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Nadia Ameli (✉ nd.ameli@gmail.com)

University College London

Olivier Dessens

University College London

Matthew Winning

University College London <https://orcid.org/0000-0002-4299-3376>

Jennifer Cronin

UCL <https://orcid.org/0000-0002-2888-400X>

Hugues Chenet

UCL

Paul Drummond

UCL

Alvaro Calzadilla

UCL

Gabrial Anandarajah

University College London <https://orcid.org/0000-0002-7455-2540>

Michael Grubb

UCL <https://orcid.org/0000-0003-2393-3041>

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A climate investment trap in developing economies

Nadia Ameli¹, Olivier Dessens^{1, 2}, Matthew Winning^{1, 2}, Jennifer Cronin², Hugues Chenet^{1, 3}, Paul Drummond¹, Alvaro Calzadilla¹, Gabriel Anandarajah², Michael Grubb¹

¹Institute for Sustainable Resources, University College London

²UCL Energy Institute, University College London

³Chair Energy and Prosperity, Paris

Abstract

Finance is vital for the green energy transition, but the access to low cost finance is uneven as the cost of capital differs substantially between regions. This study shows how modelled decarbonisation pathways of developing economies are disproportionately impacted by assumptions around their cost of capital (WACC). For example, representing regionally specific WACC values indicates 35% lower green electricity production in Africa for a cost-optimal 2°C pathway. Moreover, results show that early convergence of WACC values for green and brown technologies in 2050 would allow Africa to reach net-zero emissions approximately 10 years earlier than when convergence is not considered. A “climate investment trap” arises for developing economies when climate-related investments remain chronically insufficient. Elements of sustainable finance frameworks currently present barriers to these finance flows and radical changes are needed so that capital is better allocated to the regions that most need it.

30 Main

31 A rapid low-carbon transition is central to achieving the “well below 2°C” goal of the Paris
32 Agreement (UNFCCC 2015). In addition to current policies and plans, meeting current NDC
33 pledges is estimated to require US\$130 billion per year of further investment in low-carbon
34 technologies to 2030 - an amount which could double or even triple for 1.5-degree consistency
35 (McCollum et al. 2018). A step-change in the scale and direction of investment is required
36 especially in developing economies, where accessing the appropriate finance is a particular
37 challenge (Jakob et al 2015), many of which will also be most impacted by climate change
38 (Field et al. 2014).

39
40 Whether we meet this climate investment challenge will strongly depend on the availability of
41 finance. The geographical distribution of low-carbon finance, defined as capital flows directed
42 towards low-carbon interventions with direct greenhouse gas mitigation benefits (Buchner et
43 al 2019), is highly unequal. Developed regions are by far the largest recipients, with developing
44 economies – particularly those in Africa – receiving only a small proportion (with the exception
45 of China and, to a lesser extent, India and a few other emerging markets) (BNEF 2020,
46 Buchner et al 2019).

47
48 The capacity to mobilize funding towards low-carbon investment seems strongly linked to local
49 enabling environments (Ameli et al. 2019, Schmidt 2014). Differences in macroeconomic
50 conditions, business confidence, policy uncertainties and regulatory frameworks define
51 investment conditions (Ameli et al. 2019, Egli et al. 2019, Ragosa and Warren 2019, Acemoglu
52 and Zilibotti 1997, Schneider and Frey 1985). In most developing economies, capital markets
53 are immature and not well developed, making it difficult to secure financing (Bilir et al 2019,
54 Donaubauer et al 2019). For instance, the bond market in Africa is small and characterized by
55 high illiquidity, making investments unattractive (UNEP 2012). This is particularly detrimental
56 for low-carbon projects given their high up-front cost.

57
58 To understand how finance can be mobilised especially in developing economies, it is crucial
59 to examine local conditions and how they are reflected in investors’ perceived investment
60 risks. This is most clearly expressed by the resulting Weighted Average Cost of Capital
61 (WACC), which represents the weighted average of the costs of raising funding for a specific
62 project from different sources (Modigliani and Miller, 1985).

There is scarce empirical evidence on the cost of capital for low-carbon assets as such data is hardly available to the academic community; only lately have some studies tried to elicit the WACC for renewable energy projects at country level (Steffen 2020, Egli et al. 2018, Partridge 2018, Kumar et al. 2017, Angelopoulos et al. 2016, Noothout et al 2016, Voormolen et al. 2016, Estache and Steichen 2015, Shrimali et al. 2013, Wood and Ross 2012). Overall, these studies found a notably higher WACC in developing economies than in developed ones, but with substantial variation (Steffen 2020, Sweerts et al. 2019, Egli et al. 2019, Buhr et al 2018, Donovan and Nunez 2012, Henriques and Sadorsky, 2008).

However, most decarbonisation modelling exercises, including those by the International Energy Agency or the International Renewable Energy Agency, do not properly reflect differential financing conditions in their analyses (Egli et al 2019). Instead, a (quasi-) uniform cost of capital in the form of “hurdle rates” is assumed (Egli et al 2019). When more accurate financing costs are used, modelling suggests that the transition to a low-carbon economy in developing economies is more expensive than is usually assumed, while in developed economies the opposite is true (Egli et al. 2019). Therefore, it is clear that different financing conditions can substantially affect the attractiveness of low-carbon investment in different countries, influencing the pace and the overall cost of the transition in different geographies (Egli 2020, Sweerts et al. 2019, Egli et al. 2018, Hirth and Steckel 2016, Helms et al. 2015, Iyer et al. 2015, Schmidt 2014).

This paper introduces regionally-differentiated WACCs to the TIAM-UCL global energy systems model to assess how these assumptions for the power sector affect patterns of investment needs for the energy transition consistent with the 2°C global target. To the best of our knowledge, this is the first study showing how decarbonisation pathways differ when financial costs are unevenly distributed between developed and developing economies, providing important insights on low-carbon finance for policy-makers.

A climate investment trap

Energy system transitions in developing economies require particularly high investment, but given their under developed financial markets and domestic risks, investors apply high risk-premiums to the finance they make available, making the transition more expensive than in

countries with relatively lower perceived risk. Investments are thus barely possible creating “a climate investment trap”.

The climate investment trap is a situation in which climate-related investments remain chronically insufficient, as a set of self-reinforcing mechanisms in place with dynamics similar to those of the poverty trap (Azariadis and Stachurski 2005, Nelson 1956). High risk-premiums associated with risky contexts increase the cost of capital for low-carbon investments, thus delaying the energy system transition and the reduction of carbon emissions. Strong global climate change would lead to worse damages in these regions (Field et al 2014), which are expected to affect production systems and reduce economic output, generating unemployment and political instability. This, in turn, worsens further domestic risks and limit the development of an adequate financial market (Fig 1).

These dynamics are particularly relevant considering the recent blooming of the sustainable finance narrative which, through new policy frameworks and practitioner approaches, is expected to overhaul the financial markets’ contribution towards the low-carbon economy. While developing economies require the bulk of low-carbon investment, and developed countries are where the most capital is, developing economies currently appear to be left out of the main current sustainable finance efforts and initiatives. Understanding the impact of regional differences in the cost of capital underlines the urgency for policy-makers to overcome the climate investment trap as part of their core sustainable finance objectives.

Figure 1: The climate investment trap

Note: The strength of these links is strictly linked to local conditions implying that the set of self-reinforcing mechanism could be exacerbated (or less relevant) in some economies.

