CHAPTER 15

AN INDUSTRIAL POLICY FRAMEWORK TO ADVANCE A GLOBAL GREEN NEW DEAL

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15.1 Introduction

In October 2018, the Intergovernmental Panel on Climate Change (IPCC), the most authoritative global organization advancing climate-change research, issued an alarming report titled *Global Warming of 1.5°*. This report emphasized the imperative of limiting the increase in global mean temperatures to 1.5 degrees above pre-industrial levels as opposed to the previous consensus target 2.0 degrees. The IPCC concluded that limiting the global mean temperature increase to 1.5 rather than 2.0 degrees by 2100 will dramatically lower the likely negative consequences of climate change. These include the risks of heat extremes, heavy precipitation, droughts, sea level rise, biodiversity losses, and corresponding impacts on health, livelihoods, food security, water supply, and human security.

The IPCC estimates that to achieve the 1.5 degrees maximum global mean temperature increase target as of 2100, global net CO_2 emissions will have to fall by about 45 per cent as of 2030 and reach net-zero emissions by 2050. I focus in this chapter on what it will take for the global economy to reach net-zero CO_2 emissions by 2050, and specifically, in terms of the industrial and financing policies that will be needed for this project to succeed. In the interests of space, I do not delve into the additional specific challenges around also hitting the IPCC's intermediate target of a 45 per cent CO_2 emissions reduction by 2030, though important additional challenges do emerge with achieving this 2030 goal.

In fact, purely as an analytic proposition and policy challenge—independent of the myriad of political and economic forces arrayed around these matters—it is entirely realistic to allow that global CO_2 emissions can be driven to net zero by 2050. By my higher-end estimate, it will require an average level of investment spending throughout the global economy of about 2.5 per cent of global GDP per year, focused in two areas: 1) dramatically improving energy-efficiency standards in the stock of buildings, automobiles and public transportation systems, and industrial production processes; and 2) equally dramatically expanding the supply of clean renewable energy sources—primarily solar and wind power—available at competitive prices to all sectors and in all regions of the globe.

This level of clean energy investment spending would amount to about $2.6 trillion[1] in the first year of the programme, which I will set as 2024 and rise to an average of about $4.5 trillion per year between 2024 and 2050. This assumes that the project actually begins in 2021, but that the full-scale expansion in clean energy investments requires a three-year lead time. Thus the start date for the full-scale programme becomes 2024. Total clean energy investment spending for the full-scale twenty-seven-year investment cycle 2024–50 would amount to about $120 trillion.

These figures are for overall investment spending, including from both the public and private sectors. Establishing the right mix between public and private investment will be a major consideration within the industrial and financing policies framework. As an initial rough approximation, I assume that the breakdown should be divided equally—that is, 50 per cent public and private investment. For the first year of full-scale investment activity in 2024, this would break down to $1.3 trillion in both public and private investments. A major part of the policy challenge will be to determine how to leverage the public money most effectively to create strong incentives for private investors.

It is important to emphasize at the outset that this clean energy investment project will pay for itself in full over time. More specifically, it will deliver lower energy costs for energy consumers in all regions of the world. This results because raising energy-efficiency standards means that, by definition, consumers will spend less for a given amount of energy services, such as being able to travel 100 miles on a gallon of petrol with a high-efficiency hybrid plug-in vehicle as opposed to 25 miles per gallon with the average car on US roads today. Moreover, the costs of supplying energy through solar and wind power, as well as geothermal and hydro, are now, on average, roughly equal to or lower than those for fossil fuels and nuclear energy. As such, the initial upfront investment outlays can be repaid over time through the cost savings that will be forthcoming.

For 2018, global clean energy investments levels, including both energy efficiency and clean renewable investments, were at about $570 billion, equal to about 0.7 per cent of global GDP. Thus, the increase in clean energy investments will need to be in the range of 1.8 per cent of global GDP—that is, about $1.5 trillion at the current global GDP level of about $86 trillion, then rising in step with global GDP growth thereafter

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[1] All $ values are in US dollars.

until 2050. The consumption of oil, coal, and natural gas will also need to fall to zero over this same thirty-year period. The rate of decline can begin at a relatively modest 3.5 per cent in the initial years of the transition programme, but will then increase every year in percentage terms, as the base level of fossil-fuel supply contracts to zero as of 2050.

Of course, both the privately owned fossil-fuel companies, such as Exxon-Mobil and Chevron, and equally, the publicly owned companies such as Saudi Aramco and Gazprom in Russia, have massive self-interests at stake in preventing reductions in fossil-fuel consumption as well as enormous political power. These powerful vested interests will simply have to be defeated. How exactly this is accomplished is beyond the scope of this chapter, other than to recognize that a critical foundation for advancing a successful global Green New Deal will be to establish a viable set of industrial and financing policies to support the project.

The structure of this chapter is as follows. Section 15.2 asks the first critical question for designing a global clean energy investment project, which is: what is clean energy? I review evidence on natural gas, nuclear energy, and various forms of geoengineering as providing clean energy alternatives to fossil fuels. But I conclude that all these approaches present major problems. This conclusion then becomes the basis for recognizing that building a global clean energy economy should rely mostly on dramatically expanding investments in energy efficiency and clean renewable energy sources.

In considering the prospects for achieving major gains in energy efficiency, I introduce the concept of 'energy intensity ratios' and review evidence on this ratio for the global economy as well as for seven representative national economies, that is, China, the United States, Brazil, Germany, Indonesia, South Africa, and South Korea. I will also focus on Brazil, Germany, Indonesia, South Africa, and South Korea later in this study.

With respect to 'clean renewable energy sources', as I use the term, it excludes many forms of bioenergy, such as ethanol from corn or sugarcane using conventional refining methods. This is because, considered over a thirty-year life cycle, the emissions generated from these energy sources are comparable to those from fossil fuels.[2] The clean renewable sources on which I focus in section 15.2 and throughout the study are solar and wind power, as well as, to a more modest extent, geothermal and hydro power, as well as bioenergy generated through low-emissions technologies.

Section 15.3 presents a simple model through which I calculate the investment requirements for creating a global net-zero-emissions economy as of 2050. I show through this model that investments in energy efficiency and clean renewable energy at an average 2.5 per cent share of global GDP per year will be sufficient for achieving this end. The model builds from the assumption of the most recent global energy model of the International Energy Agency (IEA), which assumes that global GDP grows at an average annual rate of 3.4 per cent per year over 2021–40.

Section 15.4 then considers the industrial and financial policy measures that will be needed to support this global clean energy investment project. I examine a range of

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[2] See Pollin et al. (2014: 113–15).

policy approaches that have been implemented throughout the world to varying degrees. I also propose specific sources of funding that are capable of bringing total clean energy investments to $2.6 trillion as of 2024—that is, 2.5 per cent of global GDP in 2024—along with the capacity to increase funding at a rate corresponding with global GDP through 2050.

In section 15.5, I consider the domestic resource capacities in various countries to support its clean energy transformation, focusing, again, on Brazil, Germany, Indonesia, South Africa, and South Korea. To the extent that a country runs up against domestic productive capacity constraints while expanding its investments in energy efficiency and clean renewable energy, it then must either scale back the clean energy investment project or rely increasingly on imports to maintain the ambitious investment agenda. For the five representative economies, I show how this domestic resource constraint will be manageable.

One factor that will be important in enabling the expansion of domestic production in clean energy will be the fact that the fossil-fuel sectors in all countries will be correspondingly contracting. Thus, in section 15.6, I show how the freeing up of economic resources out of the activities tied to the fossil-fuel sector will be substantial in all cases, including countries such as Germany and South Korea, which are presently dependent on imports as their source of fossil-fuel energy.

In the concluding section 15.7, I briefly summarize the full set of findings in sections 15.2–15.6. These findings demonstrate how a global clean energy project—that is, a Global Green New Deal, as I understand the term—does indeed provide a viable path for achieving a net-zero-emissions global economy as of 2050. I also show that the industrial and financial policy tools needed to deliver on this project are well understood and have been well tested in various parts of the world, under a range of circumstances. These policy tools now need to be implemented on a scale appropriate to the magnitude of the challenge we now face with climate change.

This chapter covers a large number of issues within a relatively brief amount of space. At the same time, due to space limitations, it does not cover several topics that are also critical for understanding the full scope of industrial policy requirements for implementing a successful global Green New Deal. One such critical set of issues covers the employment impacts of the global clean energy investment project, which, in turn, breaks down into two components. The first is assessing the large employment creation opportunities that will be generated through investing 2.5 per cent of GDP in clean energy projects in all regions of the world. The second is recognizing the job losses that will result through the contraction of the global fossil-fuel industry, and the imperative of establishing a set of just transition policies for both the workers and communities that will be negatively impacted as a result. I have addressed these issues at length elsewhere and will continue to do so in future research.[3]

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[3] See Pollin (2015), Pollin et al. (2015), Pollin and Callaci (2019), and Pollin et al. (2019) for discussions and further references on employment effects and Just Transition policies.

