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## Abstract

The radical change in recent global climate governance calls for China and Europe to ramp up their efforts in leading the world to reach the long-term climate goals. By analyzing the results from the state-of-the-art global integrated assessment model, MESSAGEix-GLOBIOM, this paper aims to understand the future levels of financial investment needed for building and maintaining energy-related infrastructure in the two regions for fulfilling stringent targets consistent with ‘well below 2 °C’. The results indicate that a rapid upscaling and structural change of these investments towards decarbonization are necessitated by the climate stringent scenarios. China and Europe need to increase their low carbon investments by 65% and 38% in a scenario reaching the 2° target relative to their respective reference scenarios which assume no such target from 2016–2050. In a more stringent climate policy scenario of the 1.5° target, these investment needs will increase by 149% and 79% for China and Europe respectively. Among all the energy sectors, energy efficiency, renewable electricity generation and electricity transmission and distribution are the three largest investing targets for the two regions. However, those investments will not likely be realized without strong policy incentives. Implications for green finance and multilateral cooperation initiatives are discussed in the context of the scenario results.

## 1. Introduction

The Paris Agreement defines the climate target aiming at keeping a global temperature rise this century well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5 °C [1]. Fulfilling these targets will require pronounced reallocation of the investment portfolio worldwide [2]. Total energy investment worldwide is estimated to account for 2.2% of global gross domestic product (GDP) and 10% of global gross capital formation in 2016 [3]. China and Europe are the world’s top two energy investment markets. These two

regions are expected to fill the leadership gap as the US steps back from the commitment to implementing the Paris Agreement. Examining investment needs of low carbon sectors is therefore essential for decision makers to enhance their cooperation in climate actions, which is also requested by the most recent G20 (Group of 20 countries) climate and energy action plan for growth [4]. Moreover, comparison between these two regions can illustrate to some extent how the disparities between developing and developed countries impact future investment portfolio in the transition to a low-carbon world. In addition, this comparative study can also provide necessary

information for the finance communities in both the regions which have become increasingly interested in using scenario analysis in their strategic planning processes [5].

There are remarkable disparities between China and Europe with regards to energy supply and consumption patterns, which in turn affects greatly their investment landscapes. Coal still dominates in China's energy mix. But for Europe, oil and natural gas served as top two most important fuels. The share of low-carbon energy (renewables and nuclear) in China's energy mix is significantly lower than that of Europe. As the world's largest market for energy investment, China invested 357 billion dollars in 2016 into the energy sector<sup>7</sup>, roughly 21% of the global total [3]. Europe ranked the third place with an investment amount of 244 billion, or 15% of the worldwide total in the same year [3]. The past several years have seen significant progress in decarbonization of both countries' energy investments. The share of low carbon energy investment (including renewables, nuclear and energy efficiency) in total energy investment was 52% for China and 59% for Europe, respectively, in 2016. Supplementary material (SM) is available online at [stacks.iop.org/ERL/14/054017/mmedia](https://stacks.iop.org/ERL/14/054017/mmedia) provides more details of primary energy and energy investments in China and Europe at present.

Some previous studies provide analysis of these investment needs under 2 degree futures [6–8], or conduct cross-model comparisons on the global level [2, 9]. It is estimated that in a '1.5 degree' world, investments in low-carbon energy technologies (including energy efficiency) would need to approximately double in the next two decades, while investments in fossil-fuel extraction and conversion decrease by about a quarter [10]. Regarding comparison between China and Europe, some retrospective studies trace the evolution of mutual investments in the past decades [11], analyze the key drivers and barriers behind the development trend [12], and assess the impact of domestic policy priorities on bilateral energy cooperation and climate policy [13]. Nonetheless, a detailed prospective analysis is still absent in estimating capital needs for the scenarios of the two regions consistent with the Paris climate targets. This kind of analysis should address some key issues, such as the magnitudes of these investment needs corresponding to different climate goals, the investment landscapes of diverse energy technologies, and how the investment portfolio will shift to allow for the transition towards 2 °C or 1.5 °C pathways. To answer these questions, this study attempts to perform quantitative assessment by employing the state-of-the-art global integrated assessment model MESSAGEix-GLOBIOM, which represents the newest generation of MESSAGE combined with a reduced-form emulator

for GLOBIOM (hereafter we refer to this framework as simply MESSAGE).

## 2. Scenario modeling methodology

### 2.1. MESSAGE modeling framework

Integrated assessment modeling (IAM) provides a single platform for a comprehensive analysis of a complex decision-making process that combines multiple and diverse components, including the social, economic and ecological implications of different natural or anthropogenic factors [14]. It thus helps deliver a systematic and transparent approach to integration and has been widely used for climate policy analysis. The energy core of IIASA's IAM framework, MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) is a linear programming energy-economy-environment-engineering (4E) model with global coverage [15–17]. As a whole-systems optimization model, MESSAGE is primarily used for medium- to long-term energy system planning, energy policy analysis, and scenario development. In addition, this version of MESSAGE includes a reduced-form emulator for GLOBIOM (the GLObal BIOSphere Model) to consistently assess the implications of utilizing bioenergy of different types and to integrate the GHG emissions from energy and land use. This model is then linked to the aggregated macro-economic model MACRO to assess economic implications and to capture economic feedbacks.

