THREE ESSAYS ON THE POLITICAL ECONOMY OF GLOBAL INACTION ON CLIMATE CHANGE

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A Dissertation Presented

by

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DEDICATION

To Vienna and Lindsey.

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ABSTRACT

THREE ESSAYS ON THE POLITICAL ECONOMY OF GLOBAL INACTION ON CLIMATE CHANGE

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This dissertation contributes three essays exploring the political economy of global inaction on climate change.

Chapter 1 asks whether climate stabilization means the end of capitalism. Two influential perspectives within environmental political economy—the "degrowth" perspective from ecological economics and the "revolution" perspective from ecological Marxism—answer in the affirmative. If they are right, climate policy programs within capitalism, like the Green New Deal, are non-solutions. I evaluate their arguments, concluding that while environmental sustainability in general likely requires moving beyond capitalism, climate stabilization in particular does not. Given the urgency of the climate crisis, I conclude the chapter by outlining a theoretical framework for identifying and analyzing political economic obstacles to climate stabilization within capitalism.

Chapter 2 examines the economic underpinnings of the fossil fuel industry's resistance to climate stabilization. I estimate the magnitude of wealth losses from stranded assets (i.e., the devaluation of fossil fuel reserves and capital goods) that fossil fuel firms will incur under 2 °C and 1.5 °C climate stabilization scenarios, and how these losses are distributed across the industry. I also compare profitability between fossil fuel and

renewable energy firms for the period 2010-2019. Potential wealth losses amount to $13-15 trillion, impacting low-cost and high-cost producers alike. Three quarters fall on governments. Additionally, fossil fuel firms remain significantly more profitable than renewable energy firms. These results imply a strong economic incentive for industry to continue on the path of resistance. I conclude the chapter with a discussion on how to overcome the industry's resistance.

Chapter 3, coauthored with Robert Pollin, evaluates one strategy for overcoming fossil fuel industry resistance: divestment. We consider whether the fossil fuel divestment movement has succeeded in inflicting financial damage on fossil fuel firms. We present descriptive data on the level of divested fossil fuel stocks and bonds and econometric analysis of the impact of divestment events on fossil fuel firms' stock market prices. We find that divestment campaigns have not been successful in inflicting significant financial damage on fossil fuel firms, even though the movement has been successful in mobilizing activism and public opinion against them.

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CHAPTER 1

DOES CLIMATE STABILIZATION MEAN THE END OF CAPITALISM?: EVALUATING RADICAL PERSPECTIVES ON THE POLITICAL ECONOMY OF GLOBAL INACTION ON CLIMATE CHANGE

1.1 Introduction

On June 23, 1988, NASA scientist James Hansen testified before the U.S. Senate Committee on Energy and Natural Resources. Hansen confirmed the existence of human-induced global warming with 99% confidence and warned of the disastrous consequences of business-as-usual, e.g., sea level rise, heat waves, and droughts. The day after Hansen's testimony, the front-page of the New York Times read, "Global Warming Has Begun, Expert Tells Senate." They quote James Hansen saying, "It is time to stop waffling so much" (Shabecoff 1988).

Since 1988, humanity has emitted more fossil carbon than in the prior two centuries going back to the dawn of the fossil fuel era, and emissions continue to rise (Global Carbon Project 2020).[1] Global warming has been deemed, officially, a "climate emergency" by more than 11,000 climate scientists (Ripple et al. 2020). Yet, government and business leaders continue to "waffle." This continued inaction, despite decades of scientific warnings, increases in warming-induced catastrophes, and the existence of economically and technically feasible solutions, suggests that it is a systemic problem. Because the climate crisis stems from economic activities (e.g., the production, distribution, and

[1] Periodic drops in emissions occur only in recession years, such as 2020.

consumption of energy and food), the chief system of concern is capitalism, the predominant economic system the world over.

This leads to a simple question: does climate stabilization, understood as limiting global warming to 1.5-2 °C above preindustrial levels, require dismantling and replacing capitalism entirely? The implications of this question are profound. If the answer is “yes,” then the climate movement must merge with the anti-capitalist movement, and large-scale climate policy programs like the Green New Deal become false solutions. The challenge of climate stabilization becomes considerably more difficult, bordering on impossible given the short timeframe for achieving the 1.5-2 °C target. Two prominent perspectives among environmental scholars and activists argue in the affirmative—climate stabilization does indeed require dismantling and replacing capitalism in the near-future. These include the degrowth perspective, which stems from ecological economics, and what I term the “revolution” perspective, which stems from ecological Marxism and political ecology.

The main purpose of this paper is to evaluate the arguments that form the basis of their claims. For example, degrowth proponents argue that the required pace of CO_2 emissions reductions is too great without shrinking the GDP. Revolution proponents claim that capital accumulation, i.e., the perpetual cycle of wealth-expansion that defines capitalism, renders planet-wide environmental improvement impossible. I review their theoretical claims and empirical evidence, and weigh them against alternative theories and evidence. I find that while they are convincing in their claims that long-term, general environmental sustainability will likely require moving beyond capitalism, they falter on the question of climate stabilization in particular. That is, achieving the 1.5-2 °C target does not require dismantling capitalism, and allocating activist, advocacy, and research efforts towards dismantling capitalism will not make climate stabilization any easier. The degrowth and revolution perspectives—regarding climate change specifically—may actually prove detrimental to climate stabilization efforts.

A secondary purpose of this essay is to outline an alternative theoretical framework for identifying and analyzing the political economic obstacles to climate stabilization. My framework treats capitalism in general as a short- to medium-term constraint, i.e., in the timeframe for solving the climate crisis. That is, I assume that capital accumulation and economic growth will continue to form the basis of capitalist economies. However, capitalism is also varied; it comes in many different forms. Thus, my framework treats the economic, political, and cultural institutions that constitute historically-specific capitalist economies as malleable. Indeed, climate stabilization will likely require significant institutional change. For example, dismantling the anti-interventionist conception of government that characterizes the neoliberal form of capitalism. Long-term, as noted above, capitalism itself is malleable, and will likely have to be challenged to bring about general environmental sustainability. My theoretical framework also incorporates climate stabilization pathways, e.g., alternative climate stabilization policy programs, and coalitional analysis, i.e., discerning coalitions of opposition and support for each pathway. I illustrate the framework by considering two potential climate stabilization policy programs in the U.S.: the moderate Green New Deal and the radical Green New Deal.

The paper is organized as follows. Sections 1.2.1-1.2.3 introduce and evaluate the degrowth and revolution perspectives; Section 1.2.4 summarizes and assesses the structural change implied by the degrowth and revolution perspectives; Section 1.2.5 considers the implications of the degrowth and revolution perspectives for the Green New Deal in the

U.S.; Section 1.3 outlines my alternative theoretical framework; and Section 1.4 provides some concluding considerations.

1.2 Evaluating the Degrowth and Revolution Perspectives

I begin by introducing the degrowth and revolution perspectives and evaluating their claims. Most importantly, they claim that climate stabilization requires dismantling capitalism. I evaluate this claim in Sections 1.2.1-1.2.3. A secondary claim is that, even if the first claim does not hold, dismantling capitalism would make climate stabilization easier. I evaluate this claim in Section 1.2.4 by walking through what economic degrowth and a social and ecological revolution would actually entail.

My methodological approach is to evaluate the arguments made by the leading degrowth and revolution proponents based on number of citations in Google Scholar. I also consider recent publications from the leading figures for each perspective, which inevitably have fewer citations. The degrowth publications I review have accumulated 11,014 citations, and the revolution publications 6,438 citations.[2] More than 90% of these citations come from Jackson (2009; 2016), Victor (2008; 2019), Schneider et al. (2010), and Kallis (2011) for the degrowth perspective, and from Moore (2015), Patel and Moore (2017), Foster et al. (2011), Clark and York (2005), and Malm (2016) for the revolution perspective.[3]

[2] As of June 11, 2021, using Google Scholar.

[3] Jackson (2016) is the second edition of Jackson (2009); Victor (2019) is the second edition of Victor (2008); Patel and Moore (2017) is very similar to Moore (2015), but is written for a more general audience; and Clark and York (2005) is the basis of Chapter 5 of Foster et al. (2011). I focus my evaluation on the most updated editions of these publications, with the exception of Patel and Moore (2017), as Moore (2015) includes more detail.

1.2.1 Degrowth

Schneider et al. (2010) define degrowth broadly as "an equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global level, in the short and long term" (511). Degrowth proponents argue that environmental sustainability requires a reduction in material throughput, i.e., the mass of physical matter extracted from the environment and pollution emitted back into the environment, and that a reduction in material throughput requires a reduction in GDP.

They also go one step further, however, and apply this logic to climate change in particular. They argue that averting the climate crisis, i.e., limiting warming to 1.5-2 °C above pre-industrial levels, requires economic degrowth. For example, Giacomo D'Alisa and Giorgos Kallis (2020)—two leading degrowth proponents—state that ecological economists have "proved the impossibility of addressing climate change if growth were to continue" (1).[4] This statement, which comes in the second paragraph of their paper, made it through the peer review process in *Ecological Economics*, the leading academic journal for the transdisciplinary field of ecological economics. Indeed, all of the degrowth proponents considered in this paper make similar claims, though they usually stop short of using the controversial word "proved."

Degrowth proponents make two general arguments. The first consists of five parts: (1) Historically, the largest CO2 decoupling rate ever achieved was 3% per year. This occurred in the midst of the oil embargo crisis of the 1970s. (2) In recent years, the

[4] Specifically, they cite the work of Tim Jackson, arguably the leading degrowth proponent. I consider Jackson's work in detail in the next section.

decoupling rate has averaged less than 1% per year. (3) The required annual decoupling rate for climate stabilization is in the range of 12% to 14%. (4) The gap between historical and required decoupling rates are very likely too large to accomplish in a growth-based economy. (5) Therefore, degrowth is required for climate stabilization. The second argument states that climate stabilization will inevitably lead to economic degrowth, because renewable energy is incapable of supporting economic growth. As I will show, both arguments falter on closer examination.

1.2.1.1 The Arithmetic of Degrowth

I begin with Tim Jackson's 2016 book, *Prosperity Without Growth*, which is the most widely cited publication of the degrowth literature, totaling nearly 7,000 citations as of June 2021.[5] The first edition of this book, Jackson (2009), is what "proved" that climate stabilization requires GDP degrowth, according to D'Alisa and Kallis (2020). Jackson's main argument comes in the fifth chapter, titled, "The Myth of Decoupling." There are two types of decoupling: relative decoupling and absolute decoupling. Relative decoupling occurs when a society reduces the emissions intensity of GDP (i.e., emissions per dollar of GDP). Absolute decoupling occurs when the rate of relative decoupling outpaces the rate of GDP growth, so that emissions fall in absolute terms. Stabilizing the climate requires absolute decoupling. Jackson argues that, while absolute decoupling is possible, "sufficient" absolute decoupling (i.e., decoupling fast enough to stabilize the climate) is not, unless the global GDP shrinks.[6]

[5] Includes the earlier edition of the book, Jackson (2009).

[6] The term "sufficient" is used in Jackson and Victor (2019, 950).

To answer this question of sufficient absolute decoupling, Jackson carries out a simple arithmetic exercise, that he calls "the arithmetic of growth." He concludes that the required level of decoupling is not possible without degrowth. His analysis, while simple, is highly influential. In this section, I replicate Jackson's analysis, and extend it to include degrowth scenarios. My analysis shows that, even if degrowth proponents are right that sufficient absolute decoupling is impossible, degrowth is not a viable solution, thus challenging claim (5) from above.

Jackson starts from the well-known IPAT equation, tailored to the climate crisis:

$$(CO_2\ Emissions) = Population \times \frac{GDP}{Capita} \times \frac{(CO_2\ Emissions)}{GDP} \tag{1.1A}$$

Taking the natural logarithm and derivative with respect to time of both sides of Equation (1.1), Jackson gets the following:

$$\frac{\Delta\ (CO_2\ Emissions)}{(CO_2\ Emissions)} = \frac{\Delta\ Population}{Population} + \frac{\Delta\ (GDP/Capita)}{(GDP/Capita)} + \frac{\Delta\ (CO_2\ Emissions/GDP)}{(CO_2\ Emissions/GDP)} \tag{1.2A}$$

In other words, the rate of change of CO_2 emissions can be approximated as the sum of the rates of change of population, GDP/capita, and CO_2 emissions intensity (i.e., CO_2 emissions per dollar of GDP).[7]

Using this model, Jackson calculates the annual decoupling rate (i.e., the percent decrease in CO_2 emissions per dollar of GDP) necessary to meet a set of four CO_2 reduction targets, ranging from a 90% reduction by 2050 to a 95% reduction by 2035. For example, if CO_2 emissions are required to fall by 4% from 2021 to 2022, and the economy grows by 2%, then the decoupling rate is about 6%.[8] Jackson assumes an annual population growth

[7] Technically, this equation only holds for infinitesimal changes. However, as Jackson notes, this equation does a pretty good job approximating larger changes as well.

[8] Technically, 5.9%.

rate of 0.8% and an annual GDP growth rate of 2.1%, consistent with historical trends. Because the model uses constant annual percentages for rates of growth and decay, carbon emissions can approach zero but will never fully reach zero (hence, the 90% and 95% reduction targets, rather than 100%). I return to this issue in the next section. For now, I will use Jackson's model as is, updating it to reflect the current year (emission reductions begin in 2022).

The results of the replication are summarized in the first column (excluding labels) of Table 1.1. The annual decoupling rate ranges from 9.6%-21.0% across the four emission targets. In order to approximate the IPCC's (2018b) 1.5 °C emissions path, which requires reducing CO_2 emissions by 45% by 2030 and 100% by 2050, I take the average of Jackson's two middle targets (95% reduction by 2050 and 90% reduction by 2035). The result is shown in the last row: 14.4%. In other words, assuming GDP growth of 2.1% per year, to have a 50% chance of limiting global warming to 1.5 °C above preindustrial levels, humanity must decouple CO_2 emission from GDP at a rate of 14.4% per year. This is consistent with Jackson and Victor (2019) and Hickel (2020), both of which say that a 14% per year decoupling rate is needed. According to Jackson (2016) and degrowth proponents in general, decoupling rates of this magnitude are simply not feasible. I explore this further in the next section. For now, though, I will assume degrowth proponents are right. The question, then, is whether degrowth offers a viable solution. Degrowth proponents unequivocally say "yes", but they do not provide any evidence to back this up. Thus, I extend Jackson's analysis to include degrowth scenarios, and consider their implications for both CO_2 emissions and GDP.

The last four columns display results for no-growth and degrowth scenarios, characterized by annual GDP growth rates of 0%, -0.5%, -1%, and -5%. The required decoupling rates decrease by a margin approximately equal to the difference in growth rates. For example, to achieve the 1.5 °C target, annual decoupling would have to reach 12.6% in the zero-growth scenario, 11.6% in the -1% degrowth scenario, and 7.9% in the -5% degrowth scenario. According to degrowth proponents, anything above 3% or 4% is impossible (Jackson 2016; Hickel and Kallis 2019). Thus, the only scenario that comes close to being viable, according to degrowth proponents, is the -5% degrowth scenario. That is, the global economy would have to shrink by at least 5% every single year until the climate has stabilized. And even then, we would miss the 1.5 °C target.

This leads to another question: how would this impact the global economy? Table 1.2 displays the size of the global economy in 2050 for each scenario. Relative to 2021, the global economy would shrink by one quarter under -1% annual degrowth, and nearly 80% under -5% annual degrowth. However, degrowth proponents are adamant that degrowth is only for developed economies. Developed economies shrink and developing economies grow until incomes per capita converge. Table 1.3 considers what this would look like for the ten largest economies in the world, which account for two thirds of global GDP. Seven are developed economies (the U.S., Japan, Germany, the UK, France, Italy, and Canada) and three are developing economies (China, India, and Brazil). I show GDP and percent change in GDP for each country in 2050 under three scenarios: 0% annual GDP growth, -1% annual GDP growth, and -5% annual GDP growth. For each scenario, I assume per capita incomes converge in 2050.

In the zero-growth scenario, the U.S. economy shrinks by three quarters, the Italian economy by half, and the other developed economies by 60%-70%. China would have to stop growing in just seven years. Despite these drastic reductions in income, climate benefits would be minimal. Only the -5% degrowth scenario comes close to achieving decoupling rates that degrowth proponents consider to be feasible (discussed further in Section 1.2.1.3). If the global economy shrinks by 5% per year, global GDP per capita would be $2,700, similar to countries like Honduras, Lebanon, and Palestine. This is consistent with what leading degrowth proponent Peter Victor advocates in a widely cited 2012 paper.[9] In this scenario, developed economies would shrink by 92% to 96%. China and Brazil's economies would shrink by 74% and 69%, respectively. In other words, in order for degrowth to play a major role in stabilizing the climate, most economic activity in developed and developing economies alike will have to stop. Implementing these kinds of income reductions is politically impossible and economically undesirable. It also contradicts degrowth proponents' claims that developing economies, like China and Brazil, should be able to continue growing.

In considering the implications of his analysis, Jackson (2016) states, "The speed at which resource and emission efficiencies have to improve if we are to meet carbon targets are at best heroic, if the economy is growing relentlessly" (Ch. 5).[10] It is true that the required CO_2 emissions reductions to achieve the 1.5-2 °C target are quite large and unprecedented. However, it does not follow that the best option moving forward is

[9] Victor (2012) argues that a sustainable GDP per capita would be $3,815.

[10] Several of the books that I cite, such as Jackson (2016), are in the EPUB format, which does not include set page numbers. Following the Chicago Manual of Style's recommendation, I use chapter numbers in these cases.

degrowth. In extending Jackson's arithmetic analysis, I show even if the global economy could end growth, or implement degrowth, the required CO_2 intensity reductions remain large and unprecedented. This is because, all else equal, reducing the size of the economy by, say, 14%—implied in the -0.5% degrowth scenario—CO_2 emissions decrease proportionately, by approximately 14%. To have a major impact on required coupling rates to achieve the 1.5 °C scenario, degrowth would have to reach some 5% per year. The macroeconomic implications of this can only be described as civilizational collapse, the exact thing we are trying to avoid by solving the climate crisis. So, if degrowth proponents are right—i.e., that sufficient absolute decoupling is impossible in the current system—then we need alternative solutions. I evaluate this claim in the next section.

1.2.1.2 Structural Problems with the IPAT Model

Thus far, I have considered Jackson's (2016) IPAT model on its own terms. In this section, I show that the model itself suffers from two structural problems.

Geometric vs. Arithmetic Decay

As noted earlier, Jackson (2016) calls his simple modelling exercise "the arithmetic of growth." He uses the term "arithmetic" to denote simplicity. However, his model of CO_2 emissions is actually one of geometric decay, not arithmetic decay. I am not suggesting that he should change the name of that section. However, it turns out that arithmetic decay is more appropriate.

Under geometric decay, CO_2 emissions decline by a fixed ratio each year:

$$CO2_t = CO2_{t-1} \times (1 - G) \tag{1.3}$$

That is, emissions for each year are determined by multiplying the previous year's emissions by one minus the annual percent decrease in emissions (G), where G is a constant between zero and one. Under arithmetic decay, emissions are modeled by subtracting a constant level of emissions each year:

$$CO2_t = CO2_{t-1} - A \tag{1.4}$$

Emissions for year t are determined by subtracting the annual absolute change in emissions (A) from the previous year, where A is a constant greater than zero.

Figure 1.1 compares the two models. The geometric model achieves a 95% reduction in CO_2 emissions by 2050 (equivalent to one of the scenarios considered in Table 1.1). The arithmetic model, following the IPCC's (2018b) 1.5 °C emissions path, achieves a 45% reduction in CO_2 emissions by 2030 and 100% by 2050. In the geometric model, the emissions path is steep at first, then flattens out. The largest emissions reduction occurs in the first year (2022), and the smallest in the last year (2050). As a result, the emissions reductions are actually larger than necessary until the final few years. In the arithmetic model, the emissions reduction level is constant from year to year in absolute terms, with the caveat that this level changes in 2031 (this due to the 2030 emissions target). In addition to being consistent with the IPCC's recommended emissions path for 1.5 °C, it is more practical. It simply does not make sense that society would achieve its largest emissions reduction in year one, and then less with each subsequent year.

Another outcome of the geometric model is that it inflates the average decoupling rate. Table 1.4 reports the decoupling rates for the arithmetic model under different GDP growth rates, for both the 1.5 °C and 2 °C warming targets. The 2 °C target requires achieving a 25% reduction in CO_2 by 2030, and 100% by 2070. Relative to Table 1.1, which reports decoupling rates for the geometric model, these values appear significantly more manageable. This is due entirely to the way the model is setup. Under geometric decay, because the emission reductions get smaller and smaller over time, a larger decoupling rate is needed. In the arithmetic model, the decoupling rate starts smaller and grows over time, so that it is 100% in the final period. In absolute terms, however, this 100% rate is identical to the emissions reduction in every other year.

Despite the problems with the geometric model, the entirety of the degrowth literature reviewed for this paper uses it. The result is inflated decoupling rates. Jackson and Victor (2019) and Hickel (2020), for example, define sufficient absolute decoupling as a decoupling rate of 14% per year. These inflated decoupling rates are then used, in part, to argue that climate stabilization requires degrowth.

Energy Efficiency Improvements

The second structural problem in the IPAT model is that it masks the potential of energy efficiency improvements. The final term of Equation (1.1A)—the CO_2 intensity of GDP—should be further decomposed into the energy intensity of GDP (energy/GDP) multiplied by the CO_2 intensity of energy (CO_2/energy). The updated model is shown in Equations (1.1B) and (1.2B):

$$(CO_2\ Emissions) = Population \times \frac{GDP}{Capita} \times \frac{\text{Energy}}{GDP} \times \frac{CO_2}{Energy} \tag{1.1B}$$

$$\frac{\Delta\ (CO_2\ Emissions)}{(CO_2\ Emissions)} = \frac{\Delta\ Population}{Population} + \frac{\Delta\ (GDP/Capita)}{(GDP/Capita)} + \frac{\Delta\ (\text{Energy}/GDP)}{(Energy/GDP)} + \frac{\Delta\ (CO_2\ /Energy)}{(CO_2/\text{Energy})} \tag{1.2B}$$

The energy intensity of GDP represents energy efficiency. Improving energy efficiency alone—that is, reducing the level of energy required per dollar of GDP—can reduce energy consumption by about 30%, and save consumers money in the process (National Academy of Sciences 2010). Most energy efficiency measures also pay for themselves in 3-5 years (Pollin 2015). Additionally, transitioning energy systems away from fossil fuels will decrease the amount of energy wasted, especially in transportation. While gasoline-burning vehicles are only 20% efficient (i.e., they waste 80% of energy generated), electric vehicles are over 90% efficient (Prentiss 2015).

Societies, then, can reduce energy production and consumption significantly without reducing the GDP in two ways: (1) decreasing the amount of energy necessary to produce and use goods and services (e.g., replacing incandescent lighting with LED lighting and improving the insulation of buildings); and (2) reducing the substantial amount of energy wasted in fossil fuel-based energy production. The potential for low-cost and cost-saving energy efficiency improvements, thus, is substantial. The implication is that a significant portion of fossil fuels can be phased out without actually being replaced, making it easier to achieve higher decoupling rates.

1.2.1.3 Sufficient Absolute Decoupling

The key to the argument that climate stabilization requires degrowth is the claim that required decoupling rates are higher than achievable decoupling rates. In the most widely cited degrowth paper since 2020, Hickel and Kallis (2020) double-down on this claim. They do this by attempting to quantify the maximum achievable CO_2 decoupling rate, which they conclude is in the range of 3-4%. If true, then even arithmetic decay-based decoupling rates are too large. Hickel and Kallis come to this conclusion by consulting three climate models—Schandl et al. (2016), IPCC (2000), and Climate Interactive (n.d.). The most optimistic climate stabilization scenarios in these models use decoupling rates of 3%, 3.3%, and 4%. According to Hickel and Kallis, these figures must define the maximum range of decoupling rates. However, they never actually explain why decoupling rates beyond 4% are impossible.

They quote Holz et al. (2018), who state that without widespread use of negative emission technologies, the decoupling rates necessary to achieve the 1.5-2 °C target are "well outside what is currently deemed achievable, based on historical evidence and standard modelling" (8). However, given that no country has attempted a major climate stabilization policy program like the Green New Deal, historical evidence is a poor indicator of what is possible. Similarly, standard modelling tends to be biased towards the status quo. Hickel and Kallis respond to this critique as follows:

> One may insist that green growth hasn't occurred because it has not been tried, the fact that it hasn't been empirically observed till now then becoming irrelevant. We follow instead a more precautionary approach and argue that policy should be made on the basis of robust empirical evidence, rather than on the basis of speculative theoretical possibilities, particularly given the severity of the crisis that is at stake (483).

There are two problems with this response. First, they do not present "robust empirical evidence" that decoupling rates beyond 4% are impossible. Second, following their own logic, economic degrowth would also be rendered impossible. A sustained program of economic degrowth has never been attempted, and there does not exist any "robust empirical evidence" that it could work. As I argue in Section 1.2.4 below, implementing a sustained degrowth policy program in the short- to medium-term stretches the bounds of feasibility to a far greater extent than high decoupling rates.

A better approach to understanding the feasibility of sufficient absolute decoupling is to ask the following: (1) what level of economic resources is required to achieve the 1.5-

2 °C target? And (2) can society feasibly mobilize that level of resources in the short- to medium-term?

According to Robert Pollin (2015; 2019b), the level of economic resources required is actually relatively small—in the range of 1.5-2.5% of global GDP per year.[11] Using a bottom-up approach, Pollin (2015) estimates the costs of a climate stabilization program consistent with a two-thirds chance of limiting global warming to 2 °C. He assumes global economic growth of 3.4% per year, accounts for rising energy demand, and uses the best available data on lifetime costs of energy efficiency and renewable energy. To achieve the 2 °C target, humanity would have to spend 1.5-2% of global GDP per year. Pollin (2019b) updated this figure for the 1.5 °C target, which requires 2-2.5% of global GDP per year. Consistent with the energy efficiency analysis in Section 1.2.1.3, the low costs and high technical potential of energy efficiency measures are key to Pollin's overall results, i.e., that the economic costs of climate stabilization are reasonable. Pollin's results are further supported by Jacobson et al. (2019), who find that overall climate stabilization costs are around 2% of global GDP per year.[12]

Mobilizing 1.5-2.5% of global GDP per year is an enormous challenge, but also achievable. Pollin (2018; 2019a; 2019b) critiques the degrowth perspective on exactly these grounds, and several degrowth proponents have responded (Mastini et al. 2021; Schor and Jorgenson 2019a; 2019b; Kallis 2019). One would expect the degrowth proponents to

[11] For more details on his methods and analysis, see Pollin et al. (2014) and Pollin et al. (2015).

[12] Jacobson et al. (2019) estimate that achieving net-zero emissions by 2050 will cost $73 trillion. Assuming global GDP grows at 2.1% per year—the average historical rate according to Jackson (2016)—this amounts to 2.0% of GDP per year from 2021-2050.

attempt to dispute Pollin's 1.5-2.5% cost figure. Interestingly, they do not, which gives it further credibility.

1.2.1.4 Is Degrowth Inevitable?: Evaluating the EROI

The previous three sections focused mainly on the feasibility of decoupling. As noted in the introduction to Section 1.2.1, degrowth proponents make one other key argument: that climate stabilization will inevitably lead to degrowth. They argue that clean energy is not capable of supporting continual economic growth in the way that fossil fuels have. This claim, if true, has monumental implications. Not only would developed economies have to stop growing, but developing economies as well, as they too must transition to clean energy. China and India, for example, are the world's first and third largest greenhouse gas emitters. Table 1.3 in Section 1.2.1.1 shows how degrowth scenarios would lead to draconian income cuts in the world's ten largest economies. In this section, I evaluate the degrowth inevitability argument, concluding that it is deeply flawed and does not hold under scrutiny.

Their argument is based on the energy return on energy invested (EROI) concept, defined as "the ratio of the amount of usable energy delivered from a particular energy resource to the amount of usable energy used to obtain that energy resource" (Mastini et al. 2021, 3). The basic argument of degrowth proponents is that renewable energy sources tend to have lower EROI values than fossil fuel sources. This lower EROI forces societies to allocate more productive resources towards energy production, reducing the resources available for other economic activities (Mastini et al. 2021; Hall 2017; Jackson 2016; Kallis 2011). According to Mastini et al. (2021), the EROIs of clean energy sources are low enough to claim that GDP growth would no longer be possible. Jackson (2016) makes a similar claim. Mastini et al. (2021) make their case by citing Capellán-Pérez et al. (2018), a conference paper that attempts to quantify the EROI for the global energy system in the year 2050, assuming renewable energy sources make up 50% of the energy portfolio. They calculate the EROI at 3:1, which is far lower than the 11:1 ratio deemed necessary for a growing U.S. economy by Fizaine and Court (2016).

The EROI argument fails on two counts: (1) the EROI concept turns out to be a poor indicator of whether renewable energy resources can support economic growth, and (2) even if we ignore the first reason, the EROIs of wind and solar—the most important renewable resources in transitioning off fossil fuels—are sufficient to support growth.

Jason Deign (2021), a freelance clean energy journalist, provides the bulk of evidence for the first issue. Originally, the EROI was used to better understand fossil fuel resources. As societies use up conventional fossil fuel resources, production requires ever greater levels of unconventional, hard-to-extract resources. Theoretically, if the world continues to rely on fossil fuel resources, there will come a point at which the energy required for extraction outweighs the energy returned for end-use. Given the centrality of energy to power modern civilization, this would impact economic growth.

This leads to the first limitation of EROI for evaluating renewable energy. Unlike fossil energy, renewable energy is practically limitless. Use of solar, wind, hydro, and geothermal energy today does not diminish these energy resources tomorrow, or in 100 years. Until the sun reaches the end of its life, a prospect that is likely billions of years away, solar and wind energy have the potential to fuel civilization many times over.[13] Given the abundant nature of renewable energy, a low EROI is not actually a problem, as

[13] E.g., see Prentiss (2015)

long as costs of production are low. As discussed below, renewable energy resources are already at average cost parity with fossil fuel-based energy. Even Charles Hall, the originator and most ardent supporter of the EROI concept, admitted to Deign (2021) that "EROIs make a little more sense for a finite fossil fuel resource, like an oil field."

It is important to note that capturing wind and solar energy does require extraction of rare earth metals and minerals for solar panels and wind turbines. Several reports suggest that business-as-usual metal and mineral sourcing will create supply-side problems for decarbonization (IEA 2021; van Exter et al. 2018; Valero et al. 2018). However, they also show that the problem is fixable with good policy. Enough reserves do exist to support decarbonization. In the short-term, economies must ramp-up production of these metals and minerals. Long-term, primary metal and mineral production can be replaced via recycling. There is also room for technological advances to lower the level of resources needed.

Another major flaw of the EROI is that it is inherently difficult to measure. While energy output is fairly straight-forward—for example, electricity generation can be measured directly—measuring energy inputs involves defining what is and is not energy (labor, for example—an arguably essential energy source—is generally excluded); measuring the direct energy used, as well as the energy used to produce all the other inputs; and converting them to a common denominator. These difficulties are described in detail by Inman (2013). As a result, EROI measurements for the same technology vary widely. For example, Kubiszewski (2010) carry-out a meta-analysis on EROI measurements for wind energy. Their study covers 119 estimates from 50 analyses published between 1977 and 2006. Estimates range from 1.0 to 125.8. Excluding estimates prior to 2000, the estimates still range from 4.7 to 125.8 and cover everything in-between.

Palmer and Floyd (2017) explore the wide variation—what they term "divergence"—in EROI estimates of solar PV systems. They find six causes for divergence: "life-cycle assessment methodology, age of the primary data, PV cell technology, treatment of intermittency, equivalence of investment and output energy forms, and assumptions about real-world performance" (1). They conclude that EROI measurements "must be considered with specific reference to the details of the particular study context" (1).

Given the difficulties of consistently measuring the EROI of specific technologies, which result in wide variation in published estimates, the EROI should not be used to make broad claims about clean energy and economic growth. Indeed, it is difficult to give much weight to a low EROI estimate (3:1) of an unpublished conference paper (Capellán-Pérez et al. 2018) for the entire energy system in the year 2050. Similarly, Fizaine and Court's (2016) claim that EROIs lower than 11:1 preclude economic growth cannot be trusted.

Deign (2021) also interviewed Michael Liebreich, founder of Bloomberg New Energy Finance, and Euan Mearns, originator of the "Net Energy Cliff" concept. The Net Energy Cliff is widely cited and praised in the EROI literature. Mearns, however, has turned on the EROI concept, agreeing with Liebreich that the EROI is not useful for understanding renewable energy resources. Both point to the failure of EROI to consider the time it takes to produce energy. Fossil fuel-based energy, for example, requires ample time for extraction and transport of fuels. Solar and wind power, on the other hand, produce energy whenever the sun shines and wind blows. Thus, even if renewable energy sources require more energy inputs, they can produce energy more quickly.

A final problem with the EROI is that it fails to account for fossil fuel co-pollutants, i.e., non-carbon pollution from fossil fuel combustion. According to Vohra et al. (2021), co-pollutants caused 9-10 million premature deaths per year, globally, between 2012 and 2018. This is over twice as many as had been previously estimated (Cohen et al. 2017; WHO 2018). Countless others suffer debilitating morbidities, such as asthma. A clean energy transition would save tens of millions of lives, and—in relation to the EROI—would free up massive amounts of societal resources currently being allocated towards healthcare and sick leave.

A more useful approach to understanding the level of resources required to produce energy from various sources is levelized costs, i.e., total lifetime costs of producing one unit of energy, including labor, raw materials, and capital goods. Based on levelized cost data, solar, wind, and geothermal electricity generation are significantly cheaper than coal generation and already cost-competitive with natural gas generation (EIA 2021; IRENA 2020). Even if renewable energy sources have lower EROIs, if they are abundant and cheaper than fossil fuels, there is no reason to think they will require more societal resources or that they would not be able to support economic growth. The cost approach is also capable of considering pollution, albeit imperfectly, through the social cost of carbon and co-pollutant cost of carbon.[14]

[14] The climate and co-pollutant costs of emitting one more ton of carbon dioxide. See, for example, Dedoussi et al. (2019).