Related to this is the large set of questions on the developmental impact of the clean energy transition on economies that are presently net fossil-fuel exporters. These questions are linked to the broader literature around the so-called ‘resource curse’. These issues, again, lie beyond the scope of this chapter, even while the relevant literature is quite extensive.[4]

Another set of critical issues that I have not been able to address here are the land use requirements for building a global clean energy infrastructure. The work of the physicist Mara Prentiss demonstrates that, in fact, through well-designed policies, these land-use requirements will be relatively modest. But the overall global Green New Deal project will benefit through developing with greater specificity the framework that Prentiss has developed.[5]

15.2 What is Clean Energy?

15.2.1 Natural Gas

There are large differences in the emissions levels resulting through burning oil, coal, and natural gas, with natural gas generating about 40 per cent fewer emissions for a given amount of energy produced than coal and 15 per cent less than oil. It is therefore widely argued that natural gas can be a ‘bridge fuel’ to a clean energy future, through switching from coal to natural gas to produce electricity.[6] Such claims do not withstand scrutiny. At best, an implausibly large 50 per cent global fuel switch to natural gas would reduce CO_2 emissions by only 8 per cent. But even this calculation does not take account of the leakage of methane gas into the atmosphere that results through extracting natural gas through fracking. Recent research finds that when more than about 5 per cent of the gas extracted leaks into the atmosphere through fracking, the impact eliminates any environmental benefit from burning natural gas relative to coal. Various studies have reported a wide range of estimates as to what leakage rates have actually been in the United States, at fracking operations have grown rapidly. A recent survey paper puts that range at between 0.18 and 11.7 per cent for different specific sites in North Dakota, Utah, Colorado, Louisiana, Texas, Arkansas, and Pennsylvania.

It would be reasonable to assume that if fracking expands on a large scale in regions outside the United States, it is likely that leakage rates will fall closer to the higher-end figures of 12 per cent, at least until serious controls could be established. This then

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[4] Two recent survey articles on the Resource Curse are Ross (2015) and Venables (2016).

[5] See Prentiss (2015) for her calculations on land-use requirements and a brief application of her framework in Pollin (2018: 14–17).

[6] https://www.yaleclimateconnections.org/2016/07/pros-and-cons-the-promise-and-pitfalls-of-natural-gas/.

would greatly diminish, if not eliminate altogether, any emission-reduction benefits from a coal-to-natural-gas fuel switch.[7]

15.2.2 Nuclear Energy

As of 2018, nuclear power provided 28 quadrillion British Thermal Units (Q-BTUs) of energy throughout the global economy, amounting to 5 per cent of total global supply. Nearly 90 per cent of global nuclear power supply is generated in North America, Europe, China, and India. In terms of the world reaching a net-zero CO_2 emissions target by 2050, nuclear power provides the important benefit that it does not generate CO_2 emissions or air pollution of any kind while operating. At the same time, the processes for mining and refining uranium ore, making reactor fuel, and building nuclear power plants all require large amounts of energy.

But even if we put aside the emissions that result from building and operating nuclear power plants, we still need to recognize the long-standing environment and public safety issues associated with nuclear energy. These include:

- *Radioactive wastes.* These wastes include uranium mill tailings, spent reactor fuel, and other wastes, which according to the US Energy Information Agency (EIA) 'can remain radioactive and dangerous to human health for thousands of years' (EIA, 2012: 1).
- *Storage of spent reactor fuel and power plant decommissioning.* Spent reactor fuel assemblies are highly radioactive and must be stored in specially designed pools or specially designed storage containers. When a nuclear power plant stops operating, the decommissioning process involves safely removing the plant from service and reducing radioactivity to a level that permits other uses of the property.
- *Political security.* Nuclear energy can obviously be used to produce deadly weapons as well as electricity. Thus, the proliferation of nuclear energy production capacity creates dangers of this capacity being acquired by organizations—governments or otherwise—which would use that energy as instruments of war or terror.
- *Nuclear reactor meltdowns.* An uncontrolled nuclear reaction at a nuclear plant can result in widespread contamination of air and water with radioactivity for hundreds of miles around a reactor.

Even while recognizing these problems with nuclear energy, it is still the case, as noted above, that nuclear power presently supplies over 5 per cent of global energy supply. For decades, the prevalent view throughout the world was that these risks associated with nuclear power were relatively small and manageable, when balanced against its benefits. However, this view was upended in the aftermath of the March

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[7] See, for example, Alvarez et al. (2012), Romm (2014), Howarth (2015), and Peischl et al. (2016).

2011 nuclear meltdown at the Fukushima Daiichi power plant in Japan, which resulted from the massive 9.0 Tohuku earthquake and tsunami. The full effects of the Fukushima meltdown cannot possibly be known for some time. Still, these safety considerations with nuclear energy must be accorded significant weight. This is especially the case, given the high probability that the necessary tight standards for regulating nuclear power plants will become compromised if the number of such plants were to expand significantly on a global scale. As such, nuclear energy cannot be seen as providing a major reliable long-term source of non-carbon-emitting energy supplies.

15.2.3 Geoengineering

This includes a broad category of measures whose purpose is either to remove existing CO_2 or to inject cooling forces into the atmosphere to counteract the warming effects of CO_2 and other greenhouse gases. One broad category of removal technologies is carbon capture and sequestration (CCS). A category of cooling technologies is stratospheric aerosol injections (SAI).

CCS technologies aim to capture emitted carbon and transport it, usually through pipelines, to subsurface geological formations, where it would be stored permanently. One straightforward and natural variation on CCS is afforestation. This involves increasing forest cover or density in previously non-forested or deforested areas, with 'reforestation'—the more commonly used term—as one component.

The general class of CCS technologies has not been proven at a commercial scale, despite decades of efforts to accomplish this. A major problem with most CCS technologies is the prospect for carbon leakages that would result under flawed transportation and storage systems. These dangers will only increase to the extent that CCS technologies are commercialized and operating under an incentive structure in which maintaining safety standards will reduce profits. By contrast, afforestation is, of course, a natural and proven carbon removal technology. At the same time, most deforestation projects throughout the globe were undertaken to make space for raising crops and livestock. Relying heavily on afforestation as a climate change strategy would therefore likely present serious land-use competition problems.

The idea of stratospheric aerosol injections builds from the results that followed from the volcanic eruption of Mount Pinatobo in the Philippines in 1991. The eruption led to a massive injection of ash and gas, which produced sulphate particles, or aerosols, which then rose into the stratosphere. The impact was to cool the earth's average temperature by about 0.6°C for fifteen months.[8] The technologies being researched now aim to artificially replicate the impact of the Mount Pinatubo eruption through deliberately injecting sulphate particles into the stratosphere. Some researchers

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[8] https://earthobservatory.nasa.gov/images/1510/global-effects-of-mount-pinatubo.

contend that to do so would be a cost-effective method of counteracting the warming effects of greenhouse gases.

Lawrence et al. (2018) published an extensive review on the range of climate geoengineering technologies, including 201 literature references. Their overall conclusion from this review is that none of these technologies are presently at a point at which they can make a significant difference in reversing global warming. They conclude:

> Proposed climate geoengineering techniques cannot be relied on to be able to make significant contributions . . . towards counteracting climate change in the context of the Paris Agreement. Even if climate geoengineering techniques were actively pursued, and eventually worked as envisioned on global scales, they would very unlikely be implementable prior to the second half of the century . . . This would very likely be too late to sufficiently counteract the warming due to increasing levels of CO_2 and other climate forcers to stay within the 1.5°C temperature limit—and probably even the 2°C limit—especially if mitigation efforts after 2030 do not substantially exceed the planned efforts of the next decade (2018: 13–14).[9]

15.2.4 Energy Efficiency and Clean Renewable Energy

Given these major problems with natural gas as a ‘bridge fuel’, nuclear energy, and geoengineering, it follows that we focus instead on the most cautious clean energy transition programme, that is, investing in technologies that are well understood, already operating at large scale, and, without question, safe. In short, we focus on investments that can dramatically raise energy-efficiency standards and equally dramatically expand the supply of clean renewable energy sources.

15.2.5 Energy Efficiency

Energy efficiency entails using less energy to achieve the same, or even higher, levels of energy services from the adoption of improved technologies and practices. Examples include insulating buildings much more effectively to stabilize indoor temperatures; driving more fuel-efficient cars or, better yet, relying increasingly on well-functioning public transportation systems; and reducing the amount of energy that is wasted both through generating and transmitting electricity and through operating industrial machinery.

Expanding energy-efficiency investments support rising living standards because raising energy-efficiency standards, by definition, saves money for energy consumers.

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[9] In his 2019 paper, ‘There Is No Plan B for Dealing with the Climate Crisis’, the leading climate scientist and lead co-author of the Third Assessment Report of the IPCC Raymond Pierrehumbert is even more emphatic in arguing that geoengineering does not offer a viable solution to the climate crisis.

A major 2010 study by the US National Academy of Sciences (NAS) found, for the US economy, that 'energy-efficient technologies . . . exist today, or are expected to be developed in the normal course of business, that could potentially save 30 per cent of the energy used in the US economy while also saving money'. Similarly, a 2010 McKinsey & Company study, focused on developing countries, found that, using existing technologies only, energy-efficiency investments could generate savings in energy costs in the range of 10 per cent of total GDP for all low- and middle-income countries.

In her 2015 book, *Energy Revolution: The Physics and Promise of Efficient Technology*, Mara Prentiss argues, further, that such estimates understate the realistic savings potential of energy-efficiency investments. This is because, in generating energy by burning fossil fuels, about two-thirds of the total energy available is wasted while only one-third is available for powering machines. By switching to renewable energy sources, the share of wasted energy falls by 50 per cent. This is what Prentiss terms the 'burning bonus'.