The MESSAGE framework's principal results comprise, among others, estimates of technology-specific multi-sector response strategies for specific climate stabilization targets. By doing so, the model identifies the least-cost portfolio of mitigation technologies. The choice of the individual mitigation options across regions, fuels and sectors is driven by the relative economics of the abatement measures, assuming full temporal and spatial flexibility (i.e. emissions-reduction measures are assumed to occur when and where they are cheapest to implement). The combined MESSAGE framework has global coverage and divides the world into 11 regions. Detailed definition of regions and key cost assumptions in this study are provided in the SM.

### 2.2. Scenario definition

This study presents the initial results from four climate policy scenarios consistent with the Shared Socio-economic Pathway SSP2, a 'middle-of-the-road' narrative for future socio-economic development, technological change and challenges to mitigation and adaptation [15, 18, 19]. Under the SSP2 Narrative, four scenarios are explored. 'Current Policies' (CPol) takes into account those energy- and climate-related policies that were already implemented by countries as of 2015, and serves as the reference case. The other three mitigation scenarios are 'Nationally Determined

<sup>7</sup> All monetary units in this paper are expressed in US\$2015.

**Table 1.** Brief descriptions of the policy scenarios depicted in this study.

Scenario	Short description
Current policies (CPol)	Considers high-impact energy- and climate-related policies implemented in G20 countries as of 2015. Assumes these policies are included up to 2030, and equivalent effort in terms of carbon emissions development for Post-2030.
Nationally determined contributions (NDC)	Assumes implementation of all countries' NDCs by 2030, (the target year of most), and equivalent effort of carbon emissions development for Post-2030. This scenario represents a continuation of fragmented and highly diversified climate action worldwide.
Well below 2 degrees (2 C)	Consistent with the 2 degree target in the Paris Agreement (aims to hold the maximum increase in global average temperatures to 2.0 °C). 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 <sub>2</sub> ) emissions from fossil fuel and industrial operations to approximately 1000 GtCO <sub>2</sub> over the 2011–2100 timeframe. Emissions mitigation (after 2020) occurs where and when it is most cost-effective.
Toward 1.5 degrees (1.5 C)	Consistent with the 1.5 degree target in the Paris Agreement (aims to limit the increase in global average temperatures to 1.5 °C). Stylized, globally and sectorally comprehensive climate mitigation policies, in the form of carbon budgets, are included immediately after 2020 so as to limit CO <sub>2</sub> emissions from fossil fuel and industrial operations to approximately 400 GtCO <sub>2</sub> over the 2011–2100 timeframe. Emissions mitigation (after 2020) occurs where and when it is most cost-effective.

Contributions' (NDC), 'Well Below 2 degrees' (2 C) and 'Toward 1.5 degrees' (1.5 C). Short descriptions of these scenarios are listed in table 1, and more information can be found in [20] and [2].

### 2.3. Calculation of energy efficiency investments

Demand-side energy efficiency investments across the end-use sectors (buildings, transport, industry) for each scenario are calculated by utilizing a methodology that was originally developed for the Global Energy Assessment [21] and then adapted in the LIMITS project [9]. We further refine that methodology here. The methodology makes use of two separate energy efficiency components, as denoted in equations (1)–(3). The first component is the 'Base-year efficiency' investment. This is calculated by taking the level of energy efficiency investments estimated by the International Energy Agency [3] and then scaling those efficiency investments with total final energy demand in the models' scenarios (relative to 2015 final energy demand). The second is the 'Supply-side offset' component, in which the final energy demand in the tightened policy scenarios ('NDC', '2 C' and '1.5 C') is compared to that in the reference case ('CPol'), it is then assumed that, in equilibrium, the investments made to reduce energy demand equal the investments that are simultaneously offset on the supply side

$$I_{EE,s,t}^{tot} = I_{EE,s,t}^{c1} + I_{EE,s,t}^{c2} \tag{1}$$

$$I_{EE,s,t}^{c1} = I_{EE,2015} \times (FE_{s,t}/FE_{2015}), \tag{2}$$

$$I_{EE,s,t}^{c2} = (I_{ES,s,t}/FE_{s,t}) \times (FE_{CPol,t} - FE_{s,t}) \times (GDP_{s,t}/GDP_{CPol,t}), \tag{3}$$

where  $I_{EE,s,t}^{tot}$  is the total investment of energy efficiency in Scenario 's',  $I_{EE,s,t}^{c1}$  and  $I_{EE,s,t}^{c2}$  are the first and second components in Scenario 's' respectively.  $I_{EE,2015}$  is the investment of energy efficiency in the base year of 2015.  $FE_{s,t}$  is the final energy consumption in Scenario

's' in year 't'.  $FE_{2015}$  is the final energy consumption in the base year of 2015.  $I_{ES,s,t}$  is the supply-side investment in Scenario 's' in year t.  $GDP_{s,t}$  is the GDP in Scenario 's' in year 't'.