One potential issue is intermittency—solar panels and wind turbines cannot provide a constant flow of energy. However, these problems have been known for decades, and solutions exist. For example, costs of battery storage and offshore wind energy—a much less intermittent resource with the potential to supply global electricity demand in 2040 eleven times over—are quickly decreasing (EIA 2020c; IEA 2020a). Intermittency could also be ameliorated by continuing to use a very small amount of conventional natural gas generation in combination with negative emissions technologies.

Hall (2017) is a defense of the EROI concept. He attempts to address several arguments that have been used to discredit the EROI. One such argument is that, "what really matters is not EROI, but cost" (637). His response is unconvincing: "That may be true" he says, adding, "but [a recent paper] found that for US oil and gas, costs and EROI are statistically inverse" (637). In other words, he defends the EROI by saying it is inversely related to cost. He does not argue against the claim that cost is more important than EROI. In Feign (2021), Hall further undermines his argument by noting that, "Fracked oil wells have had a decent EROI—12:1 or more—when analyzed, but basically were a financial failure." He adds, "I am not sure why."

Given the major flaws described above, it is difficult to see any use for the EROI with respect to clean energy resources. Even if EROI did still matter, according to Hall (2017), "most new 'renewable' fuels have a relatively low EROI except perhaps for photovoltaics (PV) and wind" (636). Stated differently: renewable energy sources tend to have low EROI values, except the two most important ones that are expected to play the biggest role in the clean energy transition.

1.2.2 Revolution

There are two main theoretical frameworks that underpin the "revolution" perspective. The most prominent is the "metabolic rift" framework, which comes out of the Monopoly Capitalism school of Marxism.[15] Three leading scholars of this framework—sociologists John Bellamy Foster, Brett Clark, and Richard York—lay out their perspective in a collection of essays published in 2011, titled, *The Ecological Rift: Capitalism's War on the Earth*. They argue consistently throughout their book, as well as in their broader research agendas, that "nothing less than an ecological revolution—a fundamental reordering of relations of production and reproduction to generate a more sustainable society—is required to prevent a planetary disaster" (Ch. 4). Andreas Malm is another leading radical environmentalist, who can be placed in the metabolic rift framework.[16] Malm (2015) states that hoping for a revolution prior to solving climate change is "laughable" (Ch. 15), but in his more recent works he is clear that only revolutionary struggle—specifically, "ecological Leninism"—can avert climate catastrophe (Malm 2018; 2020a).

The second framework is Jason Moore's world-ecology, which he lays out in *Capitalism and the Web of Life* (Moore 2015). The metabolic rift and world ecology frameworks have vehement disagreements on ecological Marxist theory, but they agree that revolution is necessary to solve the climate crisis. For example, Moore (2015) states,

[15] This is also often called the "Monthly Review" school, referring to the socialist magazine of the same name, edited by ecological Marxist John Bellamy Foster.

[16] See Ch. 6 of Malm (2020b)

"There is no conceivable way that capitalism can address climate change in any meaningful way" (267).

In this section, I describe and evaluate their arguments. In general, both frameworks rely too heavily on a simplified, theoretical model of capitalism. They combine their theoretical arguments with anecdotes and examples, sometimes inaccurate, that fit their theories. Similar to the degrowth perspective, then, the revolution perspective lacks adequate evidence to support its claims.

1.2.2.1 The Metabolic Rift

Theory

Foster et al. (2011) conceptualize capitalism as a "grow-or-die system" organized around the process of capital accumulation, i.e., the self-reinforcing cycle of wealth expansion, for the capitalist class—those who control society's productive resources, including built-capital, natural resources, and labor power (Foster et al. 2011, Introduction). They quote Karl Marx in the *Grundrisse* to characterize capital, i.e., money and assets in the cycle of wealth expansion, as "the endless and limitless drive to go beyond its limiting barriers. Every boundary is and has to be a [mere] barrier for it. Else it would cease to be capital—money as self-reproductive" (Introduction). The process of endless capital accumulation is fueled by competition, "which ensures that each firm must grow and reinvest its 'earnings' (surplus) in order to survive" (Ch. 4). The combination of capital accumulation and competition creates the macroeconomic growth imperative. Indeed, when capitalist economies go into recession, or even stagnate, they are considered to be in crisis. Capitalists lose wealth and ordinary people suffer unemployment and general economic insecurity.

Foster et al. argue that the system of capitalism prioritizes accumulation of exchange-values, i.e., money and commodities with market-value, over wealth, defined as use-values—the degree of usefulness of a produced or natural resource. They go through an interesting history of how the concept of use-value was extricated from the discipline of economics in the transition from classical to neoclassical. To summarize the modern concept of economic value, they quote John Stuart Mill:

> Things for which nothing could be obtained in exchange, however useful or necessary they may be, are not wealth in the sense in which the term is used in Political Economy. Air, for example, though the most absolute of necessaries, bears no price in the market, because it can be obtained gratuitously: to accumulate a stock of it would yield no profit or advantage to any one; and the laws of its production and distribution are the subject of a very different study from Political Economy (Ch. 1).

Foster et al. take this one step further. Not only is use-value ignored, but the process of capital accumulation of exchange-values in capitalism necessitates the degradation of use-values, such as polluted air and water, infertile soil, and over-filled carbon sinks. This inverse relationship between exchange-value and use-value is known as the Lauderdale Paradox, named after its originator James Maitland, the eighth Earl of Lauderdale.

To describe the society-environment relationship under capitalism, they use and extend Marx's theory of the "metabolic rift." The theory consists of three key concepts: social metabolism, universal metabolism of nature, and metabolic rift. Social metabolism refers to "the complex, dynamic interchange between human beings and earth" (Ch. 2). It encompasses all human activities involved in extracting and manipulating natural resources and emitting wastes. The universal metabolism of nature (also called the "natural metabolism") incorporates all the natural processes and cycles that exist in extra-human nature and allow for the continual regeneration of the conditions of life. For example, the soil nutrient cycle creates the conditions of agriculture. Due to the capital accumulation imperative and Lauderdale Paradox described above, the social metabolism under capitalism produces "metabolic rifts," i.e., ruptures in the universal metabolism of nature (Ch. 2).

A capitalist who chooses to invest in the long-term regenerative needs of nature—e.g., ensuring that logging and beef production do not deplete the world's forests, or voluntarily sequestering CO_2 and methane emissions from fossil fuel production—will be outcompeted by those who ignore, or shift these costs to others. Natural resources, thus, are treated as "free gifts"—a term, as they show, that is used in several foundational neoclassical economics textbooks (Ch. 1). Ignoring the regenerative needs of nature increases profits in the short- to medium-term. However, in the long-term, these metabolic rifts undermine the conditions of human existence. By that time, however, it will be too late. The metabolic rift framework can be used to describe any ecological crisis that stems from economic activity. However, they focus mostly on climate change, as it is the most urgent and potentially catastrophic environmental crisis humanity faces. They do not hold back on the severity of business-as-usual: "There is a high probability, if we do not quickly change course, of a *terminal crisis*—a death of the whole period of human dominance of the planet" (Ch. 18).

Finally, they argue for social and ecological revolution—dismantling and replacing capitalism with an ecological sustainably and socially just society. The very existence of capitalism, they argue, precludes climate stabilization:

> Given the logic of capital and its basic operations, the rift in the carbon cycle and global climate change are intrinsically tied to capitalism. In fact, the continued existence of capitalism guarantees the continuation of these events. 'Short of human extinction,' [Paul] Burkett stresses, 'there is no sense in which capitalism can be relied upon to permanently 'break down' under the weight of its depletion and degradation of natural wealth' (Ch. 5).

Preventing "planetary ecocide," they argue, "requires the progressive dismantling of the regime of capital, and the construction brick by brick of a new organic social and ecological system in its place." This process must begin "immediately" (Ch. 17).

Evidence

Given that environmental degradation in general stems from economic development, it is not a stretch to argue that the predominant economic system in the world, capitalism, is at the root of these crises. Using Marxian theory, Foster et al. (2011) do exactly that: show how the workings of capitalism cause "metabolic rifts" like climate change. It is also not hard to make the case that capitalism, a growth-based economic system that can be defined by its prioritization of profit-making above all else (i.e., greed), is inconsistent with environmental sustainability. The evidence for this is vast. Environmental degradation has tended to worsen throughout the history of capitalism, and especially since the end of World War II—a period termed "The Great Acceleration" due to the rapidly deteriorating environment. What is more challenging, however, is providing convincing evidence that capitalism must be dismantled and replaced in order to solve the climate crisis in particular. Certainly, Foster et al. understand the enormity of this challenge. They attempt to overcome it with anecdotes and examples that are consistent with their theory. A summary of their claims and my responses are below.

1. **Claim:** They use the Jevon's Paradox to claim that efficiency gains will always be outdone by economic growth. Here is their claim: "An economic system devoted to profits, accumulation, and economic expansion without end will tend to use any efficiency gains or cost reductions to expand the overall scale of production." (Ch. 7).

   Response: Foster et al. admit that the rebound effect is relatively small at the micro-level, ranging from 10-30%. Purchasing a more fuel-efficient car, for example, does not lead to a substantial increase in the number of miles driven. However, they argue that at the macro-level, if an economy increases energy efficiency, the cost savings will go towards other economic activities that expand the economy, and thus increase energy consumption. In other words, they agree with degrowth proponents that an increasing GDP necessarily leads to increases in energy use. I show why this is not true in Section 1.2.1.2. As a case-in-point, one can also compare the U.S. and Germany. Germany has made great strides in improving energy efficiency in recent years. Based on the Jevon's Paradox, this should simply lead to faster economic growth and more energy use. Yet, Germany's economy has not grown any faster than the U.S. economy, and its CO_2 emissions per capita is about half that of the U.S., and continues to decline steadily (World Bank 2021a; 2021b).

2. **Claim:** "The development of a substitute for a natural resource is sometimes associated with an increase in consumption of that resource." They label this the "Paperless Office Paradox," (Ch. 8) referring to the fact that computers and the internet led to more use of paper. They then apply this to energy, giving the example of how the rise of fossil fuels, meant to replace biomass, actually ended up increasing biomass. The same thing could happen with clean energy.

   Response: One of the coauthors of Foster et al. (2011) actually published an article in *Nature Climate Change* the following year, showing exactly that: renewable energy had only displaced one tenth of fossil fuels (York 2012). However, this could easily be fixed with an effective climate policy program. The program must invest massively in clean energy, while also phasing out fossil fuels through, e.g., a hard cap on emissions combined with clean energy standards. The latter part will ensure the phase-out of fossil fuels.

3. **Claim:** Climate solutions offered within capitalism generally amount to shifting the problem elsewhere. They give the examples of nuclear power, which lead to radioactive waste; agrofuels, which lead to soil degradation and might actually increase carbon emissions; and geoengineering solutions—injecting sulfur particles into the stratosphere to reduce albedo and replacing a quarter of forests with genetically-engineered carbon-eating trees.

   Response: It is true that there are unrealistic solutions on offer, but that does not preclude realistic solutions, which are also on offer. See Section 1.2.1.2, where I discuss the work of Robert Pollin and colleagues, who show that a Green New Deal without nuclear, dirty biofuels, large-scale hydropower, or geoengineering is both technically and economically feasible. Without action soon, some negative emissions technologies may be necessary. Some of these technologies, however, do show promise (Hanna et al. 2021; Minx et al. 2018).

4. **Claim:** Nicholas Stern (2007) proposes an emissions path that is consistent with 3 °C. This is the best that can be expected from mainstream economics, which is unwilling to challenge capitalism.

   Response: Stern's (2007) recommended emissions path was based on having a 50% chance of limiting warming to 2 °C above preindustrial levels. One can certainly argue that a two-thirds chance would have been better. However, Stern (2007) is just one example. There have been many examples of more ambitious climate stabilization programs in the years since, e.g., Pollin (2015).

Theoretical blinders

The inadequacy of evidence does not, on its own, preclude the possibility that the revolution perspective is correct. Foster et al. (2011) also, however, present theoretical blinders. Most importantly, the Marxist model of capitalism, while extremely useful in understanding important aspects of the system—capital accumulation, exploitation of workers, unsustainable economic development, and class struggle, among others—is only a model. It is not identical to real-existing capitalist economies, which are versatile and resilient, and include economies as varied as U.S. neoliberalism, Scandinavian social democracy, and Chinese state bureaucracy. In general, a system driven by capital accumulation tends to degrade the natural environment. However, environmental improvement can and has occurred in capitalist economies. For example, phasing out chlorofluorocarbons (CFCs) to end ozone depletion, drastically reducing particulate pollution through the Acid Rain program in the U.S., and—for 21 countries—beginning the process of absolute decoupling. Below, I present evidence that undermines the revolution perspective.

While most real economies can be generally characterized as capitalist, driven by capital accumulation, no economy is purely capitalist. That is, real economies are mixed systems, exhibiting multiple different economic paradigms. For example, one could argue that a government-funded universal healthcare system is impossible in a capitalist economy. Providing free or low-cost healthcare, paid for through taxes, goes against the "logic of capital." Yet, the U.S. is the only developed capitalist country that does NOT offer universal healthcare (and they do offer it to older residents). While universal healthcare in the U.S. seemed politically impossible just five years ago, today over half of House Democrats support it (Diamond 2021). In a similar way, capitalist governments could offer universal clean energy and sustainably-produced food. Combined, energy and food production in the U.S. account for 10% of the GDP, about two thirds the size of the healthcare sector.

While government-funded energy and food is desirable for many (present company included), it may not actually be necessary. The economics of clean energy in particular has rapidly changed over the past 15 years. Both the U.S. Energy Information Administration (EIA) and the International Renewable Energy Agency (IRENA) find that wind, solar, and geothermal electricity generation are, on average, cheaper than coal-based generation and competitive with natural gas-based generation (EIA 2021; IRENA 2020). A clean energy transition is certainly antithetical to the interests of fossil fuel capital, it is not antithetical to the "logic of capital" in general. There is now a clean energy industry with clean energy capitalists. The competitiveness of clean energy does not mean that capitalism, left to its own devices, will solve the climate crisis. Such notions are ludicrous—governments in capitalist economies have always played an outsized and necessary role to stimulate innovation and major socio-technical transitions (Mazzucato 2014; Ruttan 2006). But it does undermine the revolution perspective.

The story of Ørsted, the largest offshore wind developer in the world, is instructive here. Ørsted was formerly named Dong Energy, where "Dong" was an acronym for "Danish Oil and Gas Company," and it served as Denmark's state-owned oil and gas company. In 2009, Dong unveiled its 85/15 vision. At the time, Dong was 85% black (fossil fuels) and 15% green, and accounted for one third of Denmark's CO_2 emissions. Within a generation—about 30 years—they would flip the ratio around: 85% green and 15% black. Unexpectedly, the transformation occurred much faster than expected. By 2017, Dong had sold off the last of its North Sea oil and gas assets (it also changed its name to Ørsted) (Reguly 2019). As of 2019, 85% of Ørsted's energy production came from renewables and it controlled nearly one third of the global offshore wind market. By 2025, 99% of its operations will be carbon neutral (Reguly 2019; Ørsted 2020). While the original impetus to transition to clean energy was climate-related, the unexpected increase in speed of the transformation was for purely economic reasons. Dong suffered major economic losses in its oil and gas operations in 2012 and 2015, while their offshore wind operations turned out to be quite lucrative (Reguly 2019).

One indicator of Ørsted's financial success is its stock price growth. In June 2016, it held an initial public offering—the second largest of the year (Reguly 2019). By February 2019, its share price had doubled, and as of June 2021 it has nearly quadrupled (Ørsted

2021). While Ørsted is technically state-owned, it operates more like a private firm. Private investors own nearly half of its stocks, and it does not rely on Danish tax dollars to thrive. Ørsted can be viewed as an example of a fossil fuel firm that not only transitioned to clean energy production, but found greater success in doing so.

Another counter-example to the revolution perspective is the case of stratospheric ozone depletion. Like climate change, stratospheric ozone depletion is one of the nine planetary boundaries. The problem was discovered in the early 1970s, and averted after the signing of the Montreal Protocol in 1987—a global agreement to phase-out chlorofluorocarbons (CFCs), the main cause of the crisis. Particularly interesting are the actions of chemical company DuPont. DuPont was the largest producer of CFCs, controlling 50% of the U.S. market and 25% of the global market. Early on, they denied and challenged the science, much like the tobacco and fossil fuel industries. However, in 1986, DuPont came out in favor of the Montreal Protocol. Other chemical companies then followed suit. DuPont's support was crucial for bringing about the success of the agreement (Maxwell and Briscoe 1997; Haas 1992). Maxwell and Briscoe (1997) lay out three reasons that DuPont ultimately came out in support of international regulation:

1. The public was heavily in favor of regulating after seeing evidence of the ozone hole. Supporting the Protocol strengthened its social standing among environmentalists and government officials.
2. DuPont believed there was a good chance the EPA would have passed stringent domestic policies on CFCs, which would have given global competitors an advantage.

3. Most importantly, DuPont determined that supporting the Protocol and phasing out CFCs were in its economic interests. They had developed and patented alternatives to CFCs, which they believed would be more profitable with an orderly phase-out of CFCs. The alternatives were five to ten times more expensive, but DuPont believed its customers could weather the price increase.

Thus, it was not that DuPont had a change in heart, choosing not to be a capitalist firm for the sake of the world. Rather, it was the combination of public pressure, the threat of domestic regulation, and the likelihood of profiting off CFC-alternatives that convinced them to support the Montreal Protocol, and thereby help avert a potentially catastrophic environmental crisis. Of course, the climate crisis is bigger than the ozone crisis, and fossil fuels are more central to the economy than CFCs. Nonetheless, the case of DuPont provides a useful example—possibly even model—for addressing the resistance of the fossil fuel industry, which is one of the main obstacles to climate stabilization. Averting the ozone crisis did not require, in the words of Foster et al. (2011), “a radical confrontation with the logic of capital” (Ch. 16).

1.2.2.2 World-Ecology

Jason Moore is the founder of the world-ecology school of ecological Marxism. The staple of world-ecology is that it claims to analyze human society not as something apart from nature, but within nature. However, the goal here is to evaluate Moore’s approach to the question of whether climate stabilization is possible within capitalism. Despite their differences, Moore agrees with Foster that capitalism is a system driven by the process of capital accumulation and inevitably leads to environmental degradation. From here, Moore departs the usual radical environmentalist logic. Rather than arguing that the actions necessary to solve climate change are inconsistent with capital accumulation, he states, “Global warming poses a fundamental threat not only to humanity, but, more immediately and directly, to capitalism itself” (278). Moore understands the novelty of his argument, and attributes it to his world-ecology framework:

> This inverts the usual line of radical critique, which overstates the resilience of capitalism in the face of these changes—an overstatement that derives from a view of capitalism as a social system that acts upon nature, rather than a world-ecology that develops through the web of life (278).

Moore predicts that humanity has about two decades before climate change inevitably leads to capitalism’s collapse.

Moore’s argument is unusual, but also influential. The book in which he makes this argument, *Capitalism and the Web of Life*, has accumulated more than 2,500 citations. Moore bases his argument on his theory of the “Four Cheaps,” which states that a functioning capitalist system requires access to cheap food, labor-power, energy, and raw materials. The capitalism collapse argument can be summarized as follows:

1. Climate change makes growing food harder, leading to reduced food supply and higher food prices.
2. Wage workers and the unpaid care workers they support (e.g., stay-at-home parents) need food to live and work, so higher food prices will force wages up.
3. Profit-making requires cheap labor, so higher wages will render profit-making impossible.
4. Capitalism is a system based on endless profit-making, so the impossibility of profit-making will collapse capitalism.

A further implication of Moore's logic, which he fails to consider, is that eco-socialism—the preferred political economic system of revolution proponents—would also likely be rendered impossible. In general terms, eco-socialism promotes long-term ecological sustainability and human well-being, and equitable distributions of wealth and political power (Löwy 2015).[17] An eco-socialist society, like any society, requires adequate supplies of food and other resources to support its population. People must be able to produce a surplus so that there is enough to go around. In capitalism, that surplus is controlled by private capitalists in the form of profits. In an eco-socialist society, it would be controlled by democratic processes that involve everyone in a workplace, community, or all of society. If climate change damages the food supply to the point of causing the collapse of capitalism, why would we expect it to be able to support eco-socialism? This becomes even harder to imagine when accounting for the necessary rebuilding after capitalism's collapse, and the necessary climate stabilization measures to avert further climate catastrophe. Moore's theory, then, borders on climate nihilism.

The key to Moore's capitalism collapse argument is the claim that climate change will increase food prices so much that capitalism accumulation becomes impossible. He provides no evidence to back up his claim, and gives no indication as to how high food prices would have to increase to lead to the collapse of capitalism. His argument is further undermined by the IPCC's 2019 *Special Report on Climate Change and Land*, which includes a chapter on climate change and food security. Under a business-as-usual scenario (i.e., a temperature rise of 3-4 °C by 2100), cereal prices would be expected to increase by

[17] Wealth in this context can be broadly defined to include all natural and produced resources that are useful to people.

1% to 29% in 2050, with a central value of 7%. For animal-sourced foods, the expected price increase is about half that of cereals. They did not have data on expected price changes for fruits and vegetables, but stated that yield impacts would be similar to those of cereals. These fairly modest price increases in 2050, which are for a business-as-usual scenario, seem extremely unlikely to cause capitalism to collapse. Food price increases in a 1.5-2 °C scenario would be far lower, and Moore does not provide any evidence to suggest that such a scenario is out of reach with aggressive climate policies. The IPCC (2019) also points to strategies that would ameliorate the food price increases. For example, reducing the 25-30% of food that is lost or wasted every year.

Moore (2015) also points out that current agricultural practices actually exacerbate climate change and degrade soil. He assumes that transitioning to sustainable agricultural practices would go against the profit-imperative. Evidence, however, overwhelmingly rejects this assumption as well. Sustainable agricultural practices, on average, increase yields and profits.[18]

Overall, Moore fails to provide empirical evidence to support his claims, and the evidence that does exist on future food prices and sustainable agriculture contradicts his claims. As a result, the capitalism collapse theory is highly unlikely to come to fruition.

1.2.3 Four Additional Arguments

There are four additional arguments made by degrowth and revolution proponents that are worth responding to. (1) Climate change is not the only crisis; (2) The costs of climate stabilization will cancel out economic growth; (3) Sufficient absolute decoupling

[18] Corselius et al. (2001) survey 20 years of literature. For more recent evidence, see, for example, Milinchuk (2020) and Kumar et al. (2018).

has not happened in the past, and thus is unlikely to happen in the future; and (4) Developed economies must reach net-zero emissions by 2030.

First, practically all degrowth and revolution proponents point out that climate change is not the only environmental crisis. It is just one of the "nine planetary boundaries." The planetary boundaries framework was developed by Earth systems scientists in the late 2000s (Rockström et al. 2009; Steffen et al. 2015). Each boundary represents a natural process or cycle on which humans depend. Together, they define "a safe operating space for humanity for human societies to develop and thrive" (Steffen et al. 2015, 1). "Transgressing a boundary," according to Will Steffen, lead author of the 2015 update to the framework, "increases the risk that human activities could inadvertently drive the Earth system into a much less hospitable state, damaging efforts to reduce poverty and leading to a deterioration of human wellbeing" (Stockholm 2015). As of 2015, four boundaries have been crossed: climate change, biodiversity loss, biogeochemical flows (i.e., the phosphorous and nitrogen cycles), and land-system change. Climate change and biodiversity loss are considered "core boundaries." Transgressing one of these boundaries for too long (humanity has transgressed both), "has the potential on its own to drive the Earth system into a new state" (Steffen et al. 2015, 1).

Revolution and degrowth proponents argue that even if solving climate change is possible within capitalism, doing so will not solve these other crises, and leaving capitalism intact will only create more crises in the future. At the same time, they focus mostly on climate change in their own work. This makes sense—climate change is the most urgent and potentially catastrophic of the environmental crises facing humanity. In addition, climate change overlaps with other crises. Solving climate change will also make substantial progress towards solving ocean acidification and slowing the sixth mass extinction (Steffen et al. 2015; Cahill et al. 2013). Thus, humanity should focus disproportionate efforts on the climate crisis in particular. While the planetary boundaries framework does not support the claim that climate stabilization in particular requires moving beyond capitalism, it does support the claim that capitalism has a strong tendency towards environmental degradation in general, which outpaces any counter-tendencies. That is, thinking longer-term, to achieve general sustainability, societies will likely have to dismantle and replace capitalism.

Second, the costs of climate stabilization are sometimes treated as pure costs. That is, stabilizing the climate will bring about only climate benefits, not economic benefits, and thus will negatively impact economic growth. Both Victor (2012) and Jackson (2016) express this view. However, investments in climate mitigation should be viewed as investments. These investments are substantial—in the range of 2-2.5% of GDP per year to achieve the 1.5 °C target (Pollin 2019b; Jacobson et al. 2019). But they can be expected to generate millions of jobs, create a more efficient energy system, stimulate a new wave of technological innovation, and save millions of lives every year from reduced air pollution. Jacobson et al. (2019), for example, estimates that a 100% clean energy transition will reduce private energy costs from $18 trillion to $7 trillion per year. In addition, a substantial portion of clean energy investments will be matched by a decline in fossil fuel investments.

Third, degrowth proponents regularly cite the fact that sufficient absolute decoupling has not occurred, and use it to support their claim that it cannot occur (e.g., Kallis 2011; Jackson 2016; Schor and Jorgenson 2019a, 2019b). The modelling and evidence presented in Sections 1.2.1.2 and 1.2.1.3 disputes these claims, showing that a global climate stabilization program amounting to 1.5-2.5% of global GDP per year can achieve sufficient absolute decoupling.

Finally, revolution and degrowth proponents tend to use extreme climate projections, especially for developed economies. For example, Jackson and Victor (2019) and Kallis (2020) argue that developed economies must achieve net-zero emission by 2030. The logic behind this claim is that developing economies should be allowed to continue increasing emissions for years to come. Schor and Jorgenson (2019a) and Malm (2014) cite a 2012 paper by Kevin Anderson suggesting that for a 50% chance of limiting warming to 2 °C, net-zero emissions must be achieved globally between 2035 and 2045. Foster et al. (2011) quote climate scientist James Hansen, who claims, "the only resolution [to climate change] is for humans to move to a fundamentally different energy system within a decade." Foster et al. then claim, "this raises the question of more revolutionary social change as an ecological as well as social necessity" (Ch. 6). The IPCC (2018b), widely considered the gold standard for climate science research, disputes these claims. According to the IPCC, for an even chance of limiting warming to 1.5 °C above preindustrial levels, humanity must achieve net-zero carbon emissions around 2050. For 2 °C, this is pushed back to 2070. Developed economies should certainly be more ambitious, but rather than allowing developing economies to continue to develop on dirty energy, a better approach is to provide them with the necessary resources to develop on clean energy. Finally, even if it turns out that Kevin Anderson is right, attempting to achieve degrowth or a revolution would only add to the challenge. This is shown in the next section.

1.2.4 Structural Change

Revolution proponents are clear about the need to abolish capitalism. Degrowth proponents focus less on capitalism and more on economic growth, but most still understand that capitalism is a growth-based system that is inconsistent with degrowth. For example, Jackson (2016) states, “The capitalist model appears to have no easy route towards a steady state position. Its natural dynamics seem to push it towards one of two states: expansion or collapse” (Ch. 4). Hickel (2020) states more explicitly that “we must take steps to evolve beyond capitalism” (Ch. 6).

Moving beyond capitalism is an enormous task. As evidence, one only needs to realize that the world is still predominantly capitalist, surviving centuries of attempted revolutions. Nonetheless, both degrowth and revolution proponents argue that their approaches will make climate stabilization easier. According to Foster (2017), “There are better and faster ways of addressing the climate crisis through revolutions in social relations themselves.” Any non-revolutionary strategy “represents a failure of nerve.” According to Victor (2012), “A slower rate of economic growth requires a slower and, arguably, more manageable rate of transformation of the economy and society” (208). Hickel (2020) argues similarly: “The less energy we use, the easier it is to achieve a rapid transition to renewables” (Ch. 5). If they are right, then whether or not degrowth or revolution is necessary is a moot point. In this section, I examine degrowth and revolution proponents’ proposed action plans, i.e., what societies should do right now to address climate change, to understand the implied structural change of their plans. In doing so, I demonstrate that their plans would in fact make climate stabilization far more difficult.

Degrowth Perspective

Tim Jackson (2016) lays out four pillars of the "economy of tomorrow", i.e., an economy based on degrowth, in Chapter 8 of *Prosperity without Growth*.

1. Enterprise as service
2. Work as participation
3. Investment as commitment
4. Money as social good

The common theme throughout all four pillars is a transformation from profit-based to well-being-based economic activities. For example, "the goal of enterprise must be to provide the capabilities for people to flourish…without destroying the ecological assets on which our future prosperity depends." Employment, too, must be re-constructed so as to serve the workers themselves, increasing their "wellbeing and fulfillment." To actualize these four pillars and make degrowth a reality, Jackson lays out four policy areas, which are to be implemented by a "progressive state": "establishing limits, countering consumerism, tackling inequality and 'fixing' economics" (Ch. 9).

In other words, Jackson is calling for an entirely new economic system. As discussed in Section 1.2.1.1, degrowth is a poor strategy for reducing emissions. Thus, in addition to radically transforming economies so that they are based on equitable degrowth, societies would still have to rapidly decarbonize energy, transportation, and agriculture. Victor (2019) and Hickel (2020) each lay out similar degrowth programs. As noted above, degrowth proponents generally understand that what they are calling for is not capitalist. However, they do not dwell on that point, and they do not consider the political implications of moving beyond capitalism. I consider these in more detail in evaluating the revolution perspective.

Revolution Perspective

As noted in Section 1.2.2, John Bellamy Foster et al. (2011) argue that the continuing existence of capitalism precludes climate stabilization. In Foster's (2021) most recent publication—the preface to the Persian edition of his book, *The Ecological Revolution*—he states the following:

> No one who takes the Earth System emergency seriously today doubts that the changes required are revolutionary in scale. Nor is this simply a question of a technological revolution. What is needed is an ecological revolution in the sense defined by environmental historian Carolyn Merchant, as consisting of 'major transformations in human relations with nonhuman nature,' associated with 'contradictions that develop between a society's mode of production and its ecology, and between its modes of production and reproduction' (Foster 2021).

This leads to the following questions: what does the ecological revolution actually entail? And more specifically, what does it entail in the near term? As far as I know, none of the authors of Foster et al. (2011) have published a concrete program for ecological revolution, answering these questions. The closest thing to it is a 2017 *Monthly Review* article by John Bellamy Foster, titled, "The Long Ecological Revolution." He states that, "A long and continuing ecological revolution is needed—one that will necessarily occur in stages, over decades and centuries." However, due to the urgency of climate change and other crises, "this transformation requires immediate reversals in the regime of accumulation." In fact, it must "commence now with a worldwide movement toward ecosocialism—one capable from its inception of setting limits on capital." He calls for "revolutionary conservation" and a "revolutionary phase-out of carbon emissions." Similarly, Foster et al. (2011) state that any short-term actions must "go against the internal logic of [capitalism]" (Ch. 2).

This leads to another question: what constitutes "revolutionary conservation" and a "revolutionary phase-out of carbon emissions?" He does not say in the 2017 article. However, Foster et al. (2011) do offer support for three near-term policies: a carbon tax and dividend,[19] a moratorium on new coal-fired power stations, and a contraction and convergence policy (i.e., high-emitting countries decrease emissions and low-emitting countries increase emissions until they converge at a specified level). They then claim that implementation of these policies would require a revolution:

> In reality, the radical proposals discussed above, although ostensibly transition strategies, present the issue of revolutionary change. Their implementation would require a popular revolt against the system itself. A movement (or movements) powerful enough to implement such changes on the necessary scale might well be powerful enough to implement a full-scale social-ecological revolution.

In terms of the first two policies, it is unclear how they would incite a revolution. A de facto moratorium on new coal-fired power stations is already in effect, as use of coal for power in the U.S. has been on the decline since its peak in 2007 (EIA 2020b). The government could go further, e.g., phasing out use of coal in a decade. However, doing so is not anti-capitalist per se. Coal capital would certainly lose, but oil/gas and renewable energy capital would benefit. Carbon pricing is arguably the most widely discussed and

[19] Revenues from the carbon tax would be returned to the entire population in equal shares

used climate policy instrument that exists. The dividend has also increased in popularity, and is currently used in cap-and-trade programs in California and British Columbia as well as Alaska's Permanent Fund (which is for oil revenues).[20] More generally, pollution pricing is a common tool for dealing with environmental degradation in capitalist economies. In terms of the third policy, implementation may be difficult, but it is also unnecessary. A better approach would be for developed countries to share technologies and provide grants and low-cost financing to developing countries so that they could also decrease CO_2 emissions.

Malm (2018) lays out a similar, but more extensive, action plan (quoted here in full):

1. Enforce a complete moratorium on all new facilities for extracting coal, oil, or natural gas.
2. Close down all power-plants running on such fuels.
3. Draw 100% of electricity from non-fossil sources, primarily wind and solar.
4. Terminate the expansion of air, sea, and road travel; convert road and sea travel to electricity and wind; ration remaining air travel to ensure a fair distribution until it can be completely replaced with other means of transport.
5. Expand mass transit systems on all scales, from subways to intercontinental high-speed trains.
6. Limit the shipping and flying of food and systematically promote local supplies.
7. End the burning of tropical forests and initiate massive programmes for reforestation.

[20] See Boyce (2019). California's dividend takes the form of rebates to electricity consumers.

8. Refurbish old buildings with insulation and require all new ones to generate their own zero-carbon power.
9. Dismantle the meat industry and move human protein requirements towards vegetable sources.
10. Pour public investment into the development and diffusion of the most efficient and sustainable renewable energy technologies, as well as technologies for carbon dioxide removal.