The cost of capital in our scenarios

In this analysis, we introduced region-specific cost of capital values (here-after referred to as 'WACC'), to the TIAM-UCL global energy system optimization model. TIAM-UCL (TIMES Integrated Assessment Model) is a technology-rich bottom-up cost optimisation model that determines least-cost energy and technology mix to meets future energy demands while respecting technical, economic and policy constraints, such that societal welfare is maximised (McGlade and Ekins, 2015). As an exogenous input to the model, any changes to the WACC affects annualised technology capital costs, and subsequently the profile of the cost-optimal energy mix and the total energy system investment requirements. We used a new WACC database covering developed and developing economies (Ameli et al. 2017). The analysis focuses on the power sector, and accounts for differences in WACC between 'green' and 'brown' electricity technologies across regions.

We study scenarios that achieve the 2°C target - rather than the 1.5°C target - to examine the impact of altering the WACC in scenarios with low reliance on negative emissions technologies, around which there is large uncertainty (Rogelj et al. 2018). When the WACC is

heterogenous, we assume convergence over time. It seems reasonable that such an effect may occur, as the finance sector grows accustomed both to the technologies and local investment contexts.

We examine the financial implications of four scenarios. The ‘Global’ scenario (GBL), where WACCs are uniform across regions but differ between green and brown electricity generation, and are set at the mean global values, weighted by GDP, of 5.9% and 5.1% respectively. The ‘Regional’ scenario (REG) employs the regional WACCs, which vary between green and brown technologies, as shown in Figure 2. The WACC is generally higher for green technologies and in developing economies. In the third and fourth scenarios, C2050 and C2100, the WACC values used in the REG scenario converge by 2050 and 2100, respectively. For each region, the values converge to whichever is lower – the global average value for brown technologies or the lower WACC of that region (Figure 2). See the Method for more details on the scenarios and the TIAM-UCL model.

Figure 2: Green, brown and converging WACC values across the TIAM-UCL regions

Note: The bubble size reflects the different WACC values for brown and green technologies and the convergence values (CONV) regions. The regions represented are: Africa (AFR), Australia (AUS), Canada (CAN), China (CHI), Central and South America (CSA), Eastern Europe (EEU), Former Soviet Union (FSU), India (IND), Japan (JAP), Mexico (MEX), Middle-east (MEA), Other Developing Asia (ODA), South Korea (SKO), United Kingdom (UK), USA (USA), Western Europe (WEU).

Results

We examine how modelling regional WACCs and different speeds of WACC convergence impact electricity decarbonisation pathways and investments in developing and developed economies. To highlight the implications for representative countries with high and low risk profiles, we focus on the results for Western Europe and Africa, which face the principal challenges of replacing fossil fuel infrastructure with green power technologies, and of scaling

up overall energy supply, respectively. Further, these regions are chosen given their totemic position in the global energy agenda: while Europe aims to be the first climate-neutral bloc in the world by 2050 (EC 2019), Africa faces rapidly rising energy demand and must ‘leapfrog’ the use of fossil fuels to meet this demand, and instead deploy clean energy sources if climate targets are to be met (Lucas et al. 2015). Results for all other regions are reported in the Annex – emerging economies like Mexico, Central and South America will have similar results to Africa given their WACCs, while India and China will be less affected. The other developed economies will follow very similar paths showed for Europe.

Regional vs uniform WACCs

We start by analysing the implications of implementing regional versus globally uniform WACCs on green electricity generation and investment requirements (figure 3). In 2050 in Africa, green electricity generation is much lower when local WACC values are applied (REG) instead of the uniform global value (GBL). This difference remains relatively consistent in absolute term after 2050 (but reduces in relative term due to the stringency of the 2°C constraint). However, this produces almost no difference in the investment requirements in green power; with undiscounted cumulative green electricity investment values over the 2020-2070 period of \$5.88 trillion and \$5.80 trillion for REG and GBL in Africa, respectively. By 2050, with the same level of investment, roughly \$80 million, and using a uniform WACC the model projects 35% more green electricity for Africa than when regional values are employed. However, for developed regions the real costs of financing (REG) are similar to the global average (GBL), producing little difference in the resulting pathways.

The impact of regional and globally uniform WACC values on CO₂ emissions is greatest for regions with regional WACCs that deviate the most from the uniform WACC. Net-zero emissions in Africa is achieved in 2058 in the GBL scenario and in 2065 in the REG scenario, while the difference is negligible in Western Europe. Our estimates show that representing the observed local financing conditions leads to regional higher emissions in Africa (20% in 2050) due to the lower renewable investments deployed.

The striking consequence of implementing regional versus globally-uniform WACC values is that decarbonisation pathways in developing economies are highly affected. Under the REG

scenario, they register a much lower (globally cost-optimal) level of renewable deployment and a slower rate of emissions reduction than in the GBL scenario.

Figure 3: Green electricity generation (left) and investment per year (right)

Different WACC convergence rates

Convergence between green and brown WACC values has a significant impact on the electricity generation mix in Africa, especially when WACC convergence is achieved by 2050 (figure 4). In 2050, in the C2050 and C2100 scenarios, green electricity production in Africa is 43.1% and 6.5% higher than the REG scenario, respectively. If convergence were brought forward, there would be considerably more green electricity production in the first half of the century. The REG and C2100 scenarios follow similar pathways until 2050, with the C2100 pathway leading to slightly more green electricity thereafter, moving toward the levels of green generation seen in the C2050 scenario by 2100. Once again, the relative difference in Western Europe in WACC values and subsequently green electricity generation, is very minor.

The timing of the WACC convergence has a large impact on green power investments in Africa (figure 5). Between 2020 and 2070 the cumulative investments in green electricity are \$370 and \$310 billion (10% and 9% respectively) more than REG for C2050 and C2100, showing that rapidly lowering the WACC and the difference between green and brown technologies, will raise green power investment in the near term in developing economies. In 2050, the differential in investment levels between the REG and the C2050 scenarios is 15.3% while it starts to diverge only after 2050 in the C2100 scenario. For Western Europe, investments in all scenarios follow a comparable path under similar WACC values.

Figure 4: Regional green electricity generation by scenarios (left) and the percentage change in generation compared to the REG scenario (right)

Figure 5: Regional investment levels in green electricity for the 2°C scenarios with different convergence years. Absolute values (left) and changes compared to the REG scenario (right)

Finally, figure 6 shows how different WACC convergence rates affect CO₂ emissions pathways. Again, the most pronounced differences are in regions with the greatest deviations from the global uniform WACC, such as Africa. Net-zero emissions in Africa would be achieved in 2058 for C2050, in 2062 for C2100 and only in 2066 for the REG scenario in a least-cost scenario.

In our scenarios, differences in the level and evolution of power sector WACC values do not impact cumulative global CO₂ emissions to 2100, as CO₂ emissions are constrained by the global temperature limit imposed by model.

Figure 6: Regional CO₂ emissions for the 2°C scenarios with different convergence years

254

255 Our results suggest that a more rapid WACC convergence will allow developing economies
 256 to achieve much higher level of green electricity deployment and faster emissions reduction.
 257 For Africa, compared to the REG scenario, WACC convergence by 2050 would lead to an
 258 almost 50% increase in green electricity generation by this time, while convergence by 2100
 259 would increase green electricity generation by 20% in 2100. Convergence by 2050 would also
 260 allow Africa to reach net-zero emissions roughly 10 years earlier than in the REG case (figure
 261 7). Earlier WACC convergence leads to higher investments in the near term - for Africa this
 262 would have a cumulative impact of \$430 billion extra green investment between 2020 and
 263 2050 when compared to the C2100 case.

264

Policy implications

The results show that earlier WACC convergence could allow developing regions to reach net-zero earlier. How can earlier WACC convergence be achieved? When considering local financing conditions in developing economies, decarbonisation pathways appear more costly than is often projected. Such economies fall into a “climate investment trap” when high investment needs are coupled with high WACCs, preventing such investment from taking place. To avoid this, radical changes are needed to better direct capital allocation towards what investors appear to perceive as high-risk assets.