## 3. Results: future energy investments in China and Europe

### 3.1. Total energy investment needs to 2050

To fulfill the longer-term climate targets consistent with 2 °C and 1.5 °C, both China and Europe will require a substantial change of their respective energy investment landscapes going forward, both in terms of total amount investment as well as structure. Figure 1 shows the average annual energy investment needs by category in China and Europe across the four scenarios over the period between 2016–2050. The results show no significant difference between the 'CPol', which depicts a continuation of current trends, and 'NDC', reflecting the most recent energy and climate policy pledges for all the regions. In the 'CPol' scenario, the investment needs amount to 358 billion for China and 248 billion for Europe (39 billion for Eastern Europe and 209 billion for Western Europe). These amounts are quite close to the levels in 2016 for both China and Europe, indicating that investments (in \$) may not necessarily scale with growing demands for energy provision (in exajoule) in these markets, due to technological and cost improvements in key energy technologies. It is noteworthy that these results are subject to a high degree of uncertainty. To illustrate the uncertainty, we perform an across-model comparison and calculate the total energy investments for China and Europe from the results of six IAMs, which span a range from least-cost optimization to computable general equilibrium models, and from game theoretic to recursive-dynamic simulation models.

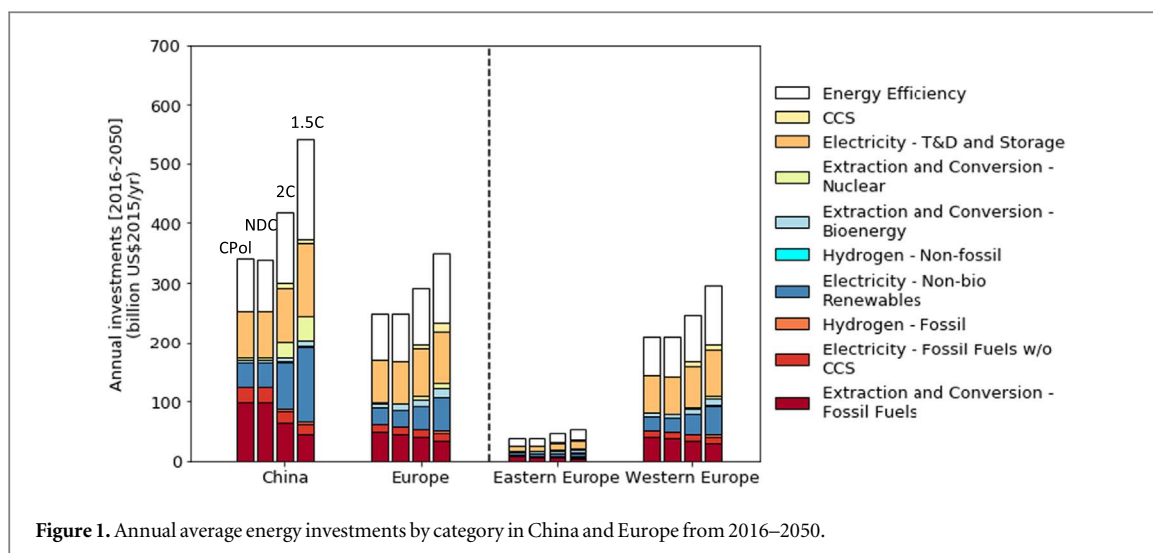


Figure 1. Annual average energy investments by category in China and Europe from 2016–2050.

The numeric results of the ranges across the models are provided in the SM. This comparison hints at the uncertainty to some extent, because IAMs are not a homogenous group of tools, but use quite different methodological approaches, parameter assumptions and apply different system boundaries [2]. In addition, key parameters such as cost estimates used by a single model are also uncertain into the future, which will significantly impact the model results. We select 10 representative electricity generation technologies and provide the cost assumptions on these technologies in our modeling work in the SM.

A remarkable increase of investments is required as a result of the considerably more aggressive energy and climate policy represented by the ‘2 C’ and ‘1.5 C’ pathways. In China’s case, the ‘2 C’ scenario requires an increase of 23%, while the ‘1.5 C’ scenario requires additional 59% investment, relative to the ‘CPol’ scenario. This increase is relatively modest for Europe, though there is major disparity existing inside Europe. For Eastern Europe, extra 21% and 47% increase of investment are required by the two stringent scenarios, whereas for Western Europe with a cleaner energy mix, this increase rate is narrowed to 18% and 38% for ‘2 C’ and ‘1.5 C’ respectively.

