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Ratcheting up climate efforts: Global Energy Investment needs to Reach the Deep Decarbonization Targets of the Paris Agreement

David L. McCollum[1,2*], Wenji Zhou[1], Christoph Bertram[3], Harmen-Sytze de Boer[4], Valentina Bosetti[5,6], Sebastian Busch[1], Jacques Després[7], Laurent Drouet[5], Johannes Emmerling[5], Marianne Fay[8], Oliver Fricko[1], Shinichiro Fujimori[1,9], Matthew Gidden[1], Mathijs Harmsen[4,10], Daniel Huppmann[1], Gokul Iyer[11], Volker Krey[1], Elmar Kriegler[3], Claire Nicolas[8], Shonali Pachauri[1], Simon Parkinson[1,12], Miguel Poblete-Cazenave[1], Peter Rafaj[1], Narasimha Rao[1], Julie Rozenberg[8], Andreas Schmitz[7], Wolfgang Schoepp[1], Detlef van Vuuren[4,10], Keywan Riahi[1,13]

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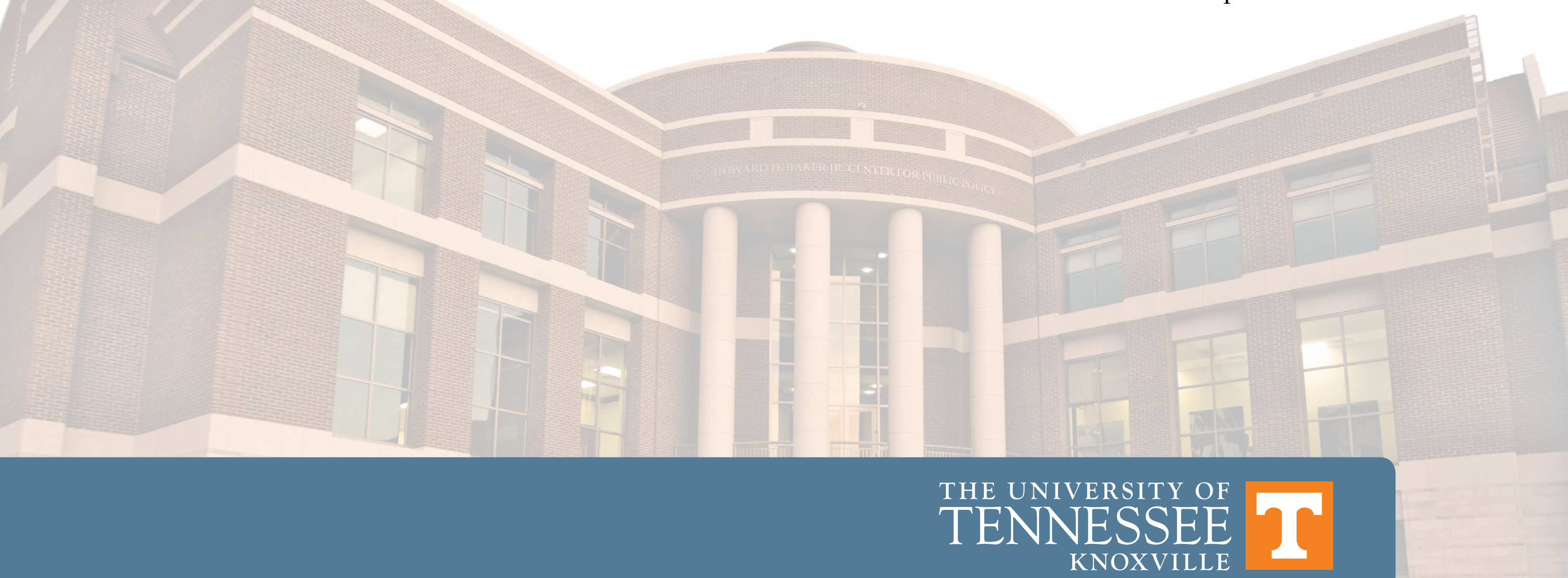