We discuss our results in relation to the existing practices in current sustainable finance (SF) frameworks (Schoenmaker and Schramade, 2018) both from a local and international perspective, and through its main constituents: private capital markets, public and development finance, financial regulation and monetary policy; and how these levers can be used to lower the cost of capital.

The sustainability links between international private capital markets and developing economies materialise through multinational enterprises (MNEs), the application of Environmental Social Governance (ESG) criteria and risks approaches in investment decision-making. Financial institutions through their investment in MNEs can theoretically influence MNEs’ green activities overseas. However, while the type of energy and technology being financed is under acute scrutiny from financial institutions (Ameli *et al.*, 2019), civil society, and governments (Braungardt *et al.* 2019, Ayling and Gunningham, 2017), the target country appears to be less of a concern (Forstater *et al.*, 2016). This tends to incentivise MNEs’ green activities ‘anywhere’ rather than in specific areas where most needed. Moreover, the use of ESG criteria to screen green investment tends to penalize countries characterised by low democratic, transparency, human rights, and ethical standards, where such criteria are difficult to apply. Similarly, approaches focusing on financial risk, which rank first among sustainable finance practices (Chenet, 2020), show high climate-related financial risks in regions that are highly exposed to the physical impacts of climate change - especially if those areas have little capacity to prevent or adapt - and in regions that are carbon-intensive, as a result of expected asset stranding. Consequently, these high-risk regions are left aside by most investors, despite being, again, the most in need of investment (Volz *et al.*, 2020).

Such limitations do not seem to be addressed by current SF frameworks. For instance, the EU Sustainable Finance Action Plan (EC 2018), which is probably the most ambitious SF policy framework to date, overlooks the impact of financing and investment outside Europe and towards developing economies in general. The Chinese Guidelines for Establishing the Green Financial System (The People's Bank of China et al., 2016), the other major SF policy framework, partly addresses this issue by defining how Chinese financial institutions may foster low-carbon finance overseas, through green bonds, the 'South-South cooperation' and the Belt and Road Initiative. Generally, current SF frameworks need to evolve to explicitly target developing economies in how they guide capital flows, if they are to play a significant global role.

Given the limited access to international capital markets by developing economies, fostering low-carbon finance requires a strengthening of local financial systems (Berensmann et al., 2017), while being careful to avoid the downsides of (over-)financialization (Akyuz 2017; Mawdsley 2018; Volz et al. 2020). Supporting the growth of local green bond markets could be a promising way to target renewable investment in developing economies, especially if backed by institutional support from both local governments and international development banks. Green bonds could also help to overcome some other investment issues linked to the minimum investment size and transaction costs (Banga, 2019). In addition, public finance and foreign direct investment can help to foster local financial markets by providing initial long-term capital for green projects (Forstater et al., 2016). Public finance through territorial and technological development, development aid and international development finance, also has a core role in leveraging private capital, and stimulating business models and targeted financial products (Forstater et al., 2016) for green technologies (Mazzucato and Semieniuk, 2018).

The last big entrants in the sustainable finance space are central banks and financial supervisors (NGFS 2019). The first movers were actually in developing economies, where they used their monetary or supervising authority to drive economic development along climate goals (Dikau and Ryan-Collins, 2017; McDaniels and Robins, 2018; D'Orazio and Popoyan, 2019; Dikau and Volz, 2019). In developed economies, to adhere to their mandates on price stability and systemic risk, such institutions have been more reluctant to shift out from their market neutrality principles. Central banks could use their capacity to influence the cost

of capital for low-carbon assets, implementing specific policies such as Bangladesh or India's initiatives on green credit allocation and prudential policies (Dikau and Ryan-Collins, 2017).

Conclusions

This study shows how developing economies are disproportionately impacted by common assumptions of globally uniform WACC rates. The reality and implications of unequal access to finance across countries are often overlooked in decarbonisation modelling exercises and the pathways they produce. By assuming globally uniform WACC values skewed towards those experienced in developed economies, such exercises underestimate the costs for developing economies of achieving decarbonisation, and thus the 'climate investment trap' they find themselves in. For developing economies, models with uniform power sector WACC rates underestimate the investments required to achieve certain levels of renewable electricity generation, and overestimate the levels of renewables deployment that would be consistent with a globally cost-optimal decarbonisation pathway. Specifically, the TIAM-UCL model overestimates the green electricity generation in Africa by 35% when local financing conditions are not considered in the 2°C pathways.

When considering pathways of WACC convergence, our analyses show that green electricity technologies deploy more quickly when the WACC values converge by 2100 than by 2100. Convergence in 2050 would allow Africa to reach net-zero emissions approximately 10 years earlier than when convergence is not considered. This in turn implies that earlier action to improve financial conditions could have a significant impact on the speed and timing of the transition.

Radical changes in finance frameworks are thus needed to better allocate capital to the regions that most need it. Elements of sustainable finance frameworks currently present barriers to these finance flows. Thus far, SF frameworks have focused mainly on capital in developed markets and do not seem able to significantly address the high cost of capital in developing economies. They should be used to trigger a virtuous circle of reducing cost of capital, improving access to finance, and increasing rates of investment to avoid a climate investment trap and allow a more even and equitable low-carbon transition to unfold around the world.

The Covid-19 crisis superimposes a huge additional shorter-term obstacle on this challenge. In the space of a few months, economies across the world have been severely stressed, with developing economies exposed most of all due to their relatively low resilience. This is particularly true for economies whose income is highly dependent on fossil fuels, such as some countries in Africa (e.g. Nigeria). Nonetheless, the pandemic may also present a window of opportunity to reframe the global commons (including public health and the climate system) with respect to international market finance, in which a lower cost of capital for developing economies would allow for low-carbon development at a more internationally equitable cost.

Methods

The cost of capital

The cost of capital (WACC) is widely used in investment appraisal and decision-making processes (Modigliani and Miller 1958, 1963, Myers 1974). The WACC allows investors to assess the profitability of different investments representing an appropriate benchmark rate to decide the acceptance or rejection of an investment (Graham and Harvey 2001, Bruner et al. 1998). The WACC is also used as discount rate in the Net Present Value calculations, which is the common method of evaluating investment opportunities to determine their likely profitability of the investment (Miller and Modigliani 1958, 1963).

The WACC thus provides a simple measure to evaluate perceived risks for a given investment in a specific market. In this study, the WACC is used as a proxy to assess the differences in risk-premiums associated with energy assets across countries and/or regions, as it represents the weighted average of the costs of raising funding (equity and debt) for a specific investment (Modigliani and Miller 1958, 1963). The cost of equity depends on the risk that equity investors perceive in the project in a specific market, while the cost of debt reflects the default risk that lenders perceive from the same investment in that market (Kumar 2016).

We used a new WACC database covering developed and developing economies as input in the modelling exercise (Ameli et al. 2017). The data reflects the single variables needed for the WACC calculation according to the following equation:

$$WACC = \left(\frac{E}{D+E} \right) * K_e + \left(\frac{D}{D+E} \right) * K_d (1 - Tax)$$

where E is the value of equity, D is the value of debt, $\left(\frac{E}{D+E} \right)$ represents the percentage of equity in the total financing and $\left(\frac{D}{D+E} \right)$ represents the percentage of debt in the total financing, K_e is the cost of equity, while K_d is the cost of debt and finally T is the tax rate on corporate income.

