

Supplementary Materials for

Post-COVID-19 recovery stimulus dwarfs near-term climate change investment needs

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Materials and Methods

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**Other Supplementary Materials for this manuscript include the following:**

Data

R script

Materials and Methods

Energy system investments

Energy system investment portfolios (*1*) were derived from six global energy-economy, or ‘integrated assessment’, models (IAMs): AIM/CGE (*2*), IMAGE (*3*), MESSAGEix-GLOBIOM (*4*), POLES (*5*),REMIND-MAgPIE (*6*), and WITCH-GLOBIOM (*7*). In this analysis we focus on the near-term (2020-2024) investment needs under a current policies scenario (i.e., each model’s baseline) and on the upscaling requirements for moving toward an energy system compatible with the 1.5°C target of the Paris Agreement. The models cover different types of energy technologies, including resource extraction, power generation, fuel conversion, transmission, energy storage and end-use demand services. We group these technologies into two broad sectors for our investments analysis:

* fossil fuels**:** extraction and conversion of fossil fuels, electricity from fossil fuels without Carbon Capture and Storage (CCS) technologies and hydrogen from fossil fuels
* low carbon sources**:** extraction and conversion of nuclear energy, CCS, electricity from non-bio renewables, hydrogen from non-fossil fuels, extraction and conversion of bioenergy, electricity transmission and distribution and storage, and energy efficiency

In this analysis, for purposes of quantifying highly uncertain ‘demand-side’, or ‘energy efficiency-increasing’ investments, we inherit the methodology of McCollum et al. (2018), the original source for all of our energy investment numbers. That study calculated demand-side energy efficiency investments across the end-use sectors (buildings, transport, industry) in a harmonized way for each of the global models. The calculations take into account two separate, additive components: (1) base-year energy efficiency and (2) supply-side offset. The base-year component is calculated by taking the level of energy efficiency investments estimated globally by the International Energy Agency in 2015 and then scaling those efficiency investments with total final energy demand in the models’ scenarios going forward. The supply-side offset component compares total final energy demand for a given model in a policy scenario (e.g., 1.5°C) to that model’s demand in the reference case, and then assumes that, in equilibrium, the investments made to reduce energy demand can be equated to investments that are simultaneously being offset on the supply side. Such an approximation, which is a first-order approximation to be sure, implicitly includes both technological (e.g., air conditioner efficiency) and systems (e.g., urban land use and transit) changes that could allow for less energy-intensive lifestyles than today. Based on this methodology, however, investments into individual demand-side measures cannot be tracked explicitly.

All investment estimates from McCollum et al. (2018) were corrected for inflation (from USD 2015 to current USD) and are reported here as model averages.

Strengths and limitations of energy investment modelling estimates

Estimating current and future energy investment flows is not an exact science. Private and publicly-traded companies, governments, stated-owned enterprises, and households are not required to report such information to statistical gathering organizations in all cases. For this reason, the numbers must be back-calculated based on physical quantities, such as gigawatts of installed power plant capacity. Energy efficiency investments are the most uncertain, largely owing to definitional issues (what exactly is the energy-related part of a demand-side device, such as a consumer appliance?). Organizations like the International Energy Agency have adopted a certain set methodologies; global integrated assessment models do similar. Importantly, base-year uncertainties can contribute to differences in future year projections, especially further out in time (e.g., 2050). Fortunately, for this analysis, which focuses on the near-term period of 2020-2024 (i.e., a single model time-step for all but one of the models relied upon here), the differences across models are relatively small. Moreover, despite the lack of temporal granularity of these models (i.e., no annual or sub-annual timesteps), one of their acknowledged strengths is that they permit the analysis of near-term system responses in the context of long-term goals. This is as much true for fuel-technology mixes and greenhouse gas emissions as it is for investments (in dollar terms), even if the latter is less often the focus of IAM research.

Stimulus packages

The International Monetary Fund (IMF) has been tracking the policy measures announced by governments in response to the COVID-19 pandemic (*8*). For this analysis, we focus on the fiscal policy responses, which span a wide range of instruments such as spending and revenue measures, equity injections, asset purchases, extra-budgetary funds, guarantees on loans, etc. We extracted data for 176 countries and the European Union, announced until July 23, 2020.