After taking account of the burning bonus as well as the efficiency gains available in the operations of buildings, transportation systems, and industrial equipment, Prentiss concludes, with respect to the US economy specifically, that economic growth could proceed at a normal rate while total energy consumption could remain constant or even decline in absolute terms. Prentiss's conclusions regarding the US economy are consistent with the most recent projections for global energy demand by the International Energy Agency (IEA, 2019). As I discuss further in section 15.3.1, the IEA assumes that the global economy will grow at a 3.4 per cent average annual rate between 2018 and 2040. Nevertheless, under their most conservative Current Policies Scenario, the IEA assumes that global energy consumption will grow at a much slower 1.3 per cent per year. Under their more ambitious Sustainable Development Scenario, they assume that global energy consumption will actually fall at an average rate of –0.3 per cent per year, while economic growth still proceeds at a 3.4 per cent average rate.[10]

A useful way to measure the relationship between the level of economic activity and the energy resources consumed to support that activity is the energy intensity ratio. The energy intensity ratio is, straightforwardly, the level of total energy resources consumed in any given economy divided by the economy's GDP. I report in Table A15.1 (in the Appendix) below the most recent energy intensity figures for the world economy as well as for seven representative large economies—China, the United States, Brazil, Germany, Indonesia, South Africa, and South Korea.

In section 15.2.6, I will focus on this ratio for the world economy as a key variable for estimating the costs of reaching a zero CO_2 emissions global economy by 2050. For now, it will be useful to consider the patterns for the global economy and the respective national economies. The units in which I measure the ratio are Q-BTUs of energy consumed/trillion dollars of GDP. As the table shows, the intensity ratio, as of 2018, was 6.6 Q-BTUs for every $1 trillion of global GDP. With the individual country

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[10] The IEA summarizes its three scenarios—the Stated Policies Scenario, the Sustainable Development Scenario, and the Current Policies Scenario, on p. 751 of its 2019 *World Energy Outlook*.

figures, we see that the intensity ratios vary widely by country. Germany is the most efficienct economy, with the lowest 3.5 intensity ratio. The United States is next, at with a 5.3 intensity ratio, following by Brazil at 7.2. South Korea and Indonesia are at similar efficiency levels, with 9.3 and 9.8 intensity ratios respectively. China is operating at a relatively low efficiency level, with a 12.7 intensity ratio. South Africa is the least energy efficient of the countries in our sample, with an intensity ratio of 20.3.[11]

15.2.6 Estimating Costs of Efficiency Gains

This range of energy intensity figures notwithstanding, the aim of the clean energy investment project will be to achieve dramatic improvements in efficiency in all national economies across the global economy. The question we therefore need to address is: how much will it cost to achieve such large-scale efficiency gains?

In fact, estimates as to the investment costs for achieving energy-efficiency gains vary widely. In Table A15.2 in the Appendix, I show summary estimates from three sets of studies. As we see, the 2008 World Bank study by Taylor et al. puts average costs at $1.9 billion per Q-BTU of energy savings, based on a study of 455 projects in both industrial and developing economies. A 2010 study by McKinsey estimates costs for a wide range of non-OECD economies at $11 billion per Q-BTU of energy savings. Focusing just on the US economy, NAS estimated average costs for energy-efficiency savings in the buildings and industrial sectors at about $29 billion per Q-BTU.[12]

It is not surprising that average costs to raise energy-efficiency standards would be significantly higher in industrialized economies. A high proportion of overall energy-efficiency investments are labour costs, especially projects to retrofit buildings and industrial equipment. However, these wide differences in cost estimates shown in Table A15.2 do not simply result from variations in labour and other input costs by regions and levels of development.

Thus, the World Bank estimate of $1.9 billion per Q-BTU includes both industrialized and developing countries, while the McKinsey $11 billion per Q-BTU estimate—nearly six times greater than the World Bank figure—is primarily coming from developing-country projects. These alternative studies do not provide sufficiently

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[11] It is, however, important to note that the pattern with these ratios is highly sensitive to the method by which one measures national GDP figures. The figures reported here are based on nominal US dollars calculated according to each country's exchange rate. If, alternatively, we measured national GDP figures based on purchasing power parity, the GDP figures would be significantly higher for the lower-income economies. This would in turn lower their energy intensity ratios. How best to deal with these methodological issues is an important question, but it is beyond the scope of this chapter.

[12] I am not aware of more recent studies that have attempted to provide comparable aggregated cost estimates. However, recent studies on the building sector in the US economy have generated results similar to those in the 2010 NAS study. These more recent studies include Molina (2014), Ackerman et al. (2016), and Rosenow and Bayer (2016).

detailed methodological discussions that would enable us to identify the main factors generating these major differences in cost estimates. But it is at least reasonable to conclude from these figures that, with on-the-ground real-world projects, there are likely to be large variations in costs down to the project-by-project level. Thus, the costs for energy-efficiency investments that will apply in any given situation will necessarily be specific to that situation, and must always be analysed on a case-by-case basis. At the same time, for our present purposes, we need to proceed with some general rules of thumb for estimating the level of savings that is attainable through a typical set of efficiency projects in various regions of the world, and more precisely an aggregated estimate for the global economy.

A conservative approach will be to allow that, relative to the World Bank and US National Academy of Sciences figures, the mid-range cost estimate provided by McKinsey at $11 billion per Q-BTU of savings, is appropriate for low- and middle-income economies, such as Brazil, Indonesia, and South Africa. Along the same lines, we could assume that the cost figure for Germany will be equivalent to what the NAS study estimated for the United States, at around $30 billion per Q-BTU of savings. The South Korean economy would then be an approximate midpoint between those two other figures, at around $20 billion per Q-BTU. As a working approximation for the global economy, this same midpoint figure of $20 billion per Q-BTU of savings should be a credible high-end estimate, especially while recognizing that the World Bank estimate for 455 projects in both developing and advanced economies is ten times higher, at about $2 billion per Q-BTU of savings.

15.2.7 Rebound Effects

Raising energy-efficiency levels will generate 'rebound effects'—i.e. energy consumption increases resulting from lower energy costs. But such rebound effects are likely to be modest within the current context of a global project focused on reducing CO_2 emissions and stabilizing the climate. Among other factors, energy consumption levels in advanced economies are close to saturation points in the use of home appliances and lighting—that is, we are not likely to clean dishes much more frequently because we have a more efficient dishwasher. The evidence shows that consumers in advanced economies are likely to heat and cool their homes as well as drive their cars more when they have access to more efficient equipment. But these increased consumption levels are usually modest. Average rebound effects are likely to be significantly larger in developing economies.[13]

But it is critical that all energy-efficiency gains will be accompanied by complimentary policies (as discussed in section 15.4.1), including setting a price on carbon emissions to discourage fossil-fuel consumption. Most significantly, expanding the

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[13] See the discussion and references in Pollin et al. (2015: 92–6).

supply of clean renewable energy will allow for higher levels of energy consumption without leading to increases in CO_2 emissions. It is important to recognize, finally, that different countries presently operate at widely varying levels of energy efficiency. For example, as we saw in Table A15.1, Germany presently operates at an efficiency level roughly 50 per cent higher than that of the United States. Brazil is at an efficiency level that is nearly three times that of South Africa. There is no evidence that large rebound effects have emerged as a result of these high efficiency standards in Germany and Brazil relative to those of the United States and South Africa.

15.2.8 Renewable Energy

A critical point for building a net-zero global economy by 2050 is the fact that, on average, the costs of generating electricity with clean renewable energy sources are now at parity or lower than those for fossil-fuel-based electricity. Table A15.3 in the Appendix shows the most recent figures reported by the International Renewable Energy Agency (IRENA), for 2010 and 2017, on the 'levellized costs' of supplying electricity through alternative energy sources. Levellized costs takes account of *all costs* of producing and delivering a kilowatt of electricity to a final consumer. The cost calculations begin with the upfront capital expenditures needed to build the generating capacity, continue through to the transmission and delivery of electricity, and include the costs of energy that is lost during the electricity-generation process.

As we see in Table A15.3, the levellized costs for fossil-fuel-generated electricity range between 4.5 and 14 cents per kilowatt hour as of 2017. The average figures for the four clean renewable sources are all within this range for fossil fuels as of 2017, with hydro at 5 cents, onshore wind at 6 cents, geothermal at 7 cents and solar PV at 10 cents. The costs of geothermal and hydro did not fall, and actually rose modestly, between 2010 and 2017. However, the costs of onshore wind fell by 25 per cent, from 8 to 6 cents. The most impressive result though is with solar PV, in which levellized costs fell by 72 per cent from 2010 to 2017, from 36 cents to 10 cents per kilowatt hour. These average cost figures for solar and wind should continue to decline by significant amounts as advances in technology and economies of scale proceed along with the rapid global expansion of these sectors.

We emphasize that these cost figures from the IRENA are simple averages. They do not show differences in costs due to regional or seasonally specific factors.[14] In particular, solar and wind energy costs will vary significantly by region and season. Moreover, both wind and solar energy are intermittent sources—that is, they only generate energy, respectively, when the sun is shining or the wind is blowing. Of course, the central role of energy storage systems to address these matters will need to be fully

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[14] Such detailed figures are also available in IRENA (2019).

accounted for when clean renewable energy systems are designed to provide a major share of an economy's overall energy load.[15]

Keeping all such considerations in mind, we can still roughly conclude from these figures that, for the most part, clean renewable energy sources are rapidly emerging into a position at which they can produce electricity at comparable or lower costs than non-renewable sources. As such, assuming that wind, solar, and geothermal energy production can be scaled up to meet virtually all global demand by 2050, then the costs to consumers of purchasing this energy should not be significantly different from what these consumers would have paid for non-renewable energy. Indeed, overall, the costs to consumers of purchasing electricity from clean renewable sources, including hydro as well as wind, solar, and geothermal power, are likely to be *lower* than what they would be from fossil-fuel sources. It is critical to also emphasize that this is *without* factoring in the environmental costs of burning oil, coal, and natural gas.