According to the WACC equation, the cost of capital is computed as the weighted average of the cost of equity and cost of debt. The risk-free rate and the market risk premium adjusted by a beta factor, are the two major building blocks for the calculation of cost of equity (Pratt

and Grabowski 2014). They reflect the risk premiums requested for investing in a specific project in a given market/country - where the risk-free rate represents the rate of return that an investor would expect from an asset that is defined as 'risk-free'; and the market risk premium captures the additional return of a given equity investment when compared to the risk-free rate. The market risk premium is adjusted by a beta factor to account for the volatility of the asset return in comparison with the market returns as a whole. Finally, the cost of debt reflects the interest rates in the market that an investor would pay, adjusted for the tax-deductibility of interest expenses. While the concept and the WACC equation is commonly accepted, there are a number of different ways to assess its components - please see Ameli et al. 2017 for more details on WACC's components, values, methodology, and the data source for each variable used in this analysis.

According to the data collected by Ameli et al 2017, the cost of financing renewables in emerging markets is almost as twice as expensive as in Germany, France and UK, and overall, it is more expensive than the other power generation investments. Such differences in WACC are mainly driven by the beta factor in the cost of equity. Indeed, the beta in the renewable power is always higher than 1 as also suggested by previous work (Henriques and Sadorsky 2008), meaning that the sector is still risky (or perceived as risky) than the market as a whole, in contrast to the beta in the brown power sector which is lower than 1.

Modelling tool

TIAM-UCL is the TIMES Integrated Assessment Model (TIAM) developed at the UCL Energy Institute. This is a global multiregional technology-rich bottom-up cost optimisation model. It is a partial equilibrium model that represents energy resource extraction through conversion processes (refineries, electricity and heat generation) and infrastructure to end-uses in the residential, commercial, industry, transport and agriculture sectors. With perfect foresight over the modelling period, the model designs a cost-optimal transition of the energy system so that future service demands are met, while obeying technical, economic and policy constraints.

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. Table M.1 outlines the key model assumptions on renewable technology costs, which are so important for strong mitigation scenarios.

In TIAM-UCL the world is represented as 16 geographic regions. There is no further representation of the heterogeneity within each region. The regions represented are: Africa, Australia, Canada, China, Central and South America, Eastern Europe, Former Soviet Union, India, Japan, Mexico, Middle-east, Other Developing Asia, South Korea, United Kingdom, USA, Western Europe (see table M.2). The regions are linked through trade in crude oil, hard coal, pipeline gas, LNG, petroleum products (such as diesel, gasoline, naphtha, and heavy fuel oil), biomass, and emission permits.

Energy service demands are exogenous inputs to the model; they 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 historic data (calibrated to 2015 values). In addition to the global social discount rate, various hurdle rates (or WACCs) are used for sector specific technologies (extraction, transformation, generation or end-use sectors).

Table M.1: Solar PV, onshore wind, and offshore wind costs in scenarios (indicative values for Western Europe)

Technology	Cost [\$ ₂₀₀₅ /kW]		
	2010	2030	2050
Solar PV generation – centralised	2587	633	376
Solar PV generation – decentralised	3118	769	442
Onshore wind generation	1620	969	527
Offshore wind generation	3420	1,749	627

Table M.2: 16 regions represented in TIAM-UCL and the countries included in each region.

Region and Description	Countries Included
Africa	Algeria, Angola, Benin, Cameroon, Congo, Congo Republic, Egypt, Ethiopia, Gabon, Ghana, Ivory Coast, Kenya, Libya, Morocco, Mozambique, Nigeria, Other Africa, Senegal, South Africa, Sudan, Tanzania, Tunisia, Zambia, Zimbabwe
Australia	Australia and New Zealand
Canada	Canada
Central and South America	Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Other Latin America, Panama, Paraguay, Peru, Trinidad-Tobago, Uruguay, Venezuela
China	China
Eastern Europe	Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Poland, Romania, Slovakia, Slovenia, Yugoslavia
Former Soviet Union	Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
India	India
Japan	Japan
Mexico	Mexico
Middle-East	Bahrain, Cyprus, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates, Yemen
Other Developing Asia	Bangladesh, Brunei, Chinese Taipei, Indonesia, North Korea, Malaysia, Myanmar, Nepal, Other Asia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam
South Korea	South Korea
United Kingdom	United Kingdom
USA	United States of America
WEU = Western Europe	Austria, Belgium, Denmark, Finland, France, Germany, Gibraltar, Greece, Greenland, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland

The green and brown WACCs are differentiated locally between the 16 regions represented in the TIAM-UCL model reflecting the cost of financing in generation projects.

Scenarios

Table M.3 summarises the scenarios used in this analysis. We design two sets of scenarios to highlight the financial implications of decarbonisation pathways. The first set includes one scenario implementing regional WACCs (REG) and one scenario using uniform WACCs at mean global values (GBL) differentiating only between the green and brown generation (5.9% and 5.1% for green and brown technologies respectively). When using a uniform cost of capital over all regions (GBL), the effect is to reduce the WACC in developing economies compared to their actual cost of financing, while the WACC will increase in developed countries compared to their current values as reflected in the REG scenario. These changes are more evident in the reduction from high WACC values than in the increase from low WACC values to uniform cost, given the WACC deviations in absolute terms.

The second set of scenarios considers WACC convergence over different time horizons, namely 2050 (C2050) and 2100 (C2100). Considering such pathways of WACC convergence is important to assess how the pace of reducing the cost of capital for green and brown technologies to uniform values impacts cost-optimal green electricity generation, power investments and emissions reduction over time. We made simplified assumptions about regions' convergence – we assumed that all countries will experience absolute convergence at the same pace, without accounting for local structural characteristics that might affect the speed of the convergence process (e.g. conditional convergence) or different growth trajectories followed by specific groups of countries (e.g. club convergence) (Galor 1996). The assumption of absolute convergence results in faster WACC convergence for developing economies as the WACC gap is more marked in absolute terms in such regions, compared to developed economies (Fig 1). Figure M.1 shows an example of WACC convergence for a selected developing economy (Africa) as a function of time (implications for all countries/regions are available in the annex).

In all scenarios, GDP growth is calibrated to match the Shared Socioeconomic Pathway SSP2. In addition, energy demand is driven by the SSP2 population growth and the structure of the global economy changes according to the SSP2 projections. 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 modelling analysis is based on scenarios achieving a 2°C target by the end of the century. Overshoot above the temperature limit is allowed in all model runs, meaning that the global

temperature rise can exceed 2°C during the model timeframe but it must return to reach 2°C or lower in 2100. In all the modelled pathways that have the temperature limit applied, the global temperature rise reaches 2.23°C in 2060.

Table M.3: Scenarios implemented in the TIAM-UCL model

Scenarios	Constraint	WACC
REG	2C in 2100	Regional (Fig 2) and constant over the period
GBL	2C in 2100	Uniform and constant over the period after 2020
C2050	2C in 2100	Regional differentiation until 2020 (Table 1) to linear convergence in 2050
C2100	2C in 2100	Regional differentiation until 2020 (Table 1) to linear convergence in 2100

Figure M.1: Evolution of the green WACC for Africa under different scenarios

Annex – Global results

Global results for the different scenarios are presented in this section. We focus on power generation and provide the total (including brown and green power) and green electricity production.

In figure M.2, we present the global results in a simplified manner by aggregating the 16 regions of TIAM-UCL in 2 blocks. The first block represents the regions experiencing large change in WACC values between the REG and GBL scenarios (namely: Africa, Central and South America, India and Mexico) and the second represents the remaining regions which experience weak or no changes in their WACCs (respectively referred to “block_1” and “block_2” in the figure). The results are similar to those discussed in the main text: in the regions with high values (block_1), lowering the WACC increases the green electricity generation in the 2C pathway, while maintaining a lower level of investment per generated unit. In the same way early convergence (C2050) increases early green generation production at least costs in block 1. Finally, the specific electricity generation (total and green) at the regional level (for the 16 regions and the 5 scenarios) are given in table M4 and the corresponding investments in table M5.