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Ratcheting up climate efforts: Global Energy Investment Needs to Reach the Deep Decarbonization Targets of the Paris Agreement

David L. McCollum[1,2*], Wenji Zhou[1], Christoph Bertram[3], Harmen-Sytze de Boer[4], Valentina Bosetti[5,6], Sebastian Busch[1], Jacques Després[7], Laurent Drouet[5], Johannes Emmerling[5], Marianne Fay[8], Oliver Fricko[1], Shinichiro Fujimori[1,9], Matthew Gidden[1], Mathijs Harmsen[4,10], Daniel Huppmann[1], Gokul Iyer[11], Volker Krey[1], Elmar Kriegler[3], Claire Nicolas[8], Shonali Pachauri[1], Simon Parkinson[1,12], Miguel Poblete-Cazenave[1], Peter Rafaj[1], Narasimha Rao[1], Julie Rozenberg[8], Andreas Schmitz[7], Wolfgang Schoepp[1], Detlef van Vuuren[4,10], Keywan Riahi[1,13]

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Introduction

The international policy community achieved a major milestone in 2015 with the passage of the Paris Agreement. Since that time, nearly 200 countries have signed or ratified the treaty, which aims to significantly reduce emissions of heat-trapping greenhouse gases over the next several decades. At the heart of the Agreement is Article 2.1, which reads[1]:

> *"This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:*
>
> *(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;*
>
> *(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and*
>
> *(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development."*

A number of model-based studies have been carried out in recent years to better understand the pathways by which society could transform its energy systems in line with the aspirational targets espoused by Article 2.1(a), namely 2 °C and 1.5 °C temperature rise over the course of the 21st century[2-5]. A dramatic upscaling of renewables and energy efficiency combined with a rapid phasing-out of fossil fuels are common elements of these narratives. On the other hand, Article 2.1(c)-related issues (finance flows consistent with low-temperature targets, i.e., the mechanism for driving the energy

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system transformation forward) have received comparatively limited treatment by the global scenarios community[6-8].

In this policy brief, we summarize key findings and insights from a recent paper by McCollum et al. (2018)[9], which utilized a multi-model approach for calculating energy investment needs across a range of alternative climate policy futures worldwide. The analysis indicates that while a transformation of the global energy system may not necessarily require a major increase in investments in total, a reallocation of the investment portfolio is certainly inevitable. Charting a course toward 2 °C and 1.5 °C would see annual investments in low-carbon energy (across the entire supply side) overtaking fossil investments globally by around 2025. Achieving countries' Nationally Determined Contributions (NDCs) or the more stringent 2 °C or 1.5 °C targets globally would demand filling a low-carbon energy and energy efficiency investment 'gap' of approximately 130, 30, or 460 billion US$/yr (model means), respectively, on average to 2030 representing upwards of one-quarter of total energy investments otherwise foreseen in a baseline scenario; and for some major economies (e.g., China and India) up to one-half. Beyond 2030 the investment gap would then continue to grow, unless global climate mitigation efforts would be tightened considerably.

Methodology: models employed and scenarios depicted

Scenario modeling tools are widely used to evaluate the costs, potentials, and consequences of different energy, climate, and human development futures over the medium-to-long term. Because models have different structures and solution algorithms and since each has its own perspective on how the future could unfold – in light of varying assumptions for socio-economic development and technological change – model inter-comparison exercises are often conducted to tease out the most robust insights inherent in forward-looking scenarios. In the current work, scenarios from six global energy-economy modelling frameworks are comparatively analyzed. The six global energy-economy models, or integrated assessment (IAM) frameworks, drawn upon include AIM/CGE[10,11], IMAGE[12], MESSAGEix-GLOBIOM[13,14], POLES[15,16], REMIND-MAgPIE[17,18], and WITCH-GLOBIOM[19,20]. These models span a range from least-cost optimization to computable general equilibrium models and from game-theoretic to recursive-dynamic simulation models. Importantly, the six models represent a variety of energy technologies across the entirety of the global energy system, including resource extraction, power generation, fuel conversion, pipelines/transmission, energy storage, and end-use/demand devices.

