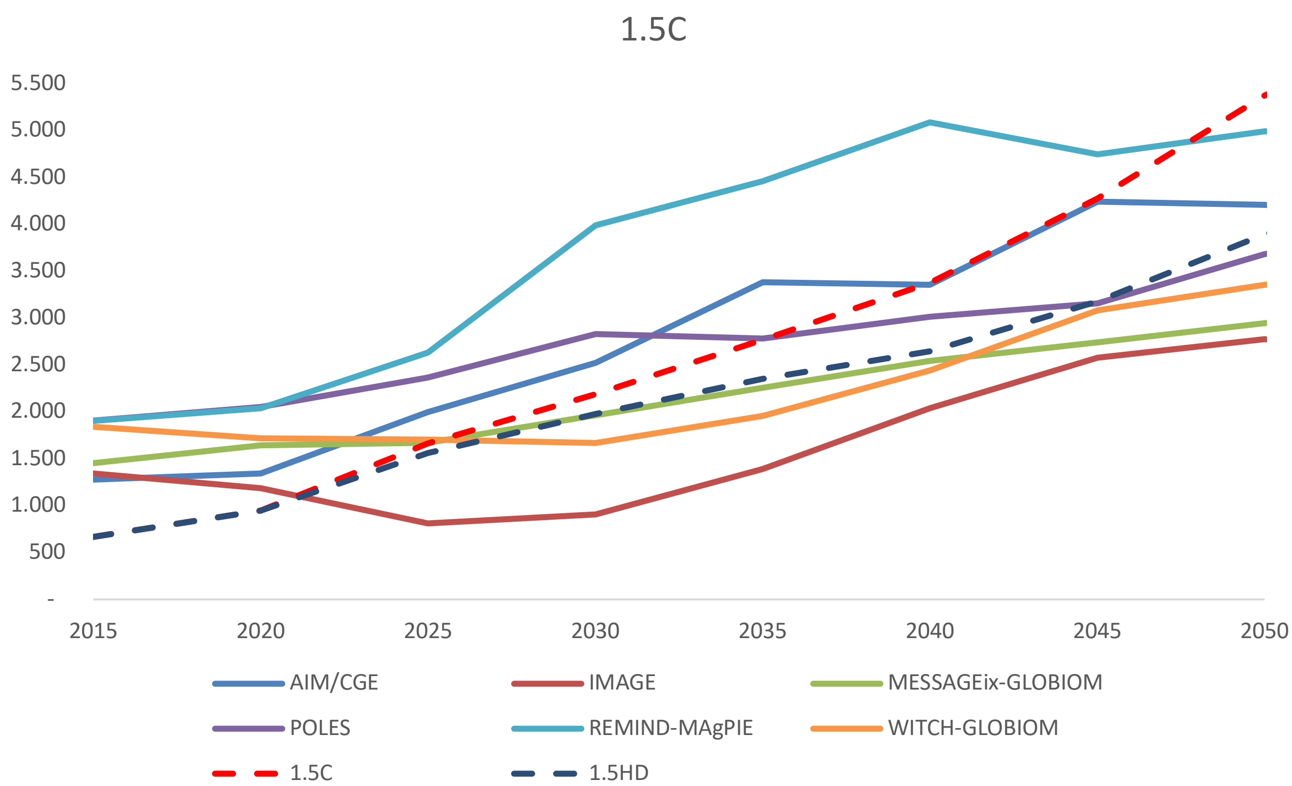
[16] To do so we convert the necessary TIAM-UCL results from Section 4 from $2005 to $2015 using OECD inflation database available at https://data.oecd.org/price/inflation-cpi.htm

Figure A9 Annual global supply-side investments for various IAMs vs. TIAM-UCL RIPPLES scenarios for (a) NDC (b) 2ºC and (c) 1.5ºC






1.5C
5.500
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
500
-
2015
2020
2025
2030
2035
2040
2045
2050
AIM/CGE
IMAGE
MESSAGEix-GLOBIOM
POLES
REMIND-MAgPIE
WITCH-GLOBIOM
1.5C
1.5HD