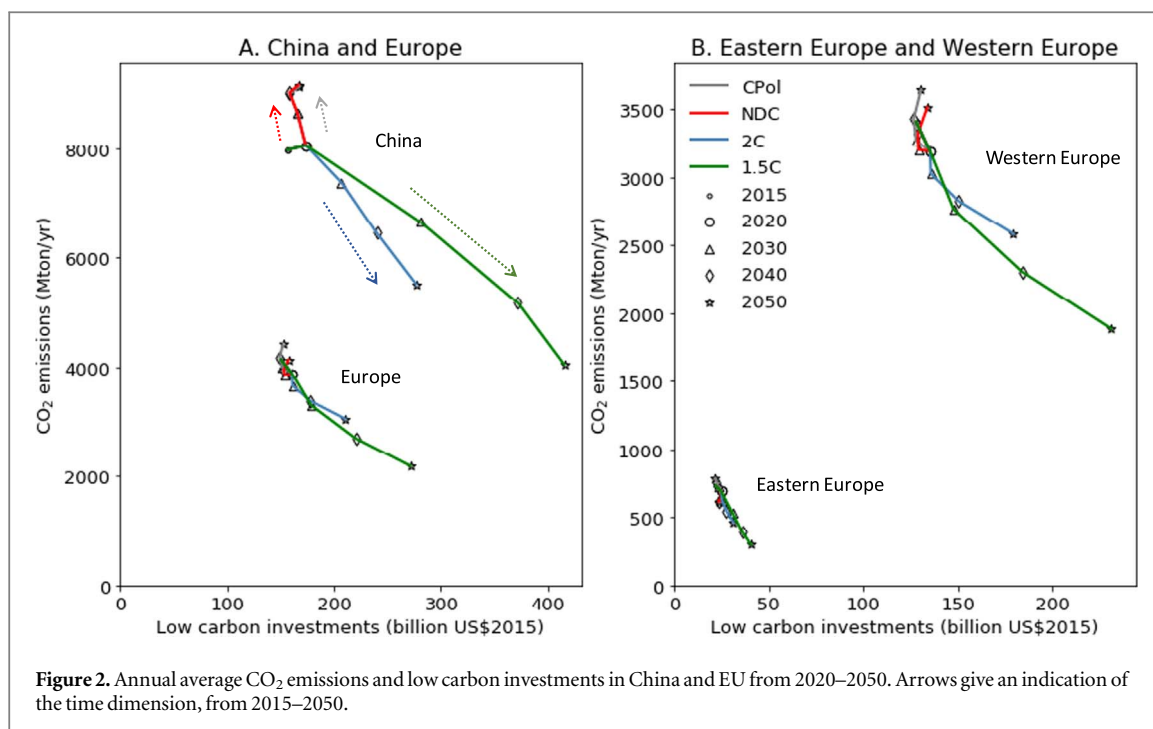
The structural change across the four scenarios is characterized by a shift in the share of renewables and fossil investments. China requires the largest increase of investments into renewable electricity generation in the more stringent scenarios. These investments in ‘2 C’ almost double from approximately 43 billion in the ‘CPol’ scenario to 83 billion. And this number triples to 131 billion in ‘1.5 C’. Europe, as a whole, also needs significant incremental investments into this category, although with a relatively moderate rate compared to China. The amount of renewable investments increases by 40% from 27 billion in the ‘CPol’ baseline to 38 billion in the ‘2 C’ scenario, and to 54 billion in the ‘1.5 C’ scenario. Although not shown in the figure, there is difference between the two regions

with regards to specific renewable technology investment. In China’s case, solar takes the largest portion of renewable investment, closely followed by wind and hydro, whereas the European case tends to use more wind and relatively smaller shares of solar and hydro. Besides, China also favors nuclear much more than Europe in the low carbon scenarios.

The investments into fossil fuels, on the contrary, would decline dramatically in the more stringent climate policy scenarios, particularly those investments for the extraction and conversion sector. This is necessitated by a transformation of the energy supply system into the direction of decarbonization and electrification. For China, the investments into fossil fuel extraction and conversion decrease from 104 billion in the baseline to 68 billion in ‘2 C’, further dropping to 47 billion for ‘1.5 C’. The European case show a drop from 50 billion in the baseline to 39 billion in ‘2 C’ and further to 33 billion in ‘1.5 C’.

The trend of electrification also requires a large amount of investments into the sector of electricity transmission, distribution and storage. As such, investments of this kind would also gain considerable importance. China’s investments in this field increases from 84 billion in the baseline to 97 billion in ‘2 C’ and further to 129 billion in ‘1.5 C’, while the European case show an increase from 71 to 90 billion across the scenarios. The investments into transmission, distribution and storage of electricity do not show a very drastic increasing rate across scenarios when compared to renewable energy and energy efficiency investments. Nevertheless, the share of these investments in the total remains one of the largest both for China and Europe across all the scenarios, indicating the sustained opportunities for investors in this sector.

The changes of the investment landscape between Eastern Europe and Western Europe move at similar paces, e.g. the total energy investments of Western Europe accounts for approximately 85% in the European total, and this share remains rather stable across



scenarios. However, some differences exist in the breakdown categories. For Western Europe, the investments into non-biomass renewable electricity increase from 24 to 55 billion between the baseline and ‘1.5 C’ scenarios, relatively higher than the case of Eastern Europe.