Countries announced their stabilization packages in different levels of detail and scope. Here we group the fiscal measures broadly in line with the IMF. The packages are split into:

* “Above-the-line” measures which contain mostly spending measures, and which are further divided into those aimed at supporting the health sector (in figures labeled as *Health sector spending*) and those intended for all other sectors of the economy (in figures labeled *General spending*), which include supporting individuals, households and businesses, as well as forgone and deferred revenue.
* Liquidity measures, which including loans, guarantees and quasi-fiscal operations (labeled *Liquidity support*).

We do not account for governments' announcements to channel funds into international assistance, nor the recovery funds agreed between governments and the international finance institutions. See Table S1 for country-level detail.

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Fig. S1.

Total amount of stimulus packages for five macro regions (see table S2 for definitions of the regions) and the world, disaggregated in three categories based on the targets of the fiscal instruments.

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Fig. S2.

Total amount of stimulus packages for four large economies (China, European Union, India and the United States), disaggregated in three categories based on the targets of the fiscal instruments.

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Fig. S3.

Annual energy system investments between 2020 and 2024 for the current policy baseline (left) and a pathway compatible with the 1.5°C limit of global mean temperature (right) for five macro regions (see table S2 for definitions of the regions) and the world.

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Fig. S4.

Annual energy system investments between 2020 and 2024 for the current policy baseline (left) and a pathway compatible with the 1.5°C limit of global mean temperature (right) for four large economies (China, European Union, India and the United States).

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Fig. S5.

Annual shift in energy investments from the current policy baseline scenario to a pathway compatible with the 1.5°C limit of global mean temperature for five macro regions and the world (left) and four large economies (right).

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Fig. S6.

Average annual energy investments compatible with the 1.5°C global mean temperature limit, and fiscal stimulus packages in response to COVID-19, expressed as a percentage of the 2018 Gross Domestic Product (GDP) for five macro regions and the world (left) and four major economies (right).

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Fig. S7.

Annual energy investments compatible with the 1.5°C global mean temperature limit, and fiscal stimulus packages in response to COVID-19, expressed in current USD, for five macro regions and the world (left) and four major economies (right).