Figure M.2: Green electricity generation (left) and investment per year (right) for the two region groups

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Table M4: Regional power generation in green electricity (green shaded) and total electricity (blue shaded) for the 16 TIAM-UCL regions and the 4 scenarios presented in the study (in PJ).

Type	Region	Scenario	2020	2030	2040	2050	2060	2070	2080	2090	2100
Green	AFR	GBL	571	1,580	3,071	7,297	13,729	24,050	36,277	44,238	48,168
Green	AFR	REG	571	2,116	5,691	11,118	20,021	30,114	40,005	49,343	51,836
Green	AFR	C2050	571	1,526	4,096	10,442	19,862	30,172	40,091	49,333	51,605
Green	AFR	C2100	571	1,580	3,618	7,771	16,012	28,548	39,257	48,384	52,408
Green	AUS	GBL	298	932	1,362	3,063	3,906	4,855	6,837	9,598	12,159
Green	AUS	REG	298	1,007	1,439	3,172	3,930	4,824	6,696	8,157	13,154
Green	AUS	C2050	298	959	1,384	3,190	3,841	4,814	6,549	8,249	13,262
Green	AUS	C2100	298	930	1,362	3,063	3,906	4,835	6,623	9,094	12,683
Green	CAN	GBL	1,501	1,996	2,672	3,784	7,152	8,545	8,858	8,998	9,818
Green	CAN	REG	1,501	2,008	2,659	3,807	7,306	8,556	8,854	9,028	9,812
Green	CAN	C2050	1,501	1,990	2,634	3,828	7,321	8,548	8,873	9,027	9,811
Green	CAN	C2100	1,501	1,996	2,669	3,788	7,273	8,542	8,844	8,993	9,813
Green	CHI	GBL	5,764	19,792	35,717	71,111	103,732	109,616	111,296	112,310	110,376
Green	CHI	REG	5,764	19,942	37,404	74,819	102,095	111,180	112,534	112,634	110,870
Green	CHI	C2050	5,764	19,931	37,226	85,050	105,499	111,187	112,569	112,271	111,205
Green	CHI	C2100	5,764	19,786	35,724	71,065	103,352	109,607	112,509	112,353	110,074
Green	CSA	GBL	3,163	4,945	7,533	13,347	24,133	33,151	37,791	40,843	46,826
Green	CSA	C2050	3,163	4,956	7,550	14,923	25,589	34,683	39,000	43,083	48,749
Green	CSA	C2100	3,163	4,956	7,596	13,700	25,100	34,003	38,896	43,125	48,771
Green	EEU	GBL	442	870	1,690	2,474	3,458	3,991	4,397	4,898	5,182
Green	EEU	REG	442	870	1,708	2,464	3,447	3,989	4,427	5,007	5,349
Green	EEU	C2050	442	871	1,714	2,492	3,514	4,016	4,424	4,968	5,339
Green	EEU	C2100	442	870	1,687	2,464	3,435	3,985	4,408	4,985	5,318
Green	FSU	GBL	1,049	3,027	5,777	10,754	15,102	17,647	23,282	27,265	28,831
Green	FSU	REG	1,049	3,089	6,157	10,898	15,018	17,701	23,160	27,246	29,147
Green	FSU	C2050	1,049	3,031	5,969	10,882	14,663	17,750	23,224	27,332	29,265
Green	FSU	C2100	1,049	3,021	5,803	10,706	15,048	17,643	23,430	27,270	28,990
Green	IND	GBL	1,963	5,155	11,128	28,694	39,550	50,694	60,065	68,866	77,308
Green	IND	REG	1,963	6,078	12,151	29,159	39,727	51,983	62,111	69,399	77,189
Green	IND	C2050	1,963	5,339	11,825	29,133	40,009	52,187	62,002	69,200	77,204
Green	IND	C2100	1,963	5,207	11,192	28,855	39,679	51,126	60,762	69,312	77,321
Green	JPN	GBL	785	1,977	2,465	4,100	6,844	8,022	8,388	8,442	8,645
Green	JPN	REG	785	1,985	2,469	4,079	6,886	8,137	8,133	8,383	8,609
Green	JPN	C2050	785	1,976	2,460	4,107	6,876	8,141	8,167	8,420	8,625
Green	JPN	C2100	785	1,976	2,462	4,097	6,901	8,166	8,342	8,574	8,753
Green	MEA	GBL	501	1,234	5,074	10,205	16,697	27,628	31,385	31,277	34,458
Green	MEA	REG	501	1,344	5,371	11,121	19,143	28,396	31,462	31,563	35,647
Green	MEA	C2050	501	1,337	5,380	11,321	19,058	28,262	31,466	31,572	35,648
Green	MEA	C2100	501	1,337	5,370	11,131	19,143	28,101	31,466	31,537	35,644
Green	MEX	GBL	183	460	1,040	1,935	3,526	4,564	5,322	5,943	6,519
Green	MEX	REG	183	501	1,219	2,232	4,230	5,060	5,672	6,356	6,846
Green	MEX	C2050	183	429	1,079	2,351	4,252	5,072	5,709	6,363	6,846
Green	MEX	C2100	183	464	1,051	1,976	3,744	4,907	5,665	6,336	6,846
Green	ODA	GBL	1,217	2,892	8,661	17,496	30,632	46,983	58,089	64,255	69,341
Green	ODA	REG	1,217	2,921	8,938	17,480	31,256	48,291	59,570	66,334	69,672
Green	ODA	C2050	1,217	2,827	8,727	17,865	31,292	48,329	59,618	66,712	69,639
Green	ODA	C2100	1,217	2,827	8,656	17,735	31,297	48,010	58,917	65,557	69,426
Green	SKO	GBL	88	350	747	1,399	1,767	2,524	3,195	3,714	3,683
Green	SKO	REG	88	355	756	1,521	2,075	3,082	3,779	4,184	4,129
Green	SKO	C2050	88	343	748	1,597	2,098	3,098	3,788	4,203	4,149
Green	SKO	C2100	88	350	748	1,498	1,930	2,727	3,447	3,959	4,084
Green	UK	GBL	327	830	1,731	4,152	6,267	7,154	7,745	8,114	8,714
Green	UK	REG	327	812	1,741	4,152	6,280	7,166	7,732	8,169	8,812
Green	UK	C2050	327	827	1,773	4,274	6,334	7,163	7,730	8,165	8,807
Green	UK	C2100	327	827	1,733	4,154	6,272	7,160	7,737	8,147	8,788
Green	USA	GBL	2,691	8,443	17,666	34,641	53,869	60,806	63,840	65,405	70,017
Green	USA	REG	2,691	8,429	17,741	34,896	53,712	60,909	63,867	66,590	70,155
Green	USA	C2050	2,691	8,426	17,791	35,536	53,798	61,348	63,990	66,816	70,252