### 3.2. Low carbon investment pathways

In this study, we define low carbon investments as those going to renewable electricity, bioenergy, nuclear, CCS, energy efficiency and the portion of electricity T&D and storage corresponding to low carbon electricity consumption. By this definition, low carbon investments in 2016 were 185 billion for China and 145 billion for Europe, or 52% and 59% in their respective total energy investments. These shares were much higher than the world average level, which was approximately 34%, indicating that China and Europe are already leading the way toward a lower carbon future. Yet, more needs to be done going forward if the countries are to put themselves on a path consistent with 2 °C and 1.5 °C. Figure 2 shows the relationship between annual CO<sub>2</sub> emissions and low carbon investments across scenarios from 2020–2050.

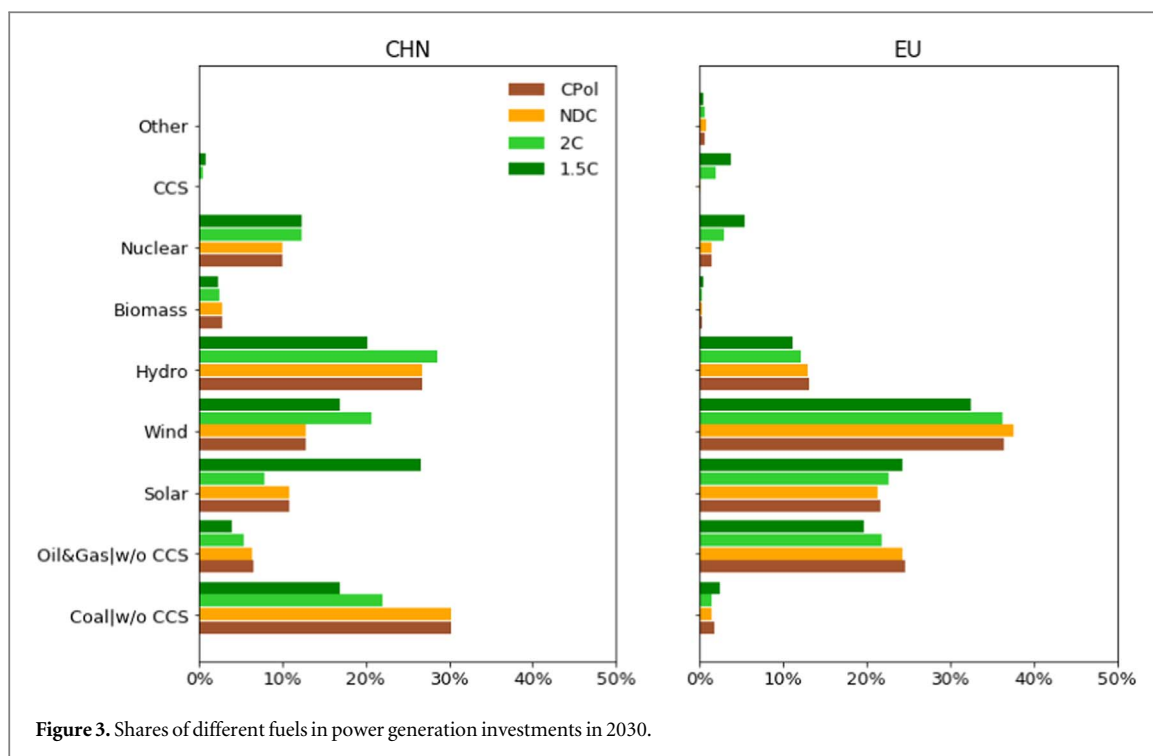
In China’s case, CO<sub>2</sub> emissions of the baseline and ‘NDC’ scenarios reach as high as 9100 million tons at some point between 2020–2050. The growth of emissions results from a slight reduction of the scale of low carbon investments. On the contrary, the ‘2 C’ and ‘1.5 C’ scenarios are characterized by persistent increase of low carbon investments and consequently deep reduction of CO<sub>2</sub> emissions. Over this period, the annual average CO<sub>2</sub> emissions of ‘2 C’ drop by 32%, and the low carbon investments increase by 59%. In the ‘1.5 C’ scenario, the emissions are reduced by

nearly half, in correspondence with an increase of low carbon investments to 2.4-fold from 174 to 415 billion.

For Europe, the current policies indicate relatively stable levels of both emissions and low carbon investments. Whereas the 2 C and 1.5 C scenarios also necessitate marked rise from the current investment levels to 161 and 179 billion to 2030, further increase to 211 and 272 billion to 2050, or by 31% and 69% relative to the level in 2020.