15.2.9 Costs of Expanding Renewable Capacity

By a substantial amount, the largest share of overall costs in generating electricity from renewable sources are capital costs—that is, the costs of producing new productive equipment, as opposed to the costs of operating that productive equipment once it has been built and is generating energy. These capital costs are at about 65 per cent of total costs for geothermal, 73 per cent for onshore wind, and 81 per cent for solar PV.[16] From these figures on levellized costs, we can also estimate the capital costs of installing renewable energy capacity as a lump sum—that is, how much investors need to spend *upfront* to put this capital equipment into place and in running order.

I produce estimates of these lump sum capital costs in Table A15.4 in the Appendix. Specifically, these figures represent the present values of total lump-sum capital expenditures needed to produce one Q-BTU of electricity from onshore wind, solar PV, and geothermal energy.[17] As we see, the average lump-sum costs range from \$112 billion per Q-BTU for geothermal, \$160 billion for onshore wind, and \$190 billion for solar.

If we assume that, roughly speaking, the global expansion of clean renewable energy capacity will consist of 45 per cent from wind and solar PV technologies, and 10 per cent from geothermal energy, this would place the average costs of producing one Q-BTU of overall renewable energy equipment at about \$169 billion, which we can round up to \$170 billion per Q-BTU of clean renewable capacity. This \$170 billion figure can therefore serve as a benchmark for estimating the average costs of expanding the supply of clean renewable energy on a global scale. At the same time,

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[15] See IRENA (2017) on electricity storage costs and markets through 2030.

[16] These figures are from the US Energy Information Agency (EIA, 2018).

[17] The full methodology for generating these costs is presented in Pollin et al. (2014: 136–7).

as with our cost estimate for investments in energy efficiency, we will want to err, if anything, on the side of overestimating, rather than underestimating, the costs of expanding clean renewable energy. Moreover, with the expansion of the globe's clean energy supply proceeding rapidly over 2024–50, the average costs are likely to rise as production bottlenecks emerge. We therefore will assume that the average costs of expanding the clean energy supply will be \$200 billion per Q-BTU, that is, about 18 per cent higher than the \$170 billion average figure we have derived from the levellized costs data.

We can now work with our two rough high-end estimates of the overall costs of both raising energy-efficiency standards and building new clean renewable energy capacity—\$20 billion per Q-BTU for efficiency gains and \$200 billion per Q-BTU for expanding renewable capacity—to generate an estimate of the total costs of achieving a net-zero global economy by 2050.

15.3 ECONOMIC GROWTH AND EMISSIONS REDUCTIONS

In this section, I present a simple model to illustrate how the global economy can achieve net-zero CO_2 emissions by 2050 through investing about 2.5 per cent of global GDP per year to raise energy-efficiency standards and to expand the supply of clean renewable energy sources. The model works from the following assumptions:

1. *Average costs for increasing energy efficiency and expanding clean renewable production.* As discussed, I assume that the average costs to increase energy efficiency by 1 Q-BTU will be \$20 billion. I also assume that the average costs to expand productive capacity of clean renewable energy by 1 Q-BTU will be \$200 billion.
2. *Global GDP growth trend.* The IEA's forecast assumes an average global GDP growth rate of 3.4 per cent between 2018 and 2040 (2019: 753). My model incorporates this figure. To date, the IEA has not published a global GDP growth forecast that extends beyond 2040. For the purposes of the current exercise, I assume that the 3.4 per cent average global GDP growth rate will extend to 2050.
3. *Clean renewable energy sources supply 100 per cent of global energy demand.* As discussed, there may be a case for relying to a limited extent on nuclear energy and some types of carbon capture technologies beyond afforestation as a supplement to clean renewable sources. But this model demonstrates how, as of 2050, it will be cost effective as well as technically feasible to deliver 100 per cent of global energy supply through clean renewables.
4. *Three-year delay in bringing the project to scale.* This is a thirty-year investment project. But given that the current level of clean energy investments is in the range

> of 0.7 per cent of global GDP,[18] we must realistically allow for some incubation time to pass before we can expect investments to rise by 1.8 percentage points as a share of GDP, to a 2.5 per cent of annual GDP level. To reflect this consideration, I assume, as noted above, that it will require three years of major initiatives within the realms of industrial policy and financing to raise global clean energy investments by roughly 1.8 per cent of GDP relative to current investment levels. We therefore assume that the 2.5 per cent of GDP per year level of clean energy investments will occur over twenty-seven years within the full thirty-year investment cycle, that is, between 2024 and 2050. The initial three years of the model, 2021–3, will be needed to develop an adequate industrial policy and financing environment to sustain clean energy investments at this level.

The results of this model are presented in Tables 15.1–15.4.

15.3.1 Global Model Framework and Calculations

In Table 15.1, we start with the actual global GDP figure in 2018 of $86 trillion.[19] We then work with the IEA's assumption of average global GDP growth over the subsequent thirty years at 3.4 per cent per year. From our initial 2018 GDP figure of $86 trillion and our assumption of 3.4 per cent average annual growth, we can then estimate the level of GDP every year through 2050. Under these assumptions, global GDP will be $260 trillion in 2050. The model projects global GDP in 2050 at $260 trillion. We can also then calculate the 'midpoint' GDP figure over the 2021–50 thirty-year investment cycle. I define this midpoint figure as being equal to the average of the estimates of GDP in 2021 and 2050, assuming average annual GDP growth at 3.4 per cent. This midpoint figure, as we see, is $178 trillion. From this midpoint figure, we can then readily calculate a ratio for average annual clean renewable investments.

In Table 15.1, I estimate the level of clean energy investments necessary to bring the average global energy intensity ratio down from its current level of 6.6 (Q-BTUs/

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[18] Renewable investments = $330 billion in 2018, https://about.bnef.com/blog/clean-energy-investment-exceeded-300-billion-2018/; but $390 billion in 2018 according to IEA (p. 309). But it doesn't break out bioenergy from the others. Energy efficiency, from IEA in 2014 is $240 billion (p. 307). Total is therefore $630 billion. But if we take out ~ 10 per cent for high-emissions bioenergy, that gets us to $570 billion. $570 billion/$86 trillion = 0.7 per cent GDP.

[19] This $86 trillion global GDP figure comes from World Development Indicators. It is derived from the prevailing exchange rates between the United States and all other global currencies as of 2018. The most widely utilized alternative measure of global GDP is derived through establishing purchasing power parities between countries. Measured according to the purchasing power parity methodology, global GDP in 2018 was $138 trillion (World Development Indicators). For the purposes of this exercise, it is important to, if anything, err by underestimating the prospects for a clean energy investment programme over the thirty-year investment cycle. Therefore, for this exercise, I utilize the lower $86 trillion figure derived on the basis of exchange rates as of 2018.

Table 15.1 Thirty-year global GDP growth trajectory, 2021–50

2018 global GDP	$86 trillion
Projected average annual GDP growth rate through 2040 (from IEA, 2019: 753)	3.4%
Projected 2021 GDP (with 3.4% average annual GDP growth)	$95 trillion
Projected 2024 GDP (First year of 27-year investment cycle; with 3.4% average annual GDP growth)	$104 trillion
Projected 2050 GDP (with 3.4% average annual GDP growth)	$260 trillion
Midpoint GDP value for investment spending estimates (= (2021 GDP + 2050 GDP)/2)	$178 trillion

Sources: World Development Indicators; International Energy Agency, *World Energy Outlook*, 2019.

trillion dollars of GDP) to 2.0, a 70 per cent improvement in average global energy efficiency. The 2.0 energy intensity ratio is the figure projected by the IEA in its 2019 Sustainable Development Scenario. This will be while, according to the IEA model, average global GDP is growing at 3.4 per cent per year.

As section A of Table 15.2 shows, if the global economy continues to operate at its current 6.6 energy intensity ratio through 2050, global energy consumption will be at 1,716 Q-BTUs in 2050. By contrast, if the global economy does succeed in driving down the energy intensity ratio to 2.0 through efficiency investments, it follows that global energy consumption will be at 512 Q-BTUs as of 2050.

As we then see in section B of Table 15.2, total energy savings achieved through operating the global economy at a 2.0 rather than a 6.6 average intensity ratio will be 1,204 Q-BTUs. Since, as our high-end figure, we assume that the average global cost of achieving efficiency gains is $20 billion per Q-BTU, this means that achieving 1,204 Q-BTUs in global efficiency gains will cost a total of $24.1 trillion. As Panel B of Table 15.2 shows, the average annual investment level of the twenty-seven-year investment period is therefore $891 billion.