Green	USA	C2100	2,691	8,440	17,708	34,800	53,889	60,901	63,869	66,007	70,448
Green	WEU	GBL	3,799	6,165	8,529	15,466	20,667	21,588	21,278	22,202	23,068
Green	WEU	REG	3,799	6,125	8,550	15,355	20,404	21,317	21,208	21,486	22,536
Green	WEU	C2050	3,799	6,155	8,665	15,794	20,356	21,061	21,125	21,467	22,627
Green	WEU	C2100	3,799	6,159	8,580	15,400	20,291	21,266	21,214	21,839	22,610
Total	AFR	GBL	2,911	3,266	4,009	7,682	13,830	24,107	36,295	44,240	48,274
Total	AFR	REG	2,911	3,338	6,213	11,251	20,137	30,189	40,023	49,345	51,836
Total	AFR	C2050	2,911	3,262	5,634	10,610	19,977	30,194	40,095	49,335	51,605
Total	AFR	C2100	2,911	3,294	4,661	8,430	16,138	28,616	39,274	48,386	52,408
Total	AUS	GBL	1,180	1,409	1,568	3,093	3,920	4,855	6,837	9,598	12,159
Total	AUS	REG	1,180	1,400	1,575	3,198	3,945	4,824	6,696	8,157	13,154
Total	AUS	C2050	1,180	1,391	1,550	3,213	3,854	4,814	6,549	8,249	13,262
Total	AUS	C2100	1,180	1,403	1,568	3,093	3,921	4,835	6,623	9,094	12,683
Total	CAN	GBL	2,491	2,815	2,898	3,921	7,218	8,595	8,891	9,014	9,818
Total	CAN	REG	2,491	2,823	2,883	3,943	7,372	8,606	8,887	9,044	9,812
Total	CAN	C2050	2,491	2,821	2,888	3,966	7,387	8,598	8,906	9,044	9,811
Total	CAN	C2100	2,491	2,814	2,895	3,925	7,339	8,592	8,877	9,009	9,813
Total	CHI	GBL	26,849	33,058	44,314	73,501	105,225	111,493	114,006	115,947	115,198
Total	CHI	REG	26,849	33,549	46,606	77,417	103,405	113,057	114,758	115,673	115,238
Total	CHI	C2050	26,849	33,218	46,052	87,330	106,419	112,992	114,606	115,244	115,492
Total	CHI	C2100	26,849	33,050	44,424	73,469	104,592	111,371	114,671	115,370	114,415
Total	CSA	GBL	4,015	5,046	7,626	13,492	24,271	33,245	37,814	40,846	46,826
Total	CSA	REG	4,015	5,139	7,824	14,846	25,550	34,476	38,993	43,084	48,774
Total	CSA	C2050	4,015	5,057	7,609	14,978	25,636	34,722	39,006	43,086	48,749
Total	CSA	C2100	4,015	5,057	7,693	13,853	25,245	34,100	38,920	43,128	48,771
Total	EEU	GBL	2,004	2,215	2,483	3,333	3,986	4,809	5,581	6,366	6,966
Total	EEU	REG	2,004	2,216	2,481	3,302	3,958	4,781	5,570	6,439	7,094
Total	EEU	C2050	2,004	2,216	2,488	3,333	3,988	4,779	5,557	6,399	7,083
Total	EEU	C2100	2,004	2,215	2,480	3,320	3,976	4,815	5,593	6,450	7,098
Total	FSU	GBL	5,477	8,661	10,036	12,781	16,568	18,330	23,588	27,344	28,866
Total	FSU	REG	5,477	8,689	10,059	12,776	16,340	18,209	23,382	27,290	29,147
Total	FSU	C2050	5,477	8,665	9,977	12,784	16,008	18,282	23,454	27,376	29,265
Total	FSU	C2100	5,477	8,657	10,031	12,784	16,566	18,335	23,694	27,313	28,990
Total	IND	GBL	5,499	6,498	12,179	30,172	40,838	51,708	60,679	68,914	77,308
Total	IND	REG	5,499	7,179	13,240	30,721	41,074	53,033	62,725	69,447	77,189
Total	IND	C2050	5,499	6,580	12,827	30,529	41,225	52,996	62,616	69,248	77,204
Total	IND	C2100	5,499	6,551	12,253	30,365	40,995	52,162	61,376	69,360	77,321
Total	JPN	GBL	3,704	4,206	3,925	5,031	7,121	8,213	8,499	8,497	8,645
Total	JPN	REG	3,704	4,206	3,967	5,041	7,170	8,329	8,245	8,438	8,609
Total	JPN	C2050	3,704	4,204	3,939	5,073	7,138	8,320	8,276	8,474	8,625
Total	JPN	C2100	3,704	4,205	3,927	5,048	7,183	8,361	8,455	8,629	8,753
Total	MEA	GBL	3,741	5,583	7,271	13,457	19,458	27,854	31,461	31,277	34,458
Total	MEA	REG	3,741	5,580	7,356	13,712	20,188	28,503	31,478	31,563	35,647
Total	MEA	C2050	3,741	5,580	7,389	13,943	20,018	28,343	31,477	31,572	35,648
Total	MEA	C2100	3,741	5,580	7,375	13,735	20,187	28,207	31,479	31,537	35,644
Total	MEX	GBL	802	863	1,127	1,948	3,534	4,570	5,326	5,945	6,519
Total	MEX	REG	802	908	1,268	2,245	4,238	5,066	5,676	6,358	6,846
Total	MEX	C2050	802	879	1,185	2,364	4,260	5,077	5,713	6,365	6,846
Total	MEX	C2100	802	876	1,155	1,989	3,752	4,913	5,669	6,338	6,846
Total	ODA	GBL	4,590	5,735	9,550	18,604	30,946	47,166	58,159	64,263	69,341
Total	ODA	REG	4,590	5,702	9,668	18,437	31,568	48,481	59,646	66,342	69,672
Total	ODA	C2050	4,590	5,723	9,703	18,712	31,591	48,496	59,700	66,720	69,639
Total	ODA	C2100	4,590	5,727	9,562	18,649	31,607	48,186	59,002	65,565	69,426
Total	SKO	GBL	1,975	2,099	2,389	3,192	3,835	4,948	5,736	6,448	6,613
Total	SKO	REG	1,975	2,099	2,390	3,229	3,903	5,125	5,860	6,543	6,714
Total	SKO	C2050	1,975	2,100	2,389	3,325	3,915	5,132	5,860	6,542	6,720
Total	SKO	C2100	1,975	2,099	2,389	3,220	3,857	4,981	5,792	6,505	6,709
Total	UK	GBL	1,350	1,541	1,870	4,219	6,304	7,154	7,745	8,114	8,714
Total	UK	REG	1,350	1,541	1,881	4,220	6,318	7,166	7,732	8,169	8,812
Total	UK	C2050	1,350	1,541	1,912	4,341	6,371	7,163	7,730	8,165	8,807
Total	UK	C2100	1,350	1,541	1,872	4,222	6,309	7,160	7,737	8,147	8,788

Total	USA	GBL	16,084	17,311	21,078	36,411	54,764	61,243	64,132	65,551	70,017
Total	USA	REG	16,084	17,310	21,086	36,659	54,601	61,348	64,159	66,735	70,155
Total	USA	C2050	16,084	17,334	21,048	37,275	54,665	61,785	64,281	66,962	70,252
Total	USA	C2100	16,084	17,317	21,079	36,564	54,781	61,339	64,160	66,153	70,448
Total	WEU	GBL	9,597	10,366	9,978	15,639	20,768	21,610	21,278	22,202	23,068
Total	WEU	REG	9,597	10,334	9,980	15,529	20,506	21,341	21,208	21,486	22,536
Total	WEU	C2050	9,597	10,305	9,951	15,914	20,406	21,065	21,125	21,467	22,627
Total	WEU	C2100	9,597	10,333	9,976	15,571	20,391	21,291	21,214	21,839	22,610

Table M5: Regional investment levels in green electricity generation (green shaded) and total electricity generation (blue shaded) for the 16 TIAM-UCL regions and the 4 scenarios presented in the study (in M\$₂₀₀₅).