The story between Eastern and Western Europe is different in some aspects. In both the scenarios of ‘2 C’ and ‘1.5 C’, most of the low carbon investments still happen in the west, with a share of approximately 85% over time. The increase of these investments over this period is quite close between the east and the west, however, the consequent reduction of CO<sub>2</sub> emissions differs to some extent. For Eastern Europe, the CO<sub>2</sub> emissions are reduced by 33% in ‘2 C’ and by 57% in ‘1.5 C’, while Western Europe reduces its emissions by 19% and 41% in the same scenarios. These results indicate that a relatively smaller marginal cost for reducing emissions in the east than in the west, particularly in more stringent climate scenarios.

For both China and Europe, maintaining the current scales of low carbon investments to 2030 would lead to fulfillment of their NDC targets and even more. A small addition of 10% increase from current low carbon investments can keep their efforts consistent with the 2 C target in the short-term future before 2030. Nevertheless, further promotion of these scales is still required afterwards in the mid-term or long-term future, especially under the more stringent 1.5 C target.



### 3.3. Electricity generation sector

A high-degree of electrification is widely considered as an important characteristic of the energy system transformation. This necessitates decarbonizing the electricity generation sector to reduce the CO<sub>2</sub> emissions of the whole energy system from the life cycle perspective. For instance, China and some European countries have announced the timetable to halt production of petrol cars by around 2030–2040. Nevertheless, some studies argue that the life cycle CO<sub>2</sub> emissions of current electric cars are not necessarily lower than those of conventional petrol cars, which depend on the power generation mix [22]. As such, we zoom in to the mix of investments and the breakdown technologies of electricity production over the period between 2020–2030. Figure 3 shows these results of each scenario for China and Europe.

A clear message from these results is that the trend of renewables dominating the power generation investments continues across all the scenarios for both regions. However, significant differences still exist inside the composition. For China, coal still accounts for as high as 30% in the total investments into electricity generation under the ‘CPol’ and ‘NDC’ scenarios. This share for Europe is negligible, but oil and gas together take a similar share of 25%. Among all the non-fossil fuels, hydro is the most favored investment type in China’s electricity sector, whereas wind takes the largest part in the European case.

The structural change of power generation investments is greater for China than for Europe across the four scenarios. The European mix shows that the allocation of the investments into each fuel type remains relatively stable from the ‘CPol’ scenario to the

stringent scenarios, despite of the considerable increase in terms of the absolute amount. Nevertheless, one can still see the waning of fossil-based electricity in the investment pie to some extent. By contrast, a much greater shrinkage of this share can be observed in China’s case, and a drastic surge of solar investment occurs in the ‘1.5 C’ scenario. To reach this most stringent target, Europe might also need to increase the share of nuclear investments to 5%, and the share of CCS to 4%, though these shares are negligible under the ‘CPol’ and ‘NDC’ scenarios.

### 3.4. Contribution to GDP

Investment constitutes an important part of economic growth. China’s economy is widely viewed to highly depend on investment. Nevertheless, it has been undergoing a revolutionary structural transition towards a more consumption-driven direction in the most recent years. In developed economies such as Western Europe, the contribution of investment to economic growth is much lower than that of developing countries and economies in transition, including both China and Eastern Europe. This is also reflected by the contributions of the total energy investments to GDP, as shown by the solid lines of figure 4. Before 2030, the contribution is larger for China and Eastern Europe than Western Europe. As the former two economies continue growing at relatively higher rates, the energy investment shares in GDP decline rapidly in the baseline. The low carbon scenarios, however, feature higher shares of energy investments in the whole economic growth for all the regions. In 2050, total energy investments make up 0.94% and 1.06% in China’s ‘2 C’ and ‘1.5 C’ cases. This share is even