In Table 15.3, we work with the 2050 global energy consumption figure of 512 Q-BTUs from Table 15.2 to calculate the investment requirements for meeting this level of total energy demand through clean renewable sources. As the table shows, as of the most recent IEA figures, global supply of clean renewables is 26 Q-BTUs. This means that the expansion of supply as of 2050 will need to be 486 Q-BTUs. It also means that the average growth rate for expanding the global supply of clean renewable energy will need to be at around 10 per cent per year for the full 2024–50 investment cycle.

In terms of estimating the costs of this investment project, I then, again, assume a high-end average cost figure for expanding global clean energy capacity, at $200 billion per Q-BTU. Working from this figure, it follows, as shown in Table 15.3, that the total costs of expanding global clean energy supply by 486 Q-BTUs as of 2050 will be $97.2 trillion. The average annual costs over the twenty-seven-year investment cycle will therefore be $3.6 trillion.

In Table 15.4, I then summarize the figures for total and annual average costs for achieving a net-zero global economy strictly on the basis of large-scale investments in

Table 15.2 Global energy demand and energy-efficiency cost projections for 2050

A) Total energy demand through alternative scenarios

	2050 Energy consumption	Average annual energy demand growth rate	Average 2050 global energy intensity ratio
2050 energy demand, with constant energy intensity ratio	1,716 Q-BTUs	3.4%	6.6
2050 energy demand through IEA Sustainable Development Scenario	512 Q-BTUs	–0.3%	2.0

B) Cost of achieving energy savings through the IEA sustainable development scenario

1. Total energy savings through the IEA Sustainable Development Scenario	1,204 Q-BTUs (= 1,716 Q-BTUs – 512 Q-BTUs)
2. Average cost of energy savings through efficiency investments	$20 billion/Q-BTU
3. Total cost of energy savings through efficiency investments	$24.1 trillion (= rows 2 x 3)
4. Average annual cost of energy savings through efficiency investments	$891 billion ($24.1 trillion/27 years)

Notes: Actual 2018 global energy consumption = 568 Q-BTUs; global energy intensity ratio = 6.6.
Source: IEA (2019: 678).

Table 15.3 Global clean renewable energy expansion and cost projection for 2050

1. Total 2050 energy consumption through the Sustainable Development Scenario	512 Q-BTUs
2. 2018 clean renewable energy supply (from IEA, 2019: 678)	26 Q-BTUs
3. Net expansion of clean renewables as of 2050	486 Q-BTUs *(= row 1 – row 2)*
4. Average cost of expanding clean renewable supply	$200 billion/Q-BTU
5. Total cost of expanding global clean renewable supply by 486 Q-BTUs as of 2050	$97.2 trillion *(= row 3 x row 4)*
Average annual cost of expanding global clean renewable supply by 286 Q-BTUs as of 2050	$3.6 trillion *(= row 5/27)*

Source: IEA (2019).

energy efficiency and clean renewables. As we see, total costs come to $121.3 trillion. Over the twenty-seven-year investment cycle, this amounts to an average of $4.5 trillion per year. Working from the estimates presented in Table 15.1, our figure for midpoint global GDP between 2021 and 2050 is $178 trillion. This is how, finally, we are able to estimate that the overall investment requirement for reaching a net-zero-emissions global economy as of 2050 will amount, on average, to 2.5 per cent of global GDP per year.

Table 15.4 Costs of thirty-year clean energy investment project as share of average GDP, 2021–50

Total costs of clean energy investments	
1. Energy efficiency	$24.1 trillion
2. Clean renewable energy	$97.2 trillion
3. TOTAL (= rows 1 + 2)	*$121.3 trillion*
2024 costs of clean energy investments (year 1 of 27-year investment cycle)	
4. Energy efficiency	$500 billion
5. Clean renewable energy	$2.1 trillion
6. TOTAL (= rows 5 + 6)	*$2.6 trillion*
Average annual costs of clean energy investments (27-year cycle)	
7. Energy efficiency	$891 billion/year
8. Clean renewable energy	$3.6 trillion/year
9. TOTAL (= rows 7 + 8)	*$4.5 trillion/year*
Total costs of clean energy investments as share of midpoint GDP	
10. Midpoint GDP *(from Table 15.1)*	$178 trillion
11. *Clean energy investments as share of midpoint GDP (= row 6/row 7)*	*2.5%*

Source: IEA (2019).

15.4 INDUSTRIAL AND FINANCIAL POLICIES

15.4.1 Industrial Policies

Depending on specific conditions within each country, industrial policies will be needed to promote technical innovations and, even more broadly, adaptations of existing clean energy technologies. Again depending on circumstances, governments will need to deploy a combination of industrial policy instruments, including research and development support, preferential tax treatment for clean energy investments, and government procurement policies. Clean energy industrial policies will also need to include regulations of both fossil-fuel and clean energy prices as well as emission standards.

One major policy intervention that can facilitate the creation of a vibrant clean energy market will be for governments to themselves become both large-scale investors in energy efficiency and purchasers of clean renewable energy. An important comparable historical experience was the development of the Internet within the US military, beginning in the 1940s. In the process of bringing the Internet to commercial scale, the US military provided a guaranteed market for thirty-five years, which enabled the technology to incubate while private investors gradually developed effective commercialization strategies.[20]

But guaranteeing stable prices with the private-sector purchases of clean renewables is also critical here. Such policies are termed *feed-in tariffs*. Specifically, these are contracts that require utility companies to purchase electricity from private renewable energy generators at prices fixed by long-term contracts. Feed-in tariffs were first implemented in the United States in the 1970s, and a number of state and local programmes are currently operational in the United States today. However, the impact of feed-in tariffs has been much more significant outside of the United States, especially in Germany, Italy, France, Spain, and Canada. A 2009 study by the US Department of Energy found that these policies in Europe 'resulted in quick and substantial renewable energy capacity expansion'.[21] This basic result has been affirmed through more recent research, including that by Milanes-Montero et al. (2018), which showed how feed-in tariffs 'have had a significant positive influence on the economic profitability' on solar PV companies in Europe. The key factor in the success of these European programmes is straightforward: the guaranteed prices for renewable energy were set to adequately reflect the costs of producing the energy along with a profit for the energy provider. This then encouraged private renewable energy investors by providing a stable long-term market environment.[22]

Feed-in tariffs have also had some successes as a policy tool in Africa. The African Development Bank reports as follows:

> Public investment is critical in bridging the gap between public demonstration of new technologies and mature deployment. Feed-in tariffs are a prominent example of such subsidies. These tariffs are a policy mechanism that offers compensation to renewable energy producers, based on the difference between the cost of electricity generation of each technology and the market price of electricity generation that, in the case of RETs, is usually lower. In Kenya, for example, feed-in tariffs led to the high level of uptake of solar PV. As of 2011, 7 African countries used feed-in tariff policies. (African Development Bank Group, 2013)

Another important set of policies are those that aim to directly reduce fossil-fuel consumption. These include carbon caps and carbon taxes. In principle at least, a carbon cap establishes a firm limit on the allowable level of emissions for major polluting entities, such as utilities. Such measures will also raise the prices of oil, coal, and natural gas by limiting their supply. A carbon tax, on the other hand, will directly raise fossil-fuel prices to consumers, and aim to reduce fossil-fuel consumption through the resulting price signals. Either approach can be effective as long as the cap is strict enough, or tax rate high enough, to significantly reduce fossil-fuel consumption and as long exemptions are minimal to none. Raising the prices for fossil fuels will also, of

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[20] See Ruttan (2006).

[21] Cory, Couture, and Kreycik (2009: 2).

[22] Cointe and Nadaï (2018) emphasize this point and contrast it with the official EU aim of liberalizing renewable energy markets.

course, create increased incentives for both energy-efficiency and clean renewable investments, as well as a source of revenue to help finance these investments. We return to this point in section 15.4.

However, significant problems are also associated with both approaches. Establishing a carbon cap or tax will have negative distributional consequences that will need to be addressed in the policy design. All else equal, increasing the price of fossil fuels would affect lower-income households more than affluent households, since petrol, home-heating fuels, and electricity absorb a higher share of lower-income households' consumption. An effective solution to this problem is to rebate to lower-income households a significant share of the revenues generated either by the cap or tax to offset the increased costs of fossil-fuel energy.[23]

Renewable energy portfolio standards for utilities, and energy-efficiency standards for buildings and transportation vehicles, are similar in their intent to a carbon cap. That is, renewable portfolio standards set a minimum standard that utilities must achieve in generating electricity from renewable energy sources. Energy-efficiency standards for automobiles set minimum miles-per-gallon levels (or comparable measures) that a given auto fleet must achieve to be in compliance with the law. Comparable efficiency standards can also be established for buildings in terms of allowable levels of energy consumption for a given building size.

However, a major problem that has emerged with carbon caps as well as renewable and efficiency standards has been with enforcement. As a major case in point, when these cap programmes are combined with a carbon permit option—as in 'cap-and-trade' policies—the enforcement of a hard cap becomes difficult to sustain or even monitor, thereby weakening the impact of the policy.[24]

15.4.2 Providing Cheap and Accessible Financing

There are two separate, but interrelated policy considerations here. The first is: where will the funding come from to support approximately $2.6 trillion in new clean energy investments in 2024 and $3.6 trillion as an annual average over 2021–50? The second issue is: how can these funds be most effectively channelled into the full range of specific projects that will need to advance every year in order to build a net-zero global economy? We consider these issues in turn.

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[23] See Boyce (2019) for an effective solution to the distributional problem, via what he terms 'carbon dividends'. Azad and Chakraborty (2019) expand on the idea of an egalitarian carbon dividend programme to the global economy.