Malm then states, "That would be a start—nothing more—yet it would probably amount to a revolution." Again, it is unclear why. Six of these steps—(1), (2), (3), (7), (8), and (10)—can be summarized as a 100% transition from dirty to clean energy production, raising energy efficiency levels as much as is possible, and investing in further research and development of zero- and negative-emissions technologies. Energy efficiency measures generally pay themselves back in three to five years, and a clean energy transition is very much feasible—even beneficial—economically (Pollin 2015; Jacobson et al. 2019).

The other four steps could be reformulated as decarbonizing both transportation and meat production. Within those four steps, two things seem particularly difficult in capitalism (or any system): reducing air travel and moving everyone to a vegetarian diet. However, they are also unnecessary. Air travel, for example, amounts to about 5% of global CO_2 emissions. Low-carbon jet fuels already exist and will likely become more feasible at scale in the coming decades (Prentiss 2015; Ripsin 2021). Negative emissions technologies have also made great strides technologically and may prove useful here.[21] In terms of meat-based emissions, over 60% comes from cows. Some combination of reducing beef and

[21] For example, see Hanna et al. (2021) on the potential of direct air capture.

dairy consumption and using more sustainable production practices should suffice (Troy et al. 2016). All of this can be accomplished in the Green New Deal framework, which certainly challenges the neoliberal form of capitalism, but not capitalism in general.

While the programs laid out by Foster et al. (2011) and Malm (2018) do not seem to be revolutionary, they also are not meant to be final solutions. Foster et al. (2011) and Moore (2015) are explicit that climate stabilization requires a revolution. Malm (2018) implies that a revolution is necessary by saying that his program would only be "a start," and that it would likely result in "a revolution." He also calls for "war communism" and "ecological Leninism" in Malm (2020a). Thus, the question remains: what would an ecological revolution entail? At the most general level, an ecological revolution means dismantling capitalism completely and replacing it with an ecologically sustainable and socially just society. Below, I make some inferences based on how the revolution proponents define capitalism.

A revolution would entail halting capital accumulation, the central process of capitalism. The wealth of the capitalist class—those who own most of society's productive resources—would be appropriated, and society's surplus would be controlled collectively by either (1) the workers who produced it, (2) the community in which it was produced, or (3) the entire society. Wealth and income caps would be required to prevent further capital accumulation of individuals and groups.

Private wealth is protected by property laws and law enforcement. These laws would have to be changed, which would require control of political institutions. In a democracy like the U.S., control of these institutions can come through elections or by directly taking power, i.e., a coup d'état—removing current elected (and unelected) officials from their positions of power. Both cases would require a mass anti-capitalist movement. Revolutionaries, including Foster and Malm, tend to frown upon the electoral approach, which is a longer-term reformist approach.[22] Thus, I will assume that they are in favor of building a mass anti-capitalist movement and directly taking power. To be successful, they would have to take control of the military, which would otherwise put an end to the attempted revolution.

In the event that a revolution is successful, the revolutionaries would then have to re-build the economic, political, and legal institutions that make up organized human society. There would be counter-revolution attempts by the former political and economic elites and their supporters, and likely by external forces (i.e., other countries). In the U.S., for example, they would have to deal with Wall Street, Silicon Valley, and the 74 million people who voted for Donald Trump in the 2020 election. They would also have to establish relationships with international trading partners to ensure that they can sufficiently provide for the entire population. Finally, they would have to implement policies to reduce CO_2 emissions in line with the 1.5-2 °C warming target, and create enforcement mechanisms to deal with those who do not follow the policies, e.g., fossil fuel producers and counter-revolutionaries.

Given the scale and timeframe for addressing climate change, the revolution approach is extremely unlikely to find success. Moreover, its short-term strategy, i.e., what to do before a revolution, is unnecessarily restrictive—it rejects all policies that do not go against the "logic of capital." Thus, like the degrowth approach, the revolution approach would make climate stabilization exceedingly difficult.

[22] For example, see Malm (2020a) and Foster (2018).

The Climate Change Counter-Movement

A final consideration is the climate change counter-movement, i.e., the coalition of individuals and groups who oppose action on climate change. Both the degrowth and revolution perspectives are anti-capitalist. If the climate movement were to become anti-capitalist, the climate change counter-movement would grow substantially in both size and power. It would include not only fossil fuel interests and market fundamentalists, but the capitalist class in general, including clean energy capital. On the other side, the climate movement would lose clean energy capital and other non-fossil fuel capital, as well as those who support climate stabilization but are not anti-capitalist.

To be sure, anti-capitalist sentiment has grown, at least in the U.S., encompassing about half of young people aged 18 to 29 (Elkins 2018). It is important to note, however, that many of those who are in favor of socialism likely conceptualize it in the way Bernie Sanders does, i.e., as social democracy—a regulated form of capitalism where the government plays a relatively large role in ameliorating poverty and inequality, e.g., by providing free healthcare and higher education. In contrast, more than 60% of young people in the U.S. are not only concerned about climate change, but support climate activism (Ballew et al. 2020).

At the global level, the United Nations Development Programme (UNDP) and the University of Oxford recently conducted the world's largest global survey of opinions on climate change. They found that nearly two thirds of the 1.2 million people surveyed believe climate change is a global emergency. Of the two-thirds, nearly 60% said "the world should do everything necessary and urgently in response," and just 10% said the world is doing enough already (UNDP 2021).[23]

Following the approaches of the revolution and degrowth perspectives, thus, would likely reduce the climate movement's widespread support. When combined with the far-reaching structural changes implied by each approach, as discussed above, it becomes clear that neither would make climate stabilization easier. On the contrary, following either the revolution or the degrowth approach would make climate stabilization nearly impossible.

1.2.5 Degrowth, Revolution, and the Green New Deal

The Green New Deal in the U.S. was popularized in 2018 when Alexandria Ocasio-Cortez and Ed Markey released the Green New Deal resolution (HR 109), and it continues to dominate climate policy discussions. In general terms, the Green New Deal is a policy program aimed at stabilizing the climate, creating significantly more jobs than will be lost, and prioritizing social justice in the process. The last aspect is known as the "just transition" and generally includes generous transitional support for fossil fuel industry-dependent workers and communities and prioritizing the interests of low-income and minority communities (Pollin and Callaci 2019).

The Green New Deal is widely popular among environmentalists and the general public, and enjoys ample empirical support (Pollin 2015; Jacobson et al. 2019). Political support for the Green New Deal became a condition of relevance for Democratic presidential candidates during the 2019-2020 primaries. It then shaped President Biden's climate plan, who included Alexandria Ocasio-Cortez and Varshina Prakash (director of

[23] The survey covered 50 countries accounting for 56% of the world's population and the results were weighted to create representative estimates of public opinion.

the Sunrise Movement) on his climate taskforce. In May 2021, the first part of Biden's climate plan was unveiled as part of the American Jobs Plan, which would implement an ambitious clean electricity standard (80% carbon-free by 2030), provide financial support to help utilities achieve the standard, and build 500,000 electric vehicle charging stations. In total, about $1 trillion is committed to climate stabilization efforts over 8 years, about 0.5% of U.S. GDP per year. The American Jobs Plan is not itself a Green New Deal, but it has been shaped by the movement for a Green New Deal and can be seen as a useful starting point for a more extensive Green New Deal program. Such a program is, for the first time, within reach in the U.S.

Despite all of this, degrowth and revolution proponents offer only lukewarm support at best. At worst, they act as an impediment to the Green New Deal's success. For example, Mastini et al. (2021) argue for a Green New Deal without growth. They understand that this is radically different from the Green New Deal as conceptualized in HR 109, which embraces economic growth in its calls to "spur economic development" and "grow domestic manufacturing" (5). Degrowth proponents tend to call for "a more radical restructuring of social organization in the mold of transition towns, low-impact living, ecoregions with minimal trade, etc." This "obviously chokes with the more statist spirt of a [Green New Deal], with its emphasis on technology, big infrastructures and large flows of money, and on jobs and salaries" (7). Thus, they see the Green New Deal *without growth* as a "revolutionary reform," i.e., a reform that leads radical structural change. They believe degrowth proponents should not "accept [the Green New Deal] acritically…but rather hijack it towards more radical positions."

Juliet Schor and Andrew Jorgenson (2019b) similarly call for a Green New Deal without growth, while Tim Jackson and Peter Victor—the two leading figures of the degrowth camp—are practically silent on the Green New Deal.[24]

John Bellamy Foster, the leading scholar advocating revolution, responded to HR 109 in a 2019 interview:

> I am impressed by some aspects of it….But none of this will really work, even if it were possible to legislate it, given the system, unless it takes on the character of an ecological revolution with a broad social base….A radical Green New Deal is, at best, just the entry point to such wider, eco-revolutionary change.

The only aspects of HR 109 Foster spoke favorably about were the calls for mass mobilization, public banking, and higher taxes for the rich. Jason Moore expresses even more doubt, also in a 2019 interview:

> Is the Green New Deal, understood as a new set of demands for economic and environmental justice, a break with the 'jobs vs. environment' rift that has dominated since the 1970s? Maybe. But the iron grip of 'sustainable development' has yet to be broken—the social democratic petrofantasy that endless accumulation can coexist with diversity and well-being in the web of life. I'm also wary of the historical metaphor….The New Deal was an effort by relatively enlightened ruling strata to contain workers' power.

Andreas Malm discussed the Green New Deal briefly in a 2021 interview, suggesting that it may be a waste of activist energy: "Who knows if in five or ten years

[24] I conducted basic Google searches and did not find anything. Moreover, Victor's 2019 book does not even mention the term "Green New Deal." Jackson (2016) briefly discusses calls for a Green New Deal in the aftermath of the 2008 economic crisis.

people will look back at the Green New Deal as a waste of activist energy because it wasn't radical enough?" However, unlike the others, he does caution against opposition to the Green New Deal. If it has a real chance of succeeding, he says, "then I would be the first to caution impatient, militant climate activists not to do anything that can damage this campaign and the momentum behind it."

Examining the degrowth and revolution perspectives in relation to the Green New Deal highlights the importance of the key question in this paper: are the degrowth and revolution proponents right? Does solving the immediate crisis of climate change require moving beyond capitalism? If so, the Green New Deal will not work. While it poses a major challenge to neoliberal capitalism—a variant of capitalism characterized by the domination of capital over labor, deregulated markets, and privatization of the public sector (Kotz 2015)—the Green New Deal does not challenge capitalism in general. If they are wrong—and I have argued they are—then climate stabilization programs like the Green New Deal are likely humanity's best chance of averting the climate emergency, and revolution and degrowth proponents risk damaging progress. This damage comes in at least three forms: (1) the degrowth and revolution proponents themselves, some of the most committed climate activists, will choose not to put their energy towards a Green New Deal; (2) sowing doubt and division more broadly among the coalition of support for the Green New Deal; and (3) making claims that support the idea that there are tradeoffs between a healthy economy and a healthy environment, a view also espoused by fossil fuel corporations and other defenders of the status quo.

On the third issue, Kallis (2019) is a case in point. Kallis acknowledges the potential risks of implementing a degrowth program within a capitalist economy, including "rising poverty, inequality, debts, austerity, etc." He therefore supports dismantling and replacing capitalism. Nonetheless, he also implies that we need degrowth, even if it does lead to mass suffering: "Should we support capitalism forever, just because a collapsing capitalism is worse for workers than a capitalism that does well?" This view is in itself an obstacle to climate stabilization.

1.3 An Alternative Theoretical Framework

I have argued that the degrowth and revolution perspectives are far from convincing. They rely on unwarranted assumptions and lack basic evidence. At the same time, world governments have yet to act at the scale and pace needed to sufficiently address the climate crisis. Global carbon emissions continue to rise year after year, the only exceptions coming during global economic crises (Osaka 2020). The climate impasse does not stem from lack of cost-effective socio-technical solutions (IPCC 2018b; Jacobson and Delucchi 2011; Delucchi and Jacobson 2011; Jacobson et al. 2017; Prentiss 2015), nor does it stem from lack of overall economic resources (Pollin 2015; Chomsky and Pollin 2020; Jacobson et al. 2019) or public demand (UNDP 2021; Ballew et al. 2020; Laville and Watts 2019). I argue that while capitalism itself is not an insurmountable obstacle to sufficient action on climate change, the obstacles at the root of the climate impasse, i.e., continued global inaction on climate change, still lie in the realm of political economy. This section outlines the main theoretical issue with the degrowth and revolution perspectives and proposes an alternative perspective, or theoretical framework, for identifying, analyzing, and overcoming the political economic obstacles to climate stabilization.

1.3.1 Theoretical Critique of Degrowth and Revolution

Ecological Marxists and ecological economists argue convincingly that capitalism, the predominant economic system across the world, is inherently environmentally unsustainable. It is worth briefly laying out their arguments and evidence. Capitalism is an economic system based on never-ending accumulation of exchange-values via profit-making and, by extension, economic growth. Central to profit-making is the continual increasing of material throughput without tending to the regenerative needs of extra-human nature. Indeed, general material throughput is tightly correlated with GDP (Jackson 2016; Hickel and Kallis 2019), and environmental crises are accumulating. Humanity has transgressed four planetary boundaries, including two core boundaries (climate change and biodiversity loss) (Steffen et al. 2015). Earth Overshoot Day—the calendar day on which humanity uses up more resources than Earth can regenerate based on current production practices—moves up every year and is expected to fall on July 29 in 2021 (Global Footprint Network 2021). One can point to instances of environmental improvement, such as the Montreal Protocol to phase-out CFCs and the U.S. Acid Rain Program to reduce sulfur dioxide emissions, but they are dwarfed by the strong tendency towards environmental degradation. It is difficult to see, therefore, how civilization could achieve general environmental sustainability as long as capitalism dominates the world economy.

Where degrowth and revolution proponents falter is in taking the general analysis of ecological economics and ecological Marxism and attempting to apply it to one specific environmental crisis: climate change. I examined their argument in Sections 1.2.1 and 1.2.2, finding that they do not hold up under scrutiny. They rely on unwarranted assumptions, e.g., that future CO_2 decoupling rates cannot exceed historical rates or that clean energy cannot support economic growth, and lack basic evidence to support their big claims, e.g., that degrowth or revolutionary strategies would make decarbonization easier. In the long-run, capitalism must be challenged. But right now, in the short- to medium-term, carbon-emitting activities must be challenged. They argue that these two struggles, i.e., anti-capitalist struggle and climate struggle, are one in the same. That movements for climate stabilization must be anti-capitalist. While the struggles do overlap, I show that climate stabilization very likely does not require dismantling and replacing capitalism. This turns out to be a good thing given the short timeframe humanity has to avert the worst impacts of climate change, which can be described as truly existential. Climate stabilization alone will not bring general environmental sustainability, but it is a precondition of sustainability—failing to stabilize the climate will leave little for humanity to fight for.

1.3.2 Theoretical Framework

Research on obstacles to climate stabilization requires disaggregation of both environmental degradation and capitalism, i.e., understanding the particular requirements for climate stabilization within historically-specific economic systems. My theoretical framework is rooted in political economy, which I define as the exploration of economic activities—the production, distribution, and consumption of wealth and "illth"—as processes that shape, and are shaped by, relations of power. "Wealth" refers to all natural and produced resources and services that provide use-value to people, whereas "illth" refers to the negative use-values caused by economic processes, including climate change.

Boyce (2007) outlines five dimensions of power that describe how individuals and groups influence social-decision-making. The first dimension is economic power—often called "purchasing power"—which is wielded by those who have disproportionate levels of income and wealth. There are then four dimensions of political power: decision power, agenda power, value power, and event power. A person or group wields decision power if they have a vote on final decisions; agenda power if they can set the agenda for the voters; value power if they have outsized influence on voters' preferences; and event power if they play a role in determining the conditions under which people make decisions. As noted by Boyce (2007), economic power and political power are highly correlated. Economic power can be used to gain political power through, for example, making or threatening to withhold donations to political organizations or campaigns. In a similar way, political power can be used to rig the rules of the economy in favor of the already rich and powerful.

My theoretical framework, drawing on relations of power, consists of four interrelated dimensions:

1. Climate stabilization pathways
2. Economic, political, and cultural institutions
3. Coalitions of opposition and support
4. Political strategy

The goal in this section is simply to provide an outline of my framework, which can be used to help guide future research on the political economy of global inaction on climate change.

1.3.2.1 Climate Stabilization Pathways

The first dimension is climate stabilization pathways. That is, considering the technical and resource requirements of climate stabilization as well as the policy program that can bring it about. For example, Pollin (2015; 2019b) proposes the following:

1. Greenhouse gas emissions reductions in line with the 1.5 °C warming target (i.e., 45% reduction by 2030 and net-zero by 2050).
2. Policies and regulations to induce the necessary clean energy investments, which amount to 2.5% of GDP per year—e.g., subsidies, feed-in-tariffs, low-cost financing, public investments, and public procurement policies.
3. Policies and regulations to phaseout fossil fuels in line with the emissions reduction targets. Following the recommendation of Boyce (2019), this would be anchored by a hard cap-and-dividend policy.[25]
4. A just transition for fossil fuel industry-dependent workers and communities, including up to three years of full income support, guaranteed pensions, job training, and job placement in the clean energy sector within three years (just transition costs are included in 2.5% of GDP).[26]

However, there are many possible scenarios. In terms of technologies, Pollin (2015) and Jacobson et al. (2019) argue that neither nuclear power nor negative emissions technologies would be needed. Most scenarios considered by the IPCC (2018a), however, do rely on negative emissions technologies. The extent to which negative emissions technologies in particular are used has major implications for the speed at which fossil fuel production would need to be phased out.

Several environmental organizations in the U.S.—including 350.org, Sunrise Movement, and Friends of the Earth—recently released a report arguing that the U.S.

[25] A cap-and-dividend policy places a hard cap on emissions (ratcheted up each year), auctions allowable emission permits, and returns the auction revenues to residents in equal shares.

[26] As Pollin and Callaci (2019) show, the cost of a just transition program is a tiny fraction of the overall cost of a Green New Deal.

should reduce emissions faster than what is required for the world as a whole. They argue for emissions reductions of 70% by 2030 domestically, and that the U.S. should provide support to developing nations that would induce additional emissions reductions equal to 125% of the U.S.'s current emissions. They base these figures on an estimation of the U.S.'s contribution to causing climate change (Reyes et al. 2021).

Another conception of the Green New Deal is put forth by Ocasio-Cortez and Markey in the Green New Deal resolution, discussed in Section 1.2.5 (Ocasio-Cortez 2019). They define the just transition more broadly to include measures like universal healthcare, a job guarantee, and addressing the racial wealth gap. Klein (2019) argues in favor of this approach on grounds that it would help to build a broader and more powerful grassroots movement for the Green New Deal.

Examining the political economy of global inaction on climate change requires understanding the similarities and differences between the various climate stabilization pathways, and choosing one or more pathways to focus on. Each pathway comes with its own set of political economic obstacles.

1.3.2.2 Social Institutions

I argue that (1) climate stabilization likely does not require moving beyond capitalism; and (2) dismantling and replacing capitalism in the U.S., let alone the entire world, is extremely unlikely within the short timeframe humanity has to solve climate change. My starting point, therefore, is to treat capitalism *in general* as a constraint. In other words, the central process driving capitalist economies, i.e., capital accumulation, and the core institutions that reproduce it (private ownership of productive resources, competitive markets, wage labor, and the social imperative to accumulate) will not be dismantled in the short- to medium-term. The economic, political, and cultural institutions that make up and support a *particular* capitalist society, on the other hand, like the U.S., are malleable within the general capitalist constraint.

To understand the malleability of institution within capitalism, I draw on social structure of accumulation theory. It was first developed by Gordon et al. (1982), who argued that analysis of capitalism tended to be too general to be applied to historically specific versions of capitalism. A social structure of accumulation (SSA) is a set of economic, political, and cultural institutions that promotes stable capital accumulation and profit-making. The goal of SSA theory was to understand and explain long waves of capitalist expansion and crisis, but it also has applications for understanding climate stabilization in capitalist economies.

For example, Kotz (2015) contrasts the postwar period (1945-1980) with the neoliberal period (1980-present) in the U.S. The postwar era was characterized by a capital-labor accord and a capital-citizen accord. Unions expelled their radical members and businesses agreed to peaceful bargaining over wages and benefits. The government maintained and increased social welfare programs. The postwar era was also characterized by co-respective behavior among capitalists and heavy government regulation of markets and finance, which eschewed price wars and led to Keynesian demand-side government policies, anti-trust laws, and a financial sector tied to the real sector (i.e., less speculative). These institutions came together to create a regulated form of capitalism with rising real wages, rapid productivity growth, a generous social safety net, and high profits.

The neoliberal SSA, on the other hand, is characterized by domination of capital over labor (e.g., stagnant wages and low unionization rates), cuts to and stigmatization of social welfare programs, economic and financial deregulation, privatization of the public sector, and general pro-market and anti-government sentiment. It is also characterized by an important contradiction, where the economic elite depend substantially on government support themselves via, for example, subsidies and economic crisis-relief. The neoliberal SSA formed in response to the profitability crisis of the 1970s, and succeeded in restoring high profits, and therefore capital accumulation. It is not difficult to see why the neoliberal period, during which climate change entered the public sphere, is less than ideal for implementing a Green New Deal, moderate or radical. Naomi Klein (2015b), for example, writes, "Climate change…landed on the public agenda at the peak of free market, end-of-history triumphalism" (Conclusion).

Climate stabilization will require institutional change. The task in the second dimension of the framework, then, is to identify institutions that are inhibiting progress on climate stabilization as well as potential ways to overcome them, within the general framework of capitalism. For example, any kind of Green New Deal in the U.S. will require major legislative victories at the federal level. Even though two-thirds of Americans want more federal action on climate change, federal climate legislation up until now has been extremely weak (Funk and Kennedy 2020). Thus, there are obstacles within the institutions that are supposed to translate what the majority of Americans want into policy.

To give a concrete example, take the U.S. Senate. North Dakota and South Dakota have the same representation in the Senate as California and New York. That is, those who are opposed to action on climate change are over-represented. While the nature of the Senate is likely to change, one change that could ameliorate the problem is ending or reforming the cloture rule (i.e., filibuster), which allows the minority party to block most legislation without a 60% majority. The legislature could also then take action to end gerrymandering and expand voting access (e.g., by passing HR 1 in the 117th Congress), which may help to ensure that U.S. Congressmembers are more representative of the U.S. population.

Another example of an institutional obstacle is the anti-interventionist conception of government that is characteristic of neoliberal capitalism. According to Mazzucato (2015), it is the interventionist governments that have been most successful in promoting innovation and growth. Some of the key characteristics of these governments are as follows: providing strategic vision for researchers and firms; identifying and funding the most promising technologies, companies, and researchers; and implementing strong industrial policies to allow for new industries to become competitive. Climate stabilization, which will involve completely remaking the energy system over a period of just three decades, will require an interventionist state.

1.3.2.3 Coalitions of Opposition and Support

Capitalist economies today are full of inequalities, including inequalities based on class, race, gender, and citizenship. For example, the world's billionaire class, consisting of just over 2,000 people, has more wealth than the world's poorest 4.6 billion people, who make-up 60% of the population (Oxfam 2020). Major transitions, like climate stabilization, are also unequal. There will be winners, e.g., the clean energy industry, and losers, e.g., the fossil fuel industry. The third dimension of my framework is to parse out the coalitions of opposition and support for climate stabilization. This task includes identifying these coalitions as they exist today, as well as searching for opportunities to expand and strengthen the coalition of support, and shrink and weaken the coalition of opposition.

Coalitional analysis should be based on economic, political, and ideological interests. For example, the fossil fuel industry and auto-manufacturers have an economic interest in opposing climate stabilization programs that are based on decarbonization (as opposed to geoengineering).[27] At least some fossil fuel workers, however, actually support a Green New Deal with a just transition (Roth 2021). Market fundamentalists will likely oppose any climate stabilization pathway that requires an interventionist government (they may support a geoengineering approach). According to Dunlap and McCright (2016), political party affiliation is the most important factor determining individuals' climate attitudes in the U.S. (Dunlap and McCright 2016). Brulle et al. (2012) found that structural economic factors were also important—increases in unemployment and decreases in GDP negatively impacted climate attitudes.

In addition to understanding the make-up of the coalitions of opposition and support, it is important to analyze the relations of power between them. While most people the world over are worried about climate change and want action on climate change, the opposition to climate stabilization is wealthy and powerful,[28] and constitutes the chief obstacle to climate stabilization.

1.3.2.4 Political Strategy

The final dimension of the framework is political strategy: discerning how to overcome the institutional and coalitional obstacles to climate stabilization. It is important to note that all of the dimensions are interdependent. Feasible political strategies, for example, will depend on the climate stabilization pathway, the particular institutional

[27] See Chapter 2.

[28] See Chapter 2 for a discussion on the wealth and power of the fossil fuel industry in particular.

context, and the current state of coalitions of opposition and support. Similarly, feasible climate stabilization pathways will depend on the array of social institutions and coalitions of opposition and support. The framework, thus, is not linear. The four dimensions must be considered together.

1.4 Conclusion

Degrowth and revolution proponents argue that climate stabilization will require moving beyond capitalism. They are convincing in arguing that capitalism cannot be sustainable in general. They falter, however, on the issue of climate stabilization in particular. They present no credible evidence to support their claims that climate stabilization means the end of capitalism. Evidence does, however, support the feasibility of Green New Deal-like policy programs within capitalist economies.

This essay is not a defense of capitalism. There are many other reasons to oppose capitalism, including that it tends to produce economic and social inequality and degrade the environment in multiple dimensions. However, climate change, which has been deemed a climate emergency by more than 11,000 scientists (Ripple et al. 2020), requires unprecedented action in the short- and medium-term. Having to also dismantle and replace capitalism—a centuries-old economic system that has survived many revolution attempts—would only make climate stabilization more difficult, bordering on impossible. In this context, making claims that degrowth or revolution is necessary to avert climate change is at best distracting, and at worst damaging to the struggle for climate stabilization. Indeed, all of the degrowth and revolution proponents I surveyed, many of whom are highly influential among academics and activists, were either critical of or silent on the Green New Deal that emerged in 2018 in the U.S.

Even though climate stabilization will likely have to occur within capitalism, it will not be automatic, and it will still require significant institutional change. To aid in navigating this process, I outlined a theoretical framework for identifying and analyzing political economic obstacles to climate stabilization within capitalism. Overcoming these obstacles is the most important task humanity faces.

1.5 Tables and Figures

Table 1.1: Decoupling rates for various scenarios					
CO_2 Emissions Reduction Target	Decoupling rate by annual GDP growth rate (*g*)				
	g=2.1%	*g*=0%	*g*=-0.5%	*g*=-1%	*g*=-5%
90% by 2050	9.6%	7.7%	7.2%	6.7%	2.8%
95% by 2050	11.7%	9.9%	9.4%	8.9%	5.1%
90% by 2035	17.0%	15.2%	14.8%	14.3%	10.7%
95% by 2035	21.0%	19.3%	18.9%	18.5%	15.0%
~1.5 °C (average of 95% by 2050 and 90% by 2035)	14.4%	12.6%	12.1%	11.6%	7.9%

Source: Author's calculations

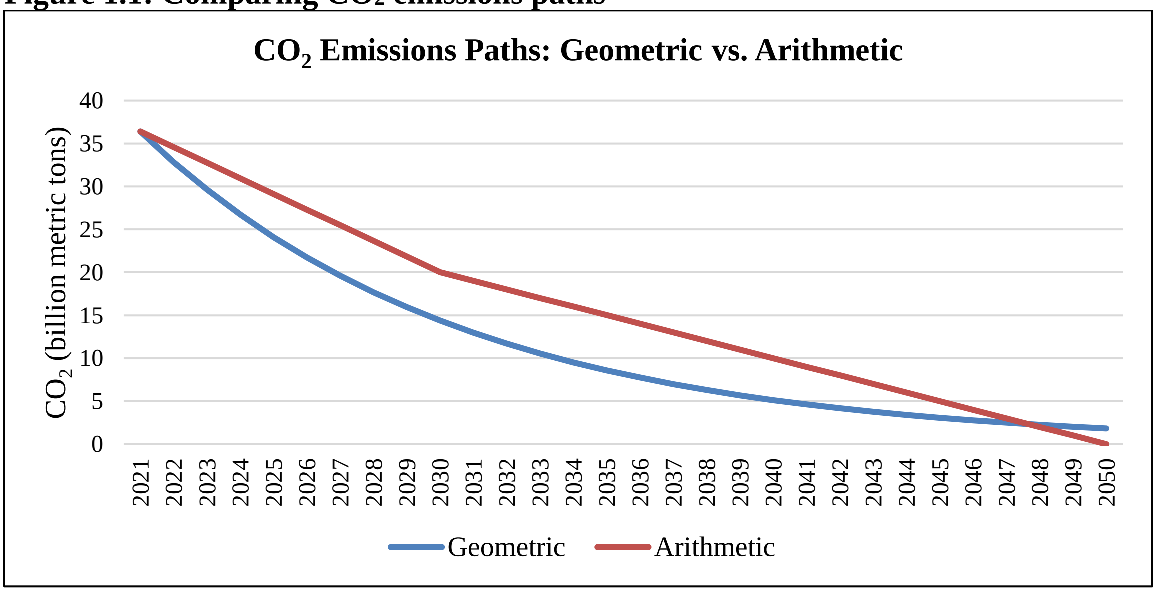
Table 1.2: Size of global GDP in 2050 relative to 2016 for various GDP (de)growth rates	
Annual GDP growth rate	Size of economy in 2050 (GDP in 2016 = 1)
2.1%	1.83
0%	1.00
-0.5%	0.86
-1%	0.74
-5%	0.22

Source: Author's calculations

Table 1.3: Impacts of degrowth for the world's ten largest economies in 2050 (2019 USD, T=Trillion)								
	GDP data for 2019		GDP per capita equalized to $15,680 in 2050 (0% annual GDP growth)		GDP per capita equalized to $11,100 in 2050 (-1% annual GDP growth)		GDP per capita equalized to $2,700 in 2050 (-5% annual GDP growth)	
Country	GDP	GDP per capita	GDP	Percent Change	GDP	Percent Change	GDP	Percent Change
US	$21.4 T	$65,298	$5.1 T	-76%	$3.6 T	-83%	$0.9 T	-96%
China	$14.3 T	$10,262	$21.9 T	53%	$15.5 T	8%	$3.8 T	-74%
Japan	$5.1 T	$40,247	$2.0 T	-61%	$1.4 T	-72%	$0.3 T	-93%
Germany	$3.9 T	$46,445	$1.3 T	-66%	$0.9 T	-76%	$0.2 T	-94%
India	$2.9 T	$2,100	$21.4 T	647%	$15.2 T	429%	$3.7 T	29%
UK	$2.8 T	$42,330	$1.0 T	-63%	$0.7 T	-74%	$0.2 T	-94%
France	$2.7 T	$40,494	$1.1 T	-61%	$0.7 T	-73%	$0.2 T	-93%
Italy	$2.0 T	$33,228	$0.9 T	-53%	$0.7 T	-67%	$0.2 T	-92%
Brazil	$1.8 T	$8,717	$3.3 T	80%	$2.3 T	27%	$0.6 T	-69%
Canada	$1.7 T	$46,195	$0.6 T	-66%	$0.4 T	-76%	$0.1 T	-94%
Total	**$58.7 T**		**$58.7 T**	**0%**	**$41.6 T**	**-29.2%**	**$10.1 T**	**-82.8%**

Sources: World Bank (2021b), author's calculations

Figure 1.1: Comparing CO_2 emissions paths



Source: Author's calculations

Table 1.4: Average decoupling rate by annual GDP growth rate (*g*) for the arithmetic model						
	1.5 °C			2 °C		
	g = 2.1%	*g* = 0%	*g* = -1%	*g* = 2.1%	*g* = 0%	*g* = -1%
2022-2030	8.3%	6.4%	5.5%	5.1%	3.1%	2.2%
2031-2040	8.6%	6.7%	5.7%	4.8%	2.8%	1.9%
2041-2050	30.7%	29.3%	28.6%	5.9%	4.0%	3.0%
2051-2070	0%	0%	0%	19.7%	18.0%	17.2%

Source: Author's calculations

CHAPTER 2

STRANDED ASSETS AND REDUCED PROFITS: ANALYZING THE ECONOMIC UNDERPINNINGS OF THE FOSSIL FUEL INDUSTRY'S RESISTANCE TO CLIMATE STABILIZATION

2.1 Introduction

The 2015 Paris Agreement sought to minimize the risk of future climate devastation by committing governments to limiting the rise in global average temperature to 1.5-2 °C above preindustrial levels (UNFCCC 2016). In the years since, governments in all regions of the world have continually failed to act at the scale and pace necessary to achieve this target.[29] In January 2020, a group of more than 11,000 scientists warned "clearly and unequivocally" that Earth is now facing a "climate emergency" (Ripple et al. 2020, 8). This paper examines one key constraint on global action to combat climate change: the resistance mounted by the fossil fuel industry, which has continued to expand fossil fuel production and has allocated substantial resources toward impeding climate stabilization efforts.

The economic losses the fossil fuel industry is likely to incur as a result of a transition from fossil fuels to clean energy include stranded assets (i.e., assets that suffer an unanticipated devaluation) and a reduction in profitability. The assets at risk include fossil fuel reserves—the large quantities of oil, gas, and coal still in the ground—and the capital goods used to extract and process them, including machinery, tools, and built

[29] Greenhouse gas emissions continue to rise, and even with the concrete mitigation commitments made by governments as part of the Agreement, the IEA (2019c) expects GHG emissions to continue rising through at least 2040.

infrastructure. Using a methodology that emulates the expectations and valuation procedures used by fossil fuel firms, I estimate the magnitude of wealth losses from stranded assets under 2 °C and 1.5 °C climate stabilization scenarios, and the distribution of these losses by region, between private firms and governments, and among the oil and gas majors.[30] I also compare profits, profit margins, and market capitalization between fossil fuel and renewable energy firms for the period 2010-2019. My analysis focuses on firms and governments involved in fossil fuel extraction, known as the "upstream fossil fuel industry". The results shed light on the economic stakes that help to explain the fossil fuel industry's past and future resistance to climate stabilization, and provide clues on how to overcome it.