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| **Table S1:**  **Inventory and categorisation of stimulus packages in response to COVID-19, based on the IMF Policy Tracker (IMF, 2020). Explanations for categories can be found in the Materials and Methods section (SM p.2).** | | | | |
| Country | Region | General spending | Health sector spending | Liquidity support |
| Afghanistan | ASIA | 0.08 | 0.02 | - |
| Albania | OECD+ | 0.15 | 0.03 | 0.24 |
| Algeria | MAF | 0.10 | 0.25 | 0.17 |
| Angola | MAF | - | 0.04 | - |
| Argentina | LAM | 11.00 | 1.00 | 8.30 |
| Armenia | REF | 0.14 | - | - |
| Australia | OECD+ | 107.00 | 3.00 | 23.00 |
| Austria | OECD+ | 44.56 | 4.35 | 0.01 |
| Azerbaijan | REF | 1.94 | - | - |
| Bahamas | LAM | 0.05 | - | 0.02 |
| Bahrain | MAF | 1.11 | 0.47 | - |
| Bangladesh | ASIA | 1.05 | - | 6.23 |
| Barbados | LAM | - | - | - |
| Belarus | REF | - | - | - |
| Belgium | OECD+ | 15.54 | 2.00 | 56.52 |
| Belize | LAM | 0.02 | - | - |
| Benin | MAF | 0.16 | 0.11 | - |
| Bhutan | ASIA | - | 0.04 | - |
| Bolivia | LAM | 0.31 | 0.20 | - |
| Bosnia & Herzegovina | OECD+ | 1.33 | 0.03 | 0.30 |
| Botswana | MAF | 0.06 | 0.05 | 0.10 |
| Brazil | LAM | 112.00 | 12.00 | 71.00 |
| Brunei | ASIA | - | - | - |
| Bulgaria | OECD+ | 1.20 | 0.30 | 2.60 |
| Burkina Faso | MAF | - | - | - |
| Burundi | MAF | 0.08 | - | - |
| C√¥te d‚ÄôIvoire | MAF | 0.90 | 0.13 | - |
| Cambodia | ASIA | - | 0.06 | - |
| Cameroon | MAF | 0.04 | 0.11 | - |
| Canada | OECD+ | 145.00 | 3.00 | 5- |
| Cape Verde | MAF | 0.02 | - | 0.03 |
| Central African Republic | MAF | 0.04 | - | - |
| Chad | MAF | 0.14 | 0.06 | - |
| Chile | LAM | 20.30 | 1.70 | 5.60 |
| China | ASIA | 841.00 | 22.00 | 8- |
| Colombia | LAM | 2.00 | 1.90 | 1.00 |
| Comoros | MAF | - | - | - |
| Congo - Brazzaville | MAF | 0.18 | - | - |
| Congo - Kinshasa | MAF | 0.14 | - | - |
| Costa Rica | LAM | 0.29 | 0.01 | - |
| Croatia | OECD+ | - | - | - |
| Cuba | LAM | - | - | - |
| Cyprus | OECD+ | 1.11 | 0.11 | - |
| Czechia | OECD+ | 9.00 | 2.00 | 20.30 |
| Denmark | OECD+ | 42.00 | - | 31.00 |
| Djibouti | MAF | - | - | - |
| Dominican Republic | LAM | 0.58 | - | - |
| Ecuador | LAM | 0.16 | - | - |
| Egypt | MAF | 5.70 | 0.50 | 0.20 |
| El Salvador | LAM | - | - | - |
| Equatorial Guinea | MAF | - | 0.02 | - |
| Eritrea | MAF | - | - | - |
| Estonia | OECD+ | 0.63 | 0.23 | 1.68 |
| Ethiopia | MAF | 1.10 | 0.50 | 0.60 |
| Fiji | OECD+ | 0.48 | - | - |
| Finland | OECD+ | 12.00 | 2.00 | 18.00 |
| France | OECD+ | 115.00 | 9.00 | 38- |
| French Polynesia | OECD+ | - | - | - |
| Gabon | MAF | 0.68 | - | - |
| Gambia | MAF | 0.03 | - | - |
| Georgia | REF | 0.93 | 0.21 | 0.40 |
| Germany | OECD+ | 307.00 | 25.00 | 1115.00 |
| Ghana | MAF | 0.20 | 0.10 | 0.20 |
| Greece | OECD+ | 23.91 | - | 2.17 |
| Guam | OECD+ | - | - | - |
| Guatemala | LAM | 2.67 | - | - |
| Guinea-Bissau | MAF | - | - | - |
| Guyana | LAM | - | - | - |
| Haiti | LAM | 0.10 | 0.04 | - |
| Honduras | LAM | 0.29 | 0.22 | 0.50 |
| Hong Kong SAR China | ASIA | 32.85 | 3.83 | - |
| Hungary | OECD+ | 2.47 | 0.95 | 6.11 |
| Iceland | OECD+ | 2.12 | - | - |
| India | ASIA | 43.00 | 2.00 | 145.00 |
| Indonesia | ASIA | 22.00 | 5.00 | 13.00 |
| Iran | MAF | 30.56 | 9.26 | 20.37 |
| Iraq | MAF | 0.03 | - | - |
| Ireland | OECD+ | 7.46 | 2.00 | 5.00 |
| Israel | MAF | 11.70 | 3.06 | 11.42 |
| Italy | OECD+ | 61.00 | 7.00 | 583.00 |
| Jamaica | LAM | 0.17 | - | - |
| Japan | OECD+ | 757.00 | 38.00 | 1169.00 |