[24] See, for example, Teeter and Sandberg (2017). There is also the problem of the caps, or renewable portfolio standards, being established in law but then ignored in policy implementation. This has been the experience, for example, in New York State. See Pollin et al. (2017: 79–80).

15.4.3 Sources of Aggregate Funding

In principle, it should not be especially challenging to solve this problem. To begin with, as of 2018, Credit Suisse estimates that the total value of global financial assets was $317 trillion.[25] The $2.4 trillion that I am proposing to channel into clean energy investments as of 2021 amounts to 0.7 per cent of this total financial asset pool.

Still, it is important to anchor the discussion in specific proposals. Therefore, for purposes of illustration, I propose four large-scale funding sources to support public investments in clean energy. Other approaches could also be viable. These four funding sources are: 1) a carbon tax, in which 75 per cent of revenues are rebated back to the public but 25 per cent are channelled into clean energy investment projects; 2) transferring funds out of military budgets from all countries, but primarily the United States; 3) a Green Bond lending programme, initiated by both the US Federal Reserve and the European Central Bank; and 4) eliminating all existing fossil-fuel subsidies and channelling 25 per cent of the funds into clean energy investments. Strong cases can be made for each of these funding measures. But each proposal does also have vulnerabilities, including around political feasibility. The most sensible approach is therefore to combine the measures into a single package that minimizes their respective weaknesses as standalone measures. Table A15.5 in the Appendix presents this set of combined proposals in summary form.

1. *Carbon tax with rebates.* As noted above, carbon taxes have the merit of impacting climate policy through two channels—they raise fossil-fuel prices and thereby discourage consumption while also generating a new source of government revenue. At least part of the carbon tax revenue can then be channelled into supporting the clean energy investment project. But the carbon tax will hit low- and middle-income people disproportionately, since they spend a larger fraction of their income on electricity, transportation, and home-heating fuel. An equal-shares rebate, as proposed by Boyce (2019), is the simplest way to ensure that the full impact of the tax will be equalizing across all population cohorts.

Consider, therefore, the following tax-and-rebate programme. Focusing, again, on 2024, the first year of the full-scale investment programme, we begin with a tax at a low rate of $20 per ton of carbon. Given current global CO_2 emissions levels, that would generate about $625 billion in revenue. If we use only 25 per cent of this revenue to finance clean energy investments, that amounts to roughly $160 billion for investment projects. The 75 per cent of the total revenue that is rebated to the public in equal shares would then amount to $465 billion. This amounts to about $60 for every person on the planet, or $240 for a family of four.[26]

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[25] file:///C:/Users/RPollin/Downloads/global-wealth-report-2018-en.pdf.

[26] Azad and Chakraborty (2019) develop a more complex rebate structure, that rewards residents of countries according to the emissions levels of each country.

2. *Transferring funds out of military budgets*. Global military spending in 2018 was at \$1.8 trillion.[27] The US military budget, at about \$700 billion, accounted for nearly 40 per cent of the global total. There are solid logical and ethical grounds for transferring substantial shares of each country's total military budget to supporting climate stabilization, if we take at face value the idea that military spending is fundamentally aimed at achieving greater security for the citizens of each country. But to remain within the realm of political feasibility, let us assume that 5 per cent of global military spending will transfer into supporting climate security. That would amount to \$90 billion.

3. *Green Bond funding by the Federal Reserve and European Central Bank*. It was demonstrated during the 2007–09 global financial crisis and subsequent Great Recession that the Federal Reserve is able to supply basically unlimited bailout funds to private financial markets during crises. The extensive 2017 study, *The Costs of the Crisis*, by Better Markets concludes that the Federal Reserve committed approximately \$12.2 trillion to stop the crash of the financial system, stabilize the economy, and try to spur economic growth. I would propose \$100 billion in Green Bond financing supplied by the Fed. This would amount to a miniscule 0.8 per cent of the Fed's 2007–09 bailout operations during the crisis. The Fed's funding support could be injected into the global economy through straightforward channels. That is, various public entities, such as the World Bank, could issue long-term zero interest rate Green Bonds. The Fed would purchase these bonds. The various public entities issuing these bonds would then have the funds to pursue the full range of projects that will fall under the rubric of the global clean energy project.

This framework has not yet been introduced into policy discussions at the Federal Reserve. But they are becoming a central area of focus at the European Central Bank. Thus, the *Financial Times* reported on 12/2/19 that the recently installed ECB President Christine Lagarde is moving quickly on the matter. The *Financial Times* reports that:

> Christine Lagarde . . . is pushing to include climate change considerations in a review the central bank is due to hold into the way it conducts monetary policy. Until now, the expectation was for a review into purely monetary matters, such as whether the inflation target should be revised. An explicit focus on climate change policy would be a huge move. Because the central bank is by far the biggest influence on financial conditions in the market, it can make a significant difference to investment decisions that determine how Europe's climate transition goes.[28]

The *Financial Times* article makes clear that the specific channels through which the ECB would intervene to support clean energy financing will require substantial fleshing out. The type of approach I have sketched for a Federal Reserve intervention would seem like a relatively straightforward and modest form of intervention. I therefore propose that the ECB undertakes Green Bond purchases at the same level as the Federal

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[27] https://www.sipri.org/media/press-release/2019/world-military-expenditure-grows-18-trillion-2018.

[28] https://www.ft.com/content/89f5f412-12bc-11ea-a225-db2f231cfeae.

Reserve, that is, at $100 billion as of 2024, and growing over time to support clean energy investments continuing at an average rate of 2.5 per cent of global GDP per year.

4. *Eliminating fossil fuel subsidies and channelling 25 per cent of funds to clean energy investments.* One recent estimate of direct fossil-fuel subsidies to consumers—measured as the difference between supply and consumer prices to purchase fossil-fuel energy—is about $3 trillion globally as of 2015, or about 0.4 per cent of global GDP.[29] Channelling these funds, in full, into supporting public clean energy investments would therefore more than pay for the $2.6 trillion estimate for total clean energy investments as of 2024. This $3 trillion would also represent more than double the amount necessary to cover a global public investment level of $1.3 trillion. However, such fossil-fuel subsidies are largely used as a form of general support for all energy consumers. Lower- and middle-income households are therefore major beneficiaries of these subsidies, along with, of course, the fossil fuel energy suppliers. Therefore, in terms of global income distribution, eliminating these subsidies altogether would likely have a significant regressive impact, comparable to establishing a carbon tax without an accompanying rebate programme. As such, to continue to provide support for lower-income households, most of the funds that are now being channelled to these households through fossil-fuel subsidies should be redirected into either supporting lower consumer prices for clean energy or to provide direct income transfers for lower-income households.

Given that we will have raised $440 billion from the carbon tax, military spending transfers and central bank Green Bond programmes, we could then assume that 25 per cent of the $3 trillion received as fossil-fuel subsidies be transferred into the clean energy investment fund. That would amount to $750 billion. With these funds, we will have reached the total $1.3 trillion in public investment funds necessary to attain the total of public and private investment spending of $2.6 trillion as of 2024.

15.4.4 Channelling Financial Resources into Specific Investment Projects

Both general purpose development banks as well as special-purpose green development banks are already significantly engaged in financing clean energy investments. It will be crucial to build from these efforts to achieve the necessary level of financing for clean energy investments.

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[29] Coady et al. (2017). This study distinguishes direct fossil-fuel subsidies—what it terms 'pre-tax' subsidies—and 'post-tax' subsidies. They define post-tax subsidies as including global warming damages, air pollution damages, and vehicle externalities, including congestion, accidents, and road damage. They estimate post-tax subsidies as amounting to roughly 6 per cent of global GDP. These are valuable calculations. But for the purposes of this discussion on financing, the standard, and much more narrowly defined, measure of pre-tax subsidies are more directly relevant.

Germany's KfW Bank. The case of Germany is instructive, since it has been the most successful large advanced economy to date in developing its clean energy economy. The publicly owned development bank in Germany, KfW, has been critical to this success. Griffith-Jones (2016) considers KfW's impact on Germany's overall green transformation, including renewable energy as well as energy-efficiency investments. She finds that KfW has underwritten roughly one-third of all financing for green investments in Germany. KfW has thus been instrumental in moving policy ideas into effective investment projects, with respect to both energy efficiency and clean renewables. KfW has also been highly active in financing green investment projects elsewhere in Europe and in developing countries. As Griffith-Jones writes:

> KfW plays a key role, domestically and internationally, in supporting energy revolution, through funding major investments in renewable energy and in energy efficiency. In the national German case, this was to a large extent implemented within a clear institutional and policy framework, namely the renewable energy law, through strong policy measures, such as feed in tariffs (FITs) and reverse competitive auctions, which made investment in renewables commercially attractive. A similar modus operandi existed for energy efficiency . . . The combination of clear government policies and associated development bank targets has produced very positive results in green infrastructure in Germany, which can be replicated in emerging and developing countries. (2016: 4)[30]

Griffith-Jones also describes the financing terms offered by KfW in all of their areas of active lending. These include long-term loans and below-market interest rates, 100 per cent disbursement rates, up to three years holidays in making repayments, and repayment bonuses of up to 17.5 per cent.