The stranded assets analysis indicates that fossil fuel reserves will suffer a devaluation of 37%-44%, amounting to losses of $13-$15 trillion, while the losses due to stranded investments in capital goods will be comparatively minimal. Together these two findings imply a strong economic incentive to continue on the path of resistance. About half (45%-63%) of the devaluation in reserves stems not from fossil fuels left in the ground but from price decreases for reserves still extracted and sold during climate stabilization, leading to the conclusion that even low-cost producers will bear significant losses. The distributional analysis reveals that 76% of stranded assets belong to governments, suggesting that the political obstacles to climate policies will be especially high in nations with nationalized ownership of substantial fossil fuel reserves. This implies that actions that reduce demand from their trading partners is likely to be crucial for climate

[30] BP, Chevron, ConocoPhillips, Eni, ExxonMobil, Shell, and Total.

stabilization. A comparative analysis shows that fossil fuel firms remain substantially more profitable than renewable energy firms, reinforcing the above conclusions.

This paper is organized as follows: Section 2.2 reviews the relevant literature on the fossil fuel industry's resistance to climate stabilization. Section 2.3 outlines the methods and data employed for the stranded assets analysis. Section 2.4 presents the results of the stranded assets analysis. Section 2.5 presents the results of the energy industry comparative analysis. Section 2.6 concludes with a discussion of the implications of the results for strategies to overcome resistance to effective climate stabilization policies.

2.2 Fossil Fuel Industry Resistance to Climate Stabilization

Climate change entered the public sphere in 1988, when eminent climate scientist James Hansen testified before U.S. Congress on the existence and consequences of human-induced global warming, and the United Nations and World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC). The fossil fuel industry was already well aware of the causes and consequences of climate change (Banerjee et al. 2015, Banerjee 2015; Young 2019). Nonetheless, they responded by vehemently resisting climate stabilization efforts. This resistance takes two broad forms: (1) economic resistance, entailing the continued expansion of fossil fuel operations despite the clear need for the opposite; and (2) political resistance, comprising of efforts aimed at impeding government action to combat climate change.

2.2.1 Economic Resistance

According to the International Energy Agency (IEA) (2020a), the world's largest oil and gas firms allocated just 0.5%-0.8% of capital expenditures toward clean energy from 2015-2019. These investments accounted for a negligible share of investments in all clean energy technologies, with one exception: carbon capture and storage (CCS). CCS technology removes and stores carbon emissions resulting from fossil fuel combustion, thereby prolonging the potential use of fossil fuels in a climate stabilization scenario. CCS, however, remains expensive and unproven on a large scale.

The limited available evidence on coal companies' investments suggests that the industry remains strongly committed to coal. Despite the drop in coal-fired power generation from 2018 to 2019, global coal supply actually increased by 15%. The IEA (2020c) explains the apparent contradiction as follows:

> Coal still represents more than one-third of global electricity generation and remains the second-largest fuel in the global energy mix after oil and the second-largest traded bulk commodity after iron ore. Investments are being proposed on that basis, in response to economic signals coming from the coal market (65).

Amidst growing public pressure to address climate change and the economic struggles induced by COVID-19, several European oil and gas firms, including BP, Eni, Shell, and Total, have made greenhouse gas (GHG) reduction commitments to signal that they are taking climate change seriously. However, none are consistent with the 1.5-2 °C target, and the commitments from BP, Shell, and Total in particular are misleading. Shell excludes all emissions from its products, Total excludes emission from its products sold outside Europe, and BP excludes its 20% stake in Rosneft, accounting for 40% of BP's oil production and 15% of its gas production (Kusnetz 2020; Carbon Tracker 2020). Whether these commitments are credible remains to be seen. BP made similar commitments in the early 2000s through its "Beyond Petroleum" campaign, but abandoned it due to low returns on renewable energy (Kusnetz 2020). As shown in Section 2.5, low returns continues to plague the renewable energy industry today.

2.2.2 Political Resistance

Political resistance to climate stabilization exists among both private firms and government producers. In the private sector, political resistance comes in three forms: misinformation campaigns, political lobbying, and corporate promotional activities. Climate change misinformation is produced by a network of conservative think tanks and front groups (i.e., "social movement organizations" created by fossil fuel interests), which are largely funded by the fossil fuel industry and other fossil fuel interests (McCright 2011). Farrell (2016a; 2016b) found evidence that in addition to funding the contrarian network, fossil fuel firms have played an active role in determining the content of misinformation. Boussalis and Coan (2016)—the most recent assessment of the amount of climate change misinformation produced over time—found that misinformation grew substantially from 1998-2013, and showed no signs of slowing down.

Political lobbying involves allocating resources toward directly influencing government decision-making, while corporate promotional activities, such as advertising, serves as a form of greenwashing—efforts aimed at changing the public's perception of the fossil fuel industry as a polluter. Brulle (2018) finds that fossil fuel interests, including the fossil fuel industry, consistently outspend clean energy interests on political lobbying by a ratio of ten to one. To exemplify the level of corporate promotion in the fossil fuel industry, Kalhoefer (2016) calculated the ratio of industry advertisements to climate change news coverage on CNN for one week. Fossil fuel ads were given five times as much air time as climate coverage. Brulle et al. (2020) analyzed the advertising spending of five oil and gas firms—ExxonMobil, Shell, Chevron, BP, and ConocoPhillips—and found that average annual per company spending increased from $35 million to $216 million between 1986 and 2016. For both lobbying and advertising, proposed climate legislation was the most important determinant of the levels of annual expenditures (Brulle 2018; Brulle et al. 2020). For example, from 2007-2010—the period with the highest amount of proposed climate legislation—political lobbying from fossil fuel interests accounted for nearly 10% of all lobbying expenditures in the U.S. (Brulle 2018).

Political resistance also exists among government producers, yet very little has been written about it. This is likely due to the secretive nature of state-owned fossil fuel firms. While private firms must lobby government officials to influence policy, state-owned firms are controlled by, and operate for the benefit of, government officials. Many private firms, including large publicly-listed corporations, must disclose substantial amounts of information about their economic and political activities. State-owned firms can operate mostly behind closed doors.

Harvey (2019) illustrates this point with two examples. First, the Natural Resource Governance Institute (NRGI) recently published the National Oil Company Database after three years of research. According to the lead author, Patrick Heller, less than one-third of state-owned oil and gas firms disclosed enough information to fill out the “key indicators” that he argued were necessary for public accountability (Harvey 2019). Second, *The Guardian* in 2019 asked 12 of the largest state-owned fossil fuel firms about their plans for meeting the goals of the Paris Agreement, which their countries had signed. The only firm to respond was Petrobras of Brazil, and the response was short and rehearsed, simply stating that the firm is planning to cut carbon emissions from its operations (not from its products) (Harvey 2019).

Despite the secrecy, Michael Mann (2021) points to several anecdotes of oil states engaging in political resistance to climate stabilization:

1. In 1995, the governments of Saudi Arabia and Kuwait successfully changed some of the language of the IPCC's 1995 Second Assessment report. IPCC scientists had originally stated in the "Summary for Policymakers"—the most widely read part of the report—that humans were having an "appreciable" influence on the climate. That word was watered down to "discernible."
2. Fifteen years later, the governments of Saudi Arabia and Russia played an important role in promoting the false allegations of "Climategate"[31] (Mann 2021).
3. More recently, Russia, Saudi Arabia, and Kuwait joined the U.S. in refusing to support an official motion at the 2018 United Nations Climate Change Conference in Poland to "embrace" the IPCC's (2018b) special report on the consequences of 1.5 °C of warming.

More generally, Johnsson et al. (2019) finds that countries with large levels of fossil fuel reserves, which include mostly countries with nationalized fossil fuel ownership, are doing less to address climate change than countries with small levels of reserves. State-owned fossil fuel firms' resistance to climate stabilization is an important area for further research. According to the NRGI (2021), if these firms alone follow through on planned fossil fuel investments, the 1.5-2 °C target would become unachievable.

[31] Thousands of emails from climate scientists were stolen from a private computer and misrepresented to suggest that climate change was a hoax.

2.2.3 Effectiveness

Evidence suggests that resistance to climate stabilization has been effective. A 2001 memorandum from a top U.S. State Dept. official suggests that the Global Climate Coalition, an anti-climate change front group created by fossil fuel firms and related interests, played a pivotal role in the George W. Bush's decision to reject the Kyoto Protocol, i.e., the first major international agreement aimed at combating climate change (DeSmog 2020). Climate change misinformation campaigns have successfully created a rift between climate science and the public. For example, from 2007 to 2011, the percent of the U.S. population that believed human-induced climate change was real decreased from 71% to 54%. Similar trends were found in the U.K. and Australia (Klein 2015a). These percentages have since increased, e.g., 80% in the U.S. in 2019 (Funk and Hefferon 2019), but still fall short of the scientific consensus comprising 97% of publishing climate scientists (Cook et al. 2016). In a more general analysis, Johnsson et al. (2019) finds that nations with large fossil fuel endowments have accomplished significantly less than nations with small fossil fuel endowments.

2.2.4 The Economic Underpinnings of Resistance

In any economic system where an economic elite holds a very large share of society's wealth, members of that elite can be expected to act at great lengths to protect their hold on wealth and power. Today's economic elite includes those who wield power in the fossil fuel industry: the chief executives, major shareholders, and boards of directors of private firms, and senior officials in governments with nationalized fossil fuel production. As an example of the sector's immense wealth, on average five of the top ten firms in Fortune's Global 500 list—a ranking of the world's largest companies based on revenue—from 2010 to 2020 were oil and gas producers. This includes five firms in fiscal year 2020, despite the pandemic-induced crash in oil prices (Fortune 2020). Saudi Aramco—Saudi Arabia's state-owned oil company—remained the world's most profitable company by a sizable margin in 2020.

Climate stabilization poses an existential threat to humanity, but it also poses an existential threat to current and future fossil fuel wealth. It is the latter that motivates the industry to resist climate stabilization, a premise well-established in the literature (Farrell et al. 2019; Banerjee 2015; Jennings et al. 2015; Brulle et al. 2012; Dunlap and McCright 2011). Understanding how to overcome the industry's resistance therefore requires a careful analysis of its economic motivations, i.e., the wealth and profits at stake. Sections 2.3-2.5 undertake this task.

2.3 Method and Data for Stranded Assets Analysis

2.3.1 Estimating Losses from Stranded Assets

Two types of assets are at risk of becoming stranded from climate stabilization: (1) fossil fuel reserves, and (2) the capital goods used to extract, process, and transport fossil fuel reserves. The loss of wealth from stranded assets (*SA*) for each fuel (*i*) is equal to the sum of wealth losses from stranded reserves (*SR*) and stranded capital (*SC*). This is shown in equation (2.1). The terms "stranded reserves" and "stranded capital" refer to stranded assets in the forms of fossil fuel reserves and capital goods, respectively.

$$SA_i = SR_i + SC_i \tag{2.1}$$

Wealth losses from stranded reserves (*SR*) and stranded capital (*SC*) are estimated through scenario comparison, as shown in equations (2.2) and (2.3). The value of reserves (*VR*) and the value of capital goods (*VC*) are estimated in a baseline scenario and a climate stabilization scenario, denoted with subscripts *BS* and *CSS*, respectively. The baseline scenario represents a future in which current trends in fossil fuel supply and demand continue with minimal changes, whereas the climate stabilization scenario represents a future that is consistent with the 1.5-2 °C climate stabilization target.

$$SR_i = VR_{i,BS} - VR_{i,CSS} \tag{2.2}$$

$$SC_i = VC_{i,BS} - VC_{i,CSS} \tag{2.3}$$

Stranded capital can be further disaggregated into losses from stranding existing capital goods and losses from stranding investments in future capital goods. If industry refrains from overinvesting in the future, stranded capital from climate stabilization is limited to the existing capital goods left unused. The magnitude of future capital expenditures at risk is difficult to quantify. If the world transitions from the baseline scenario to the climate stabilization scenario, firms will transition their future capital expenditures accordingly. One way to assess future capital expenditures at risk is in terms of the potential time lag between when governments implement climate stabilization measures, and when industry transitions capital expenditures to be consistent with those measures. In other words, if governments shift policies from the baseline scenario to a climate stabilization scenario—either 1.5 °C or 2 °C—it may take some time before industry follows suit. I call this the "government-industry time lag". Wealth losses from future capital expenditures is equal to the excess capital expenditures made during this time.

The value of losses from stranded capital (*SC*) shown in equation (2.3) can thus be reformulated into equation (2.4),

$$SC_i = EC_{i,BS} - EC_{i,CSS} + \sum_{t=1}^{L} \frac{(CE_{t,i,BS} - CE_{t,i,CSS})}{(1+d)^t} \tag{2.4}$$

where *EC* is the value of existing capital goods, *CE* is the value of future capital expenditures, *d* is the discount rate, *L* is the length of the time lag, and *t* is the specific year of the time lag. In the case of future capital expenditures, the losses are discounted in order to convert future cashflows into present value terms. The discount rate is discussed in depth in Section 2.3.4.

2.3.2 Valuing Fossil Fuel Reserves

Estimating losses from stranded reserves requires valuing fossil fuel reserves. Academic researchers and industry practitioners generally agree that the market value of a quantity of fossil fuel reserves is equivalent to the present value of expected cumulative net income from producing them.[32] This is captured in the discounted cashflow (DCF) model in equation (2.5).

$$VR_i = \sum_{t=0}^{T} \frac{(P_{t,i} - MC_{t,i})Q_i S_{t,i} - CE_{t,i}}{(1+d)^t} \tag{2.5}$$

Variables are defined as follows:

- VR_i: Value of fossil fuel reserves for fuel *i*.
- $P_{t,i}$: Market price of fuel *i* in year *t*.
- $MC_{t,i}$: Marginal cost of production per unit of reserves for fuel *i* in year *t*.
- Q_i: Total quantity of proved reserves for fuel *i*.
- S_t: Share of proved reserves expected to be extracted for fuel *i* in year *t*.
- $CE_{t,i}$: Future capital expenditures for fuel *i* in year *t*.
- *d*: Discount rate.

[32] This is stated explicitly in Caldwell et al. (2018), Schumann (2014), McGowan (2000), Weir (1993) and PetroWiki (2017).

- T: Time period—the number of years it will take to fully extract the resource in question.

Under the DCF model, the net income from producing fossil fuel reserves is determined for each year, discounted at rate d (this determines how future cashflows are valued in the present), and then summed over the entire time period. An alternative valuation method promoted by some researchers is the Hotelling Valuation Principle, which holds that the value of any non-renewable natural resource is equivalent to its net price (P-MC) (Miller and Upton 1985a) This method is a special case of the DCF model in equation (2.5) where capital costs are ignored and the net price increases at the rate of discount, implying that the timing of extraction does not matter. Empirical evidence, however, overwhelmingly rejects the viability of this method for valuing fossil fuel reserves (Livernois 2009). For a more in-depth discussion, see Appendix A.

Based on equation (2.5), fossil fuel reserves risk two forms of stranding. First, large quantities of reserves will be left in the ground in a climate stabilization scenario. Research indicates that this includes most proved reserves and all probable and possible reserves.[33] The value of these reserves will drop to zero. I refer to this as the "carbon budget effect." Second, climate stabilization will cause the demand for fossil fuels to decrease, which will push down the expected prices of fossil fuels received by producers. The decrease in expected prices leads to a decrease in value of the reserves that are still extracted and sold during climate stabilization. I refer to this as the "price effect."[34]

[33] See Meinshausen et al. (2009), Leaton (2011), Leaton et al. (2013), McGlade and Ekins (2015), and Heede and Oreskes (2016).

[34] van der Ploeg and Rezai (2020) and Semieniuk et al. (2021) use similar categories.

2.3.2.1 Prior Estimates

To my knowledge, no one has estimated the potential wealth losses from fossil fuel reserves specifically. Six studies have, however, estimated global economic losses from fossil fuel production in a 2 °C scenario using methods similar to equation (2.5). Two of these studies measure losses in terms of foregone profits, with estimates of $12 trillion and $25 trillion (Bauer et al. 2016, Nelson et al. 2014), while four studies measure losses in terms of foregone revenue, with estimates ranging from $3-$185 trillion (Mercure et al. 2018; Linquiti and Cogswell 2016; Channell et al 2015; Lewis 2014). The variation among the estimates is especially concerning—losses of $3 trillion carries drastically different implications than losses of $185 trillion. This section seeks to understand the causes of this variation in order to inform the stranded assets estimation in this paper. A comparison of the methods and data across the studies reveals three main causes of variation: differences in the timeframe of estimation, discount rate, and sources of future projections.

Each study uses scenario comparison, estimating the magnitude of foregone profits or revenue as the difference in profits or revenue between a baseline scenario and a 2 °C scenario. It is important to note that none of the studies considers the more ambitious 1.5 °C target set by the Paris Agreement. As shown in Table 2.1, timeframes of estimation range from 18-100 years, discount rates range from 0%-10%, and several different sources are used for future projections of fossil fuel supply, prices, and production costs.

The higher estimates generally use longer timeframes and a lower discount rate. The highest estimate, for example—$185 trillion from Linquiti and Cogswell (2016)—uses the longest timeframe (100 years) and a low discount rate (3.18%). It is also important to note that estimates of foregone revenue ignore production costs, making them generally higher than estimates of foregone profits.

Much of the variation, however, is caused by the use of different sources of projections. Most of the studies use one of three sources: the E3ME-FTT-GENIE model, the REMIND model, or the International Energy Agency's (IEA) World Energy Outlook (WEO). The WEO, published annually, includes two baseline scenarios: The Current Policies Scenario (CPS) and the Stated Policies Scenario (STEPS). CPS assumes that no new climate policies will be implemented in the future, while STEPS assumes governments will follow through on announced climate policies. Two studies use CPS as the baseline, while one study uses STEPS. Channell et al. (2015) do not use any of these projection sources. Rather, they simply multiply the magnitude of fossil fuel reserves expected to be left in the ground in a 2 °C scenario (as estimated by McGlade and Ekins 2015) by fossil fuel prices at the time of analysis.

To get a sense of the differences across the sources, Table 2.2 displays oil price projections for the years 2019 and 2040 in the baseline and 2 °C scenarios.[35] I also include the prices used in the present study for comparison. Price projections for the year 2040 vary significantly across the sources, and projections from the E3ME-FTT-GENIE model are especially low. In 2040, this model projects a price of $42 per barrel in the baseline scenario—similar to crude oil prices throughout the COVID-19 pandemic.[36]

[35] I used linear extrapolation to fill in any missing years. It is also important to note that the IEA projections displayed are from the 2019 edition of the WEO.

[36] While oil prices briefly turned negative in April 2020, they have generally hovered around $40 per barrel through October 2020 (FRED 2020).

With these methodological and data differences in mind, the wide variation in estimates becomes clear. Linquiti and Cogswell's (2016) $185 trillion estimate is nearly two times the next highest estimate, $100 trillion from Channell et al. (2015). While both studies measure foregone revenue using long timeframes and low discount rates, their oil price projections differ substantially. Channell et al. use a constant oil price of $70 per barrel for both the baseline and climate stabilization scenarios, while Linquiti and Cogswell use price projections from the WEO, which are higher for the baseline scenario and lower for the climate stabilization scenario. The estimates from Mercure et al. (2018) lie at the lower end of the range: $3-$4 trillion.[37] They measure foregone revenue using the shortest timeframe, highest discount rate, and lowest fossil fuel price projections.

The wide variation across the estimates illustrates the importance of carefully choosing the parameters and projections based on the goals of the analysis. In the sections that follow, I describe my choices and provide justifications. My overall goal is to estimate losses from stranded assets from the perspective of the fossil fuel industry, so that I can draw conclusions about the industry's resistance to climate stabilization. In the results section, I include a sensitivity analysis exploring alternative parameters and projection sources for comparison.

2.3.3 Scenarios and Timeframe

The main source I use for scenario projections is the IEA's 2019 World Energy Outlook (WEO). The WEO provides scenario projections for baseline and climate stabilization scenarios for 2020-2040. The scenarios are defined in Table 2.3. For the

[37] The estimate stated in their paper is $1-$4 trillion. However, the lower estimates incorporate scenarios that are irrelevant to this paper.

baseline scenario, I use the average of the Current Policies Scenario (CPS) and the Stated Policies Scenario (STEPS). Given the 1.5-2 °C target set by the Paris Agreement, I include a 2 °C climate stabilization scenario and a 1.5 °C climate stabilization scenario. Both are based on the Sustainable Development Scenario (SDS) from the WEO. They are abbreviated "SDS2" and "SDS1.5". SDS2 is identical to SDS, whereas SDS1.5 is altered slightly to be consistent with the 1.5 °C target.

In general, a baseline scenario represents a future with relatively little change from current trends. In the context of this paper, the baseline scenario should also reflect the expectations of fossil fuel firms. As described in Table 2.3, the CPS scenario represents a future in which no new climate policies are implemented. This is highly unlikely, even if preferred by the fossil fuel industry. The STEPS scenario, on the other hand, assumes that governments will implement further climate policies according to their policy announcements and targets, including those made as part of the Paris Agreement. These policies, however, should not be taken for granted. Given the fossil fuel industry's continued resistance to climate policies, it seems unlikely they would expect STEPS to come to fruition. Industry expectations, therefore, likely lie somewhere in-between CPS and STEPS.

This hypothesis is supported by the 2020 Global Energy Outlook from Resources for the Future (RFF), which reviews energy market projections from leading energy organizations and corporations around the world (RFF 2020). In their comparison of energy-related CO_2 emission projections, they include 13 scenarios from eight organizations, including the IEA, U.S. Energy Information Administration (EIA), Organization for Petroleum Exporting Countries (OPEC), Institute of Energy Economics

Japan (IEEJ), BP, ExxonMobil, Shell, and Equinor. Among the eight baseline scenarios, STEPS and CPS generally constitute the upper and lower bounds, with the others dispersed in-between.[38] Thus, I use the average of STEPS and CPS as the baseline scenario.

I use two climate stabilization scenarios for estimation: SDS2 and SDS1.5. Based on the language of the Paris Agreement, civilization should limit global warming to "well-below 2 °C" above preindustrial levels, and strive for 1.5 °C. Accordingly, SDS2 is a stringent 2 °C scenario, entailing a two-thirds chance of limiting warming to 1.8 °C above preindustrial levels. SDS1.5 is a less stringent 1.5 °C scenario, entailing a one half to two-thirds chance of limiting warming to 1.5 °C above preindustrial levels by 2100, with the possibility of a 0.1 °C overshoot before 2100. STEPS, CPS, and SDS2 are directly from the WEO. SDS1.5 is identical to SDS2, with the exception of fossil fuel supply projections. Supply projections are adjusted to be consistent with the 1.5 °C target.

In light of the reduction in fossil fuel demand from the COVID-19 pandemic, some fossil fuel companies have already written off small amounts of assets. It seems unlikely that fossil fuel demand will remain low after the pandemic ends, at least without major policy interventions. Nonetheless, I consider this possibility in the sensitivity analysis by including a baseline scenario with depressed projections of fossil fuel prices and supply.

The scenarios discussed in this section are limited to the timeframe of 2020-2040. During this time, only a fraction of the world's known fossil fuel reserves will be extracted, even in the baseline scenario. This leads to the potential problem of under-valuation of reserves. However, evidence suggests that the present value of reserves that will not be extracted until after 2040 is extremely small, alleviating this concern. Bauer et al. (2016)

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[38] The exception is ExxonMobil, which dips below STEPS near 2040.

show that most post-2040 reserves are unprofitable by today's standards due to high production costs, leading to a low market value. This value is further depressed by the discount rate, discussed in detail in the next section.

2.3.4 Discount Rate

The discount rate indicates how future cashflows are valued in the present. The higher the discount rate, the lower the present value of future cashflows. Before considering what the discount rate should be, it is important to first answer the following question: why discount at all? There are certainly cases where discounting is controversial and arguably does not make sense. For example, when economists discount the value of future climate damages or human lives (Ackerman and Heinzerling 2002). However, discounting does make sense for valuing fossil fuel reserves. This can be illustrated with a simple example. Assume an oil well will produce $1 million in net income in ten years. Without discounting, the firm would value this income as equivalent to receiving $1 million today. However, if the firm received $1 million today, it would likely invest that money. Assuming a positive rate of return on investment, the $1 million received today would be worth more than $1 million in ten years. Thus, $1 million received in ten years is not valued as highly as $1 million received today. The market value of fossil fuel reserves incorporates this phenomenon through the discount rate, which—for a firm—represents the required rate of return on investment. I argue that a real discount rate (i.e., adjusted for inflation) of 10% is appropriate for valuing fossil fuel reserves.

The literature reviewed in the previous section use real discount rates ranging from 0% to 10%. Only two of these studies—Mercure et al. (2018) and Linquiti and Cogswell (2016)—justify their chosen rates. Mercure et al. (2018) use a rate of 10%, calling it the “corporate” rate, suggesting that it reflects corporations discount future cashflows. They provide no evidence for this, however. Linquiti and Cogswell use a rate of 9.42% for private firms, which represents the weighted average cost of capital of fossil fuel firms (i.e., the cost of debt and equity). They use 3% for state-controlled production, representing a “risk-free” rate.

Anderson et al. (2018) and Adelman and Watkins (1995)—two studies that value oil and gas properties—use similar discount rates: 8.6% and 10%, respectively, in real terms. Anderson et al. calculated their rate as the average S&P 500 return from 1928-2014. Adelman and Watkins do not offer any reasoning for the 10% real discount rate. However, their analysis suggests that it is accurate. They test the conventional DCF method using the 10% real discount rate against the Hotelling Valuation Principle in valuing oil and gas properties. Their results show that the values produced by the conventional method were consistent with actual data on oil and gas property sales from the time. Studies have used survey data to estimate discount rates for corporations in general. This includes Jagannathan et al. (2016), Graham and Harvey (2011), and Poterba and Summers (1995) who find the average real discount rate to range from 12%-13%.

As stated at the beginning of this section, I argue that 10% is appropriate. It serves as a good mid-point between the studies surveyed above. While the survey data suggests firms discount at rates between 12% and 13%, S&P500 returns and the weighted average cost of capital suggest rates of 8%-9%. Additionally, the fossil fuel-specific studies use real discount rates of no more than 10%. In the sensitivity analysis, I use discount rates of 0%, 7%, and 12.5% for comparison.

2.3.5 Projecting Fossil Fuel Supply

With a 10% discount rate, fossil fuel reserves produced in 20 years are worth just 15% as much as they would be if the same quantity of reserves were produced today. Thus, obtaining future supply projections is extremely important. There are two methods for obtaining these projections. The first entails using yearly scenario projections from the WEO or some other source, which projects the quantity of reserves expected to be produced each year. This is the method used by the studies reviewed in Section 2.3.2. However, in determining the market value of fossil fuel reserves, industry practitioners use a different method. They value reserves based on the assumption that the reserves will enter the production process immediately. For coal reserves, the methods are practically identical. Most reserves expected to be produced over the next two decades are already in production. For oil and gas production, however, the methods differ significantly. Thus, I use the second method, or the "practitioner method" for oil and gas reserves.

Understanding the practitioner method requires understanding how reserves are categorized. Every quantity of reserves is categorized as proved, probable, or possible, based on the probability that the reserves can be profitably extracted with current technologies (90%-100% for proved, 50%-90% for probable, and 10%-50% for possible). As noted in Section 2.3.3, this paper only considers reserves expected to be burned from 2020-2040. Probable and possible reserves, thus, are excluded. Proved oil and gas reserves are further categorized as proved developed and proved undeveloped. Proved developed reserves can be extracted from existing wells with little to no further capital investments. Proved undeveloped reserves require substantial capital investments to be developed.

The practitioner method in the oil and gas industry can be traced back to J.J. Arps (1945). Production rates from oil and gas wells are governed by the physical properties of reservoirs, and can be described by three types of production decline curves: exponential, hyperbolic, and harmonic. Oil and gas wells are most productive in their first days of production. Production then declines at a declining rate until the wells are no longer profitable. While a company may not be planning to produce the reserves immediately, this assumption makes sense in terms of determining market value. For proved developed reserves, production is assumed to begin immediately. Proved undeveloped reserves must first be developed, which takes an average of three years (IEA 2019b). Thus, I assume they enter production in year four. For my analysis, I use the exponential curve as shown in equation (2.6), where Q is the quantity of oil or gas produced, D is the annual production decline rate, and t denotes the year.

$$Q_t = Q_0(1 - D)^t \tag{2.6}$$

I assume a 10% decline rate (D=0.1), consistent with the oil and gas valuation literature (Anderson et al. 2018; Adelman 1990; Cairns and Davis 2001). The typical lifetime of oil and gas wells is 15-30 years (Hyne 2008; CAPP n.d.). The 21-year estimation timeframe used in this paper falls near the middle of this range. Thus, I assume that all wells stop producing after 21 years.

In the sensitivity analysis, I consider alternative production decline curves for comparison. For a more in-depth discussion on decline curves, and additional evidence on the efficacy of the practitioner method, see Appendix B.

2.3.6 Projection Data

2.3.6.1 Stranded Reserves

I compiled data projections from several government and non-government sources. For fossil fuel supply, price, and capital expenditure projections, I use the WEO, EIA (2020a), and IIASA and IAMC (2018). For marginal cost of production estimates, I use the EIA (2011), Statista (2015), and the Wall Street Journal (WSJ) (2016). Below, I describe the data used for each variable in the model to value fossil fuel reserves, reproduced here.

$$VR_i = \sum_{t=0}^{n} \frac{(P_{t,i} - MC_{t,i})Q_i S_{t,i} - CE_{t,i}}{(1+d)^t} \tag{2.5}$$

Supply projections (Q) for each scenario are from the WEO for the baseline and 2 °C scenarios, and from IIASA and IAMC (2018) for the 1.5 °C scenario. Projections of supply only include reserves that will be extracted for the time period in question: 2020-2040. All reserves extracted over this timeframe are proved reserves. The practitioner method of estimating yearly production requires proved developed reserves to be distinguished from proved undeveloped reserves. The method for this is outlined in Appendix B. Table 2.4 reports the total supply for each scenario (i.e., reserves produced from 2020-2040), the supply of proved developed reserves, and total proved and unproved reserves (i.e., including reserves that will not be extracted from 2020-2040).

Natural gas and coal price projections are from the WEO. For oil, WEO projections for 2019 are higher than actual 2019 prices. Thus, I supplement them with baseline oil price projections from the EIA (2020a), which start at about $9 per barrel lower.[39] I use the EIA

[39] I take the average of the West Texas Intermediate and Brent Crude oil prices.

baseline scenario projections for STEPS (prices increase at about the same rate in both scenarios) and then adjust the other scenarios proportionately.[40] For both fossil fuel supply and prices, the WEO provides data for 2018 and projections for 2025, 2030, 2035, and 2040. I use a linear interpolation to fill in the missing years.

Projections for future capital expenditures (*CE*) are taken from the WEO and amortized equally over the entire time period.[41] For marginal costs of production (*MC*), I use operational costs per barrel of oil equivalent from the EIA (2011), Statista (2015), and WSJ (2016). The EIA provides data for 2008 and 2009, Statista for 2015, and WSJ for 2016. For oil, I average the per unit operational costs from all three sources. For gas, I use just EIA (2011), as the other sources only consider oil. In order to account for the extremely low natural gas prices in the U.S., I adjust operating costs for U.S. natural gas by a factor of 0.5, and allocate 20% of the U.S. natural gas capital costs to oil.[42] I assume these costs remain constant over the timeframe of estimation. While unconventional oil and gas production entails higher production costs, about 90% of production in the baseline scenario, and even more in the climate stabilization scenarios, is conventional. Moreover, according to the IEA (2019c), capital costs for oil and gas production over the past decade have remained relatively stable. If follows that operational costs are likely stable as well.

[40] For example, to obtain the adjusted CPS oil price for each year, I multiplied the EIA baseline price by the ratio of the WEO CPS price to WEO STEPS price.

[41] Projections for oil and gas are combined in the WEO. However, in the text they give the annual average capital expenditures for gas development for STEPS ($370 billion total, $240 billion for upstream resource development) (IEA 2019c, 187). Under the assumption that the ratio of gas to oil capital expenditures is constant across all scenarios, I split the oil and gas capital expenditure figures into oil expenditures and gas expenditures.

[42] U.S. natural gas prices are less than half the prices elsewhere in the world. Without making these adjustments, U.S. natural gas would have negative value.

Data on marginal costs of production for coal were unavailable publicly. Thus, I extrapolate from oil and gas. I assume that the ratio of the marginal cost of production to the market price for coal is equivalent to the average of such ratios for oil and gas for the year 2020.

2.3.6.2 Stranded Capital

Estimating wealth losses from stranded capital includes the devaluation of existing capital goods and the potential devaluation of future capital expenditures. Future capital expenditure projections are taken from the WEO, which provides projections for 2020-2030 and 2031-2040. I assume that capital expenditures are spread equally across each time period.

Estimates of losses from existing capital goods are based on the IEA (2020b), which estimates that $250 billion of existing oil and gas infrastructure will be stranded under a 2 °C scenario.[43] I extrapolate the $250 billion figure to coal under the assumption that the ratio of losses from existing capital goods to losses from future capital expenditures is equal across industries.[44] I then extrapolate from 2 °C to 1.5 °C based on the assumption that losses from existing capital goods increase proportionately to the change in future capital expenditures between the two scenarios.

2.3.7 Distributional Analysis

I use regional categories from the WEO: North America, Central and South America, Europe, Africa, the Middle East, Eurasia, and Asia Pacific. For the distribution between private firms and governments, I use the reserves distribution shown in Table 2.5

[43] I split this up into oil expenditures and gas expenditures as described in previous footnote.

[44] I do not have evidence supporting this assumption. However, its impact on overall SFFA is insignificant.

and assume a 29% combined royalty and tax rate based on PwC (2019). For the distribution among the majors, I use Forms 10-K from the U.S. Securities and Exchange Commission (SEC) and company annual reports. The remainder of this section outlines these data in more detail.

The WEO provides projections for fossil fuel supply (Q) and future capital expenditures (CE) by region. IIASA and IAMC (2018)—used for the 1.5 °C scenario—provides only aggregate projections. I create regional projections by assuming that production from each region relative to world production for each year is proportionate between the 2 °C and 1.5 °C scenarios. For price projections, the WEO assumes oil prices are equal across all regions, whereas natural gas and coal prices are provided for the U.S., EU, China, and Japan. Additionally, the sources used for marginal cost of production (EIA 2011, Statista 2015, and WSJ 2016) each provides data for a set of regions or top producing countries. I map price and marginal cost data onto the WEO regions as described in Appendix C.