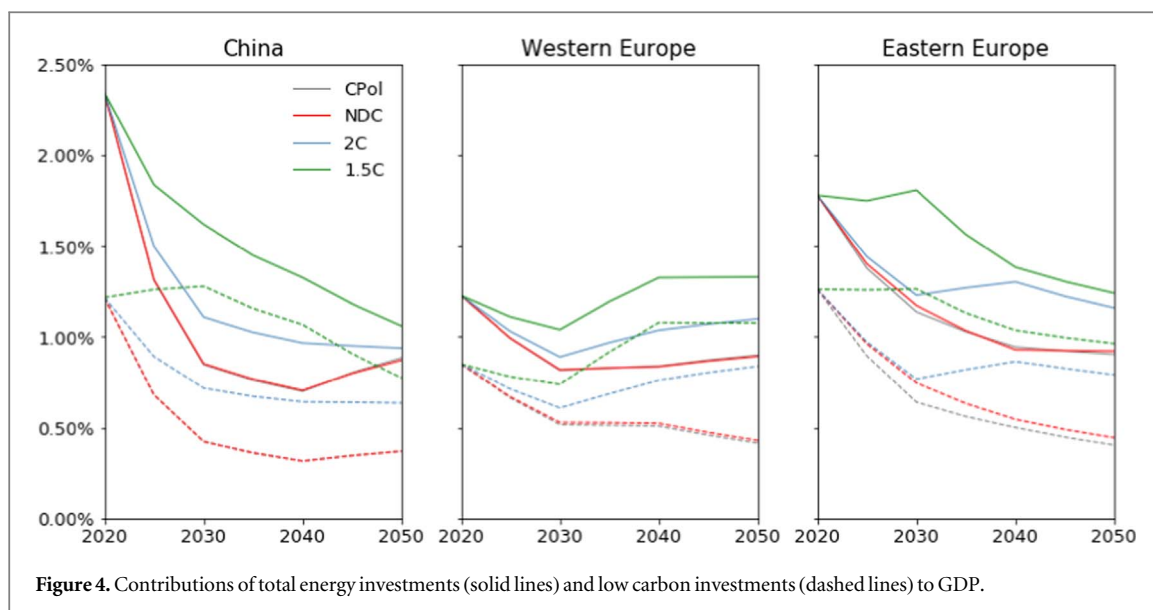


Figure 4. Contributions of total energy investments (solid lines) and low carbon investments (dashed lines) to GDP.

slightly higher for both Western and Eastern Europe, between which the former has 1.10% and 1.33% in '2 C', and the latter has 1.16% and 1.24% of GDP coming from energy investments in the same scenarios.

It is obvious that the higher contribution of energy investments to GDP in the mitigation scenarios is the result of enhancing low carbon investments, which is demonstrated by the dashed lines in figure 4. Although the trends of these shares are still declining for China and Eastern Europe, the decline rates are significantly slower than those of total energy investments. In 2050, China's low carbon investments contribute 0.63% and 0.77% to its economy in the '2 C' and '1.5 C' scenarios, which are 70% and 108% higher than the baseline case. This promotion of contribution for Western and Eastern Europe is even more significant. This contribution in the '2 C' scenario almost doubles from the baseline for both the two regions, while in '1.5 C', the contribution increases to 2.6 fold for the west and 2.4 fold for the east. On the other hand, high energy costs induce long-term reductions in consumption and then exert negative impacts on economic development. Periods of high or suddenly increasing energy expenditure levels are associated with low economic growth rates [23]. Priority of energy efficiency has been reflected in energy development strategies in both China and Europe. These facts highlight the necessity of investments into energy efficiency technologies, in combination of other measures, to lower down the costs on the supply side, to minimize energy expenditures without hindering economic development.

#### 4. Discussion and policy implications

By applying the state-of-the art IAM, this study performs quantitative assessment on low-carbon

investment needs for China and Europe in line with the global climate targets made by the Paris agreement. The assessment reveals that despite the two regions are increasing investments into low-carbon sectors, the gaps are still large to keep their efforts on track with the global climate targets. Three sectors, namely, energy efficiency, renewable electricity generation and electricity transmission and distribution are identified as the key areas of investment. In the '2 C' scenario, the share of these investments in the total energy investments is 69% for China and 72% for Europe. While in the '1.5' scenario, this share increases to 77% for China and 74% for Europe. This model-based comparative assessment complements the existing literature focused on retrospective comparison [11, 13] or qualitative analysis [24, 25]. In addition, these results are also informative for the finance community which has become increasingly interested in using scenario analysis in their strategic planning processes [5]. Below we extend our discussion to policy implications particularly in green finance.

##### 4.1. Challenges to meet the investment gap

Some characteristics of low carbon technologies also bring challenges in financing those investments. Many of these technologies have higher upfront costs and are more dependent on long-term finance than traditional investments in the same sectors [26]. In the model assumptions, the capital cost of solar power is approximately 2–3 times higher than that of conventional coal power plant in China and Europe. Relevant policies exert huge influences on some aspects such as the general investment environment, the types of investors involved and the structure and timing of their investments, etc Some other critical issues have been emerging along with the elevation of low carbon investments in recent years, e.g. increasingly severe curtailment of renewable electricity in China [27], and a growing number of lawsuits from low carbon energy



investors in some European countries due to policy instability. In addition, the transition itself might increase the risks of 'stranded' assets. The results from a group of IAMs show that on average, 60 percent of coal power plants without CCS have to become stranded assets by 2030 for the world to stay on track for the 2 °C scenario [28]. A part of these assets would occur as a result of an already ongoing technological trajectory, irrespective of whether or not new climate policies are adopted [29]. Such risks may not only lead to economic losses and unemployment, but could also affect the market valuation of the companies that own these assets, thus negatively impacting their investors [25, 30]. And should China and European countries adopt stringent new climate policies to reach the 2 °C target of the Paris Agreement, then the negative impacts on the fossil fuel sector could be amplified [29]. Therefore, to maintain a sustainable investment flow, these issues need to be addressed by taking into account many different factors such as energy supply structure, energy end-use characteristics, and financial environment, etc.

#### 4.2. Towards low carbon and green finance

The concept of green finance or sustainable finance is gaining increasing attention in both China and the European countries. In 2016, G20 leaders recognized the need to 'scale up green finance' for the first time, setting out a series of steps to make this happen [31]. On a conceptual level, green finance can be understood as financing of investments that provide environmental benefits in the broader context of environmentally sustainable development [32]. The associated instruments include green loans, green bonds, green investment trusts and funds as well as green indices and ETFs (exchange-traded funds) etc [31].