Four scenarios are depicted by each of the six global models (See 'Additional Information' section for details). 'Current Policies' ('CPol') serves as each model's reference case (or baseline), taking into account those energy- and climate-related policies that were already "on the books" of countries as of 2015. In addition to the reference case, the modeling teams each ran three scenarios where policies for low-carbon energy, energy efficiency, and climate change mitigation are tightened: 'Nationally Determined Contributions' ('NDC'), 'Well Below 2 Degrees' ('2C'), and 'Toward 1.5 Degrees' ('1.5C'). Population and socio-economic development assumptions across all scenarios and models are harmonized across models and are in line with the 'middle-of-the-road' storyline of the Shared Socioeconomic Pathways (SSP2)[13,21].

Findings

Total investments in the global energy system were approximately 1800 billion US$2015/yr in 2015, according to the International Energy Agency (IEA)[22,23]. (By 'investments', we mean excluding fuel and operations and maintenance costs.) This amounted to over 2% of global gross domestic product (GDP) and 10% of gross capital formation in that year. The vast majority of these investments (~1600 billion US$/yr) were made to add or replace equipment on the supply side of the energy system, while a further 220 billion US$/yr was invested in energy efficiency across the end-use sectors (buildings, transport and industry). While investments into renewable energy supplies, particularly solar and wind power, have been growing rapidly in recent years, fossil energy investments still dominate.

As global population and incomes grows, energy investments are likely to follow, at least to some extent. These future trends are clearly exhibited by the six global models (see Figure 1); scenarios from the International Energy Agency (IEA) and International Renewable Energy Agency (IRENA) are shown for comparison[7]. Notable model differences exist, which can be explained by endogenously determined technology choices and varying representations for how unit-level capital costs evolve over time. Note that given the nature of the models employed, we expressly address the question of 'where are the investment needs', not 'who pays for them'.

The impact of future energy and climate policies on total energy investments depends on the nature and extent of those policies. Meeting the most recent suite of countries' climate pledges ('NDC' scenario) would likely only necessitate a marginal increase in total future investments globally, relative to a continuation of current trends ('CPol'). In contrast, more aggressive policies promoting deep decarbonization through a global energy system transformation ('2C' and '1.5C' pathways) would, according to most models, require a marked increase (Figure 1). One of the principal reasons why *supply-side* investments do not increase more than one might expect in these pathways, or why some models project them to decline, is because of the rapid acceleration in *demand-side* energy efficiency and conservation investments foreseen, relative to the 'CPol' and 'NDC' cases. As a share of global GDP, the total energy investments projected by the models do not rise significantly from today in any of the scenarios, hovering just over 2% (model range: 1.5–2.6%) in 'CPol' and 'NDC' and growing to 2.5% (1.6–3.4%) and 2.8% (1.8–3.9%) in the '2C' and '1.5C' pathways, respectively. Regional results can diverge widely though, with wealthier countries showing per-GDP costs lower than the global average and emerging economies showing higher.