Table 2.5 displays my estimates for the shares of fossil fuel reserves controlled by governments and private firms for each region. For oil and gas reserves, I begin with a recent report from the IEA (2020b). The IEA provides aggregate data on who controls oil and gas proved + probable reserves and production as of 2018. Governments exercise control through state-owned firms, which are defined as firms in which a government has a controlling share. All other firms are considered private. Governments own 66% of oil reserves and 60% of gas reserves, and private firms own 34% and 40%, respectively. Regarding 2018 production, governments control 58% of oil production and 51% of gas production, and private firms control 42% and 49%, respectively.

The reserves distribution provided by the IEA (2020b) is not directly applicable to my analysis. Whereas they consider all proved and probable reserves, my analysis only includes proved reserves that will be produced from 2020-2040. Thus, I take the midpoint between the reserves and production shares. That is, I assume governments control 62% of 2020-2040 oil reserves and 56% of 2020-2040 gas reserves, and private firms control 38% and 44%, respectively. I make this adjustment for two reasons. First, it is likely that private firms control a greater share of 2020-2040 reserves, as they generally hold less reserves than governments. The average reserves to production ratio of the majors, for example, is just 12 years.[45] However, it is also likely that governments will continue to increase their role in production, as they own the bulk of the lowest-cost reserves. Taking the average of the shares of production and reserves accounts for both of these phenomena. In order to translate the aggregate distribution between governments and private firms from the IEA (2020b) into a regional distribution, I use the National Oil Company Database from the Natural Resource Governance Institute (NRGI) (2020). Details are outlined in Appendix C.

For coal reserves, due to data limitations, I use a bottom-up approach. I estimate the distribution of reserves between governments and private firms in several top producing countries, including China, India, Australia, Indonesia, Russia, the U.S., South Africa, and Colombia. Together, they account for 93% of global coal production.[46] The resulting regional estimates are shown in Table 2.5. Sources and a more detailed explanation of my approach are in Appendix C.

[45] Author's calculations using data from Forms 10-K and company annual reports.

[46] Author's calculations based on 2018 production data from the WEO.

According to the PwC (2019), in 2018 both the oil/gas and coal industries paid 29% of their income to governments in the form of direct taxes and royalties. Accordingly, I transfer 29% of net income from private firms to governments.

To estimate the distribution of stranded assets among the majors—BP, Chevron, ConocoPhillips, Eni, ExxonMobil, Shell, and Total—I compiled data on proved net developed and undeveloped reserves,[47] future capital expenditures, marginal costs, and taxes from SEC Forms 10-K and company annual reports.[48]

2.4 Results for Stranded Assets Analysis

2.4.1 Stranded Capital

Wealth losses from stranded capital are presented in Table 2.6. Losses from existing infrastructure amount to \$303 billion in the 2 °C scenario and \$364 billion in the 1.5 °C scenario. As noted in Section 2.3.1, I estimate potential losses from future capital expenditures as the unneeded capital expenditures made during the government-industry time lag. For example, if governments implement climate stabilization policies in 2021, but industry does not transition investments accordingly until 2023, the government-industry time lag is equal to two years. Wealth losses are equivalent to the excess capital expenditures made during this time. Estimates of wealth losses from stranded capital with one-year and two-year time lags amount to \$539-\$754 billion in the 2 °C scenario and \$649-\$908 billion in the 1.5 °C scenario.

[47] Net reserves exclude reserves due others in the form of royalties.

[48] See BP (2020), Chevron (2020), ConocoPhillips (2020), Eni (2020), ExxonMobil (2020), Shell (2020), and Total (2020).

While these wealth losses are large in absolute terms, they are insignificant in relative terms. From 2014-2018, capital expenditures for fossil fuel production totaled $925 billion per year (IEA 2019c). Losses from existing capital goods amount to just one third of capital expenditures for a single year. The risk is similar for future capital expenditures. In terms of revenue, fossil fuel production will bring in about $3 trillion in 2020 alone.[49]

When singling out the coal industry, the results are more significant. Future coal capital expenditures at risk amount to 65% of the industry's projected capital expenditures per year in the 2 °C scenario and 73% in the 1.5 °C scenario. In terms of existing capital goods, my estimates for the coal industry are less reliable, as they are extrapolated from the estimates for the oil and gas industry (details in Section 2.3.6.2).

The low levels of stranded capital for the oil and gas industry deserve further examination. In Figure 2.1, I compare oil and gas demand under 2 °C and 1.5 °C scenarios with oil and gas supply from existing wells with no new capital investments. Supply from existing wells is modeled assuming a 10% exponential production decline curve from 2020 production levels (see Section 2.3.5). I also include an 8% annual decline rate, which the IEA (2020b) uses in a similar exercise.[50] Under every supply-demand combination, oil and gas supply from existing wells leads to a substantial undersupply. In the 1.5 °C scenario, demand falls by an average of just 3.2% per year for oil and 2.6% per year for gas. In other words, substantial capital expenditures in oil and gas will continue to be needed even if the world follows a 1.5 °C path.

[49] Author's calculations based on data for the baseline scenario.

[50] According to the IEA, 8% represents the average oil and gas field decline rate.

2.4.2 Stranded Reserves

Wealth losses from stranded reserves—presented in Table 2.7—amount to $12.7 trillion in the 2 °C scenario ($9.9 trillion for oil, $1.7 trillion for gas, and $1.1 trillion for coal) and $15.3 trillion in the 1.5 °C scenario ($10.8 trillion for oil, $3.0 trillion for gas, and $1.5 trillion for coal). In both scenarios, 90% of stranded reserves belong to the oil and gas industry. These losses can be understood as the reduction in market value of proved fossil fuel reserves that private firms and governments expect to extract and sell in the baseline scenario between 2020 and 2040.

The magnitude of wealth losses from stranded reserves can be disaggregated into the price effect, which captures the devaluation in reserves from price decreases for reserves still extracted and sold during climate stabilization, and the carbon budget effect, which captures the devaluation in reserves left in the ground. This is best understood with an example. In the 2 °C scenario 633 billion barrels of oil reserves will be produced and sold from 2020 to 2040. Due to a decrease in demand, the market price of oil drops in the 2 °C scenario relative to the baseline scenario. This reduction in prices, i.e., the price effect, leads to a devaluation in reserves. Additionally, 172 billion barrels of oil will remain in the ground in the 2 °C scenario that would have been extracted in the baseline scenario. The value of these reserves falls to zero, constituting the carbon budget effect.

Table 2.8 displays the shares of losses from stranded reserves attributed to each effect. In the 2 °C scenario, 63% of stranded reserves can be attributed to the price effect. Only 37% is attributed reserves that remain in the ground. Under the 1.5 °C scenario, more reserves are left in the ground, leading to a larger carbon budget effect. Nonetheless, 45% of wealth losses is still attributed to the price effect. The price effect is smaller for coal, as coal production declines much faster than oil or gas production in both climate stabilization scenarios, but it remains substantial at 17-36%.

2.4.3 Distributional Analysis

I estimate the distribution of wealth losses from stranded assets by region, between private firms and governments, and among the seven influential oil and gas majors.[51] The main results can be summarized as follows:

1. Governments will bear about 76% of total stranded assets.
2. The three regions with the greatest shares of stranded assets are the Middle East (33%), North America (19%) and Eurasia (17%), together accounting for nearly 70% of total stranded assets.
3. Stranded reserves for the majors amount to \$402-\$456 billion, equivalent to about five years' worth of typical profits.

Table 2.9 displays the distribution between private firms and governments for each region.[52] Governments will bear 76% of total stranded assets, while private firms bear just 24%. The three regions with the greatest shares of stranded assets are the Middle East (33%), North America (19%) and Eurasia (17%), together accounting for nearly 70% of total stranded assets. For all three, the bulk of stranded assets comes in the form of stranded oil and gas reserves. Asia Pacific accounts for just 6% of stranded oil and gas assets, but 79% of stranded coal assets. In total, they account for 15% of stranded assets.

[51] The distributional results are based on the distribution of stranded reserves. However, stranded capital are likely distributed similarly.

[52] Distributional analysis is based on stranded reserves. Stranded capital accounts for a much smaller portion of overall stranded assets, and is likely distributed similarly to reserves.

Table 2.10 presents wealth losses from stranded oil and gas reserves for the majors. In total, these seven companies account for just 3% of total stranded reserves (14% among private firms). As noted in Section 2.3.7, the majors on average carry reserves equivalent to just 12 years of production (i.e., reserves to production ratio is 12), leading to relatively low levels of stranded reserves. Most of their proved reserves are developed, and thus will be produced from 2020-2040. Nonetheless, the $402-$456 billion in stranded reserves for 1.5-2 °C—mainly due to the price effect—is equivalent to about five years of profits between 2010 and 2019.[53]

2.4.4 Sensitivity Analysis

The results presented above are based on the methods, data, and assumptions outlined in Section 2.3. This section presents a sensitivity analysis to test how wealth losses from stranded reserves changes from alternative estimation methods and projections.

Tables 2.12 and 2.13 compare a variety of estimates of the value of stranded reserves for 2 °C and 1.5 °C scenarios, respectively. The estimations vary by method of projecting supply (practitioner method vs. scenario projection method), discount rate (0%, 3%, 5%, 10%, and 12.5%), and sources for price and supply projection data ("Present study", "WEO-STEPS", "WEO-CPS", and "Mercure/STEPS"). "Present study" refers to the projection data used in this paper. "WEO-STEPS" and "WEO-CPS" refer to projections from the STEPS and CPS scenarios in the WEO. "Mercure/STEPS" refers to price projections from Mercure et al. (2018) combined with supply projections for STEPS. I chose these specific variables and data sources based on the literature reviewed in Section

[53] This is based on the analysis in Section 2.5.

2.3.2.1. The estimates that most closely resemble the methods and data of each study are in bold font and denoted with superscripts.

These estimates are not exact replications of studies reviewed. All estimates presented in the tables use the 2020-2040 timeframe and the capital and marginal cost projections used in my main analysis. This differs from Mercure et al. (2018), Lewis (2014), and Linquiti and Cogswell (2016) as they estimated revenue only. Additionally, all WEO projections are from the 2019 edition of the report, while Lewis (2014), Linquiti and Cogswell (2016), and Nelson et al. (2014) used previous editions. Nelson et al. use an 8% discount rate, whereas I show 0%, 3%, 5%, 10%, and 12.5%. Mercure et al. (2018) provide incomplete price projection data, so I used linear interpolation to fill in the missing years. Finally, I do not have access to sufficient price and supply data from Bauer et al. (2016). They average prices for their baseline scenario, but not their climate stabilization scenario. I represent their estimate using STEPS, as the baseline projections are similar to STEPS.

The estimates of wealth losses are highly sensitive to the discount rate and sources used for projections. The estimates that are representative of Lewis (2014) and Bauer et al. (2016), for example, are identical in every way except the discount rate. Lewis' 0% rate leads to an estimate two times that of Bauer's 5% rate. Estimates for STEPS and the present study are quite similar. The estimates using CPS are significantly higher while those using Mercure/STEPS are significantly lower. The practitioner and scenario projection methods of projecting oil and gas supply generally did not lead to substantial differences in estimates, the exceptions being the 0% and 12.5% discount rates.

In Table 2.14, I present estimates of losses from stranded reserves using alternative production decline curves. The differences between the curves are insignificant.

Finally, as noted in Section 2.3.3, some believe the COVID-19 pandemic and resultant economic crisis will lead to a permanent decrease in future fossil fuel demand. While this seems unlikely, if this does occur, the baseline scenario would shift closer to the WEO's STEPS scenario. Table 2.15 presents stranded reserves using STEPS as the baseline scenario (rather than the average of STEPS and CPS). Recall from Section 2.3.6.1 that for oil price projections for STEPS, I replace the WEO projections with projections from the EIA (2020a), which leads to lower overall estimates of wealth losses. The results in Table 2.15 therefore differ from the STEPS projections in Tables 2.12 and 2.13 above. Wealth losses from stranded reserves are lower under the COVID-19 case, dropping from $12-$15 trillion to $9-$12 trillion. Nonetheless, they are still significant, and they do not change any of the major implications of this paper.

2.5 Energy Industry Comparison

The stranded assets analysis reveals what is at stake for the upstream fossil fuel industry in terms of assets they already own. In the case of a clean energy transition, the industry will also experience economic gains from clean energy production. This section compares profits, profit margins, and market capitalization between the fossil fuel and renewable energy industries for the period 2010-2019. The results give an indication as to what extent the losses from fossil fuel production could be recouped through gains from clean energy production. These gains assume firms will be able to obtain access to sufficient clean energy resources, e.g., land with the most sunlight and wind.

I compiled data on publicly traded companies from 2010-2019 from Bloomberg L.P. (2020). I only included companies which had revenue and profit data for every year between 2010-2019, and excluded companies with revenues of less than $10 million.[54] I compared six groups of firms:

1. Oil and gas exploration and production (E&P) sector (pre-defined in Bloomberg Terminal)
2. Integrated oil and gas sector (pre-defined in Bloomberg Terminal)
3. The seven oil and gas majors[55]
4. Coal operations sector (pre-defined in Bloomberg Terminal)
5. Renewable energy sector (pre-defined in Bloomberg Terminal)[56]
6. Solar energy firms from four solar energy stock indices[57] (the Ardour Solar Energy Index, BlueStar Solar Energy Industry Index, MAC Global Solar Energy Index, and MVIS Global Solar Energy Index).

Table 2.11 presents average profits, revenue, and profit margins for fossil fuel and renewable energy companies. The sample size for each sector is shown in parentheses. Two sets of values are given for each metric: the per company average of the full sample and of the ten largest companies (by revenue). The integrated oil and gas sector contains the largest companies by a wide margin, and includes six of the majors. ConocoPhillips is included in the exploration and production (E&P) sector. Coal companies are comparable to oil and gas E&P companies in size, and—surprisingly—have the highest profit rate. The

[54] The data for these firms was less consistent from year to year. For example, firms often recorded the exact same amounts of revenue and profits for every year. Also, I am less interested in small companies, which have little leverage is affecting politics.

[55] The majors are also included in the E&P and integrated sectors. ConocoPhillips is in the E&P sector, and the other six in the integrated sector.

[56] The one exception is that I added Ørsted to this group, as Bloomberg had excluded it, likely by mistake.

[57] These firms are also part of the renewable energy sector.

average renewable energy company is much smaller than oil and gas or coal companies, and has yet to turn a profit. Solar companies are just above the breakeven point, with a profit margin of 0.2%. It is worth noting that the top ten renewable energy companies, which includes Ørsted, do turn a small profit margin of 3.2%.

The lower profits of renewable energy companies is consistent with an analysis by the IEA (2020b), which compares internal rates of return of typical upstream oil and gas projects to wind and solar projects. Renewable energy is still a young industry competing with the centuries-old fossil fuel status quo. The declining per unit production costs of renewable energy, owing to technological advancements, are encouraging. This phenomenon makes renewable energy more competitive with fossil fuels. However, it can also make past renewable energy investments unprofitable. Capital investments made in wind and solar energy ten years ago, for example, are necessarily expensive and inefficient by today's standards. Das et al. (2020) show that wind and solar companies in particular also face a problem of diminishing marginal revenues. Wind turbines and solar panels in a particular area all produce electricity at the same time (i.e., when it is windy or sunny). Without scaling up electricity storage capabilities—a technology that remains small in scale and relatively expensive—this phenomenon leads to an oversupply of electricity. Oversupply lowers electricity prices, and therefore firm revenues.

Figures 2.2 and 2.3 show how average revenue and profit margins have changed over time. In terms of revenue, renewable energy companies show a small upward trend, but still lie far below fossil fuel companies. In terms of profit margins, renewable energy generally remains below fossil fuels. The E&P sector shows the highest profit margin for most years, but is most susceptible to collapses in oil prices, which is what caused the -55% profit margin in 2015. There are no clear upward or downward trends.

Finally, Figure 2.4 displays the average market capitalization of publicly listed firms in each industry. Interestingly, renewable energy stocks show an upward trend while all fossil fuel stocks show a downward trend. This suggests that investors expect renewable energy to become more important and profitable in the future.

2.6 Conclusions

All of the evidence from the stranded assets analysis and energy industry comparison point to the general conclusion that the fossil fuel industry faces strong economic incentives to continue resisting climate stabilization. This evidence includes (1) aggregate estimates of the wealth losses from stranded assets; (2) the disaggregation of the devaluation in fossil fuel reserves into the carbon budget effect (i.e., losses from reserves being left in the ground) and the price effect (i.e., losses from price decreases for reserves still extracted and sold); (3) the distribution of the wealth losses from stranded assets by world region, between private firms and governments, and among the oil and gas majors; and (4) a comparison of profits, profit margins, and market capitalization between the fossil fuel and renewable energy industries. The results shed light on the economic incentives facing the industry, and approaches to overcoming the industry's resistance.

2.6.1 Incentives Facing the Industry

Based on the results of the stranded assets analysis, proved fossil fuel reserves will lose 37%-44% of their value, amounting to \$13-\$15 trillion in losses from stranded reserves, while the wealth losses from stranded capital are minimal—just \$303-\$364 billion for existing capital goods, amounting to about one third of the industry's capital expenditures for a single year. These results imply that the fossil fuel industry, in general, has little to lose and much to gain from continuing on the path of resistance. If industry were to alternatively choose to transition its operations to clean energy production, consistent with the 1.5 °C or 2 °C scenario, it would end up undermining the economic value of future fossil fuel production, leading to stranded reserves. Transitioning to clean energy now would help to minimize the potential losses from stranded capital, but these losses are insignificant compared to those of stranded reserves.

These conclusions are strengthened by the results of the energy industry comparison. Fossil fuel firms consistently outperformed renewable energy firms from 2010-2019. Most important is the significant differential in profit margins: 6%-8% for fossil fuel firms and -0.5% for renewable energy firms. Renewable energy firms did not become more profitable over time—they reported negative profit margins in both 2018 and 2019. While this may change with technological advancements and climate policies, the future prospects for profitmaking from clean energy production remains uncertain. The profitability analysis, thus, provides further incentive for the fossil fuel industry to resist climate stabilization efforts.

Most of the research on stranded reserves has focused on the quantities of reserves that will be left in the ground in 2 °C scenarios.[58] Based on my results, the reserves that are still extracted and sold under climate stabilization are just as important, as they account for 45%-63% of the wealth losses from stranded reserves. This is due to the expected decrease in fossil fuel prices in the climate stabilization scenarios, or the price effect. This has major implications for the fossil fuel industry in general, and low-cost producers in

[58] See footnote 33.

particular. The level of production from low-cost producers, e.g., Saudi Aramco's oil production, does not change significantly in either the 1.5 °C or 2 °C scenario, as fossil fuels continue to supply a significant portion of the world's energy demand through 2040. The large price effect implies that even these producers will bear substantial wealth losses from stranded reserves. It also implies that, for the entire industry, the per unit profits from fossil fuel production will be drastically reduced relative to the baseline scenario.

The distributional analysis shows that government producers also deserve more attention than they have received in the scholarly literature and news media, as they will bear 76% of wealth losses from stranded assets. The 76% figure is significantly greater than the share of fossil fuel production governments control. From 2020-2040—the time period in question—governments are expected to account for 62% of oil production, 56% of gas production, and 59% of coal production. This discrepancy is for two reasons. First, private producers pay 29% of their gross profits to governments in the form of taxes and royalties. Second, governments control the world's lowest cost, most lucrative oil. This includes the Middle East, followed by North Africa and Eurasia. The large price effect described above is therefore especially debilitating for governments.

Approximately 90% of stranded assets occur in the oil and gas industry, mostly from oil production. Regionally, the Middle East, North America, and Eurasia account for 38%, 25%, and 14% of stranded assets, respectively, almost entirely from oil and gas production. Asia Pacific is the one region in which coal is more important. It accounts for just 15% of total stranded assets, but 79% of coal-based stranded assets. Of these regions, North America is the only one in which private firms account for more stranded assets than governments.

The analysis of the oil and gas majors suggests that they are relatively well-positioned to weather a transition to clean energy, but are unlikely to undertake this transition on their own. The majors controlled 16% of the world's oil and gas production in 2018, yet account for just 3.5% of stranded oil and gas reserves. This follows from the fact that these firms hold an average of just 12 years' worth of oil and gas reserves, most of which are proved developed reserves. Compared to smaller private firms and most state-owned firms, the majors are less confined by borders, making it easier to locate and invest in clean energy resources. The majors are also some of the largest firms in the world, with BP, Shell, and ExxonMobil ranking 5th, 8th, and 11th in Fortune's Global 500 list for fiscal year 2020 (Fortune 2020). One can therefore conclude that the majors have the monetary capital necessary to make an orderly transition from fossil fuels to clean energy production.

Having the ability to transition, however, does not mean that they will transition on their own. Wealth losses from stranded reserves for the majors still amount to $402 billion in the 2 °C scenario and $456 billion in the 1.5 °C scenario. These losses are approximately five times greater than their average profits from 2010-2019. When combined with the low profit margins for renewable energy firms, a transition away from fossil fuels seems unlikely for the foreseeable future. Recent leaked documents and recordings from ExxonMobil and BP support this argument. ExxonMobil expects its emissions to increase 17% by 2025 (Crowley and Rathi 2020), and according to BP CEO Bernard Looney, BP is "probably going to be in oil and gas for decades to come," adding, "because how else is that $8 billion dividend going to get serviced?" (Westervelt 2020).

The results discussed above also point to several potential avenues for future research. Researchers can use firm-level data to examine the variation in stranded asset risk and profitability across firms to better understand how they influence firms' approaches to climate change. The distributional analysis suggests more research is needed on state-owned fossil fuel production. For example, how are these governments responding to the need for a clean energy transition? What do the intra- and inter-government struggles over the future of fossil fuels look like, and how do they manifest themselves in geopolitics? The price effect points to the importance of the actions of importers of fossil fuels. What are the obstacles to climate stabilization in these countries, and what role can they play in effecting a clean energy transition? Finally, the upstream fossil fuel industry is not the only industry with stranded asset risk from climate stabilization. Similar analyses for midstream (transportation) and downstream (refining) oil and gas operations, electric utilities, auto manufacturers, and the insurance industry, among others, may prove enlightening.

2.6.2 Overcoming Industry Resistance

The fossil fuel industry has gone to great lengths to protect its hold on wealth and power. These include efforts to mislead the public and lobby governments to forestall major changes in energy policy. The vested interests in the sector also include fossil fuel-dependent governments, operating in a global environment of contests for geopolitical power. I conclude this paper with a discussion of my results in relation to two broad approaches to overcoming this resistance: (1) appeasing the fossil fuel industry, and (2) defeating it.

The appeasement approach attempts to entice the industry to change. It prioritizes fossil fuel producers in climate policies and international agreements so as to induce them into taking a leading role in remaking the energy system. This approach would likely require some form of compensation for the \$13-\$16 trillion in wealth losses from stranded assets, as well as ensuring that whatever the industry transitions to, such as clean energy production, is as profitable and exclusive as fossil fuel production.

The feasibility of this approach varies by country and depends on several factors. In the U.S., fossil fuel production makes up a relatively small percentage of overall GDP, and the government is not dependent upon fossil fuel revenues for its tax base. The U.S. is also home to substantial clean energy resources to which fossil fuel firms could transition. Thus, compensation may be feasible. Wealth losses from stranded assets in North America—the bulk of which are from the U.S.—amount to $2-$3 trillion. For comparison, the COVID-19 relief package passed in the U.S. in March 2020 (the CARES Act) amounted to $2.2 trillion.

The path to appeasing industry will be more difficult in countries where fossil fuel production constitutes a substantial portion of economic activity, and where fossil fuel production is nationalized, as in the Middle East. In Saudi Arabia, Iran, and Iraq, for example, oil rents accounted for 29%, 16%, and 45% of GDP in 2018, respectively (World Bank 2020). Because oil production is nationalized across the Middle East, governments are particularly vulnerable to economic losses from climate stabilization. This is illustrated by the fiscal breakeven oil prices (i.e., the crude oil price required by a government to balance its budget) in the region for 2020, which range from $46-$194 per barrel (Knoema 2020). Compensation for wealth losses from stranded assets in the Middle East, which amount to $4-$5 trillion, would therefore have to come from the international community. This kind and level of compensation is highly unlikely, especially without major strings attached.

It is important to note that, even when appeasing industry is economically feasible, it may not be politically feasible. The Yellow Vests movement in France, triggered by a small increase in fuel prices, provides an example of how people may react if the burden of climate stabilization is transferred from polluters to ordinary people.

The second approach—defeating industry—aims to hold fossil fuel producers accountable for their decades of resistance, and to disempower them to the point that their continued resistance becomes inconsequential. The sentiment behind this approach is well captured in the writings of environmentalist Bill McKibben, who has termed the fossil fuel industry “a rogue industry, reckless like no other force on Earth” and “Public Enemy Number One to the survival of our planetary civilization” (McKibben 2012).

As long as fossil fuels are in high demand as essential commodities, the industry will retain significant leverage in shaping politics. As the analysis in this paper indicates, the economic viability of fossil fuel production quickly diminishes as demand for fossil fuels declines. Eroding demand, thus, is the key to the approach of defeating industry. Other strategies, such as attempts at isolating the fossil fuel industry socially and politically (i.e., deeming it “Public Enemy Number One”) can help to create the political space necessary for enacting policies to curtail demand. These policies are likely to find more success in non-fossil fuel producing countries, and among producer countries in those with privatized fossil fuel production.

The first approach—appeasing industry—may find more support among those in positions of wealth and power, while the second—defeating industry—may find greater support among the lower and middle classes. However, the two approaches are not mutually exclusive, and can be complementary. For example, the curtailment of fossil fuel demand would reduce the fossil fuel industry’s bargaining power. This in turn would reduce the level of compensation necessary to appease industry. Both approaches are likely to be attempted in some combination, both domestically and internationally, in efforts to avert the global climate emergency.

2.7 Tables and Figures

Table 2.1: Summary of previous estimates of fossil fuel industry losses (estimates are shown in US$; T=Trillion)						
Study	Estimate	Metric	Timeframe	Baseline projections	Climate stabilization projections	Dis-count rate
Mercure et al. (2018)	$3-$4 T	Revenue	2018-2035	Baseline from E3ME-FTT-GENIE	2 °C from E3ME-FTT-GENIE	10%
Bauer et al. (2016)	$12 T	Profit	2010-2100	Baseline from REMIND	2 °C (450e from REMIND)	5%
Nelson et. al (2014)	$25 T	Profit	2015-2035	CPS from 2013 WEO	2 °C (450S from 2013 WEO)	8%
Lewis (2014)	$28 T	Revenue	2013-2035	STEPS** from 2013 WEO	2 °C (450S from 2013 WEO)	0%
Channell et al. (2015)	$100 T	Revenue	Unknown*	Baseline from McGlade and Ekins (2015)	2 °C from McGlade and Ekins (2015)	0%
Linquiti and Cogswell (2016)	$185 T	Revenue	2016-2115	CPS from 2015 WEO	2 °C (450S from 2015 WEO)	3.18%

* See text for details—the timeframe is unknown, but is likely similar to that of Linquiti and Cogswell (2016).
** In the 2013 WEO, STEPS was called the New Policies Scenario (NPS).

Table 2.2: Comparison of oil prices across projection sources (US$ per barrel)				
	Baseline		2 °C	
Source	2019	2040	2019	2040
E3ME-FTT-GENIE	$38	$42	$36	$27
REMIND	$71	$89	N/A	N/A
2019 WEO - STEPS & SDS	$70	$103	$67	$59
2019 WEO - CPS & SDS	$71	$134	$67	$59
Constant price from Channell et al. (2015)	$70	$70	$70	$70
Present study	$60	$102	$60	$51

Sources: Mercure et al. (2018), Bauer et al. (2016), IEA (2019c), and Channell et al. (2015).

Table 2.3: Scenario descriptions	
Scenario	Description
Stated Policies Scenario (STEPS)	According to the IEA, "The Stated Policies Scenario (identical in design to the previous New Policies Scenario) provides a detailed sense of the direction in which today's policy ambitions would take the energy sector. The change in name to 'Stated' from 'New' is intended to clarify that this scenario does not speculate on how policies might evolve in the future. It incorporates policies and measures that governments around the world have already put in place, as well as the effects of announced policies, as expressed in official targets and plans." They add, "Given that intended policies are typically not fully reflected in legislation or regulation, the prospects and timing for their realization are based upon our assessment of relevant regulatory, market, infrastructure and financial constraints" (IEA 2019c, 751).
Current Policies Scenario (CPS)	According to the IEA, "The Current Policies Scenario provides a baseline for the analysis by considering only the consequences of existing laws and regulation. It excludes the effects of stated ambitions and targets that have not yet been translated into operational laws and regulations" (IEA 2019c, 751).
Sustainable Development Scenario - 2 °C (SDS2)	SDS2 is the Sustainable Development Scenario (SDS) from the WEO, which represents a stringent 2 °C pathway. The WEO describes SDS as follows: "The outcomes embodied in the Sustainable Development Scenario are derived from the Sustainable Development Goals (SDGs) of the United Nations….The Sustainable Development Scenario is fully aligned with the Paris Agreement and lays out an integrated strategy to achieve climate, air quality and access objectives while also having a strong accent on energy security" (IEA 2019c, 751).
Sustainable Development Scenario - 1.5 °C (SDS1.5)	SDS1.5 is identical to SDS2, with the exception of fossil fuel supply. For supply, I use the average projections from all 1.5 °C-consistent pathways used by the IPCC (2018a), which include below-1.5 °C pathways and 1.5 °C pathways with low overshoot. Below-1.5 °C pathways "[limit] peak warming to below 1.5°C during the entire 21st century with 50–66% likelihood," and 1.5 °C with low-overshoot pathways "[limit] median warming to below 1.5°C in 2100 and with a 50–67% probability of temporarily overshooting that level earlier, generally implying less than 0.1°C higher peak warming than Below-1.5°C pathways" (IPCC 2018a, 100). The data is available from IIASA and IAMC (2018).

Table 2.4: Fossil fuel reserves						
	Reserves by Scenario (2020-2040)			Total Known Reserves		
Fuel	CPS-STEPS Average*	SDS2	SDS1.5	Proved Developed	Proved	Probable + Possible
Oil (billions of barrels)	805	633	462	296	1,700	6,165
Gas (trillions of cubic feet)	102	87	55	38	225	803
Coal (billions of metric tons)	120	75	62	N/A	1,043	23,014

Sources: IEA (2019c); IIASA and IAMC (2018). * Used for baseline scenario in stranded assets analysis.

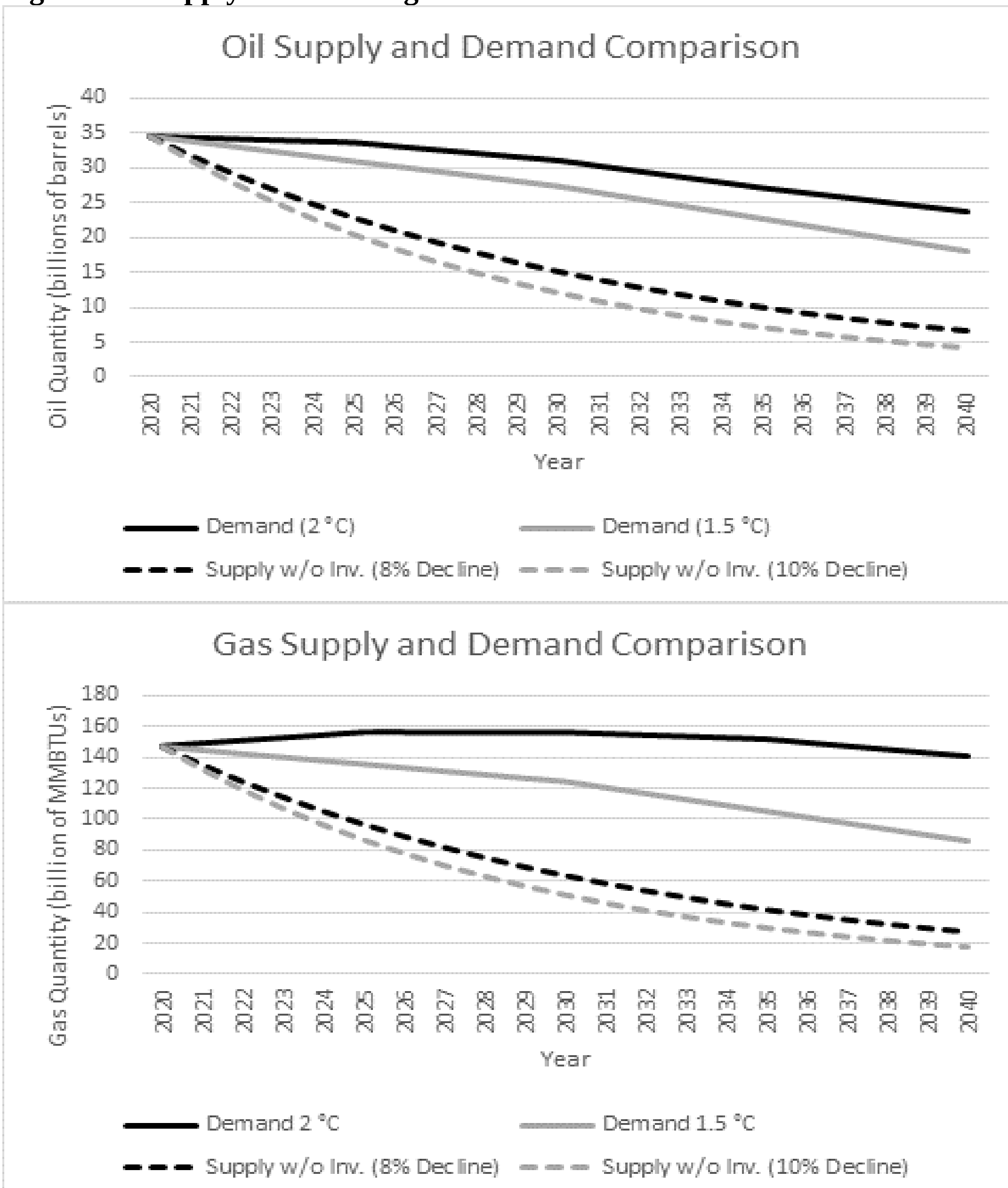
Table 2.5: Reserves distribution between governments and private firms						
	Oil		Gas		Coal	
Region	Private	Public	Private	Public	Private	Public
North America	90%	10%	98%	2%	100%	0%
Central & South America	20%	80%	20%	80%	90%	10%
Europe	70%	30%	70%	30%	100%	0%
Africa	8%	92%	8%	92%	90%	10%
Middle East	5%	95%	5%	95%	5%	95%
Eurasia	50%	50%	50%	50%	90%	10%
Asia Pacific	5%	95%	5%	95%	25%	75%
World	**38%**	**62%**	**44%**	**56%**	**41%**	**59%**

Source: Appendix C.