Green banks. Special purpose green development banks have also become increasingly active in recent years. A 2016 OECD study defines a green investment bank as 'a publicly capitalized entity established specifically to facilitate private investment into domestic low-carbon and climate-resistant infrastructure and other green sectors such as water and waste management' (2016: 15). These special purpose banks have been established at the national level in Australia, Japan, Malaysia, Switzerland, and the United Kingdom. Within the United States, the states of California, Connecticut, Hawaii, New Jersey, New York, and Rhode Island have created green banks. The OECD study describes the banks as having 'diverse rationales and goals, including meeting ambitious emissions targets, mobilizing private capital, lowering the cost of capital, lowering energy costs, developing green technology markets, supporting local community development and creating jobs' (2016: 15). The OECD study does not provide systematic evidence as to the scale at which these institutions are currently

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[30] Griffith-Jones's conclusions are fully in line with those of other researchers. For example, the overview of the IEA's 2013 *Energy Efficiency Market Report* concluded that 'Germany is a world leader in energy efficiency. Germany's state-owned development bank, KfW, plays a crucial role by providing loans and subsidies for investment in energy-efficiency measures in buildings and industry, which have leveraged significant private funds' (IEA, 2013: 149).

providing investment financing. But considering other references, it is reasonable to assume that, in general, their scale of operations is much smaller than KfW.[31] This raises the question as to whether the necessary level of financing can be achieved without the full backing of large-scale national or regional entities, such as the equivalent of KfW.

Emerging trends in developing countries. Within developing economies there has been a general movement in the aftermath of the 2007–09 global financial crisis away from the predominant neo-liberal financial market policy framework that prevailed prior to the crisis. This trend has included the formation or expansion of development banks. For example, Grabel (2018) describes the emergence of the Development Bank of Latin America and the New Development Bank as potentially significant new sources of subsidized long-term financing for developing economies, including in the area of green energy investments.

Recent studies by the World Bank (Hussain, 2013) and African Development Bank (African Development Bank Group, 2013) examine specific financial models for advancing green investments in developing countries. Both studies consider financing arrangements through which concessionary public financing can be mobilized to encourage, as opposed to crowd out, private investments, thereby creating viable public–private partnerships with clean energy investment projects. The World Bank study in particular, which focuses on renewable energy investments, emphasizes that the long-term funding for these investments has been limited by the range of risks private investors face while working with still relatively unfamiliar technologies. These risks include uncertainty over the reliability of the technology within any given project and shifts in the relevant regulatory environment. The World Bank proposes a series of financing techniques for reducing these risks for private investors. Yet the overall point remains that the public financing interventions—whether they be implemented through formal development banks or otherwise—will need to absorb a disproportionate share of these risks in order for the financing levels to reach scale rapidly enough.

With respect to financing clean energy investments in developing countries in particular, it is also critical that the benefits of these investments be shared fully by society's least-advantaged groups. Spratt, Griffith-Jones, and Ocampo emphasize this consideration in their 2013 study 'Mobilizing Investment for Inclusive Green Growth in Low-income Countries'. This would mean, as important examples, expanding access to electricity and providing clean energy for electricity and other needs at affordable prices.[32] To accomplish these ends, Spratt et al. emphasize that it is not

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[31] See, for example, Pollin et al. (2017) for a discussion of the New York State green bank and related public financing initiatives within New York State. See also Pollin et al. (2014) for a discussion of green banks within the US economy, and as one element within a broader framework of measures to support clean energy investments.

[32] As one specific policy proposal, Azad and Chakraborty (2020) develop a programme for rapidly advancing the expansion of renewable energy supply in India. The proposal includes a carbon tax, with

realistic to expect clean energy investments to consistently generate profits for private businesses at rates comparable to mature investment areas, including fossil-fuel energy. The requirement that the financing terms for clean energy investments be affordable for borrowers—that is, not always yielding high returns for lenders—reinforces the centrality of public investment banks with clear social criteria guiding their financing strategies.

15.5 Domestic Resource Capacities for Clean Energy Investments

One of the major questions that all countries will face in undertaking a clean energy transformation will be the extent to which the large-scale expansion in clean energy investment activity can be accomplished through utilizing domestic resources as opposed to having to rely increasingly on imports. To the extent that a country runs up against domestic productive capacity constraints while expanding its investments in energy efficiency and clean renewable energy, it then faces two alternatives: either scale back the clean energy investment project or rely increasingly on imports to maintain the ambitious investment agenda.

Within this framework, it is critical to establish some measures of the range at which, in any given country, import dependency is likely to increase as it establishes a clean energy investment project at around 2.5 per cent of the country's GDP. To generate a rough estimate of this, I examine here the relative domestic and import content for the set of industrial sectors that will be mobilized to expand a country's energy-efficiency and renewable energy investments. I report these figures for five large economies in different regions of the world, that is, Brazil, Germany, Indonesia, South Africa, and South Korea.

To be more specific, I undertake the following exercise. Working from the most recent country-specific input–output tables from the OECD, those from 2015, I first calculate the current level of domestic content for all activities that will be mobilized to undertake clean energy investments in five major areas. These five areas are energy-efficiency investments in building retrofits, industrial-efficiency and grid upgrades as well as renewable investments in solar and wind power. Two examples of the specific set of inputs within a given investment project, along with the relative contributions of each of these inputs, are as follows:

- Solar industry investments in Brazil:
    - Computer and electronic products—35 per cent weight
    - Construction—30 per cent weight
    - Business sector services—18 per cent weight

the revenues from the tax being channelled into clean renewable energy investments that will then supply free electricity to low-income communities, many of which still have no access to electricity.

  - General machinery and equipment products—12 per cent weight
  - Basic metals manufacturing—5 per cent weight
- Grid upgrades in South Africa:
  - Construction—25 per cent weight
  - Computer and electronic products—25 per cent weight
  - Electrical equipment—25 per cent weight
  - General machinery and equipment products—25 per cent weight

Within these input–output frameworks, I then divide each of the specific activities associated with each of the five investment projects into non-tradable and tradable activities. Following from the literature, I define a 'tradable' activity as one in which less than 90 per cent of this activity's inputs come from domestic sources.[33]

Within these definitions of 'tradable' and 'non-tradable' activities, I then assume that the domestic content levels for non-tradable activities will remain constant as the country's clean energy investment project proceeds. These non-tradable activities include construction, ground transportation, and administration. With tradable activities, I allow that domestic content will fall by up to 20 per cent. This enables us to then observe how much overall domestic content within any given investment project area will decline when the domestic content of specific tradable activities declines by 20 per cent.

In Table A15.6 in the Appendix, I show the results of this exercise for the five clean energy investment areas and five representative countries. As we see, overall, domestic content levels are generally high for all five countries with all five clean energy projects. In virtually all cases, domestic content levels are higher than 80 per cent. When we then allow domestic content for tradable activities to fall by 20 per cent, we still find that, in virtually all cases, overall domestic content remains above 70 per cent.

Thus, after the 20 per cent decline in domestic content for tradable activities, we see that the largest declines in overall domestic content are with grid upgrades in South Africa, in which domestic content falls from 79 to 63 per cent; grid upgrades in South Korea, in which overall domestic content falls from 84 to 67 per cent; and wind energy in South Africa, in which overall domestic content declines from 83 to 68 per cent. These changes would all represent significant increases in the respective countries' import requirements. But they should not entail major strains in the countries' overall balance of payments. Thus, for the most part, most countries should be able to undertake clean energy transformations mostly through mobilizing the country's existing supply of domestic resources.

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[33] This discussion and set of calculations are an updated version of that presented in Pollin et al. (2015: 111–19). Full references on methodology and related matters are presented in this 2015 publication.

15.5.1 Fossil Fuel Consumption and Imports/Exports

One factor in enabling the expansion of domestic production in sectors of economies linked to clean energy will be the fact that the fossil-fuel sectors in all countries will be correspondingly contracting. The freeing up of economic resources out of the activities tied to the fossil-fuel sector will be substantial in all cases. These activities include extracting, transporting, refining, and the retail distribution of fossil-fuel energy, along with all the sectors that provide supplies to support these activities.

The data in Table A15.7 in the Appendix provide a sense of the magnitudes involved. The first column of the table shows, for 2014, the extent to which each of our five representative economies relies on fossil fuels to meet its overall energy consumption levels.[34] As we see, fossil fuels supply more than half of each country's total energy consumption. Brazil has the lowest proportion of fossil-fuel consumption, at 59 per cent of total energy consumption. This is because of its uniquely high levels of both hydro and biofuel production. Indonesia is next lowest, at 66 per cent reliance on fossil fuels. But this figure includes Indonesia's still heavy reliance on burning peat as a high-emissions renewable energy source. Exclusive of peat, coal, oil, and natural gas provide roughly 90 per cent of Indonesia's remaining energy supply. Germany, South Africa, and South Korea all rely on fossil fuels for between about 80 and 88 per cent of their overall energy supply. These figures show that, as these economies undergo transitions to clean energy sources, major shares of their economies' overall resources will be released from the current demands generated by their fossil-fuel sectors.

We obtain additional perspective as to how such scenarios might play out through the figures shown in the second column of Table A15.7. Here I show the import shares as a proportion of total energy consumption for our five selected economies as of 2014. As we see, Indonesia and South Africa were energy exporters, both through their coal exports. With Brazil, as the table shows, imports constituted a relatively modest 12 per cent of its overall energy supply as of 2014, while Germany and South Korea were major energy importers, at 61 and 82 per cent of their overall energy supply. These figures are representative of longer-term energy consumption patterns for both countries.