Type	Region	Scenario	2020	2030	2040	2050	2060	2070	2080	2090	2100
Green	AFR	GBL	571	1,580	3,071	7,297	13,729	24,050	36,277	44,238	48,168
Green	AFR	REG	571	2,116	5,691	11,118	20,021	30,114	40,005	49,343	51,836
Green	AFR	C2050	571	1,526	4,096	10,442	19,862	30,172	40,091	49,333	51,605
Green	AFR	C2100	571	1,580	3,618	7,771	16,012	28,548	39,257	48,384	52,408
Green	AUS	GBL	298	932	1,362	3,063	3,906	4,855	6,837	9,598	12,159
Green	AUS	REG	298	1,007	1,439	3,172	3,930	4,824	6,696	8,157	13,154
Green	AUS	C2050	298	959	1,384	3,190	3,841	4,814	6,549	8,249	13,262
Green	AUS	C2100	298	930	1,362	3,063	3,906	4,835	6,623	9,094	12,683
Green	CAN	GBL	1,501	1,996	2,672	3,784	7,152	8,545	8,858	8,998	9,818
Green	CAN	REG	1,501	2,008	2,659	3,807	7,306	8,556	8,854	9,028	9,812
Green	CAN	C2050	1,501	1,990	2,634	3,828	7,321	8,548	8,873	9,027	9,811
Green	CAN	C2100	1,501	1,996	2,669	3,788	7,273	8,542	8,844	8,993	9,813
Green	CHI	GBL	5,764	19,792	35,717	71,111	103,732	109,616	111,296	112,310	110,376
Green	CHI	REG	5,764	19,942	37,404	74,819	102,095	111,180	112,534	112,634	110,870
Green	CHI	C2050	5,764	19,931	37,226	85,050	105,499	111,187	112,569	112,271	111,205
Green	CHI	C2100	5,764	19,786	35,724	71,065	103,352	109,607	112,509	112,353	110,074
Green	CSA	GBL	3,163	4,945	7,533	13,347	24,133	33,151	37,791	40,843	46,826
Green	CSA	REG	3,163	5,038	7,720	14,683	25,395	34,376	38,968	43,081	48,774
Green	CSA	C2050	3,163	4,956	7,550	14,923	25,589	34,683	39,000	43,083	48,749
Green	CSA	C2100	3,163	4,956	7,596	13,700	25,100	34,003	38,896	43,125	48,771
Green	EEU	GBL	442	870	1,690	2,474	3,458	3,991	4,397	4,898	5,182
Green	EEU	REG	442	870	1,708	2,464	3,447	3,989	4,427	5,007	5,349
Green	EEU	C2050	442	871	1,714	2,492	3,514	4,016	4,424	4,968	5,339
Green	EEU	C2100	442	870	1,687	2,464	3,435	3,985	4,408	4,985	5,318
Green	FSU	GBL	1,049	3,027	5,777	10,754	15,102	17,647	23,282	27,265	28,831
Green	FSU	REG	1,049	3,089	6,157	10,898	15,018	17,701	23,160	27,246	29,147
Green	FSU	C2050	1,049	3,031	5,969	10,882	14,663	17,750	23,224	27,332	29,265
Green	FSU	C2100	1,049	3,021	5,803	10,706	15,048	17,643	23,430	27,270	28,990
Green	IND	GBL	1,963	5,155	11,128	28,694	39,550	50,694	60,065	68,866	77,308
Green	IND	REG	1,963	6,078	12,151	29,159	39,727	51,983	62,111	69,399	77,189
Green	IND	C2050	1,963	5,339	11,825	29,133	40,009	52,187	62,002	69,200	77,204
Green	IND	C2100	1,963	5,207	11,192	28,855	39,679	51,126	60,762	69,312	77,321
Green	JPN	GBL	785	1,977	2,465	4,100	6,844	8,022	8,388	8,442	8,645
Green	JPN	REG	785	1,985	2,469	4,079	6,886	8,137	8,133	8,383	8,609
Green	JPN	C2050	785	1,976	2,460	4,107	6,876	8,141	8,167	8,420	8,625
Green	JPN	C2100	785	1,976	2,462	4,097	6,901	8,166	8,342	8,574	8,753
Green	MEA	GBL	501	1,234	5,074	10,205	16,697	27,628	31,385	31,277	34,458
Green	MEA	REG	501	1,344	5,371	11,121	19,143	28,396	31,462	31,563	35,647
Green	MEA	C2050	501	1,337	5,380	11,321	19,058	28,262	31,466	31,572	35,648
Green	MEA	C2100	501	1,337	5,370	11,131	19,143	28,101	31,466	31,537	35,644
Green	MEX	GBL	183	460	1,040	1,935	3,526	4,564	5,322	5,943	6,519
Green	MEX	REG	183	501	1,219	2,232	4,230	5,060	5,672	6,356	6,846
Green	MEX	C2050	183	429	1,079	2,351	4,252	5,072	5,709	6,363	6,846
Green	MEX	C2100	183	464	1,051	1,976	3,744	4,907	5,665	6,336	6,846
Green	ODA	GBL	1,217	2,892	8,661	17,496	30,632	46,983	58,089	64,255	69,341
Green	ODA	REG	1,217	2,921	8,938	17,480	31,256	48,291	59,570	66,334	69,672
Green	ODA	C2050	1,217	2,827	8,727	17,865	31,292	48,329	59,618	66,712	69,639
Green	ODA	C2100	1,217	2,827	8,656	17,735	31,297	48,010	58,917	65,557	69,426
Green	SKO	GBL	88	350	747	1,399	1,767	2,524	3,195	3,714	3,683