Table 2.6: Losses from stranded capital for 1.5 °C and 2 °C by government-industry time lag (2018 US$, B=Billion)						
Scenario	2 °C			1.5 °C		
Time lag	0 years	1 year	2 years	0 years	1 year	2 years
Oil + Gas	$250 B	$445 B	$623 B	$306 B	$545 B	$762 B
Oil	$163 B	$290 B	$406 B	$192 B	$343 B	$479 B
Gas	$87 B	$155 B	$217 B	$113 B	$202 B	$283 B
Coal	$53 B	$94 B	$131 B	$59 B	$104 B	$146 B
Total	**$303 B**	**$539 B**	**$754 B**	**$364 B**	**$649 B**	**$908 B**

Source: Author’s calculations (data and methods described in Section 2.3).

Figure 2.1: Supply from existing wells vs. demand under climate stabilization



Sources: IEA (2019c); Author’s calculations (see text for details).

Table 2.7: Wealth losses from stranded reserves (percentage loss in parentheses) (2018 US$, B=Billion)		
	2 °C	1.5 °C
Stranded oil + gas reserves	$11,628 B (-37%)	$13,754 B (-44%)
Stranded oil reserves	$9,920 B (-46%)	$10,789 B (-50%)
Stranded gas reserves	$1,708 B (-17%)	$2,965 B (-30%)
Stranded coal reserves	$1,089 B (-32%)	$1,514 B (-45%)
Total stranded reserves	**$12,717 B (-37%)**	**$15,268 B (-44%)**

Source: Author's calculations (data and methods described in Section 2.3).

Table 2.8: Wealth losses from stranded reserves disaggregated into the price effect and carbon budget effect				
	2 °C		1.5 °C	
	Price Effect	Carbon Budget Effect	Price Effect	Carbon Budget Effect
Stranded oil + gas reserves	65%	35%	48%	52%
Stranded oil reserves	66%	34%	53%	47%
Stranded gas reserves	62%	38%	28%	72%
Stranded coal reserves	36%	64%	17%	83%
Total stranded reserves	**63%**	**37%**	**45%**	**55%**

Source: Author's calculations based on the results in Table 2.7.

Table 2.9: Distribution of wealth losses from stranded assets between governments and private firms and by region			
	Private Firms	Governments	Regional Total
Oil and Gas			
North America	16%	9%	25%
Central & South America	1%	7%	8%
Europe	1%	1%	2%
Africa	0%	7%	8%
Middle East	1%	37%	38%
Eurasia	5%	9%	14%
Asia Pacific	0%	5%	6%
World	24%	76%	100%
Coal			
North America	4%	2%	5%
Central & South America	1%	0%	1%
Europe	2%	1%	3%
Africa	2%	1%	3%
Middle East	0%	0%	0%
Eurasia	5%	3%	8%
Asia Pacific	14%	65%	79%
World	28%	72%	100%
Total fossil fuels			
North America	12%	7%	19%
Central & South America	1%	6%	7%
Europe	1%	1%	2%
Africa	1%	7%	7%
Middle East	1%	32%	33%
Eurasia	6%	11%	17%
Asia Pacific	2%	13%	15%
World	24%	76%	100%

Source: Author’s calculations (data and methods described in Section 2.3 and Appendix C).

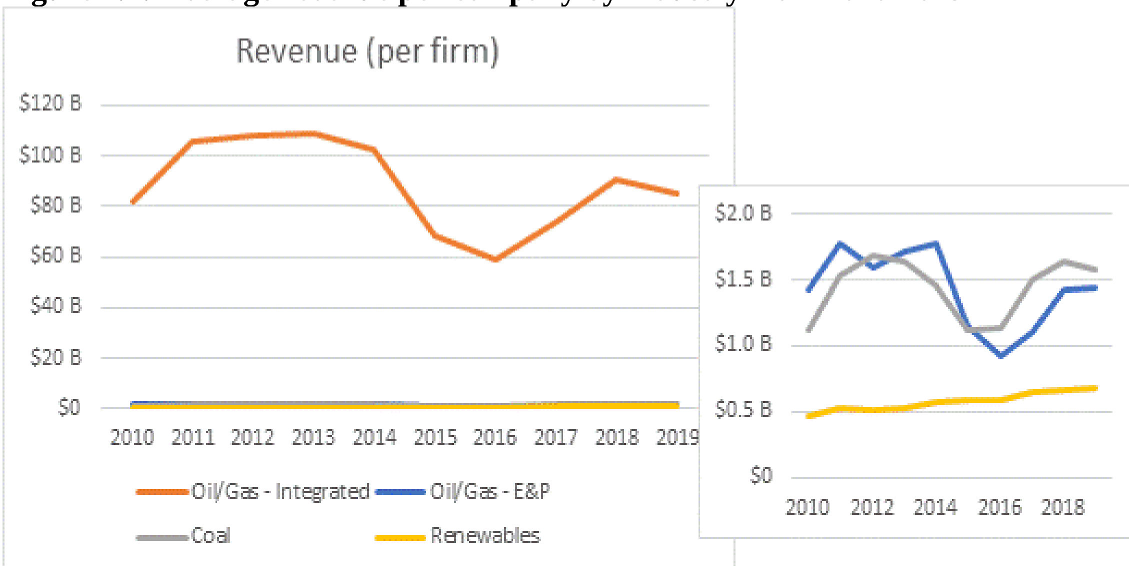
Table 2.10: The value of stranded reserves as distributed among the majors (2018 US$, B=Billion)						
	2 °C			1.5 °C		
Company	Stranded reserves	Share of total	Share of total of private firms	Stranded reserves	Share of total	Share of total of private firms
BP	$100 B	0.9%	3.6%	$122 B	0.9%	3.8%
ExxonMobil	$87 B	0.7%	3.1%	$93 B	0.7%	2.9%
Chevron	$62 B	0.5%	2.2%	$74 B	0.5%	2.3%
Total (company)	$62 B	0.5%	2.2%	$71 B	0.5%	2.2%
Shell	$39 B	0.3%	1.4%	$39 B	0.3%	1.2%
Eni	$30 B	0.3%	1.1%	$33 B	0.2%	1.0%
ConocoPhillips	$23 B	0.2%	0.8%	$23 B	0.2%	0.7%
Majors (in total)	**$402 B**	**3.5%**	**14.4%**	**$456 B**	**3.3%**	**14.2%**

Source: Author's calculations (data and methods described in Section 2.3).

Table 2.11: Mean annual profits, revenues, and profit margins for listed fossil fuel and renewable energy companies from 2010-2019 (2018 US$, M=Million)						
	Mean annual profits (per company)		Mean annual revenue (per company)		Mean annual profit margin	
Industry	All firms	Top 10	All firms	Top 10	All firms	Top 10
Oil & Gas						
E&P (n=201)	$81 M	$1,463 M	$1,433 M	$17,841 M	5.6%	8.2%
Integrated oil/gas (n=36)	$5,314 M	$12,822 M	$88,401 M	$239,460 M	6.0%	5.4%
Majors (n=7)	$11,888 M	N/A	$214,261 M	N/A	5.5%	N/A
Coal						
Coal operations (n=130)	$120 M	$1,093 M	$1,440 M	$10,411 M	8.4%	10.5%
Clean energy						
All renewable energy (n=201)	-$3 M	$144 M	$576 M	$4,509 M	-0.5%	3.2%
Solar energy (n=26)	$2 M	-$6 M	$843 M	$1,797 M	0.2%	-0.3%

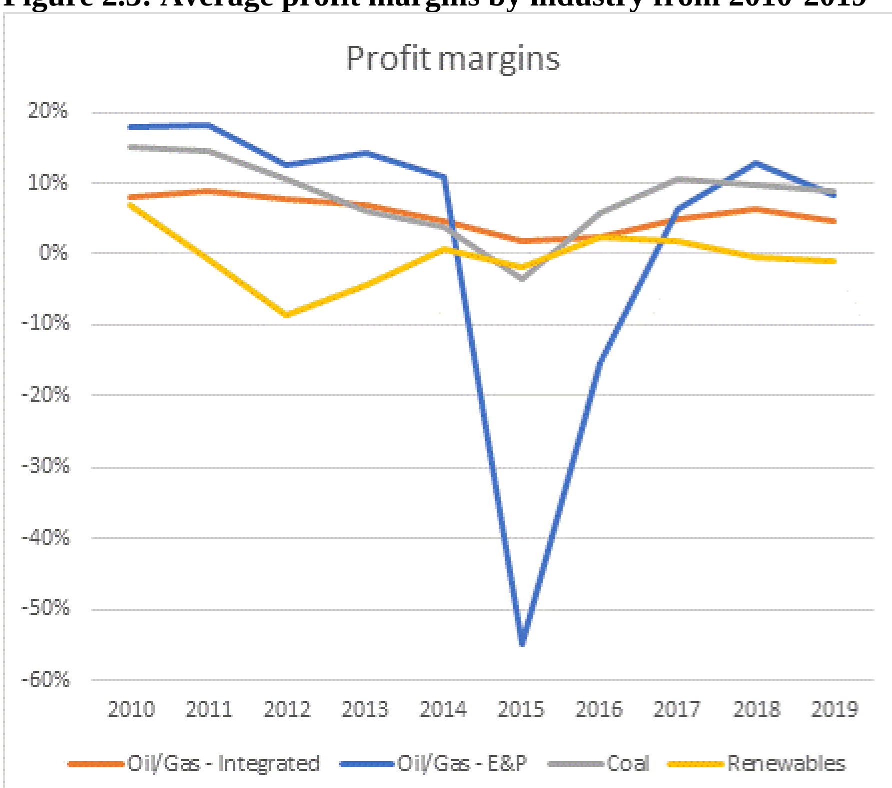
Sources: Author's calculations using data from Bloomberg L.P. (2020)

Figure 2.2: Average revenue per company by industry from 2010-2019



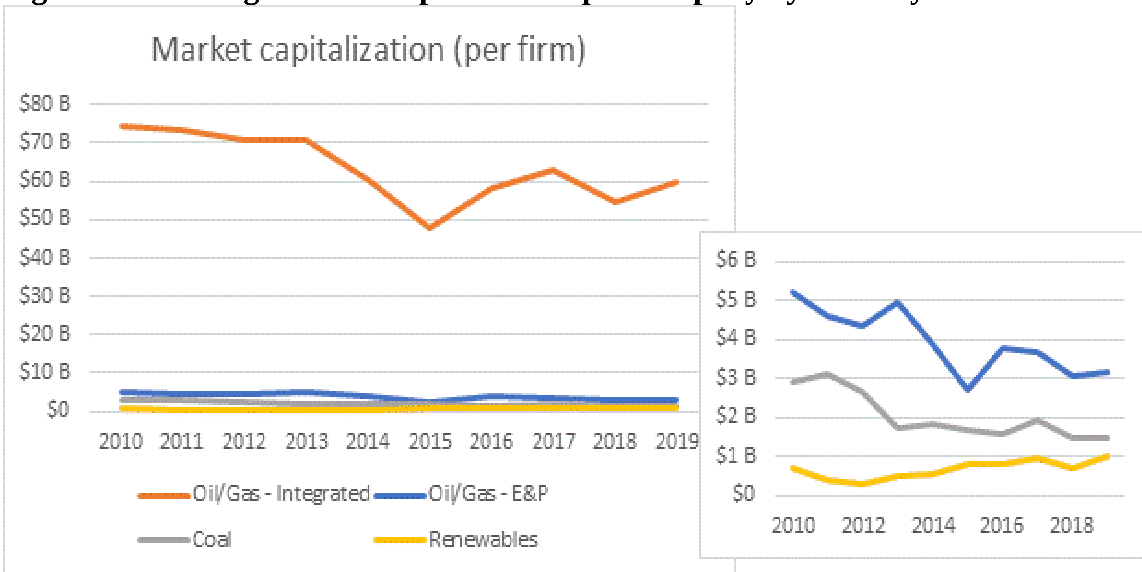
Source: Author's calculations using Bloomberg L.P. (2020).

Figure 2.3: Average profit margins by industry from 2010-2019



Source: Author's calculations using Bloomberg L.P. (2020).

Figure 2.4: Average market capitalization per company by industry from 2010-2019



Source: Author's calculations using Bloomberg L.P. (2020).

Table 2.12: Alternative estimates of wealth losses from stranded reserves in the 2 °C scenario (*d*=discount rate; values are in billions of 2018 US$)										
Source of Price and Supply Projections	**2 °C - Practitioner method**					**2 °C – Scenario Projection Method**				
	***d*=0%**	**3%**	**5%**	**10%**	**12.5%**	***d*=0%**	**3%**	**5%**	**10%**	**12.5%**
Oil Reserves										
Present study	23,471	17,589	14,737	**9,920**[a]	8,316	27,233	18,394	14,417	8,323	6,517
WEO - STEPS	21,424	16,141	13,573	9,223	7,769	**24,210**[b]	16,465	**12,971**[c]	7,599	6,000
WEO - CPS	37,028	27,796	23,316	15,746	13,224	42,618	**28,926**[d]	22,752	**13,266**[e]	10,446
Mercure/STEPS	5,225	3,981	3,365	2,296	1,930	5,930	3,887	2,977	**1,604**[f]	1,205
Gas Reserves										
Present study	3,914	2,977	2,513	**1,708**[a]	1,432	4,596	2,900	2,157	1,061	753
WEO - STEPS	2,811	2,156	1,829	1,260	1,063	**3,230**[b]	2,022	**1,495**[c]	726	511
WEO - CPS	5,016	3,798	3,196	2,156	1,801	5,962	**3,778**[d]	2,819	**1,397**[e]	996
Mercure/STEPS	599	463	391	255	205	841	424	248	**7**[f]	(54)
Coal Reserves										
Present study	3,509	2,384	1,875	**1,089**[a]	855	3,509	2,384	1,875	1,089	855
WEO - STEPS	2,645	1,769	1,374	768	589	**2,645**[b]	1,769	**1,374**[c]	768	589
WEO - CPS	4,374	2,999	2,376	1,410	1,120	4,374	**2,999**[d]	2,376	**1,410**[e]	1,120
Mercure/STEPS	154	67	30	(21)	(35)	154	67	30	**(21)**[f]	(35)
Total										
Present study	30,895	22,950	19,124	**12,717**[a]	10,602	35,339	23,679	18,449	10,474	8,125
WEO - STEPS	26,880	20,066	16,777	11,251	9,421	**30,085**[b]	20,256	**15,840**[c]	9,093	7,100
WEO - CPS	46,418	34,593	28,888	19,312	16,144	52,954	**35,703**[d]	27,946	**16,074**[e]	12,561
Mercure/STEPS	5,979	4,511	3,786	2,530	2,100	6,925	4,378	3,256	**1,589**[f]	1,116

Source: Author's calculations (see text for details on data sources).

[a] Uses method from this paper (identical to results in Section 2.4.2)

[b] Method analogous to Lewis (2014)

[c] Method analogous to Bauer et al. (2016)

[d] Method analogous to Linquiti and Cogswell (2016)

[e] Method analogous to Nelson et al. (2014) (they use a slightly lower discount rate at 8%)

[f] Method analogous to Mercure et al. (2018)

Table 2.13: Alternative estimates of wealth losses from stranded reserves in the 1.5 °C scenario (d=discount rate; values are in billions of 2018 US$)

Source of Price and Supply Projections	**1.5 °C - Practitioner Method**					**1.5 °C – Scenario Projection Method**				
	***d*=0%**	**3%**	**5%**	**10%**	**12.5%**	***d*=0%**	**3%**	**5%**	**10%**	**12.5%**
Oil										
Present study	25,258	19,006	15,961	**10,789**[a]	9,056	28,970	19,530	15,281	8,772	6,843
WEO - STEPS	23,958	18,144	15,302	10,455	8,821	**26,642**[b]	18,090	**14,231**[c]	8,294	6,526
WEO - CPS	39,562	29,799	25,045	16,978	14,276	45,050	**30,551**[d]	24,012	**13,961**[e]	10,971
Mercure/STEPS	5,580	4,294	3,647	2,505	2,107	6,176	3,996	3,026	**1,564**[f]	1,141
Gas										
Present study	6,554	5,045	4,290	**2,965**[a]	2,504	7,224	4,618	3,468	1,756	1,267
WEO - STEPS	5,451	4,224	3,607	2,517	2,135	**5,857**[b]	3,740	**2,807**[c]	1,420	1,025
WEO - CPS	7,656	5,867	4,974	3,412	2,873	8,590	**5,496**[d]	4,130	**2,092**[e]	1,510
Mercure/STEPS	1,284	1,010	862	584	481	1,562	838	529	**91**[f]	(24)
Coal										
Present study	4,616	3,188	2,535	**1,514**[a]	1,204	4,616	3,188	2,535	1,514	1,204
WEO - STEPS	3,752	2,573	2,035	1,193	938	**3,752**[b]	2,573	**2,035**[c]	1,193	938
WEO - CPS	5,481	3,803	3,036	1,835	1,469	5,481	**3,803**[d]	3,036	**1,835**[e]	1,469
Mercure/STEPS	375	223	155	53	23	375	223	155	**53**[f]	23
Total										
Present study	36,428	27,240	22,786	**15,268**[a]	12,764	40,810	27,336	21,285	12,042	9,314
WEO - STEPS	33,161	24,941	20,944	14,165	11,894	**36,251**[b]	24,403	**19,072**[c]	10,907	8,489
WEO - CPS	52,699	39,469	33,055	22,225	18,618	59,121	**39,851**[d]	31,178	**17,888**[e]	13,950
Mercure/STEPS	7,240	5,527	4,665	3,142	2,611	8,113	5,057	3,710	**1,708**[f]	1,141

Source: Author's calculations (see text for details on data sources).
[a] Uses method from this paper (identical to results in Section 2.4.2)
[b] Method analogous to Lewis (2014)
[c] Method analogous to Bauer et al. (2016)
[d] Method analogous to Linquiti and Cogswell (2016)
[e] Method analogous to Nelson et al. (2014) (they use a slightly lower discount rate at 8%)
[f] Method analogous to Mercure et al. (2018)

Table 2.14: Wealth losses from stranded oil and gas reserves for alternate production decline curves (2018 US$, B=Billion)		
Production decline curve	**2 °C**	**1.5 °C**
Exponential with 8% decline	$11,431 B	$13,434 B
Exponential with 10% decline	$11,628 B	$13,754 B
Hyperbolic with 20% initial decline (B=0.5)	$11,759 B	$14,041 B
Hyperbolic with 30% initial decline (B=0.5)	$12,006 B	$14,513 B

Source: Author's calculations based on results from Table 2.7 and production decline curves described in Appendix B.

Table 2.15: Wealth losses from stranded reserves under a permanent decrease in demand from COVID-19 (2018 US$, B=Billion)		
	2 °C	**1.5 °C**
Stranded oil + gas reserves	$8,573 B	$10,699 B
Stranded oil reserves	$7,313 B	$8,182 B
Stranded gas reserves	$1,260 B	$2,517 B
Stranded coal reserves	$768 B	$1,193 B
Total stranded reserves	**$9,341 B**	**$11,892 B**

Source: Author's calculations (see text for details).

CHAPTER 3

ECONOMICS AND CLIMATE JUSTICE ACTIVISM: ASSESSING THE FINANCIAL IMPACT OF THE FOSSIL FUEL DIVESTMENT MOVEMENT

3.1 Introduction

We know from climate science that humanity faces a potentially existential threat resulting from climate change. The single most important task that needs to be achieved to stabilize the climate is to dramatically reduce emissions of CO_2 generated through burning fossil fuels—oil, coal, and natural gas—to produce energy. Climate change cannot be entirely blamed on we humans consuming oil, coal, and natural gas to generate energy. But people consuming fossil fuels for energy can be blamed for about 80% of the problem.

This reality raises the urgent question: what are the most effective ways to transform the global economy away from its ongoing dependency on fossil fuels? Throughout the world, a wide range of policy approaches have been debated and, to a lesser extent, implemented. These include regulations to limit CO_2 emissions from various sources; subsidies to support investments in both energy efficiency and clean renewable energy sources such as solar and wind power; and putting a price on CO_2 emissions through taxation or a carbon cap. Such measures are having positive impacts where they are being implemented, but not nearly to the extent necessary to reverse the persistent rise of global CO_2 emissions.

This becomes clear from considering the most recent October 2018 report by the Intergovernmental Panel on Climate Change (IPCC), the most authoritative global organization advancing climate change research. The October 2018 report emphasized the importance of limiting the increase in global mean temperatures to 1.5 °C above preindustrial levels by 2100 as opposed to its previous primary target of 2 °C. The IPCC has now concluded that limiting the global mean temperature increase to 1.5 °C rather than 2 °C will have major impacts in terms of diminishing the negative impacts 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 concludes that to achieve the 1.5 °C maximum global mean temperature increase target as of 2100, global net CO_2 emissions will have to fall by about 45% as of 2030 and reach net zero emissions by 2050.[59]

These highly challenging 2030 and 2050 emissions reduction goals stand in sharp contrast with the current trajectory for global CO_2 emissions. Thus, according to the 2019 forecast by the International Energy Agency, if current global economic and energy consumption patterns prevail through 2040, global CO_2 emissions will not fall at all, but rather rise from the current level of about 33 billion metric tons to 41 billion tons (IEA 2019, 680-681). If this is the actual situation in 2040, then there would be virtually no chance to bring global emissions down to net zero, or any figure close to that, by 2050.[60] Clearly, much more effective interventions are urgently needed to successfully drive down CO_2 emissions both in the US and globally.

Beginning in 2011, climate activists, primarily in the US and Western Europe but also elsewhere in the world, have advanced divestment campaigns against private fossil

[59] The precise wording of the IPCC's assessment is as follows:

> In model pathways with no or limited overshoot of 1.5 degrees, global net anthropogenic CO_2 emissions decline by about 45 percent from 2010 levels by 2030 (40-60 percent interquartile range), reaching net zero around 2050 (2045-2055 interquartile range) (IPCC 2018b, 14).

[60] The IEA forecasting model extents only to 2040. The formal analysis in this paper remains within the parameters of the IEA forecast.

fuel corporations, such as Exxon/Mobil, Chevron, and Cloud Peak Energy, as one strategy for strengthening the necessary global decarbonization project. These divestment campaigns entail that all entities that own stocks or bonds in private fossil fuel corporations sell these assets. The fossil fuel divestment campaigns are roughly modeled on earlier such campaigns around ending apartheid in South Africa and opposing the sale of tobacco products.

The divestment campaigns have aimed to inflict damage on fossil fuel corporations through two channels. The first is to stigmatize them—to eliminate what has been termed their "social license to operate"—through forcefully establishing the culpability of these corporations as contributing to and profiting from the climate crisis. The second is to undermine their financial operations by weakening their prospects as profitable enterprises.

In this paper, our focus is on analyzing this second purpose of the movement. More specifically, we ask these questions: (1) To what extent have divestment campaigns succeeded to date in inflicting financial damage on fossil fuel corporations; and (2) What is the likelihood that they can succeed in this aim moving forward? Our examination includes an analysis of the available descriptive data on global divestment patterns, an estimation of the level of divested fossil fuel stocks and bonds, and an econometric modeling exercise that evaluates the impact of divestment events on the stock market prices of fossil fuel companies. Our overarching conclusion from examining the evidence brought together in this paper is that divestment campaigns have not been successful in inflicting significant economic damage on fossil fuel corporations and are not likely to do so in the future.

In reaching these conclusions, we recognize that, in the early phases of the divestment movement, such economic impacts were a secondary focus of the campaigns, with the primary purpose being to turn public opinion against the fossil fuel corporations through stigmatization. But it is also the case that the goal of directly imposing economic costs on the corporations has become increasingly significant to the movement over time. Here is the perspective, as of December 2018, of Bill McKibben, one of the founders and ongoing leaders of the movement, in an article titled “At Last, Divestment is Hitting the Fossil Fuel Industry Where It Hurts”:

> At first we thought our biggest effect would be to rob fossil fuel companies of their social license. Since their political lobbying power is about all what prevents governments taking serious action on global warming, that would have been worth the fight As time went on, though, it became clear that divestment was about squeezing the industry.

McKibben argues that the movement has indeed succeeded in “squeezing the industry.” He cites as evidence that Peabody Coal stated in its 2016 bankruptcy proceedings that the divestment movement had been a factor weakening its capacity to raise funds on financial markets, and that Shell Oil stated in 2018 that the divestment movement represented a “material risk” to its business.

This same perspective is advanced in other major outlets of the divestment movement. Thus, the GoFossilFree.org website states the following:

> The campaign began in an effort to stigmatize the Fossil Fuel Industry—the financial impact was secondary to the socio-political impact. But now, with trillions of USD of assets under management divesting, and more commitments flowing in

> all the time, money is moving. We have a responsibility and an opportunity to ask ourselves how moving the money itself (and not just the fight to move it) can help us usher forth our vision (GFF n.d.).

It is true that not all proponents of the divestment movement hold the view that the financial impacts of the movement are significant. For example, Gunningham (2017) argues that:

> The movement is fully aware that divestment of holdings in fossil fuels by the main institutional targets of the campaign is unlikely to have much, if any, short-term effect on the valuations of fossil fuel companies themselves. In any event, other, less ethically concerned investors will snap up the divested shares…. These matters, however, are of little concern to the movement because it views pressuring vulnerable institutional investors as primarily a vehicle through which to achieve its main goal(s); raising awareness of the climate change crisis and of the role played by fossil fuel extracting companies in precipitating it, and labeling these companies as morally reprehensible (311).

Gunningham's position is significant in articulating the primary motivations of some divestment activists. But for the present discussion, we will work from the current perspectives of the leading proponents of the divestment movement that we have cited above, i.e., those who do regard "squeezing the industry" as a major goal of the movement at present. As such, it is appropriate to evaluate systematically the extent to which the movement has, in fact, succeeded in "squeezing the industry." If we conclude from a systematic review of evidence that the divestment movement has not been successful in inflicting significant economic damage on the fossil fuel industry, it would then be appropriate for the climate movement to shift its focus towards alternative approaches to phasing out the fossil fuel industry.

In raising such issues, our purpose is certainly not merely to criticize the divestment movement. To the contrary, we recognize several important contributions of the movement. To begin with, the divestment movement has been a critical vehicle through which activists have been able to fight for goals that can be clearly articulated and achieved within the institutions and communities in which they work and live, as opposed to attempting to influence public policies where the decision-making process is more remote. Divestment campaigns also have a demonstrated record of success in forcing climate change into mainstream public debates—on college campuses, in religious institutions as well as at the levels of municipal and state governments.[61] In turn, these activities have galvanized and trained a new generation of climate activists.

At the same time, as the IPCC's October 2018 report makes clear, we face formidable hard deadlines to achieve dramatic reductions in global CO2 emissions (IPCC 2018b). We therefore have no choice but to prioritize political actions and policy interventions that are capable of contributing to driving down fossil fuel consumption and CO2 emissions as much as possible and as rapidly as possible. Correspondingly, we need to shift focus and energy away from strategies that are less likely to contribute significantly to driving down CO2 emissions significantly and rapidly.

The overall structure of the rest of the paper is as follows. Section 3.2 provides general background on the fossil fuel divestment movement and financial conditions for fossil fuel companies as they relate to the questions at hand. Section 3.3 reviews the

[61] See Schifeling and Hoffman (2017).

relevant literature as a framework through which we can then most effectively focus our own empirical analyses. Section 3.4 presents a range of descriptive evidence on global divestment activity. In Section 3.5, we present our econometric analysis as to how major fossil fuel divestment events have affected stock market prices of fossil fuel firms. Section 3.6 offers some concluding observations, including brief observations on alternative strategies for advancing the global climate stabilization project.

3.2 Background on the Fossil Fuel Divestment Movement

The first fossil fuel divestment campaign began in October of 2011 at Swarthmore College, a small elite liberal arts college outside of Philadelphia, Pennsylvania (Swarthmore 2012). While ultimately unsuccessful in forcing the college to divest, the Swarthmore campaign caught the attention of other environmentalists, including the well-known environmental journalist, activist, and co-founder of 350.org, Bill McKibben.

Following McKibben's publication of a 2012 article in Rolling Stone titled "Global Warming's Terrifying New Math," the fossil fuel divestment movement gained major momentum. McKibben's article argued that, in order for global CO2 emissions to fall sufficiently to stabilize the climate, 80% of all existing proven oil, gas and coal reserves will have to remain in the ground. That is, these fossil fuel assets cannot be used to generate energy if climate stabilization is a serious goal. McKibben reached the logical conclusion that the value of these assets for both the public and private entities which own them will have to fall to zero. While the exact level of fossil fuel reserves that must remain in the ground is up for debate, McKibben's general thesis that most reserves must remain in the ground is consistent with a range of evidence.[62]

The McKibben article generated huge interest, becoming the most widely read article in Rolling Stone's history (Hopke and Hestres 2017). Building from this response, 350.org, the climate justice organization that McKibben helped to found and lead, began mobilizing divestment campaigns widely. Within five months of the publication of McKibben's article, the movement had spread to more than 150 college campuses and continued to expand further from there (Bagley 2012). As of 5 September 2018, institutions across 37 countries including religious institutions, municipal and state-level governments, pension funds as well as colleges and universities—had committed to some form of fossil fuel divestment (Arabella 2018).

As McKibben himself pointed out in the passage we quoted in our introduction, the movement began increasingly to focus on the goal of inflicting financial damage on fossil fuel corporations as divestment campaigns spread. Divestment activists pointed to the trillions of dollars in "assets under management"—i.e., the total value of assets held across all industries—by entities that had divested themselves to some degree from their fossil fuel holdings. Despite this, the process through which divestment activity would inflict significant economic damage on fossil fuel corporations remained an open question. Indeed, as we consider in detail below, it is not clear that "assets under management" is a reliable metric as to the actual scope of the divestment movement.

[62] McKibben uses Leaton (2011) for his analysis. For an updated version, see Leaton et al. (2013). Other literature confirming the general thesis that most fossil fuel reserves must stay in the ground to stabilize the climate includes McGlade and Ekins (2015), Heede and Oreskes (2016), and Meinshausen et al. (2009), among others. The carbon budget included in the latest report from the Intergovernmental Panel on Climate Change (IPCC) also supports this thesis (IPCC 2018b).

These are the issues at hand. Ethically motivated owners of fossil fuel stocks and bonds certainly have the power to sell these assets as a statement of principle and act of protest. Equally significantly, the public debates that are central to all such divestment campaigns have demonstrated their ability to raise awareness of the climate crisis and to inspire increasing numbers of people to join the climate justice movement. Nevertheless, these accomplishments significant as they are—will still have no direct impact on the operations of the fossil fuel corporations as long as investors who are profit-seekers, as opposed to being motivated ethically, are willing to purchase the stocks and bonds that ethically motivated divestors have been put up for sale. At the very least, the direct impacts of the core divestment strategy of selling fossil fuel assets remain an open question until one also evaluates who will be purchasing these for-sale divested assets and under what circumstances.

It is a truism that profit-seeking investors will continue to purchase these divested fossil fuel assets as long as they can profit from them. Their profit opportunities will not be diminished through the divestment-led sales per se. This is because divestment per se does not affect either the cost structure of the corporations' productive operations or the goods markets in which consumers buy energy. In other words, divestments are capable of exerting a direct impact on the financial market valuation only of fossil fuel companies, not their sales on goods markets or their production cost structure. But still further, it is also likely that any such impacts on financial market valuations will be minimal as long as profit-seeking investors continue to see profit opportunities in owning oil, gas, and coal stocks.

The critical question then becomes: What can succeed in cutting into the profitability of fossil fuel corporations? The short answer to this question includes the following: policies that raise the costs of producing and consuming fossil fuels, such as a carbon tax; regulations that establish tight and binding limits on allowable emissions; and various sorts of subsidies and supports for energy efficiency and clean renewable energy as viable substitutes for fossil fuel energy. Such policies raise the costs of both producing and consuming fossil fuel energy, and lower the costs of substituting energy efficiency and clean renewable energy for fossil fuels. The profitability of firms producing and selling oil, coal and natural gas will decline as a result, while opportunities for clean energy will correspondingly rise.

The coal industry is an obvious case-in-point for understanding what effects profitability in the fossil fuel industry. Coal companies in the US and elsewhere have faced direct challenges to their profitability for decades. The emergence of low-cost natural gas supplies extracted through fracking, and, increasingly through low-cost wind and solar power,[63] has created viable substitutes for coal as a raw material in generating electricity. Coal companies have been further burdened by environmental regulations that have raised their production costs. The competition created by low-cost substitutes has prevented the coal companies from passing on their increased regulatory costs to consumers through raising consumer prices. The coal companies' profits have consequently been squeezed. These companies are now mostly generating losses. Profit-seeking investors have moved

[63] E.g., for a comparison of levelized costs of electricity generation between coal, natural gas, and renewable sources, see EIA (2019) and IRENA (2018).

out of coal, and share prices have fallen. By contrast, oil and gas companies have generally not faced challenges to their profitability at a comparable scale.[64]

We can obtain a sense of these broad patterns in Table 3.1, which provides evidence on net income between 2012 and 2015 for the five largest U.S. oil/gas and coal companies, respectively. As the table shows, there are large variations in the profitability of the individual companies, both in oil/gas and coal. But the overall patterns are clear. Over 2012-2015, the largest oil/gas companies earned a total of $203.8 billion in net income while the largest coal companies lost $17.2 billion. Moreover, Peabody Energy, Arch Coal and Alpha Coal have all been in and out of bankruptcy in recent years. Coal-fired power plants have also been shutting down steadily, despite pledges of support from the Trump Administration (Campbell and Lustig 2018).