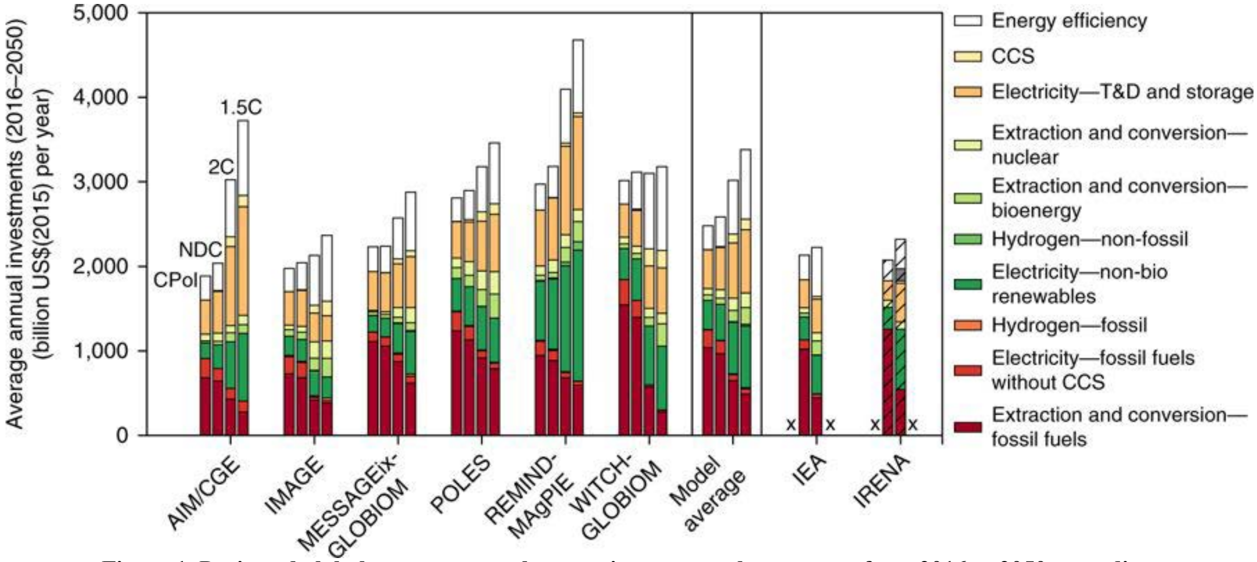

Figure 1. Projected global average annual energy investments by category from 2016 to 2050 according to different models. Values are calculated by cumulating the models' undiscounted investment estimates and averaging them over the full 2016-2050 period. Source of IEA and IRENA supply-side investment numbers is ref [7]. Lack of complete data in the IRENA case does not allow for a full breakdown of results into the investment categories used here (hence the cross-hatching). Analogous versions of the 'CPol' and '1.5C' scenarios are not available from IEA and IRENA (hence the 'x' markers). Energy efficiency investments for IEA and IRENA are calculated by the authors using the same methodology as for the models, except that the IEA and IRENA baselines are taken as their respective 'NDC' analogous scenarios; this leads to a slight underestimate of the IEA and IRENA efficiency investments.

Of perhaps greater significance to investors than total capital flows is how the energy investment portfolio might be expected to evolve over time under varying assumptions for future energy and climate policies. That portfolio continues to look very similar to today in the 'CPol' baseline, and to a large extent also in the 'NDC' case (Figure 1). In contrast, the transformational '2C' and '1.5C' pathways exhibit a shift from fossil (especially coal) to low-carbon and efficiency investments that is much more pronounced. Declines in unabated (i.e., not equipped with carbon capture and storage, CCS) coal, gas, and oil investments imply increases in renewables, nuclear, and demand-side energy efficiency (and to a lesser extent fossils equipped with CCS), especially in the more transformative '2C' and '1.5C' pathways. Additionally, several models provide evidence of significantly increased investment requirements for electricity T&D and storage. This highlights the greater demands for delivering electricity to the end-use sectors (buildings, industry, and transport) in a deeply decarbonized energy system as well as needs for large-scale electricity storage when the contribution from intermittent sources of electricity (solar, wind) is substantially greater.

Full implementation of the NDCs by countries throughout the world would require that low-carbon supply-side investment shares grow over the next decades to levels somewhat higher than today, yet remaining below 50% up to mid-century (Figure 2; multi-model means shown; individual model results vary). In other words, total low-carbon investments would continue to remain smaller than fossil investments for the foreseeable future. The '2C' and '1.5C' pathways offer a marked departure from these trends, with low-carbon supply-side investments overtaking fossil investments already by around 2025 or before. Then, some years later low-carbon supply-side investments would need to reach and/or surpass the 80% threshold, a mark that is projected to occur close to mid-century in the '2C' pathway and much sooner (~2035) in the '1.5C' case.