| Jordan | MAF | 0.21 | - | - |
| Kazakhstan | REF | 9.86 | - | - |
| Kenya | MAF | 0.92 | - | - |
| Kuwait | MAF | 1.60 | - | - |
| Kyrgyzstan | REF | 0.56 | 0.02 | - |
| Laos | ASIA | 0.01 | - | - |
| Latvia | OECD+ | 1.08 | 0.02 | 0.90 |
| Lebanon | MAF | 1.09 | - | - |
| Lesotho | MAF | 0.08 | 0.03 | 0.03 |
| Liberia | MAF | - | - | - |
| Libya | MAF | 0.37 | - | - |
| Lithuania | OECD+ | 8.70 | 0.54 | 2.50 |
| Luxembourg | OECD+ | 7.18 | 0.21 | 3.91 |
| Macau SAR China | ASIA | 6.67 | - | - |
| Macedonia | OECD+ | 0.03 | - | - |
| Madagascar | MAF | 0.16 | - | - |
| Malawi | MAF | 0.05 | 0.02 | - |
| Malaysia | ASIA | 15.52 | - | - |
| Maldives | ASIA | 0.23 | - | - |
| Mali | MAF | 0.09 | - | - |
| Malta | OECD+ | 1.40 | 0.15 | - |
| Mauritania | MAF | 0.29 | - | - |
| Mauritius | MAF | 0.32 | 0.04 | 0.01 |
| Mexico | LAM | 7.00 | 2.00 | 5.00 |
| Moldova | REF | - | - | - |
| Mongolia | ASIA | 0.26 | 0.01 | - |
| Montenegro | OECD+ | 0.21 | - | - |
| Morocco | MAF | 3.18 | - | - |
| Mozambique | MAF | - | 0.03 | - |
| Myanmar (Burma) | ASIA | 0.03 | - | 0.07 |
| NA | EU | 499.00 | - | 866.00 |
| Namibia | MAF | 0.26 | 0.17 | 0.17 |
| Nepal | ASIA | - | - | - |
| Netherlands | OECD+ | 67.78 | 1.00 | 33.26 |
| New Caledonia | OECD+ | - | - | - |
| New Zealand | OECD+ | 37.00 | - | 8.00 |
| Nicaragua | LAM | - | - | - |
| Niger | MAF | - | - | - |
| Nigeria | MAF | 1.40 | 0.40 | - |
| Norway | OECD+ | 16.00 | - | 18.00 |
| Oman | MAF | - | - | - |
| Pakistan | ASIA | 7.10 | 1.10 | - |
| Panama | LAM | 1.30 | - | - |
| Papua New Guinea | ASIA | 1.71 | - | - |
| Paraguay | LAM | 0.45 | 0.50 | - |
| Peru | LAM | 18.30 | 0.30 | 17.10 |
| Philippines | ASIA | 10.80 | 1.30 | - |
| Poland | OECD+ | 40.80 | 2.20 | 29.10 |
| Portugal | OECD+ | 10.76 | - | - |
| Puerto Rico | LAM | - | - | - |
| Qatar | MAF | 20.60 | - | - |
| Romania | OECD+ | 2.40 | 1.50 | 7.40 |
| Russia | REF | 29.00 | 3.00 | 15.00 |
| Rwanda | MAF | 0.31 | - | - |
| Samoa | OECD+ | 0.03 | - | - |
| Saudi Arabia | MAF | 16.00 | 13.00 | 6.00 |
| Senegal | MAF | 0.60 | 0.10 | 0.10 |
| Serbia | OECD+ | 2.83 | 0.39 | 2.64 |
| Sierra Leone | MAF | 0.01 | - | - |
| Singapore | ASIA | 51.00 | 1.00 | 14.00 |
| Slovakia | OECD+ | 2.03 | - | - |
| Slovenia | OECD+ | 7.61 | - | - |
| Solomon Islands | OECD+ | 0.04 | - | - |
| Somalia | MAF | - | - | - |
| South Africa | MAF | 17.00 | 1.00 | 12.00 |
| South Korea | ASIA | 44.00 | 4.00 | 149.00 |
| Spain | OECD+ | 40.71 | 4.62 | - |
| Sri Lanka | ASIA | 40.01 | - | - |
| Sudan | MAF | 4.06 | 1.24 | - |
| Suriname | LAM | 0.09 | 0.05 | - |
| Swaziland | MAF | 0.01 | - | - |
| Sweden | OECD+ | 58.00 | 1.00 | 23.00 |
| Switzerland | OECD+ | 29.00 | 3.00 | 42.00 |
| Syria | MAF | - | - | - |
| Tajikistan | REF | - | - | - |
| Tanzania | MAF | 0.38 | - | - |
| Thailand | ASIA | 42.00 | - | 18.00 |
| Timor-Leste | ASIA | - | - | - |
| Togo | MAF | 0.02 | 0.19 | - |
| Trinidad & Tobago | LAM | - | - | - |
| Tunisia | MAF | 0.60 | 0.10 | 0.50 |
| Turkey | OECD+ | 12.00 | - | 63.00 |
| Turkmenistan | REF | 2.98 | 0.82 | 1.79 |
| Uganda | MAF | 0.37 | - | - |
| Ukraine | REF | 8.44 | 0.58 | - |
| United Arab Emirates | MAF | 7.22 | - | - |
| United Kingdom | OECD+ | 70.71 | 19.61 | 1.33 |
| United States | OECD+ | 2139.00 | 304.00 | 51- |
| Uruguay | LAM | 0.80 | - | - |
| Uzbekistan | REF | - | - | - |
| Venezuela | LAM | - | - | - |
| Vietnam | ASIA | 11.20 | 0.70 | 0.50 |
| Zambia | MAF | 0.25 | - | - |
| Zimbabwe | MAF | - | - | - |