In short, the simple logic of a fossil fuel divestment campaign suggests that it is not likely to produce a major impact on the operations of fossil fuel companies, much less produce significant reductions in CO_2 emissions. The coal industry is in a steady trajectory of decline, but the divestment movement is not likely to have impacted this trend significantly.

We address these issues more formally in the next three sections, first through reviewing the existing literature on the relevant questions, then presenting our own empirical findings and analysis.

[64] We recognize, of course, that during the first half of 2020, the market value of oil and gas companies collapsed. For example, the combined value of U.S. companies fell by nearly 50% from January to April, from $1.27 trillion to $700 billion. This was due first to the price war between Russia and Saudi Arabia, but still more, to the global economic crisis resulting from the COVID-19 pandemic. But the market value of the private oil and gas corporations is likely to return to something like their early 2020 levels once a recovery from the COVID crisis takes hold. As of this writing (May 2020), we cannot know when that recovery will commence.

3.3 Literature Review

The relevant research literature and journalistic reporting on divestment covers three broad topics: (1) estimates of amount of fossil fuel assets that have been divested; (2) financial impacts of divestments; and (3) indirect impacts through generating public debates. We consider these in turn.

3.3.1 Total Amount of Fossil Fuel Assets Divested

Efforts at measuring the scope of the divestment movement have mainly focused on the "assets under management" of the entities that have committed to divestment to some extent—that is, the total amount of assets held by these entities across all industries and classes of financial assets. A 2018 report by Arabella Advisors (which follows from similar earlier reports) finds that "nearly 1,000 institutional investors with $6.24 trillion in assets have committed to divest from fossil fuels, up from $52 billion four years ago—an increase of 11,900 percent" (1). To be sure, this figure for assets under management is large in absolute dollar terms, and the growth in the amount of assets under management held by divesting entities was indeed rapid from 2014 to 2018. Still, a more relevant measure for assessing the impact of divestments would be the total amount of assets that have actually been divested from fossil fuel companies, as distinct from all the other assets held by the divesting entities. To our knowledge, a 2016 news article by Carrington is the only published estimate of this figure. Carrington recognizes that "it is often difficult to calculate the precise proportion of fossil fuel investments in complex funds," but nevertheless reports the figure of divested fossil fuel assets to be about $400 billion as of 2016.[65] However, he offers no explanation as to how he derived this figure.

[65] Carrington's article more generally is summarizing the findings of the December 2016 report by Arabella Advisors, "The Global Fossil Fuel Divestment and Clean Energy Investment Movement"

3.3.2 Financial Impact of Divestments

Some recent studies and news stories show that divestment actions have had a negative impact on the financial market valuation of fossil fuel companies. As one prominent example, Dordi and Weber (2019) analyzed the impact of 24 fossil fuel divestment commitments, endorsements, and campaigns between 2012 and 2015 on fossil fuel share prices. Their primary methodology is econometric analysis, and specifically an "event study." With this approach, they aim to formally measure the extent to which fossil fuel share prices may respond to specific divestment "events." The events Dordi and Weber analyze include 13 announcements of divestment pledges, 5 endorsements of the divestment movement, and the launching of 6 divestment campaigns. Dordi and Weber conclude that these events have produced negative impact on fossil fuel share prices, writing that "Our results suggest that prominent divestment announcements have a statistically significant negative impact on the price of fossil fuel shares" (14).

In fact, however, Dordi and Weber's results actually show that the effects they observe are very short-term, modest, and inconsistent. Thus, in terms of one-day impacts only, they find that only 14 of the 24 events registered any statistically significant impacts on fossil fuel share prices, with 10 of the 24 events exerting no statistically significant effect even on the day of the event itself. Moreover, the impact of 8 of the 24 events on one-day share prices was positive, as opposed to the expected negative effect. When Dordi and Weber allow for a longer 10-day time period for measuring the impact of the various

https://www.arabellaadvisors.com/wp-content/uploads/2016/12/Global_Divestment_Report_2016.pdf. In 2013, Ansar et al. provided a very wide range for an upper limit figure for the total amount of fossil fuel assets, at between $360 and $900 billion. But they also cautioned that even this broad estimate was itself preliminary.

events, they then find that only 8 of the 24 total events exerted any statistically significant impact on fossil fuel share prices. That is, 16 of the 24 events—fully two-thirds of their sample—exerted no statistically significant impact within the 10-day time frame. Moreover, with the 10-day impact analysis, 11 of the 24 events exerted a positive impact on share prices.

In order to assess the longer-term impacts of divestment, Dordi and Weber present a graph comparing fossil fuel share prices with the MSCI All-Country World Index over a 260-day event window. However, as the authors concede, "This study cannot make any inference to the long-term effect (10+ days) of divestment due to confounding effects" (Dordi and Weber 2019, 15). As we demonstrate in section 3.5, the most important of these confounding effects is likely to be movements in the price of crude oil. Crude oil prices fell sharply in 2014 and 2015, two of the four years in their period of study.[66]

A final problem with Dordi and Weber's model is that the 24 events they analyze are not representative of the divestment movement as it has developed since 2011. This is because their data sample is limited to events that occurred between 2012 and 2015. As such, their model does not incorporate the largest divestment commitments, which have occurred after 2015.[67]

A distinct but related issue in terms of assessing the financial impact of divestment campaigns is evaluating how rates of return for investors may be affected through

[66] See a time series of the West Texas Intermediate crude oil price at https://www.macrotrends.net/1369/crude-oil-price-history-chart.

[67] In terms of more anecdotal evidence, Davies (2019) reported in a news story that the market value of five UK-based oil companies decreased by about 3% on the day that Norway's sovereign wealth fund divested from upstream oil and gas companies. But we do not have evidence as to how long these stock prices remained at this lower level.

eliminating fossil fuel stocks from their portfolios. Trinks et al. (2018) provide the most comprehensive analysis on this question. They compare the financial performance of fossil fuel free portfolios with unconstrained portfolios using U.S. stock market data from 1927 to 2016. They find that "fossil fuel divestment has not significantly impaired financial performance of investment portfolios." They explain their result as follows:

> The absence of diversification costs from divestment can be explained by the fact that fossil fuel company stocks have thus far not outperformed other stocks on a risk-adjusted basis and only provide relatively limited diversification benefits. We find that fossil fuel stocks are more or less substitutes for the market index (747).

Trinks et al. do also make clear that, according to their results, the returns on a fossil-free portfolio are not higher than an unconstrained portfolio. This result contradicts the findings of Hunt and Weber (2018) who do show that, over 2011-2015 for the Canadian stock index TSX 260, the risk-adjusted returns on a fossil fuel free portfolio are higher than an unconstrained portfolio. The primary factor explaining the difference between the two sets of results is the respective time periods under consideration. Trinks et al. explain that the "underperformance of fossil fuel stocks in the most recent period (2011-2016) can be attributed mainly to the oil price shock in that time period."[68]

3.3.3 Indirect Impacts through Public Debates

A key study here is that by Schifeling and Hoffman (2017). Similar to Gunningham's position that we cited above, Schifeling and Hoffman acknowledge that the

[68] Bergman (2018) presents another discussion of the financial impact of divestment actions on fossil fuel companies, within a broader context of impacts on policy environment and public discourse. Bergman concludes that "the direct impacts of divestment are small," but he holds that the "indirect impacts, in terms of public discourse shift, are significant." His discussion on direct financial impacts is brief and does not include a systematic review of evidence.

divestment campaigns were never likely to have a significant effect on the financial operations of fossil fuel companies. Nevertheless, Schifeling and Hoffman argue that the indirect effects have been substantial. Using a dataset of more than 42,000 articles from nearly 300 newspapers spanning 2011-2015, they found that, as a result of the divestment movement, “radical” issues (e.g., carbon bubble, unburnable carbon) moved closer to the mainstream, and “liberal” issues (e.g., carbon tax, mitigation) moved into the mainstream. They write,

> Although the divestment campaign chose an objective that is largely impossible to fulfill, as divestment will not likely undermine the valuations of fossil fuel companies, this objective also provided leverage to expand the boundaries of the public debate and enhance the position of progressive issues (17).

Overall, we can conclude from the relevant literature that the divestment movement has certainly been successful in raising public consciousness around climate change. But beyond this, we have found no reliable evidence to date as to the actual amount of fossil fuel assets that have been divested, as opposed to the total assets under management of the divesting entities. We also have only sketchy evidence from the literature as to any possible impacts of divestment activity on the financial conditions of fossil fuel companies. We do see substantial evidence that investors will not experience losses through holding a fossil fuel divested portfolio. This result can be used to support divestment campaigns. But it still does not follow that divestment activity can succeed in inflicting significant financial damage on the private fossil fuel corporations. This is because fossil fuel corporations will still maintain their capacity to earn profits from selling oil, coal, and natural gas to generate energy, and profit-oriented investors will still be able to purchase fossil fuel company stocks from the ethically motivated investors and earn favorable returns from these stocks.

We now turn to examining a range of empirical evidence that will enable us to evaluate these issues more systematically.

3.4 Descriptive Evidence on Global Divestment Activity

Our starting point for estimating global divestment levels among all entities is the valuable dataset produced by GoFossilFree.org (GFF). GFF is a project of 350.org, serving as a major website providing information on the divestment movement, including all available data on divestment commitments. The GFF dataset includes information for each entity that has either already divested or has committed to divest its portfolio of fossil fuel assets. These entities include asset management firms, pension funds, religious institutions, educational institutions, and government bodies such as municipalities (primarily in France). The information provided by GFF includes: the home countries of each entity; the total assets under management at the time of the divestment commitment; and the extent of the divestment commitment.

As an initial matter, it is critical to be clear on the distinction between the assets under management of an entity committed to divestment and the actual level of divestment by that entity. As an example, CalPERS (the California Public Employees Retirement System) manages the largest public pension fund in the United States. It has about $350 billion in assets under management as of February 2018. On 8 October 2015, CalPERS committed to divest its coal holdings of $83 million. Thus, its level of divestment out of coal, at $83 million, amounts to about 0.02% of its total assets under management.

It is equally important to be clear on distinctions in terms of divestment commitments levels among various entities, since these commitment levels do vary significantly. We list different commitment levels in Table 3.2. As we see there, we divide commitment levels into two broad categories, “limited” and “full” divestment commitments. Under limited commitments, we include three more specific categories—divestment from (1) coal only; (2) coal and tar sands only; and (3) some other mix of fossil fuel divestments, such as coal plus some natural gas, or (as is often the case) a limited portion of coal companies. Under full divestment commitments, we include entities that have either: (1) already fully divested themselves of all their fossil fuel holdings; or (2) formally committed to doing so.

The GFF database includes some ambiguities and gaps which we have addressed to the extent possible. First, GFF states that all of the divestment commitments that it reports in its dataset are ‘binding.’ But we found that not all commitments are in fact binding. For example, city councils of some municipalities have voted to divest. But the final decision to sell off fossil fuel assets rests with the fund managers, not the council itself. We were also unable to consistently establish whether some entities have already divested, are in the process of divesting, or have yet to initiate the asset sale process. Additionally, for some entities, figures for commitment dates, commitment levels, and amount of assets under management are unavailable.

We have referenced additional sources beyond the GFF to fill in the data gaps to the extent possible.[69] Specifically, we obtained additional information on both the level of divestment commitment as well as total assets under management for two sets of large

[69] These references are documented in detail in Appendix 1.

entities within the overall GFF database. These are: (1) entities with assets under management of $1 billion or more that have made full divestment commitments; and (2) entities with assets under management of $90 billion or more that have made limited divestment commitments.

3.4.1 Composition of Divesting Entities

Table 3.3 presents summary statistics on entities in the GFF dataset that have divested at any commitment level as of 26 March 2018. As the table shows, there are a total of 796 entities in this dataset. Of these 796 entities, we have figures on assets under management for a total of 480 of them, i.e., 60.3% of the entities listed by GFF. From the available data, we assess that the remaining 316 entities, for which we do not have figures on assets under management, hold insignificant amounts of assets under management.[70] Even in the aggregate, the level of assets under management for all 249 entities is modest, almost certainly less than $15 billion.[71]

Focusing on the 480 entities for which we do have data on assets under management, the total assets under management for these entities, as we show in Table 3.3, amounts to $6.5 trillion.[72] But, critically, we also see in Table 3.3 that total assets under management are highly concentrated in a small number of the overall pool of 480 entitles. Specifically, 15 entities—only 1.9% of the 796 entities with some known level of

[70] The one exception among this group of entities would be the city of Paris. But data on assets under management for Paris are unavailable. Moreover, the extent of the divestment commitment by Paris remains unclear as of this writing.

[71] Median assets under management are $35.7 million. Multiply this by the 316 entities gives us $11.3 bil- lion. However, this is likely an overestimate based on the types of entities represented among the 316 entities (e.g., disproportionate number of small churches and municipalities).

[72] Our estimate is consistent with Arabella Advisors (2018), who provide a slightly lower estimate of $6.24 trillion as of 5 September 2018.

divestment commitment—account for $5.7 trillion of the $6.5 trillion of assets under management that we can identify. That is, these 15 entities account for about 88% of all the assets under management among the 480 entities that GFF has identified as having taken some divestment action and for which assets under management data are available. Only one of these entities (the New York City pension fund system) committed to full divestment, leaving 14 entities with limited commitments accounting for 85% of the $6.5 trillion in assets under management.

Working from these figures in Table 3.3, we can usefully divide all divesting entities into three broad categories:

1. The 14 largest entities with limited commitment levels, which account for roughly 85% of all assets under management among divesting entities.
2. The remaining smaller entities—aside from the 14 largest entities—committed to limited divestment levels.
3. All entities committed to full divestment levels.

3.4.1.1 The 14 Largest Divestment Entities with Limited Commitments

Table 3.4 lists the 14 largest global entities that have made limited divestment commitments. The table shows both the level of assets under management for these entities and their divestment commitment levels. As noted above, all of these entities have made limited divestment commitments only, some specifics of which we present in Table 3.4.

For all of these entities, the figures on assets under management come directly either from the GFF database or other published sources. For the figures on divestment levels, the figures come from other published sources for 9 of the 14 entities. With five of the entities—Aegon, Aviva, Lloyd's, Bank J. Safra Sarasin, and Swiss Reinsurance

Company—no published data were available on divestment commitment levels. We therefore extrapolated figures for these five entities based on data for the other 9 divesting entities.[73]

As Table 3.4 shows, the entity with the largest divestment commitment is the Government Pension Fund Global. This is a Norwegian sovereign wealth fund that was created to manage the country's oil revenues, with total assets under management amounting to $890 billion at the time of the divestment commitment (5 June 2015). Their total divestment, which is for coal only, is $9 billion, i.e., 1% of their total assets under management. The next largest divesting entity is AXA Investment Managers (IM), a French asset management firm. The total assets under management by AXA IM were $782 billion at the time of the divestment commitment (25 April 2017). Their divestment commitment was for $209 million, i.e., about 0.03% of their total assets under management. AXA IM's level of commitment was a coal-only divestment.

Overall, we estimate the total funds divested from the 14 largest divesting entities to be $21.7 billion.[74] This amounts to roughly 0.4% of their total assets under management. The level of their divestment commitments ranges between 0.01% and 1.17% of their assets under management.

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[73] Appendix 1, again, provides full references to our data sources. Appendix 2 describes our extrapolation methods.

[74] After compiling our data, on 8 March 2019 Norway's sovereign wealth fund committed to divest an estimated $7.5 billion from upstream oil and gas companies (a small portion of their total investments in oil/gas companies), beyond their original coal divestment displayed in Table 3.4 (Davies 2019). This was not part of the divestment movement, but was instead done for economic reasons (reducing risk expo-

sure to a permanent decline in oil prices). Even if we did include this additional $7.5 billion, it would not change our overall results.

3.4.1.2 Smaller Entities with Limited Divestment Commitments

As we show in Table 3.5, there are a total of 94 entities in this category of entities with limited divestment commitments. These smaller divesting entities control a total of $675 billion under management. We do not have direct figures on the extent of total coal and tar sands stocks for which they had divested. But to approximate, we assume that the pre-divestment portfolio of these firms is the same as that for the 9 large firms listed in Table 3.4 for which we do have data. That overall level of holdings was 0.43% of the total portfolio. We therefore assume that the level of divestment for these entitles is 0.43% of their total assets under management. This implies that the level of limited divestments by these firms amounts to $2.9 billion.

3.4.1.3 Entities with Full Divestment Commitments

Table 3.6 presents figures on these entities. As we see, most of the entities in the GFF dataset—671 of 796 in total—are committed at this full divestment level. Of those 671 entities, we have asset information on 372 of them. The assets under management for these firms amount to $290 billion, i.e., only 3.2% of the total assets under management for both the limited and full divestment entities. Moreover, of these entities with full divestment commitments, two of them—New York City pension funds and MP Pension Fund—manage $208 billion, or 71.3% of the total assets under management for entities committed to full divestment. These two entities have committed to divesting $5.2 billion from fossil fuels.

Using data on the fossil fuel industry's share of the global stock market (see Appendix E), we estimate the total funds divested from the other 371 entities fully divesting to be $6.3 billion. That amounts to a total of $11.5 billion for all entities that have divested fully, including the $5.2 billion from New York City and MP Pension Fund as well as the $6.3 billion from all other fully divesting entities.

3.4.1.4 Summary of Descriptive Evidence

As we have seen, the data we have been able to compile on global fossil fuel divestment activity are incomplete. In particular, we have data on assets under management for only about 60% of all entities listed in the GFF database. Of these entities, we have documented data on divestment levels for only 11 entities in total. However, these 11 entities do account for roughly 63% of all assets under management for all divesting entities. We are also confident that our methods of estimating divestment levels for the remaining firms are broadly reliable. Our basic approach is to assume that the levels of fossil fuel asset holdings prior to divestment for the divesting entities broadly match the fossil fuel asset holdings for all entities in global financial markets.

Based on the data we have compiled and estimated on assets under management and divestment levels, the main patterns we observe are as follows:

1. Virtually all of the entities that have committed to divestment at any level are very small, as measured by assets under management.
2. Most of the entities are committed at full divestment levels. But here as well, virtually all of the entities committed to full divestment are small.
3. Fifteen large entities dominate the overall pool of divesting entities, as measured both directly by assets under management, and, through our estimations, by levels of divestment. Moreover, all but one of these 15 large entities have made only limited divestment commitments.

Table 3.7 summarizes the estimates we have derived for overall levels of divestment. As we see in Panel A of Table 3.7, we estimate that total divestment commitments as of March 2018 amount to $36.1 billion. Of this total, $21.7 billion, or about 60%, are the divestments committed by the 14 largest entities with limited divestment commitments.

In Panel B, we show these divestment commitment levels as a share of the market value of fossil fuel assets in all global financial markets, using figures from 2014. As we see, the $24.6 billion in limited divestment commitments, including the commitments of both the 14 largest entities and the 94 smaller entities, amounts to 10.6% of the $233 billion in total market value for global coal corporations. The full divestment commitments of $11.5 billion amount to 0.2% of total market value for all global fossil fuel companies. The $36.1 billion in total divestment commitments—including all limited and full commitments—amounts to 0.7% of the total market value of global fossil fuel companies as of August 2014 (Bullard 2014).[75]

3.5 Econometric Analysis of Divestment Events

In this section, we conduct time-series econometric analysis to assess the impact of specific divestment events on the stock market share prices of oil/gas and coal companies, respectively. Our modeling approach is a standard "events study" methodology.[76] The dependent variables in the regressions are the share prices of the oil/gas and coal

[75] We note that entities continue to commit to divest. As of 2 June 2019, GFF estimates total assets under management to be $8.77 trillion (see www.gofossilfree.org/commitments). We cannot confirm this amount because we have not cleaned the data since 29 March 2018, but if we extrapolate from our estimate of $36 billion, this would entail an additional $12 billion, bringing the total to about $48 billion.

[76] The econometrics of event studies in the finance literature is well summarized in Campbell et al. (1997), Chapter 4.

companies, measured according to three alternative specifications. In terms of explanatory variables, we run a first set of regressions with variables that typically influence fossil fuel share prices. We then run a second set of regressions, in which we add the divestment events as additional dummy variables in the time series models. Through this approach, we are able to formally test the extent to which any given divestment event affects fossil fuel share prices, after controlling for the effects of explanatory variables that are typically significant. We are also able to measure the extent to which all the divestment events, considered cumulatively, are influencing fossil fuel share prices.

As we have shown in the previous section, the assets under management of divesting entities are heavily concentrated in a small number of large entities. Given this, we are able to concentrate our regression analysis on these largest divestment commitments to estimate the overall impact of divestments on the share prices of fossil fuel companies. With respect to oil and gas divestments, the 11 divestment commitments we use in our event study account for roughly 78% of all assets that have been divested, with the New York City pension fund system accounting for 65% on its own. With coal, the 12 divestment commitments we use in our event study similarly account for about 78% of all assets that have been divested.

Our basic model is a single equation:

$$Fossil\ Fuel\ Share\ Price = \beta_0 + \beta_1(Fossil\ Fuel\ Price\ Index)_t + \beta_2(S\&P\ 500\ Fossil\ Fuel\ Free\ Index)_t + \beta_3(Divestment\ Events)_t + \varepsilon_t$$

This equation tests how much variation the share prices of either oil/gas or coal companies are affected by the following:

1. Changes in the market prices of oil/gas or coal respectively in goods markets;

2. Changes in overall stock market prices exclusive of the fossil fuel share prices; and
3. Any of the 11 divestment events with respect of oil and gas stock holdings or the 12 divestment events of the coal companies.

The specific variables we use in these regression models are as follows:

Oil and Gas Share Price Analysis

1. *Fossil Fuel Share Price*. We specify this through three data series, running separate regressions with each data series as the dependent variable:

   • The Dow Jones US Oil & Gas Index;

   • The Royal Dutch Shell share price;

   • The Exxon/Mobil share price.

2. *Fossil Fuel Price Index*. Two benchmark oil and gas prices in the US—the West Texas Intermediate oil price and the Henry Hub natural gas price.
3. *S&P 500 Fossil Fuel Free Index*. This is an S&P stock market index that excludes all fossil fuel firms, but otherwise incorporates a broad set of 500 publicly listed corporations.
4. *Divestment Events*. Dummy variables for the dates of 11 of the largest full divestment commitments.[77] We list these 11 divestment commitment events in Table 3.8. We include the divestment commitments from Syracuse University and the Guardian Media Group as one event since they occurred within one day of each other, i.e., 3/31/15 and 4/1/15.

[77] We excluded four divestment commitments because we either did not know the commitment date, could not verify the commitment from a published source outside of GFF, or the commitment date was too recent (e.g., MP Pension Fund's divestment on 26 March 2018 was too recent to include in the event study).

Coal Share Price Analysis

1. *Fossil Fuel Share Price*. We specify this through three data series, again running separate regressions with each data series as the dependent variable:

   • The Dow Jones US Coal Index;

   • The Cloud Peak Energy share price;

   • The Alliance Resource Partners share price.

2. *Fossil Fuel Price Index*. We include here four separate coal prices: (1) an Appalachian price, derived averaging separate prices for Central and Northern Appalachia; (2) the Illinois Basin price; (3) the Powder River Basin price; and (4) the Uinta Basin price.[78]

3. *S&P 500 Fossil Fuel Free Index*. As described above for the oil/gas regression variables.

4. *Divestment Events*. Dummy variables for the dates of 12 of the largest coal divestment commitments.[79] We list these 12 divestment commitments in Table 3.9. We include the divestment commitments from CalPERS and the California State Teachers' Retirement System (CalStrs) as one event since they occurred on the same day, 8 October 2015. Similarly, we considered the coal divestments by PFZW and Allianz Group as one divestment event, since they occurred in consecutive

[78] We experimented with different combinations of coal prices in the regressions but decided to keep them all because there was not one single price that could serve adequately as a benchmark. Moreover, the statistical significance of the event dummies was essentially the same across the different combinations.

[79] We excluded three divestment commitments because we did not know the commitment date, or the details surrounding the commitment were ambiguous.

weeks, 16 November 2015 and 23 November 2015 (coal price data are reported weekly).

3.5.1 Adjustments with Data and Models

We ran the model using ordinary least squares with heteroskedastic-consistent standard errors to control for heteroskedasticity. Most variables with both sets of data include stochastic unit roots, as measured by Augmented Dickey Fuller tests. We therefore converted the variables into stationary series through taking first differences in all cases.

3.5.2 Results of Oil and Gas Share Price Analysis

We show the results for oil and gas share prices in Tables 3.10 and 3.11. There we report results for 12 separate regressions. In regressions R1-3, we show results for our three different measures of oil/gas share prices as the dependent variable. For the explanatory variables in these regressions, we include only the oil goods market price index, and the S&P 500 fossil free share price index. In regressions R4-6, we then include the natural gas goods market price index as an explanatory variable. In regressions R7-9, we work with the same three oil/gas share prices as dependent variables, and we again exclude the natural gas goods market price as an explanatory variable. But in regressions R7-9, we now include the 10 divestment events as dummy variables, along with the oil goods market price and the S&P 500 fossil free index. In regressions R10-12, we include the natural gas goods market price index, along with all the other explanatory variables, including the 10 divestment event dummies.

The results for regressions R1-6, which do not include the divestment dummies, are consistent. Both the oil goods market price and the S&P 500 fossil free index have large statistically significant effects on oil/gas share prices, with the anticipated positive signs in all 6 regressions. Natural gas goods market prices do not produce any additional statistically significant explanatory power. The magnitude of the positive effects does vary, depending on whether the dependent variable is the overall oil/gas share price index or the specific share prices for Shell and Exxon, respectively. Not surprisingly, the coefficient values, t-statistics, and R2 values are all much higher with the broad oil/gas share price index as the dependent variable. When we use the specific share prices for Shell and Exxon as dependent variables, there will be more firm-specific influences on these share prices that are not included in our explanatory variables.

In regressions R7-12, we see that adding the 10 divestment event dummies as explanatory variables does not alter the oil/gas share price in any significant way relative to what we see in regressions R1-6. That is, the coefficient values for all the divestment event dummies are either statistically insignificant or, in two cases only, significant at the 5 percent level, but in the theoretically unanticipated positive direction. That is, in regressions R9 and R12, with the Exxon share price as the dependent variable, the HCF and CIFF divestment event dummies are statistically significant explanatory variables, shown to be contributing positively to the Exxon share price. These positive coefficients are almost certainly capturing some other unspecified influence on Exxon's share price. But in any case, we do not have an explanation as to why these divestment events would contribute toward increasing Exxon's share price.

With these regressions, we are also able to test whether the divestment events may, in combination, have had a cumulative impact on oil/gas share prices, even if no single event has a significant effect. We can test for this possible effect through the F-statistics for each regression, which are measuring whether the coefficients on all the divestment event dummies are statistically significant in combination. In fact, as we see, the F-statistics for each of the regressions R7-12 are strongly insignificant.

Overall then, the results from regressions R1-12 consistently show that the divestment events had no negative impact on the share prices for oil/gas firms. Neither the share prices as measured by the oil/gas price index nor the individual share prices for Shell or Exxon have been negatively affected by either any single divestment event or by the combined impact of all the divestment events included in our model.

3.5.3 Coal Share Price Analysis

We present our regression results for the coal share prices in Tables 3.12 and 3.13, including regressions R13-24. We present these results within a framework similar to that with the oil/gas regressions. That is, we include three separate dependent variables, the Dow Jones Coal share price index as well as the share prices for Cloud Peak and Alliance. Regressions R13-15 include only coal goods market prices and the S&P 500 Fossil Free price index as explanatory variables. Regressions R16-18 then include both the natural gas price and oil price in goods markets as additional explanatory variables. We would expect price increases in oil and gas to positively influence coal share prices, by making coal more competitive as a substitute energy source.

With regressions R13-18, variation in the coal goods market prices do not influence coal share prices in any consistent pattern. In most cases, the coefficients on the price variables are insignificant. The signs are also not consistently positive, as would be expected. One interpretation of this pattern is that they reflect the general difficulties that the coal industry has experienced for roughly the past two decades, as we discussed in Section 3.2. The impact of these broader problems could be frequently exerting greater influence on share prices than the positive influences that we would expect commodity prices to have on share prices.

By contrast, we do see in regressions R13-18 that the S&P 500 Fossil Free Index is exerting a consistently positive influence on coal share prices. The coal share prices do also respond positively to increases in both natural gas and oil prices, as expected. These effects are especially strong with the broader Dow Jones share price index included as the dependent variable.

As with the oil/gas regressions, we next use the independent variables in regressions R13-18 as control variables to test whether the coal divestment events provide any additional explanatory power in the regressions. With these regressions, there is some modest evidence that coal share prices have been impacted by divestment events, though not on a consistently negative basis, as we would expect. Thus, we see that the AXA-SA divestment event in May of 2015 does produce a statistically significant negative effect on both the Dow-Jones Coal share index and on the Cloud Peak share price. The University of California divestment event in September of 2009 generates a statistically significant negative effect on the Cloud Peak and Alliance share prices. Other divestment events in our model also generate negative coefficients, though none that are statistically significant. But in addition, the Nordea, Aviva, CalPension, and PFZW/Allianz divestment events all generate positive coefficients on the dummy variables, though none that are statistically significant.

The F-statistics measuring the combined effects of all divestment effects on coal share prices are statistically significant, indicating that the divestment events are having a measurable cumulative impact on coal share prices. However, because the signs on the individual coefficients do not have a consistent pattern—either positive or negative—we cannot draw an overall conclusion that the divestment events are generating a consistently negative impact on coal share prices, as we would anticipate theoretically.

The long-term decline in the coal industry, as discussed above, has had a major negative effect on the share prices of coal firms. Beyond this, we do see some evidence that the coal divestment events have contributed in some cases to lowering coal share prices. This evidence is relatively weak and mixed. But it still contrasts with our results for the oil/gas industry, where we saw no evidence at all that divestment events negatively impacted share prices.

One major difference with the coal divestments is that, as we have seen, the relative magnitude of these divestments has been far greater than has been the case with oil and gas. Specifically, as we saw in Table 3.7, the full divestment events, including oil and gas divestments, amounted to about 0.2% of the overall market value for oil/gas stocks. The coal divestments, by contrast, amounted to over 10% of the market value of coal stocks. In addition, the oil/gas industry has remained broadly profitable while the coal industry has been experiencing a decline.

3.6 Concluding Considerations

Our empirical investigations in Sections 3.4 and 3.5 lead us to one basic conclusion: that the fossil fuel divestment movement has not been successful in inflicting significant economic damage on fossil fuel corporations and is not likely to do so in the future. We reach this conclusion based on two main sets of findings.

From our analysis of descriptive evidence in Section 3.4, we conclude that total fossil fuel divestment commitments as of March 2018 amount to $36.1 billion. Of that amount, \$21.7 billion, or about 60%, are divestments committed by the 14 largest entities. These 14 entities have made limited divestment commitments only. In particular, they have not committed to fully divesting from oil and gas stocks. We estimate full divestment commitments to be about \$11.2 billion, equal to about 0.2% of the total market value for all global fossil fuel companies. The \$36.1 billion in total divestment commitments, including limited as well as full divestment commitments, is equal to roughly 0.7% of the total market value of all fossil fuel assets.

The econometric analysis we present in Section 3.5 finds that divestment activity has had no measurable impact on the share prices of oil and gas companies. There is some evidence that share prices of coal companies have been affected by divestments. But, at most, such effects have been relatively weak and mixed. This is despite the fact that coal divestments amounted to over 10% of the market value of coal stocks.

In short, we find no evidence that the divestment movement has succeeded in “squeezing the industry.” Beyond our own main findings, there is also nothing in the relevant literature that significantly contradicts our main results. Rather, as we reviewed in Section 3.3, the empirical evidence to date on the financial impacts of the divestment movement has been quite limited. Thus, at the very least, the research we present here provides a more in-depth foundation from which others may also evaluate the financial impacts of the fossil fuel divestment movement.

Assuming our main findings are at least broadly accurate, these results still do not gainsay the contributions of the fossil fuel divestment movement. The movement has succeeded in stigmatizing private fossil fuel corporations for profiting off of the climate crisis. More broadly, it has also successfully mobilized public opinion and activism around climate issues. These accomplishments are significant. Nevertheless, the fact that the divestment movement is not inflicting economic damage on the fossil fuel corporations should at least invite consideration of alternative approaches to climate activism that offer the prospect of significant financial impacts. Such reconsiderations should be seen as especially appropriate given the urgency for climate activists to focus their commitments on initiatives that offer the greatest possible likelihood of success.

As a brief concluding observation, we note one such alternative strategy that has begun to gain support on college and university campuses. That is for activists to demand that the institutions to which they belong commit to eliminating altogether their own CO_2 emissions by 2035, or some other date that falls well within the IPCC's stipulated climate stabilization time frame.[80] The institutions can choose a range of specific measures for accomplishing this goal. But fundamentally, meeting the goal will require that the institutions invest heavily in clean renewable energy sources—primarily solar and wind power—to eliminate their current dependency on fossil fuels. Correspondingly, they will also need to invest significantly in measures that can raise energy efficiency levels in their buildings, equipment, and transportation systems.

Note that through this approach, the financial viability of fossil fuel corporations is being directly attacked. This is simply because, of course, fossil fuel corporations can sustain themselves only to the extent that they are able to sell oil, coal, and natural gas as energy sources. This approach can therefore be seen as effectively amounting to a direct

[80] We are aware of activities at our own institution, University of Massachusetts Amherst, as well as Smith, Amherst, Middlebury and Williams Colleges, the University of California Berkeley, as well as Vanderbilt, Boston, and Cornell Universities. One of the authors (Pollin) has received much of this information as a member of the UMass Amherst Carbon Mitigation Task Force.

consumer boycott on purchasing oil, coal, and natural gas, as opposed to the indirect approach of impacting the stock market prices of fossil fuel corporations. This direct consumer boycott approach should also be able to produce impacts similar to divestment campaigns with respect to stigmatizing fossil fuel corporations.