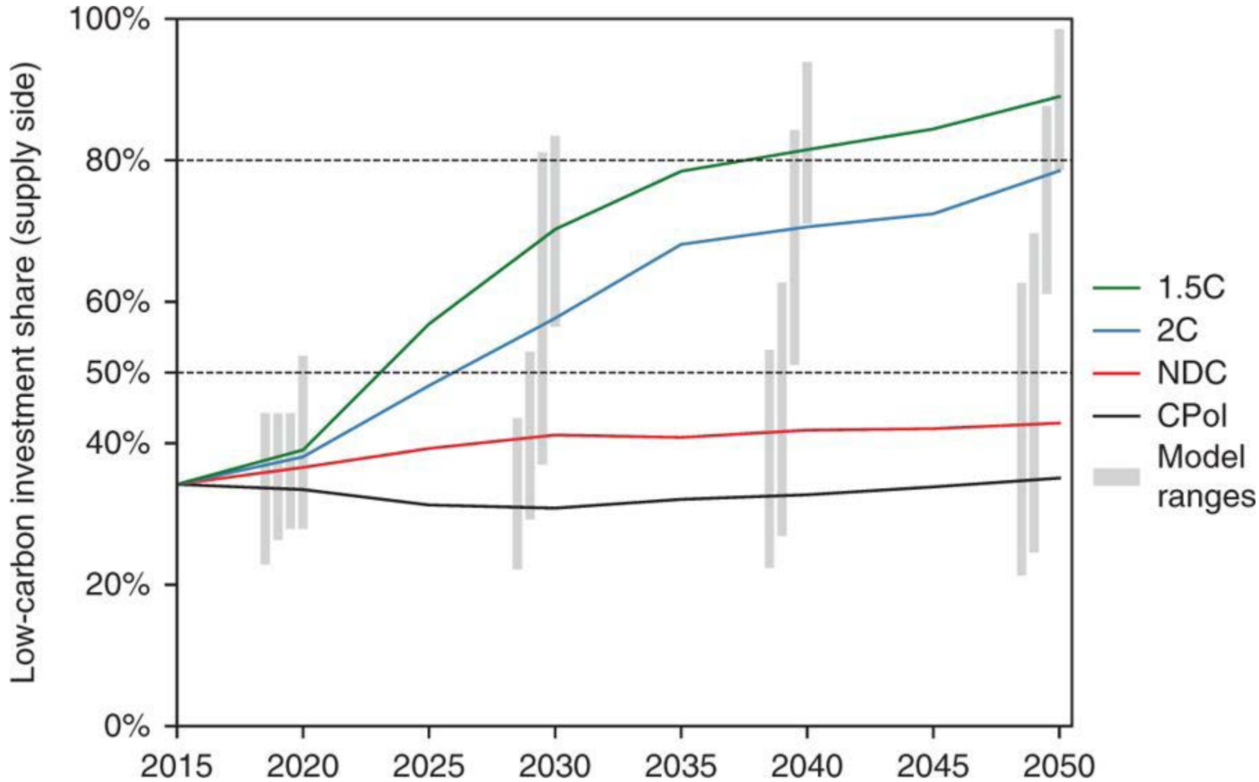

Figure 2. Projected global average annual low-carbon energy supply-side investments as a share of total supply-side investments. Solid lines represent multi-model means; floating bars give the min-max ranges across the models. Estimates shown here include supply-side investments in renewable electricity and hydrogen production, bioenergy extraction and conversion, uranium mining and nuclear power, fossil energy equipped with CCS, and the portion of electricity T&D and storage investments that can be attributed to low-carbon electricity generation. Dashed lines denote important thresholds for low-carbon energy investment.