Green	SKO	REG	88	355	756	1,521	2,075	3,082	3,779	4,184	4,129
Green	SKO	C2050	88	343	748	1,597	2,098	3,098	3,788	4,203	4,149
Green	SKO	C2100	88	350	748	1,498	1,930	2,727	3,447	3,959	4,084
Green	UK	GBL	327	830	1,731	4,152	6,267	7,154	7,745	8,114	8,714
Green	UK	REG	327	812	1,741	4,152	6,280	7,166	7,732	8,169	8,812
Green	UK	C2050	327	827	1,773	4,274	6,334	7,163	7,730	8,165	8,807
Green	UK	C2100	327	827	1,733	4,154	6,272	7,160	7,737	8,147	8,788
Green	USA	GBL	2,691	8,443	17,666	34,641	53,869	60,806	63,840	65,405	70,017
Green	USA	REG	2,691	8,429	17,741	34,896	53,712	60,909	63,867	66,590	70,155
Green	USA	C2050	2,691	8,426	17,791	35,536	53,798	61,348	63,990	66,816	70,252
Green	USA	C2100	2,691	8,440	17,708	34,800	53,889	60,901	63,869	66,007	70,448
Green	WEU	GBL	3,799	6,165	8,529	15,466	20,667	21,588	21,278	22,202	23,068
Green	WEU	REG	3,799	6,125	8,550	15,355	20,404	21,317	21,208	21,486	22,536
Green	WEU	C2050	3,799	6,155	8,665	15,794	20,356	21,061	21,125	21,467	22,627
Green	WEU	C2100	3,799	6,159	8,580	15,400	20,291	21,266	21,214	21,839	22,610
Total	AFR	GBL	4,643	4,693	5,644	9,347	15,789	26,120	38,357	46,328	50,268
Total	AFR	REG	2,911	3,802	6,629	11,503	20,122	30,171	40,024	49,345	51,943
Total	AFR	C2050	2,911	2,748	4,618	10,576	19,977	30,247	40,110	49,335	51,605
Total	AFR	C2100	2,911	3,316	5,156	7,938	16,128	28,570	39,261	48,386	52,408
Total	AUS	GBL	2,639	2,535	2,645	4,893	5,674	6,199	7,849	9,864	13,105
Total	AUS	REG	1,180	1,484	1,645	3,202	3,945	4,824	6,696	8,157	13,154
Total	AUS	C2050	1,180	1,352	1,520	3,215	3,856	4,814	6,549	8,249	13,262
Total	AUS	C2100	1,180	1,363	1,528	3,087	3,919	4,835	6,623	9,094	12,683
Total	CAN	GBL	2,383	2,626	3,152	4,013	7,234	8,630	8,939	9,081	9,878
Total	CAN	REG	2,491	2,826	2,885	3,943	7,372	8,606	8,887	9,044	9,812
Total	CAN	C2050	2,491	2,806	2,857	3,965	7,387	8,598	8,906	9,044	9,811
Total	CAN	C2100	2,491	2,827	2,922	3,925	7,339	8,592	8,877	9,009	9,813
Total	CHI	GBL	6,755	20,732	36,406	71,971	103,857	109,707	111,338	112,343	110,393
Total	CHI	REG	26,849	33,208	46,000	77,209	103,589	113,057	115,245	116,271	115,692
Total	CHI	C2050	26,849	33,539	46,427	87,648	106,809	113,064	114,792	115,309	115,573
Total	CHI	C2100	26,849	33,073	44,551	73,345	104,271	111,412	114,546	115,327	114,361
Total	CSA	GBL	24,248	22,434	25,736	22,565	27,784	34,264	38,966	42,273	48,845
Total	CSA	REG	4,015	5,139	7,813	14,829	25,533	34,470	38,992	43,084	48,774
Total	CSA	C2050	4,015	5,057	7,653	15,085	25,744	34,784	39,025	43,086	48,749
Total	CSA	C2100	4,015	5,057	7,655	13,755	25,147	34,042	38,902	43,128	48,771
Total	EEU	GBL	1,293	1,128	1,793	2,651	3,692	4,251	4,647	5,157	5,369
Total	EEU	REG	2,004	2,215	2,501	3,323	3,975	4,807	5,611	6,476	7,133
Total	EEU	C2050	2,004	2,217	2,487	3,330	4,025	4,809	5,567	6,399	7,083
Total	EEU	C2100	2,004	2,215	2,461	3,305	3,909	4,748	5,541	6,416	7,062
Total	FSU	GBL	2,612	4,828	8,032	13,410	17,560	20,104	25,360	29,345	30,928
Total	FSU	REG	5,477	8,722	10,416	12,924	16,484	18,383	23,466	27,325	29,182
Total	FSU	C2050	5,477	8,632	9,871	12,760	15,984	18,258	23,445	27,376	29,265
Total	FSU	C2100	5,477	8,655	9,811	12,607	16,394	18,176	23,660	27,313	28,990
Total	IND	GBL	6,390	11,811	19,038	38,316	46,748	56,167	63,555	70,179	78,509
Total	IND	REG	5,499	7,421	13,202	30,637	41,015	52,997	62,725	69,447	77,189
Total	IND	C2050	5,499	6,440	12,914	30,695	41,355	53,237	62,616	69,248	77,204
Total	IND	C2100	5,499	6,448	12,195	30,251	40,896	51,935	61,376	69,360	77,321
Total	JPN	GBL	4,321	4,614	6,170	6,288	8,303	9,192	9,043	8,491	8,645
Total	JPN	REG	3,704	4,214	3,929	5,009	7,164	8,328	8,244	8,438	8,609
Total	JPN	C2050	3,704	4,197	3,958	5,069	7,160	8,333	8,279	8,474	8,625
Total	JPN	C2100	3,704	4,205	3,941	5,063	7,163	8,345	8,452	8,629	8,753
Total	MEA	GBL	3,420	3,763	7,272	12,196	17,448	28,146	31,795	31,632	34,745
Total	MEA	REG	3,741	5,693	7,568	14,373	21,903	28,622	31,538	31,563	35,647
Total	MEA	C2050	3,741	5,574	7,365	13,913	20,102	28,369	31,482	31,572	35,648
Total	MEA	C2100	3,741	5,580	7,380	13,753	20,103	28,183	31,477	31,537	35,644
Total	MEX	GBL	3,424	4,938	3,796	5,658	7,834	10,440	11,545	11,864	11,180
Total	MEX	REG	802	904	1,306	2,244	4,238	5,066	5,676	6,358	6,846
Total	MEX	C2050	802	836	1,127	2,364	4,260	5,077	5,713	6,365	6,846
Total	MEX	C2100	802	914	1,157	1,989	3,751	4,913	5,669	6,338	6,846
Total	ODA	GBL	1,835	3,480	9,252	18,045	30,721	47,019	58,099	64,257	69,341
Total	ODA	REG	4,590	5,763	9,827	18,588	31,571	48,474	59,639	66,342	69,672
Total	ODA	C2050	4,590	5,608	9,457	18,823	31,604	48,520	59,694	66,720	69,639

Total	ODA	C2100	4,590	5,723	9,632	18,582	31,597	48,176	58,999	65,565	69,426
Total	SKO	GBL	3,462	3,595	2,837	3,560	2,827	3,345	3,654	4,424	4,434
Total	SKO	REG	1,975	2,104	2,397	3,314	4,143	5,507	6,320	6,918	7,060
Total	SKO	C2050	1,975	2,086	2,382	3,305	3,926	5,141	5,869	6,562	6,733
Total	SKO	C2100	1,975	2,107	2,388	3,225	3,747	4,762	5,519	6,298	6,656
Total	UK	GBL	2,214	2,728	3,808	6,401	7,982	8,812	9,295	9,524	10,091
Total	UK	REG	1,350	1,522	1,880	4,220	6,317	7,166	7,732	8,169	8,812
Total	UK	C2050	1,350	1,556	1,913	4,343	6,372	7,163	7,730	8,165	8,807
Total	UK	C2100	1,350	1,540	1,872	4,221	6,309	7,160	7,737	8,147	8,788
Total	USA	GBL	3,714	9,225	17,913	34,748	53,943	60,834	63,845	65,417	70,029
Total	USA	REG	16,084	17,297	21,152	36,665	54,607	61,347	64,159	66,735	70,155
Total	USA	C2050	16,084	17,307	21,136	37,299	54,687	61,787	64,281	66,962	70,252
Total	USA	C2100	16,084	17,348	20,965	36,539	54,756	61,339	64,160	66,153	70,448
Total	WEU	GBL	17,192	15,523	15,139	18,347	21,982	22,317	21,615	22,348	23,068
Total	WEU	REG	9,597	10,326	9,999	15,527	20,505	21,339	21,208	21,486	22,536
Total	WEU	C2050	9,597	10,364	10,094	15,968	20,458	21,086	21,125	21,467	22,627
Total	WEU	C2100	9,597	10,309	9,866	15,520	20,341	21,270	21,214	21,839	22,610

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NA coordinated the research. NA, OD, MW and JC wrote the article, with support from PD, AC and HC on specific sections. NA, MW, OD, GA and AC designed the scenarios, with inputs from MG. OD and MW led the modelling work, with support from JC. HC contributed to the policy section. All authors reviewed the article.

Corresponding author

Correspondence to Nadia Ameli (n.ameli@ucl.ac.uk).

Figures

Figure 1

The climate investment trap. Note: The strength of these links is strictly linked to local conditions implying that the set of self-reinforcing mechanism could be exacerbated (or less relevant) in some economies

Figure 2

Green, brown and converging WACC values across the TIAM-UCL regions Note: The bubble size reflects the different WACC values for brown and green technologies and the convergence values (CONV) regions. The regions represented are: Africa (AFR), Australia (AUS), Canada (CAN), China (CHI), Central and South America (CSA), Eastern Europe (EEU), Former Soviet Union (FSU), India (IND), Japan (JAP), Mexico (MEX), Middle-east (MEA), Other Developing Asia (ODA), South Korea (SKO), United Kingdom (UK), USA (USA), Western Europe (WEU).

Figure 3

Green electricity generation (left) and investment per year (right)

Figure 4

Regional green electricity generation by scenarios (left) and the percentage change in generation compared to the REG scenario (right)

Figure 5

Regional investment levels in green electricity for the 2°C scenarios with different convergence years. Absolute values (left) and changes compared to the REG scenario (right)

Figure 6

Regional CO₂ emissions for the 2°C scenarios with different convergence years