Therefore mobilising the additional investments depends on the financing from other channels, such as the promotion of current green finance systems [33]. In particular, to meet stringent climate goals, much larger amounts of investments need to be mobilised from private sectors such as institutional investors, notably pension funds, insurance companies, sovereign wealth funds and mutual funds [34]. A good practice is green investment banks that some countries have established, e.g. the Green Investment Bank (now Green Investment Group) launched by the UK government in 2012 and viewed as the first institution of its type in the world, which has created one of Europe's largest teams of dedicated green infrastructure investors [35]. Another example is Switzerland's Technology Fund, which focuses on scaling up innovative environmental and low-carbon technologies that face a deployment gap [36]. The Chinese government has also proposed to establish a series of national and regional green funds of public-private partnership [37]. These entities have been capitalized by using a

variety of funding sources including: government appropriations and programmes (including reallocation of funds from existing programmes); revenue from carbon taxes, emissions trading schemes, renewable portfolio standards and energy efficiency resource standards; utility bill charges; and bond issuance [38].

#### 4.3. Cooperation between China and Europe in energy and climate change

China and Europe are strengthening bilateral cooperation in climate change and aiming to fill the leadership gap as the US steps back from the commitment to implementing the Paris Agreement. The jointly published 'China-EU Roadmap on energy cooperation (2016–2020)' in 2015 ensures that energy cooperation makes a key contribution to the comprehensive strategic partnership between China and the EU [39]. Some areas for cooperation include the circular economy, clean energy, climate change and investment [40]. Strengthening this cooperation can be done via the following means:

##### 4.3.1. Strengthen multilateral communications in capacity building

Exchange of information and experiences among countries in improving their financial system in this field would greatly facilitate the financing process. And spreading knowledge of the commercial viability of low carbon technologies and policies on low carbon investment among stakeholders will alleviate risk aversion towards projects in low carbon energy technologies [24].

##### 4.3.2. Promote cross-border capital flow in the field of low carbon energy investment

Increasing cross-border capital flow for low carbon energy investment would not only broaden the financial sources, but also accelerate diffusion of new technologies. Since the financial crisis of 2008–10, the global cross-border capital flow—in all economic sectors—has been undergoing deep decline, as a result of a variety of factors, e.g. a collapse in cross-border bank lending, primarily by European banks [41]. In addition, to lift the barriers that restrict the investment capital flow, dedicated policy measures, such as simplifying approval processes for green bond issuers, providing guidance on reporting and disclosure, and providing clearer policy guidance on market-entering schemes [42], would also bring significant benefits.

## 5. Conclusions

This study presents the analysis of energy investment needs for China and Europe under baseline scenarios as well as pathways in line with the global climate targets made by the Paris agreement ('well below 2 °C'). The results show that significant change of energy investments for the two regions is necessary to

reach the stringent targets in two dimensions: one is the incremental amount of investment in absolute terms, and the other is critical decarbonization of investment structure. The challenges in the medium-term future are greater than that of near-term. Maintaining the current level of low carbon investment would fulfill the NDC pledges of China and Europe to 2030, while an increase of 10% investment would keep the efforts consistent with those required by the 2 °C target during the same period. Pursuing the 1.5 °C target would, however, require a considerably stepped-up investment effort by 2030. Energy efficiency, low carbon electricity generation and electricity transmission and storage are the three most important sectors of investment to meet the goals. Marginal cost for emissions reduction differs among regions. Our results show that the marginal abatement cost for China is roughly 30% lower than that of Europe to 2050 in the '2 C' scenario, whereas under the most stringent '1.5 C' target, this gap decreases to only 8%.

The scenario results presented here indicate that significant investment opportunities exist in both China and Europe. These opportunities will be never realized, however, without strong policy incentives. Low carbon investments are characterized of higher upfront costs and more dependence on long-term finance than traditional fossil energy investments. The policies aimed at enhancing low carbon investments shall be carefully designed to facilitate the implementation processes. It is still challenging to incorporate long-term climate benefits into short-term evaluation on the performance of investment portfolio, which usually draws more interest from the finance sector. Discussions on the countermeasures will be important for both researchers and policy-makers. Well-designed climate policies will create many of the favorable conditions necessary to stimulate low carbon investments. Yet, more general economic policies can also be helpful in the low carbon energy sector, such as broadening channels of private investment into low-carbon projects, promoting cross-border capital flow in the field of low carbon energy investment, increasing flexibility of electricity network cross borders and strengthening multilateral communications in capacity building.

Due to many factors such as parameter settings and socio-economic assumptions in the modeling framework, there is considerable uncertainty with regard to the results discussed in this paper, as well as their interpretation [2, 9]. In future work, it would be important to go beyond the current analysis and explore the co-benefits of low carbon investments and the relation of these investments to broader sustainable development goals (e.g. air pollution, water availability, etc).

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