Clearly, compared to where countries are heading at the moment, there exist substantial low-carbon energy and energy efficiency investment gaps ('LCEI-Gap') on the path toward 2 °C and 1.5 °C (i.e., the total incremental investment needs for these cleaner options beyond those likely to happen anyway based on a continuation of today's trends, assuming no future tightening of energy and climate policies worldwide, as is envisioned in the 'CPol' reference case). According to our calculations, achieving the current NDC pledges of countries implies that a global near-term (to 2030) LCEI-Gap of approximately 130 billion US$/yr (model mean), accounting for around 7% of all energy investments worldwide in 2015, needs to be filled over the next several years (Table 1). If the aim is instead to keep global temperatures below 2 °C or 1.5 °C in the long term, then this near-term LCEI-Gap quickly escalates to 300 or 460 billion US$/yr, respectively (or 17-26% of 2015 investments). Looking toward mid-century, the global LCEI-Gap reaches far higher levels in each scenario, with the relative up-scaling of investment effort being particularly strong in the 2 °C and 1.5 °C futures (1050 and 1560 billion US$/yr, respectively). Drilling down to the regional and national levels, we see that the largest LCEI-Gaps exist for the countries of Asia and those comprising the OECD (Organisation for Economic Co-operation and Development), above all China, India, Europe, and USA. We note, however, that while the LCEI-Gap for some regions and countries may appear to be rather low in absolute dollar terms, the gap could actually be fairly large in relative terms, i.e., as a share of a particular economy's future investment needs in the 'CPol' baseline. India is a prime example.

Table 1. Projected global, regional, and national average annual low-carbon energy and energy efficiency investment gaps in tightened policy scenarios. Values along top row for each regional classification represent the incremental investment requirements beyond the 'CPol' baseline. They are calculated as average annual investments (in billion US$/yr) over two separate timeframes (undiscounted). Mean values across models are given for each region, with min-max ranges in parentheses; numbers may therefore not add up to global totals. Values along bottom row for each region represent the ratio of the LCEI-Gap in each model's tightened policy scenarios relative to total supply-side and energy efficiency investments in that model's 'CPol' baseline. Based on this calculation method, the shares can potentially exceed 100%. Mean values across models are given for each region, with min-max ranges in parentheses. See Supplementary Methods for regional definitions.