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| **Table S2: Definitions of the five macro regions used for aggregating energy investments and stimulus packages** | |
| **Macro region** | **Definition** |
| ASIA | Includes most Asian countries with the exception of the Middle East, Japan and Former Soviet Union states. |
| LAM | Includes the countries of Latin America and the Caribbean. |
| MAF | Includes the countries of the Middle East and Africa. |
| OECD+ | Includes the OECD 1990 countries as well as EU members and candidates. |
| REF | Countries from the Reforming Ecomonies of the Former Soviet Union. |
|  | |
| **ISO-3 country code** | **Country** |
| CHN | China |
| EU | European Union |
| IND | India |
| USA | United States of America |

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| **Table S3: Derivation of numbers cited in the manuscript** | | |
| **Citation** | **Calculation** | **Figures** |
| At the time of writing, announced COVID-19 fiscal stimulus (as a proportion of GDP) already exceeded the stimulus provided in the wake of the 2008-2009 Global Financial Crisis (*4*) by a factor of 2. | USD 12500 billion (current global stimulus, Fig.1)/USD 3000 billion (after the GFC, based on ref. 4) | Fig. 1 |
| As of July 2020, our tracking framework showed aggregate fiscal stimuli amounting to USD 12.5 trillion, 80% of which comes from OECD countries (Fig. 1, Figures S1,S2). | OECD+ countries (see table S2 for the full definition) add up to USD ~10000 billion | Fig. 1; Fig. S1 |
| What we can glean from the available data is that at present, 55% about is dedicated to the “above-the-line” measures (of which 4% targeted at the health sector, and 51% percent to other sectors), while 45% is intended for liquidity support. | We focus on the global stimulus estimate (left-most panel on Fig. 1, and right-most panel on Fig. S1) | Fig. 1; Fig. S1 |
| Average annual low-carbon energy and efficiency investments under a Paris-compatible pathway have been estimated at about 1.3 trillion USD per year over the near term between 2020 and 2024 (11, 12). This amounts to about 10% of the total pledged post-COVID-19 stimulus to date (Fig. 1, Figures S3,S4). | We read these estimates from the left-most set of bars on Fig. 1. | Fig. 1; Fig. S3, S4 |
| These incremental low-carbon invest-ments globally amount to about 300 billion USD per year over the coming five years (Fig. 1, Fig. S5). This number in isolation, however, masks an important part of the story, as increases in low-carbon investments would necessarily be accompanied by divestment from high-carbon fossil-fuel investments of about 280 billion USD per year over the same time period. Subtracting these two estimates (investments – divestments) indicates that the additional net annual investments to achieve an ambitious low-carbon trans-formation in the energy sector amounts to about 20 billion USD per year, which is around 0.16% of the total announced stimulus to date (compare Fig. S5 to S1 and S2). | Fig. S5, the right-most bar on the left panel shows the annual shifts in investments:  300 b (additional annual investments into low-carbon energy) – 280 b (annual divestments from fossil fuels) = 20 b (net annual investments, marked by the horizontal black line)  In S1, the total global stimulus is shown on the right-most bar, with the total value of 12500 b (and 20 b from above being 0.16%) | Fig. S5; Fig. S1 |
| The situation is quite different for developing economies. So far, stimulus packages in these geographies only amount to a small fraction (~18%) of what developed countries are putting forward. | On Fig. S1, the stimulus packages of developing countries (here considered in ASIA, LAM, MAF and REF) add up to about 2200 b, which is about 18% of the global total of 12500 b (right-most bar) | Fig. S1 |
| For example, India’s total annual low-carbon energy investment needs relative to GDP are about 4 times higher than those of the EU; but the countries’ stimulus package is only about half the size in relative terms. | We compare the energy investment needs shown on Fig. S6 (right set of panels, for the EU and India (IND)), with the EU’s estimates at about 1% of the GDP, and for India about 4%. | Fig. 1, Fig. S6 |

Data S1. (separate file)

All data underlying this analysis are available at: <https://github.com/marina-andrijevic/covid_recovery/tree/master/data>