Of course, the energy-importing countries, Brazil, Germany, and South Korea, are presently utilizing a smaller share of their total domestic resources in the fossil-fuel sector. Their share of total economic resources devoted to energy-linked activities could rise as a result of increasing investments in energy efficiency and renewable energy. However, the share of total domestic resources devoted to supplying oil, coal, and natural gas in these importing countries is still substantial. In Germany, the shares are 70 per cent for the coal sector and 80 per cent for oil and gas. In South Korea, the proportions are 63 per cent for coal and 79 per cent for oil and gas. Thus, even with

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[34] The 2014 data reported in Table A15.7 are the most recent complete set of figures for all five countries.

Germany and South Korea, as major energy importers, the move out of fossil fuels and into clean energy will entail releasing domestic resources that can be repurposed for the clean energy transition.

15.6 CONCLUSION

This chapter has demonstrated that achieving a net-zero-emissions global economy by 2050—in line with the IPCC's climate stabilization goals—is an entirely feasible project with respect to its technical and economic requirements. As its foundation, it will require investments in energy efficiency and clean renewable energy at an average of $4.5 trillion per year globally between 2024 and 2050. This is a formidable level of spending in absolute terms, but still amounts to only 2.5 per cent of average global GDP per year over 2021–50. Put another way, it implies that 97.5 per cent of global economic activity can proceed largely independently of the clean energy investment project, as long as the 2.5 per cent of GDP goal is achieved each year.

The success of the global clean energy investment project—and thereby, the Global Green New Deal—will depend on whether effective industrial and financial policies will be enacted. Fundamentally, the Green New Deal amounts to a unified, and globally coordinated set of industrial policies—policies, which, taken as a whole, are capable of creating an entirely new global energy industry infrastructure within thirty years. Accomplishing this goal will require a range of specific policy initiatives, working in conjunction with each other to undergird energy-efficiency and clean renewable energy investments on an unprecedented scale. The first specific requirement will be to mobilize a large enough pool of investment funds to finance the project at the needed scale. As an illustration, I have shown how this can be achieved through a combination of four major funding sources—a 25 per cent share of funds from carbon tax revenues; a transfer of 5 per cent of military spending into clean energy investments; Green Bond purchases by both the Federal Reserve and the European Central Bank, at an initial combined level of $200 billion and rising with economic growth thereafter; and the elimination of all fossil-fuel subsidies and the transfer of 25 per cent of these funds into clean energy projects.

Working with this pool of funds, public investments will need to play the leadership role in ramping up clean investment activities in most countries at the required pace. But private investments will be equally critical over time. Indeed, I have assumed that public and private investment levels will need to be roughly comparable in magnitude in order to maintain the overall project at scale. Both carrots and sticks will be needed to induce and sustain a sufficient level of private investments. These include, as carrots, generous financial subsidies, concessionary borrowing rates, and guaranteed markets. As sticks, they include an ambitious renewable portfolio and energy-efficiency standards whose requirements cannot be readily circumvented, in contrast with some existing cap-and-trade and renewable portfolio systems. Achieving the appropriate mix of these measures in any given country setting will represent a major challenge in industrial policy design.

Operating at the ground level, to advance this clean energy investment project at scale will of course require the mobilization of productive resources in all countries. But as I have shown, this should not create major problems with respect to domestic capacity bottlenecks, at least not after an initial adjustment period. For one thing, the domestic content levels for most clean energy investment activities are already high in the relevant productive sectors in most countries. Domestic content ratios should also remain high even as the demands on these sectors grow with the scaling up of clean energy investment activities. This is because a high proportion of the productive activity that will be required are in non-tradable sectors, such as construction, ground transportation, and administration. In addition, the fossil-fuel sectors in all countries will be undergoing major contractions as the clean energy sectors grow, thereby freeing up resources that can be redeployed into clean energy activities.

In summary: the challenge facing humanity today with climate change is without precedent. Within the context of this urgent historical moment, the design and implementation of an effective set of clean energy industrial policies will play a critical role towards achieving the target of net-zero emissions in the global economy by 2050.

15.7 APPENDIX

Table A15.1 Energy intensity ratios, global average and selected countries

World Average	6.6
China	12.7
United States	5.3
Brazil	7.2
Germany	3.5
Indonesia	9.8
South Africa	20.3
South Korea	9.3

Note: Energy Intensity = Q-BTUs of energy consumed/GDP (in trillions of US dollars) World average for 2018; Individual Country figures for 2016. GDP figures in current US dollars.

Sources: Energy consumption figures from EIA, International Energy Statistics, http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=44&pid=44&aid=2. GDP figures from World Development Indicators: https://data.worldbank.org/indicator.

Table A15.2 Estimates of cost savings from energy-efficiency investments

Source	Regions/Countries/Sectors estimated	Estimated savings in Q-BTUs
World Bank (Taylor et al., 2008: 29)	455 projects in eleven industrial and developing countries	$1.9 billion per Q-BTU
McKinsey & Co. (2010: 27)	Africa, India, Middle East, South East Asia, Eastern Europe, China	$11 billion per Q-BTU
United States National Academy of Sciences (2010)	United States	~ $29 billion per Q-BTU for buildings, industry

Source: Pollin et al. (2015: 88).

Table A15.3 Average global levellized costs of electricity from utility-scale renewable energy sources vs. fossil-fuel sources, 2010–17

	2010	2017
Solar PV	36 cents	10 cents
Onshore wind	8 cents	6 cents
Geothermal	5 cents	7 cents
Hydro	4 cents	5 cents

Note: Average levellized costs for fossil-fuel generated electricity: 4.5–14 cents per kilowatt hour. *Source*: https://www.irena.org/Statistics/View-Data-by-Topic/Costs/LCOE-2010-2017.

Table A15.4 Capital expenditure costs for building renewable electricity productive equipment, present values of total lump-sum capital costs per Q-BTU of electricity

Wind	$160 billion
Solar PV	$190 billion
Geothermal	$112 billion
Average costs *Assuming investments are 45 per cent wind, 45 per cent solar, and 10 per cent geothermal*	$169 billion

Source: EIA, https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf. See Pollin et al. (2014: 136–7) for methodology in converting levelized costs per Q-BTU into lump-sum capital costs.

Table A15.5 Major funding sources for global clean energy investments

Investment level for 2024—Year 1 of investment cycle: $2.6 trillion in public and private investments, at 2.5 per cent of GDP

Clean energy investment areas:

- *Clean renewable energy: $2.1 trillion*
    - Wind, solar, geothermal, small-scale hydro, low-emissions bioenergy
- *Energy efficiency: $500 billion*
    - Buildings, transportation, industrial equipment, grid and battery storage upgrades

Public sources of funds: $1.3 trillion:

- *Carbon tax revenues: $160 billion*
    - 25 per cent of revenues from tax; 75 per cent returned to consumers as rebate
- *Transfers from military budgets: $90 billion*
    - 5 per cent of global military spending
- *Green bond purchases by Federal Reserve and European Central Bank: $200 billion*
    - 1.6 per cent of Federal Reserve Wall Street bailout support during financial crisis
- *Transfers of 25 per cent of fossil-fuel subsidies: $750 billion*
    - Total fossil-fuel subsidies = $3 trillion
    - 75 per cent of funds for lower clean energy prices or direct income transfers for lower-income households

Private sources of funds: $1.3 trillion:

- *Policies for Incentivizing Private Investors*
    - Government procurement
    - Regulations
        - Carbon caps and taxes
        - Renewable energy portfolio standards for utilities
        - Energy efficiency standards for buildings and transportation vehicles
    - Investment Subsidies
        - Feed-in tariffs
        - Low-cost financing through development banks and green banks

Table A15.6 Change in overall domestic content of clean energy investment activities after 20 per cent import increase with tradable activities

	Energy efficiency investments			Renewable investments	
	Building retrofits	Industrial efficiency	Grid upgrades	Solar	Wind
Brazil	95 per cent → 95 per cent	93 per cent → 84 per cent	87 per cent → 75 per cent	90 per cent → 81 per cent	92 per cent → 85 per cent
Germany	91 per cent → 91 per cent	88 per cent → 80 per cent	85 per cent → 72 per cent	88 per cent → 79 per cent	87 per cent → 75 per cent
Indonesia	91 per cent → 91 per cent	87 per cent → 79 per cent	82 per cent → 70 per cent	86 per cent → 78 per cent	83 per cent → 73 per cent
South Africa	86 per cent → 69 per cent	84 per cent → 73 per cent	79 per cent → 63 per cent	84 per cent → 70 per cent	83 per cent → 68 per cent
South Korea	89 per cent → 71 per cent	89 per cent → 77 per cent	84 per cent → 67 per cent	86 per cent → 72 per cent	87 per cent → 71 per cent

Sources: 2015 OECD input–output country-specific tables. Methodological details in Pollin et al. (2015: chapter 5 and appendix 2).

Table A15.7 Reliance on fossil fuels and imports as energy sources in selected countries, 2014

	Fossil fuels as a share of total energy consumption	Imports as a share of total energy consumption
Brazil	59.1 per cent	11.9 per cent
Germany	79.7 per cent	60.9 per cent
Indonesia	66.1 per cent	−103.1 per cent
South Africa	86.8 per cent	−14.5 per cent
South Korea	82.4 per cent	81.7 per cent

Note: Negative figures indicate net export proportion.
Source: World Development Indicators, World Bank.

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