		2016 to 2030			2016 to 2050		
		NDC	**2C**	**1.5C**	**NDC**	**2C**	**1.5C**
	WORLD	$132 ($38 to $273)	$303 ($38 to $554)	$458 ($75 to $822)	$229 ($71 to $373)	$1052 ($590 to $1559)	$1567 ($885 to $2290)
		6% (2% to 11%)	*15% (2% to 32%)*	*22% (5% to 37%)*	*9% (3% to 14%)*	*43% (26% to 80%)*	*65% (43% to 121%)*
5 Regions	ASIA	$48 ($10 to $98)	$163 ($56 to $314)	$243 ($85 to $430)	$92 ($14 to $194)	$476 ($241 to $780)	$715 ($380 to $1104)
		8% (3% to 16%)	*30% (9% to 78%)*	*44% (14% to 89%)*	*12% (4% to 25%)*	*72% (45% to 143%)*	*110% (65% to 220%)*
	LAM	$12 ($0 to $50)	$14 ($-3 to $34)	$24 ($-5 to $54)	$18 ($5 to $33)	$77 ($52 to $121)	$102 ($58 to $168)
		6% (0% to 22%)	*10% (-3% to 27%)*	*17% (-4% to 30%)*	*9% (3% to 18%)*	*42% (22% to 80%)*	*56% (29% to 117%)*
	MAF	$5 ($-1 to $19)	$32 ($9 to $59)	$60 ($6 to $125)	$10 ($-1 to $24)	$187 ($95 to $294)	$299 ($96 to $558)
		2% (0% to 4%)	*12% (5% to 35%)*	*21% (3% to 52%)*	*3% (0% to 7%)*	*43% (26% to 91%)*	*67% (28% to 131%)*
	OECD90	$65 ($0 to $132)	$84 ($-11 to $190)	$136 ($12 to $255)	$108 ($33 to $217)	$309 ($157 to $497)	$487 ($288 to $771)
		12% (0% to 31%)	*14% (-3% to 30%)*	*24% (3% to 38%)*	*17% (7% to 44%)*	*51% (21% to 100%)*	*81% (35% to 156%)*
	REF	$1 ($-2 to $7)	$23 ($6 to $58)	$36 ($13 to $73)	$3 ($-3 to $15)	$72 ($36 to $150)	$109 ($56 to $205)
		2% (-1% to 6%)	*20% (4% to 52%)*	*31% (9% to 64%)*	*3% (-1% to 12%)*	*51% (20% to 119%)*	*75% (34% to 163%)*
Major Economies	China	$31 ($0 to $87)	$113 ($30 to $236)	$166 ($65 to $268)	$61 ($-3 to $186)	$261 ($116 to $399)	$370 ($159 to $538)
		8% (0% to 22%)	*34% (8% to 95%)*	*49% (17% to 108%)*	*13% (-1% to 40%)*	*69% (41% to 149%)*	*101% (57% to 214%)*
	India	$6 ($1 to $19)	$33 ($10 to $81)	$46 ($17 to $108)	$8 ($0 to $31)	$118 ($64 to $219)	$175 ($75 to $306)
		5% (1% to 13%)	*35% (9% to 84%)*	*47% (16% to 95%)*	*4% (0% to 10%)*	*86% (45% to 159%)*	*137% (53% to 312%)*
	Europe	$17 ($-1 to $38)	$19 ($-8 to $59)	$41 ($-4 to $103)	$22 ($7 to $42)	$70 ($27 to $123)	$119 ($54 to $188)
		8% (-2% to 21%)	*6% (-9% to 21%)*	*16% (-5% to 36%)*	*10% (4% to 21%)*	*33% (14% to 46%)*	*56% (27% to 77%)*
	USA	$31 ($2 to $53)	$38 ($-3 to $85)	$58 ($8 to $132)	$55 ($11 to $96)	$149 ($74 to $236)	$222 ($129 to $328)
		14% (1% to 27%)	*16% (-1% to 34%)*	*25% (4% to 57%)*	*21% (5% to 44%)*	*57% (25% to 109%)*	*85% (41% to 151%)*

Conclusions

Professionals engaged in the business of 'green financing' (i.e., those responsible for mobilizing capital to launch low-carbon energy and efficiency projects) should be aware of the stepped-up investment effort required to lay the groundwork for a future consistent with 2 °C, and even more so 1.5 °C. The NDC pledges made by countries over the past two years are certainly a move in the right direction, but as we show here, they are wholly insufficient for incentivizing the kind of deeper, structural changes in the energy investment portfolio required for reaching the low temperature targets of the Paris Agreement[24].

While our study does not comment on the exact sources of the investment requirements quantified here, we note that funding for individual projects could come from all manner of sources: businesses, governments, households, banks (private, state-owned, development), multilateral climate finance institutions, or via other means. And this funding could be sourced domestically or be provided by foreign entities. The ultimate funding portfolio, from the macro- to micro-scale, will be determined by some mixture of the world's financial system, countries' fiscal and monetary policies, and foreign development aid institutions, among others.

The good news, for backers of sustainable energy at least, is that the world's largest economies have already agreed that spurring low-carbon energy investments should be placed high on their collective priority list. For example, one of the stated action items from the recent *G20 Hamburg Climate and Energy Action Plan for Growth* is "to create an enabling environment that is conducive to making public and private investments consistent with the goals of the Paris Agreement as well as with the national sustainable development priorities and economic growth"[25] (in other words consistent with Article 2.1(c) of the Paris Agreement[1]). In support of this effort, G20 countries have 'reemphasized' the previously agreed commitment of wealthy countries to jointly mobilize 100 billion $/yr (during the period 2020-2025) for mitigation actions in developing countries. According to our analysis, this level of support would go a long way toward closing – if not fully covering – the low-carbon energy and energy efficiency investment gap faced by developing countries as they work to fulfill their NDC commitments. Considerably more capital would have to be mobilized, however, in order to fully close the investment gap for a 2 °C- or 1.5 °C-consistent future.

Additional information

A full reference for the manuscript underlying this study can be found below. That manuscript should also be cited when referring to this policy brief:

McCollum, D.L., W. Zhou, C. Bertram, H.-S. de Boer, V. Bosetti, S. Busch, J. Després, L. Drouet, J. Emmerling, M. Fay, O. Fricko, S. Fujimori, M. Gidden, M. Harmsen, D. Huppmann, G. Iyer, V. Krey, E. Kriegler, C. Nicolas, S. Pachauri, S. Parkinson, M. Poblete-Cazenave, P. Rafaj, N. Rao, J. Rozenberg, A. Schmitz, W. Schoepp, D. van Vuuren, and K. Riahi, 2018. "Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals," Nature Energy, Vol. 3, 589-599.

All investment data supporting this analysis – including the numbers behind the tables and figures – are available to any interested parties as online supplementary material to the original paper (McCollum et al. (2018)). The CD-LINKS scenario database will also eventually house this information, along with a host of other data describing the various scenarios discussed here (e.g., energy and emissions time-series by fuel, sector and region). The database will be available here when it is made public: https://db1.ene.iiasa.ac.at/CDLINKSDB/.

Documentation for the six global energy-economy models employed in this study (AIM/CGE[10,11], IMAGE[12], MESSAGEix-GLOBIOM[13,14], POLES[15,16], REMIND-MAgPIE[17,18], and WITCH-GLOBIOM[19,20]) can be found in The Common Integrated Assessment Model (CIAM) documentation website developed within the context of the ADVANCE project[26].

Table 2 provides further details about the scenarios analyzed in this study:

Table 2. Scenarios depicted by the models.

Scenario	***Description***
Current Policies (CPol)	Considers high-impact energy- and climate-related policies implemented in G20 countries as of 2015. These policies are included up to 2030; afterward, an assumption of equivalent effort, in terms of carbon emissions development, is assumed. Examples of policies include greenhouse gas (GHG) emissions reduction targets, GHG intensity reduction targets, and nuclear power and renewable energy targets.
Nationally Determined Contributions (NDC)	Assumes implementation of all countries' NDCs (conditional commitments) by 2030, the target year of most. Post-2030, an assumption of equivalent effort, in terms of carbon emissions development, is assumed (i.e., no intensification). The scenario thus represents a continuation of fragmented and highly diversified climate action worldwide.
Well Below 2 Degrees (2C)	Aims to hold the maximum increase in global average temperatures to 2.0 °C (above the pre-industrial level) over the course of the 21st century with >66% likelihood. Stylized, globally and sectorally comprehensive climate mitigation policies, in the form of carbon budgets, are included immediately after 2020 so as to limit carbon dioxide (CO_2) emissions from fossil fuel and industrial operations to approximately 1000 GtCO2 over the 2011-2100 timeframe (actual model results vary). Emissions mitigation (after 2020) occurs where and when it is most cost-effective; no burden-sharing regimes are in place. The pathway of the 'Current Policies' scenario is followed up through 2020.
Toward 1.5 Degrees (1.5C)	Aims to limit the increase in global average temperatures to 1.5 °C (above the pre-industrial level) in 2100 with >50% likelihood. Stylized, globally and sectorally comprehensive climate mitigation policies, in the form of carbon budgets, are included immediately after 2020 so as to limit CO_2 emissions from fossil fuel and industrial operations to approximately 400 GtCO2 over the 2011-2100 timeframe (actual model results vary). Emissions mitigation (after 2020) occurs where and when it is most cost-effective; no burden-sharing regimes are in place. The pathway of the 'Current Policies' scenario is followed up through 2020.

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