Of course, the overarching commitment of the climate movement should be to advancing climate stabilization, not to any particular strategy that may be more or less effective at advancing this ultimate goal. The research we present here demonstrates limitations of the divestment movement as a climate stabilization strategy, while also recognizing the contributions of the movement to date. These results will serve a useful purpose if they contribute towards the development of still more effective strategies in behalf of the climate stabilization imperative before us.

3.7 Tables

Table 3.1: Net income for major U.S. oil/gas and coal companies, 2012-2015	
Oil/Gas Companies	
■ Exxon/Mobil	$131.2 billion
■ Chevron	$71.9 billion
■ Conoco-Phillips	$19.8 billion
■ Anadarko	-$5.0 billion
■ Devon	-$13.7 billion
Oil/Gas Total	**$203.8 billion**
Coal Companies	
■ Peabody Energy	-$3.9 billion
■ Arch Coal	-$4.8 billion
■ Cloud Peak Energy	$100 million
■ Alpha Natural Resources	-$10.1 billion
■ Alliance Resource Partners	$1.5 billion
Coal Total	**-$17.2 billion**

Sources: Pollin and Callaci (2019)

Table 3.2: Commitment levels among divesting entities
Limited divestment commitments ■ Coal only ■ Coal and tar sands only ■ Partial commitments from varied fossil fuel assets
Full divestment commitments ■ Fully divested from all fossil fuel assets ■ Committed to full divestment

Source: Gofossilfree.org (2018)

Table 3.3: Entities at all divestment commitment levels and assets under management data, as available		
	Number of Entities	Assets under Management
All entities with known commitment types	796	Not available for 316 entities
All entities with Assets under Management Data	480 *(60.3% of total entitles)*	$6.5 trillion
Largest Entities, with +$90 billion in assets under management	15 *(1.9% of total entities)*	$5.7 trillion *(88.0% of assets under management)*
Largest Entities (+$90 billion in assets under management) with limited commitment levels	14 *(1.8% of total entities)*	$5.5 trillion *(85% of assets under management)*

Sources: Gofossilfree.org (2018); Appendix D

Table 3.4: Largest divesting entities with limited divested commitments						
Entity	1)Home Country of Entity	2) Assets under Management (at time of divestment)	3)Funds Divested or Committed (at time of divestment)	4)Level of Divestment Commitment	5) Date of Divestment Commitment	6)Divestment Commitment as share of Assets Under Management *(= column 3/2)*
1.Government Pension Fund, Global	Norway	$890 billion	$9.0 billion	Coal Only	6/5/2015	1.01%
2.AXA Investment Managers	France	$782 billion	$209 million	Coal Only	4/25/2017	0.03%
3.Allianz SE	Germany	$668 billion	$4.38 billion	Coal Only	11/23/2015	0.66%
4.AXA SA	France	$589 billion	$590 million	Coal Only	5/22/2015	0.1%
5.Aviva	UK	$572 billion	$492 million	Coal Only	7/24/2015	0.09%
6.Aegon	Netherlands	$382 billion	$1.64 billion	Coal Only	5/25/2016	0.43%
7.Lloyd's Corporation	UK	$378 billion	$1.63 billion	Coal Only	11/17/2017	0.43%
8.CalPERS	USA	$289 billion	$83 million	Coal Only	10/8/2015	0.03%
9.Nordea Asset Management	Sweden	$228 billion	$100 million	Coal Only	1/17/2015	0.04%
10.CalSTRS	USA	$186 billion	$10 million	Coal Only	10/8/2015	0.01%
11.PFZW	Netherlands	$172 billion	$2.01 billion	Partial (100% coal, 30% other fossil fuels)	11/16/2015	1.17%
12.Bank J. Safra Sarasin	Switzerland	$150 billion	$643 million	Coal Only	3/2017	0.43%
13.Swiss Reinsurance Company Ltd	Switzerland	$130 billion	$559 million	Coal Only	2016	0.43%
14.University of California	USA	$98 billion	$350 million	Coal & Tar Sands	9/29/2015	0.36%
TOTAL	**---**	**$5.5 trillion**	**21.7 billion**	**---**	**---**	**0.39%**

Sources: Gofossilfree.org (2018); Appendices 1 and 2.

Table 3.5: Smaller entities with limited divestment commitments	
Total number of entities	94
Assets under management	$675 billion
Estimated level of divestment	$2.9 billion
Estimated divestment level as share of assets under management	0.43%

Sources: Gofossilfree.org (2018); Appendices 1 and 2.

Table 3.6: Entities with full divestment commitments	
Total number of entities	671
Entities with assets under management data	372
Assets under management for 373 entities with data	$290 billion
Assets under management for 2 largest entities (NYC Pension Funds and MP Pension Fund)	$208 billion *(= 71.8% of assets under management for entities with data)*
Divestment level of 2 largest entities	$5.2 billion
Average divestment level as share of assets under management for 2 largest entities	2.5%
Estimated divestment levels for 371 smaller entities with asset under management data	$6.3 billion
Estimated divestment level as share of assets under management for 371 smaller entities	7.7%
Total divestment level	**$11.5 billion**

Sources: Gofossilfree.org (2018); Appendices 1 and 2.

Table 3.7: Overall level of divestment commitments for all entities with assets under management data

A) Divestment Commitments

1) Limited Divestment Commitments -- 106 entities	$24.6 billion
■ 14 largest entities	$21.7 billion
■ 94 smaller entities	$2.9 billion
3)Full Divestment Commitments -- 348 entities	$11.5 billion
■ 2 largest entities	$5.2 billion
■ 346 smaller entities	$6.3 billion
Total Divestment Commitments ***(= rows 1+5)***	**$36.1 billion**

B) Divestment Commitments as Share of Global Fossil Fuel Assets
-- Global Fossil Fuel Assets at $4.88 trillion as of 2014

$24.6 Billion in Limited Divestment Commitments as share of $233 billion Coal Market Value	10.6% *(=$24.6 billion/$233 billion)*
$11.5 Billion in Full Divestment Commitments as share of $4.88 trillion in Total Fossil Fuel Market Value	0.2% *(=$11.5 billion/$4.88 trillion)*
$36.1 Billion in Total Divestment Commitments as share of $4.88 trillion in Total Fossil Free Market Value	0.7% *(= $36.1 billion/$4.88 trillion)*

Sources: Tables 3.4-3.6; Bullard (2014)

Table 3.8: List of divestment events for oil & gas study			
Entity	1)Home country of entity	2) Assets under management (at time of divestment)	5) Date of divestment commitment
NYC Pension Funds	USA	$189 billion	1/10/2018
Oslo Pensjonsforsikring	Norway	$9.3 billion	10/19/2015
Ireland	Ireland	$8.5 billion	1/27/2017
Children's Investment Fund Foundation (CIFF)	UK	$4.7 billion	9/22/2015
Amalgamated Bank	USA	$4.0 billion	9/21/2016
Protestant Church Hessen-Nassau	Germany	$3.1 billion	11/30/2015
Medibank	Australia	$1.9 billion	11/13/2017
HCF	Australia	$1.5 billion	2/9/2017
London Borough of Southwark Pension Fund	UK	$1.5 billion	12/13/2016
Guardian Media Group	UK	$1.2 billion	4/1/2015
Syracuse University	USA	$1.2 billion	3/31/2015
TOTAL	**---**	**$226 billion**	**---**

Sources: Gofossilfree.org (2018); Appendix D

Table 3.9: List of divestment events for coal study			
Entity	1)Home Country of Entity	2) Assets under Management (at time of divestment)	5) Date of Divestment Commitment
Government Pension Fund, Global	Norway	$890 billion	6/5/2015
AXA Investment Managers	France	$782 billion	4/25/2017
Allianz SE	Germany	$668 billion	11/23/2015
AXA SA	France	$589 billion	5/22/2015
Aviva	UK	$572 billion	7/24/2015
Aegon	Netherlands	$382 billion	5/25/2016
CalPERS	USA	$289 billion	10/8/2015
Nordea Asset Management	Sweden	$228 billion	1/17/2015
NYC Pension Funds	USA	$189 billion	1/10/2018
CalSTRS	USA	$186 billion	10/8/2015
PFZW	Netherlands	$172 billion	11/16/2015
University of California	USA	$98 billion	9/29/2015
Total	**---**	**$5.0 trillion**	**---**

Sources: Gofossilfree.org (2018); Appendix D

Table 3.10: Regression results: oil & gas (excluding divestment events; t-statistics in parentheses)						
	(R1)	(R2)	(R3)	(R4)	(R5)	(R6)
	D.Jones_ Oil/Gas	*Shell*	*Exxon*	*D.Jones_ Oil/Gas*	*Shell*	*Exxon*
Oil_Price	2.816***	0.138***	0.135***	0.591***	0.138***	0.134***
	(19.11)	(5.61)	(6.51)	(18.89)	(5.61)	(6.50)
Nat_Gas_Price				-0.0409	0.0252	0.00302
				(-0.31)	(0.27)	(0.03)
SP500_FFF	0.317***	0.0130***	0.0120***	0.0671***	0.0130***	0.0121***
	(25.46)	(5.53)	(4.69)	(26.18)	(5.52)	(4.69)
_cons	-0.210	-0.0145	-0.0140	-0.0358	-0.0147	-0.0139
	(-1.82)	(-0.68)	(-0.65)	(-1.48)	(-0.69)	(-0.64)
N	1564	1564	1564	1562	1562	1562
R-sq	0.637	0.092	0.081	0.637	0.092	0.081

Table 3.11: Regression results: oil & gas (including divestment events; t-statistics in parentheses)						
	(R7)	(R8)	(R9)	(R10)	(R11)	(R12)
	D.Jones_ Oil/Gas	*Shell*	*Exxon*	*D.Jones_ Oil/Gas*	*Shell*	*Exxon*
Oil_Price	2.821***	0.138***	0.135***	2.819***	0.138***	0.135***
	(19.15)	(5.61)	(6.52)	(19.13)	(5.60)	(6.51)
Nat_Gas_Price				-0.211	0.0205	-0.00459
				(-0.33)	(0.22)	(-0.04)
SP500_FFF	0.316***	0.0128***	0.0117***	0.316***	0.0128***	0.0117***
	(25.33)	(5.41)	(4.58)	(25.29)	(5.40)	(4.57)
Syracuse/Guardian	-0.719	-0.0967	-0.0974	-0.718	-0.0967	-0.0974
	(-1.66)	(-1.07)	(-1.05)	(-1.66)	(-1.07)	(-1.05)
CIFF	1.969	0.500	0.566*	1.966	0.501	0.566*
	(1.56)	(1.71)	(2.08)	(1.56)	(1.71)	(2.08)
Oslo_Pension	-1.238	-0.572	-0.479	-1.238	-0.572	-0.479
	(-0.80)	(-1.70)	(-1.36)	(-0.79)	(-1.70)	(-1.36)
Church_HN	-0.166	0.178	0.0117	-0.163	0.178	0.0119
	(-0.16)	(0.90)	(0.05)	(-0.15)	(0.90)	(0.05)
Amalgamated_Bank	0.680	0.0911	0.122	0.680	0.0911	0.122
	(0.92)	(0.64)	(0.87)	(0.92)	(0.64)	(0.87)
Southwark_Pension	-1.696	-0.0673	-0.352	-1.700	-0.0669	-0.353
	(-1.86)	(-0.45)	(-1.79)	(-1.86)	(-0.45)	(-1.79)
Ireland	-0.969	-0.249	-0.209	-0.971	-0.249	-0.210
	(-0.66)	(-1.19)	(-0.86)	(-0.66)	(-1.18)	(-0.86)
HCF	1.570	0.265	0.425*	1.575	0.265	0.425*
	(1.16)	(1.34)	(2.21)	(1.16)	(1.34)	(2.22)
Medibank	0.275	0.0328	0.0613	0.331	0.0279	0.0720
	(0.40)	(0.39)	(0.69)	(0.46)	(0.32)	(0.77)
NYC_Pension	-0.325	-0.169	-0.286	-0.384	-0.164	-0.297
	(-0.32)	(-1.11)	(-1.64)	(-0.37)	(-1.07)	(-1.68)
_cons	-0.0374	-0.0183	-0.00148	-0.0377	-0.0183	-0.00149
	(-0.24)	(-0.64)	(-0.05)	(-0.24)	(-0.64)	(-0.05)
N	1564	1564	1564	1562	1562	1562
R-sq	0.639	0.098	0.091	0.640	0.098	0.091
F stat (divestment events = 0)	1.270	0.900	1.573	1.272	0.879	1.583
Prob > F	0.242	0.532	0.109	0.241	0.553	0.106

Table 3.12: Regression results: coal (excluding divestment events; t-statistics in parentheses)						
	(R13)	(R14)	(R15)	(R16)	(R17)	(R18)
	D.Jones_ Coal	*Cloud_ Peak*	*Alliance*	*D.Jones_ Coal*	*Cloud_ Peak*	*Alliance*
Appalachia_Price	-0.141	-0.00172	0.209*	-0.476	-0.0189	0.197
	(-0.33)	(-0.05)	(2.05)	(-1.16)	(-0.51)	(1.92)
Powder_River_Price	-0.309	-0.0597	-0.410	0.189	-0.0304	-0.386
	(-0.34)	(-0.68)	(-1.48)	(0.22)	(-0.36)	(-1.40)
Illinois_Price	1.189*	0.0702	-0.0682	1.096*	0.0623	-0.0762
	(2.24)	(1.59)	(-0.64)	(2.01)	(1.45)	(-0.69)
Uinta_Price	0.0198	0.0133	0.0755	-0.0113	0.00566	0.0657
	(0.03)	(0.19)	(0.62)	(-0.02)	(0.08)	(0.54)
SP500_FFF	0.0509***	0.00512***	0.0123***	0.0487***	0.00475***	0.0119***
	(4.36)	(4.41)	(4.69)	(4.32)	(4.07)	(4.40)
Nat_Gas_Price				3.228*	0.254	0.205
				(2.41)	(1.56)	(0.71)
Oil_Price				0.369**	0.0241	0.0221
				(3.04)	(1.73)	(0.78)
_cons	-0.694*	-0.0651	-0.105	-0.630	-0.0641	-0.105
	(-2.04)	(-1.89)	(-1.49)	(-1.88)	(-1.87)	(-1.48)
N	314	314	314	312	312	312
R-sq	0.073	0.059	0.090	0.125	0.079	0.092

Table 3.13: Regression results: coal (including divestment events; t-statistics in parentheses)						
	(R19)	(R20)	(R21)	R22)	(R23)	(R24)
	D.Jones_ Coal	*Cloud_ Peak*	*Alliance*	*D.Jones_ Coal*	*Cloud_ Peak*	*Alliance*
Appalachia_Price	-0.302	-0.0156	0.182	-0.642	-0.0305	0.172
	(-0.66)	(-0.41)	(1.70)	(-1.48)	(-0.81)	(1.60)
Powder_River_Price	0.0579	-0.0312	-0.434	0.531	-0.00521	-0.411
	(0.06)	(-0.31)	(-1.50)	(0.56)	(-0.05)	(-1.45)
Illinois_Price	1.007	0.0510	-0.145	0.905	0.0435	-0.153
	(1.72)	(1.09)	(-1.11)	(1.49)	(0.92)	(-1.14)
Uinta_Price	-0.0369	0.00161	0.120	-0.0474	-0.00374	0.112
	(-0.06)	(0.02)	(0.95)	(-0.09)	(-0.05)	(0.88)
SP500_FFF	0.0517***	0.00527***	0.0128***	0.0508***	0.00489***	0.0123***
	(4.40)	(4.59)	(4.81)	(4.44)	(4.18)	(4.38)
Nat_Gas_Price	---	---	---	3.304*	0.250	0.202
				(2.40)	(1.48)	(0.68)
Oil_Price	---	---	---	0.339**	0.0231	0.0242
				(2.69)	(1.58)	(0.81)
Nordea	0.790	0.0174	-0.686	0.425	-0.00799	-0.713
	(0.61)	(0.12)	(-1.76)	(0.35)	(-0.06)	(-1.82)
AXA_SA	-4.569*	-0.337*	0.0936	-3.748	-0.282*	0.137
	(-2.36)	(-2.29)	(0.15)	(-1.74)	(-2.07)	(0.22)
Gov_Pension_Fund	1.466	0.0620	-0.453	1.007	0.0352	-0.460
	(0.73)	(0.37)	(-0.69)	(0.43)	(0.21)	(-0.66)
Aviva	3.613	0.605**	1.630**	3.732	0.603**	1.615**
	(1.65)	(2.71)	(2.86)	(1.78)	(2.76)	(2.71)
Univ_CA	-3.702	-0.546*	-1.293*	-3.956	-0.550*	-1.292*
	(-1.69)	(-2.09)	(-2.28)	(-1.96)	(-2.24)	(-2.25)
CalPension	2.100	0.236	0.112	2.477	0.262	0.142
	(1.04)	(0.97)	(0.20)	(1.27)	(1.13)	(0.26)
PFZW_Allianz	2.094	0.0240	0.520	1.671	-0.0138	0.476
	(1.24)	(0.18)	(1.00)	(1.04)	(-0.11)	(0.93)
Aegon	-0.761	0.0577	0.164	-0.727	0.0602	0.170
	(-1.05)	(0.56)	(0.48)	(-0.99)	(0.58)	(0.51)
AXA_IM	0.274	-0.0469	-0.215	0.493	-0.0515	-0.230
	(0.38)	(-0.45)	(-1.03)	(0.80)	(-0.48)	(-1.09)
NYC_Pension	-0.548	-0.0480	0.0438	-0.00980	-0.0637	0.0104
	(-0.47)	(-0.32)	(0.13)	(-0.01)	(-0.43)	(0.03)
_cons	-1.144	-0.0984	-0.0335	-1.066	-0.0908	-0.0242
	(-1.86)	(-1.65)	(-0.30)	(-1.72)	(-1.52)	(-0.21)
N	314	314	314	312	312	312
R-sq	0.095	0.077	0.127	0.145	0.095	0.129
F stat (divestment events = 0)	2.467	4.330	1.736	2.089	4.996	1.678
Prob > F	0.00755	0.0000115	0.0722	0.0253	0.00000104	0.0852

APPENDIX A

VALUING OIL AND GAS RESERVES

The Hotelling Valuation Principle (HVP) is based on Harold Hotelling's 1931 paper, "The Economics of Exhaustible Resources". Responding to the conservationist movement of the time, which warned of over-use of nonrenewable resources from unregulated private markets, Hotelling argued that nonrenewable resource markets, theoretically, should lead to the socially optimal rate of non-renewable resource use (Livernois 2008). This paper led to the "Hotelling Rule", which posits that the net price (market price minus marginal cost) of a nonrenewable resource rises at the rate of discount (Hotelling called this the "interest rate", by which he means the normal or required rate of return on an investment). The Hotelling Rule implies that an investor has no incentive to over-use nonrenewable resources today—the present value of the net price of a nonrenewable resource is the same in every period.

Hotelling assumed the conditions of competitive market equilibrium, including perfect competition, complete property rights, and zero externalities, none of which hold in the real world. As such, in an extensive literature review of the empirical literature on the Hotelling Rule, Livernois (2008) finds that empirical tests of the rule have been "mostly unsuccessful," and that "one cannot conclude that the Hotelling Rule has been a significant force governing the evolution of observed price paths of nonrenewable resources" (37). However, in one of the most widely cited tests of the Hotelling Rule, Miller and Upton (1985a) found evidence supporting the rule for oil and gas firms. This paper led to the HVP, which suggests that the value of any quantity of nonrenewable resources is equal to its current net price. Its simplicity makes it an attractive valuation method. To value fossil fuel reserves, all one needs is current net price and quantity of reserves. Net price is assumed to increase at the rate of discount, making the timing of production irrelevant.

The evidence since 1985 overwhelmingly rejects the HVP for valuing oil and gas reserves, finding that the principle substantially overvalues reserves. This includes another paper from Miller and Upton (1985b), though they continue to support the HVP. The most compelling rejection both theoretically and empirically comes in a series of papers led by the late Morris A. Adelman,[81] leading to what Cairns and Davis (2001) call "Adelman's Rule". Adelman (1990) found that the HVP overvalued oil and gas reserves by a factor of approximately two, which is also consistent with the rule-of-thumb used by practitioners in the oil and gas industry (see Appendix B). Livernois (2008) reviews several factors to explain why net prices of nonrenewable resources historically have not increased at the discount rate, including technological advancement, continual discoveries of proved reserves, and imperfect competition.

As far as I know, Adelman was the first in the economics literature to connect valuation of oil and gas reserves to the practitioner literature, i.e., how oil and gas engineers actually value fossil fuel reserves in the field. As noted above, Adelman and others have confirmed the practitioner rule-of-thumb that value of reserves equals half of net price. But why does it work? Adelman (1990) pointed to the production constraint. Economists generally viewed oil and gas producers as choosing not only when to drill a new oil or gas well, but how much to extract and produce from that well on any particular day. When resource prices decreased, one would expect producers to decrease production, and vice

[81] Most of the papers are summarized in Adelman (1993), which is a collection of his essays in book form. However, Adelman (1990) is arguably the most important regarding the HVP. See also Adelman and Watkins (1995).

versa. Adelman (1990) noted that extraction rate was not actually determined by prices, but by reservoir characteristics. The conceptual counterpart in the practitioner literature is the production decline curve, discussed in Section 2.3.5 and Appendix B.

Thompson (2001) translated the practitioner methodology of reserve valuation into an economic model, which assumed that "developed reserves have a maximum daily rate of production, and price-takers maximized wealth by producing at capacity" (153). He then provided an empirical test showing the model's viability. More recently, Anderson et al. (2018) analyzed oil production data confirming that it does indeed decline in accordance with Arps' curves. While it is technically feasible for an oil operator to "shut in" a well (i.e., temporarily stop production), doing so for economic reasons is extremely rare. Only in extreme cases, where the discount rate is below 4% or the production decline rate at least 30% annually, would the operator gain anything from shutting in a well (Anderson et al. 2017). This stems from the fact that the marginal cost of producing another barrel of oil (or cubic meter of natural gas) is extremely low, and oil and gas operators cannot predict future prices.

For the purposes of this study—measuring stranded assets to better understand the economic underpinnings of the fossil fuel industry's resistance to clean energy—it is important to value reserves the way fossil fuel companies do. Thus, I follow the lead of practitioners, whose methods have been justified empirically. Fossil fuel reserves should be valued according to the net present value of the future income they will create. The industry rule-of-thumb suggests that this will be approximately equal to one half of current net price. However, it is not meant to replace a full DCF analysis. The evidence here suggests that the net price will not rise at the rate of discount, and the timing of extraction is important for valuation.

APPENDIX B

FURTHER DETAILS ON METHODOLOGY

J. J. Arps (1945) laid out three models, called "production decline curves", that accurately describe the production rate of conventional oil and gas wells over time. These curves are used by petroleum and natural gas engineers to estimate future production rates and cumulative production from wells. The three decline curves are the exponential curve, hyperbolic curve, and harmonic curve. The exponential curve is modeled by equation (B.1), and the hyperbolic and harmonic curves from equation (B.2). The variables are defined as follows: P_t is quantity produced in time period t; P_0 is initial quantity produced; D_0 is initial decline rate; and b is a unitless coefficient determining the curve's steepness.

$$P_t = P_0(1 - D_0)^t \tag{B.1}$$

$$P_t = \frac{P_0}{(1+bD_0t)^{1/b}} \tag{B.2}$$

In the case of exponential decline curves, the decline rate is constant over time. For hyperbolic and harmonic curves, the decline curve generally starts out steeper, and gets shallower over time, based on the value of b. The coefficient b also determines whether equation (B.2) is hyperbolic or harmonic. For hyperbolic curves, $0 < b < 1$; for harmonic curves, $b = 1$. Most global proved reserves are characterized as conventional, and production from most conventional oil and gas wells is accurately described by exponential curves or hyperbolic curves where $b \leq 0.5$ (Fetkovich et al. 1996). Adelman (1990) and Anderson et al. (2018) both used an exponential decline curve with a 10% decline rate. While Adelman did not provide evidence for this rate, Cairns and Davis (2001) argued that it was accurate based on their knowledge of the industry. Anderson et al. (2018) further confirm the credence of this assumption, saying that an exponential curve with a decline rate of 10% is consistent with their empirical results based on Texas oil lease data.

Oil and Gas Supply Projections

In Section 2.3.5, I introduced two methods for valuing oil and gas reserves: the practitioner method and the scenario projection method. Theoretically, the practitioner method is best suited for valuing reserves. If an oil company were to consider selling its oil reserves, the reserves would be valued based on the corresponding production decline curve, not based on when the buyer or seller planned to produce them. A third method used by oil and gas industry practitioners is a simple rule-of-thumb. Practitioners have found that the value of proved oil or gas reserves in a reservoir is equal to approximately one third of the market price of oil or gas, or one half of the net price (i.e., market price minus marginal cost of production). Multiple empirical papers confirm the accuracy of the rule-of-thumb hypothesis (Miller and Upton 1985b; Adelman 1993; Adelman and Watkins 1995; Davis and Cairns 1998; Cairns and Davis 2001). The rule-of-thumb is limited in that it can only be used to estimate the value of reserves under normal conditions, i.e., without the prospect of climate policy and clean energy substitutes. Thus, it cannot be used to estimate wealth losses from stranded assets. However, it can be used to evaluate the efficacy of the practitioner and scenario projection methods.

In Table B.1, I compare the value of oil and gas reserves for the baseline scenario using each of the three methods. As expected, the values estimated by the industry rule-of-thumb method most closely resemble the practitioner method.

Table B.1. Value of oil and gas reserves for different methods of projecting fossil fuel supply (2018 US$, B=Billion)		
	Oil	**Gas**
Practitioner method	$21,425 B	$9,863 B
Scenario projection method	$18,408 B	$7,763 B
Rule-of-thumb method	$20,060 B	$10,769 B

Source: Author's calculations (data and methods described in Section 2.3).

Estimating Proved Developed vs. Undeveloped Reserves

I use two methods to estimate the distribution between proved developed and proved undeveloped oil and gas reserves. First, I assume proved developed reserves include reserves from wells that are in production in year one (2020) for STEPS. I then assume production declines by 10% per year through 2040. Developed reserves are equal to the sum of reserves produced from wells that were in production in 2020. For oil, this constitutes 40%% of total reserves produced in STEPS, and for gas 36%. 38% constitutes the average. The problem with this method is that many wells producing in 2020 will stop producing before 2040.

The second method is a model of developed vs. undeveloped reserves. I assume that wells last 21 years, production from wells declines at 10% per year, and that 1 unit of oil/gas is produced per year. This most closely resembles production in STEPS. Each year, new production is equivalent to the loss of old production. I consider three definition of developed reserves: reserves that enter production within 1 year, within 1.5 years, and within 2 years. Based on the three definitions, developed reserves constitute 35% (for 1 year), 38% (for 1.5 years), and 40% (for 2 years) of the total reserves produced over a 21-year period. Given that undeveloped proved reserves take an average of three years to enter production, the 1.5-year definition, which matches the results of the first method, seems reasonable. Thus, for estimating stranded assets, I assume developed reserves constitute 38% of oil and gas reserves produced in STEPS.

APPENDIX C

FURTHER DETAILS ON DATA

Mapping data onto WEO regions

I map gas and coal prices onto the WEO regions as follows: for North America and Europe, I use the U.S. and EU prices, respectively; for Asia Pacific, I average the prices for China and Japan; and for Africa, the Middle East, and Eurasia, I average the EU and Asia Pacific prices. The price projections for the EU, China, and Japan are very similar, so the way in which I map the prices onto regions outside of North America does not have a significant impact on stranded assets estimates.

The EIA provides combined data for oil and natural gas for the U.S., Canada, Europe, former Soviet Union, Middle East, "Other Eastern Hemisphere", and "Other Western Hemisphere." Statista and the Wall Street Journal provide data for oil for a subset of oil producing countries. I map these costs onto the WEO regions by taking an average of the countries for which data is available in each region, weighted by each country's production for STEPS. STEPS was the only scenario for which country-level data was available. For example, for North America I take a weighted average of the costs for the U.S., Canada, and Mexico.

Distribution by Region between Private Firms and Governments

NRGI (2020) provides data on all state-owned oil and gas firms for which data is publicly available. To estimate the share of reserves owned by governments in each region, I divided the total reserves produced by state-owned firms by the total reserves produced in their respective countries for the latest years for which data was available. The exception was Africa, for which very little data was available. For Africa, the share of government reserves was determined by the shares in all of the other regions. In other words, Africa's government share was allowed to vary, so as to ensure that the regional shares matched with the global share from the IEA (2020b). This method is not exact, as data was missing for several state-owned firms. Moreover, some of the largest state-owned firms, including Sinopec and CNPC of China, own substantial reserves in other countries. The IEA (2020b) calls these "international national oil companies". Thus, I had to adjust percentages upward for other regions using my best judgement. Other sources I consulted include Jones Day (n.d.) and EIA (2017).

To estimate the shares of coal reserves owned by governments and private firms, I researched coal firms in the largest coal producing states. Exact percentages were not available. Thus, I looked for evidence suggesting whether the coal industry in these countries was mainly state-controlled or private-controlled. The most important country is China, which accounts for nearly 80% of global coal production on its own. The most useful sources are listed below.

- China: IEA (2019a)
- India: IEA (2019c)
- Indonesia: Listiyorini (2020)
- Russia: Vorotnikov (2013)
- United States: EIA (2018c)
- South Africa: Africa Mining IQ (n.d.)
- Colombia: Strambo and Valasco (2017)

APPENDIX D

CHAPTER 3 DATA SOURCES

This appendix includes all the references used in cleaning and supplementing the GoFossilFree.org data, as well as detailed information on the stock price/index and commodity price variables used in the event study.

References used for Data Cleaning

We only looked into the large entities, which included entities with limited commitments that managed at least $90 billion in assets, and entities with full divestments that managed at least $1 billion in assets.

Table D.1. References for Limited Divestment Commitments

Entity	**References**
Government Pension Fund Global	Carrington (2015b); Schwartz (2015a)
AXA Investment Managers	Paredes-Vanheule (2017); Sharman (2017)
Allianz SE	Allianz SE (2015); Arabella (2016)
AXA SA	Clark (2015a)
Aviva	Arabella (2016); Clark (2015b)
Aegon	Aegon (2016); SEC (2016)
Lloyd's Corporation	Moorcraft (2017)
CalPERS	CalPERS Investment Committee (2015); Kozlowski (2015); Starkman (2015)
Nordea Asset Management	Marriage (2015); Nordea Asset Management (2015)
CalSTRS	Duran (2016); Duran (2017)
Pensionfonds Zorg en Welzijn (PFZW)	Reuters Staff (2015a)
Bank J. Safra Sarasin	J. Safra Sarasin (2018); Weber et al. (2017)
Swiss Reinsurance Company Ltd	Swiss Re (2018); Unfriend Coal (2017)
University of California	Hirji (2015); Howard (2015b); Riley (2017)
Other Sources Used	Cowie (2014); Fossil Free USA (2016); McIlroy (2015); Mertens (2015); Pielichata (2017); Weiner (2018)

Table D.2. References for Full Divestment Commitments	
Entity	**References**
New York City pension fund system	Office NYC Comptroller (2018)
MP Pension Fund	Leaper (2018); Pielichata (2018)
Oslo Pensjonsforsikring	Bloomberg (2015); Reuters Staff (2015b)
Ireland	Gorey (2017); Osborne (2017)
District of Columbia Retirement Board	Bradford (2016a); (Hirji 2016)
Children's Investment Fund Foundation (CIFF)	CIFF (2015)
Amalgamated Bank	Stewart (2016)
Protestant Church Hessen-Nassau (EKHN)	EKHN (2015)
Medibank	Medibank (2017)
HCF	HCF Group (2016); Slezak (2017)
London Borough of Southwark Pension Fund	Colley (2017); Fossil Free UK (2016)
Oakland	Solitei (2014); 350.org (2014)
Guardian Media Group	Carrington (2015a); Rusbridger (2015)
Syracuse University	Howard (2015a); Schwartz (2015b)
Australian Ethical	Australian Ethical (2016); Rose (2016)
Copenhagen	Neslen (2016)
Other references	Bradford (2016b); Connolly (2016); Hughes (2017); Kommuninvest (2016)

Information on Event Study Variables

We used opening price for company stock price and coal index data, and last price for oil and gas index and S&P 500 Fossil Fuel Free index data, all of which are publicly accessible (see Data Availability Statement). Coal stock prices are end of week opening prices, and coal commodity prices are weekly averages. Our data spans 30 December 2011 to 23 March 2018 (30 December 2011 is the first day for which the S&P 500 Fossil Fuel Free Index was available).

Table D.3. References for Event Study Variables	
Variable	**Reference**
Dow Jones US Oil & Gas Index	S&P Dow Jones 2018a
Dow Jones US Coal Index	Investing.com 2018
S&P 500 Fossil Fuel Free Index	S&P Dow Jones 2018b
Royal Dutch Shell share price	Yahoo Finance 2018d
Exxon/Mobil share price	Yahoo Finance 2018c
Cloud Peak Energy share price	Yahoo Finance 2018b
Alliance Resource Partners share price	Yahoo Finance 2018a
Oil price	FRED 2018
Natural gas price	EIA 2018b
Coal prices	EIA 2018a
Divestment events	See first two panels above in this appendix

APPENDIX E

METHODOLOGY FOR ESTIMATING FUNDS DIVESTED

The 14 Largest Divestment Entities with Limited Commitment Levels

The largest 14 entities with limited commitment levels account for about 85% of total assets under management, and thus gained fairly widespread media attention. Researching each of these events individually (see Appendix 1 for references), we were able to find estimates of commitment levels for nine of them.[82]

For the remaining five entities, we considered two methods. First—the method that we decided to use—we looked just at the nine entities for which we had data on funds divested. Dividing their funds divested by assets under management ($16.7 billion/$3.902 trillion), we found that their overall share of funds invested in coal prior to divestment was about 0.43% (Gofossilfree.org 2018; Appendix 1). We then multiplied 0.43% by the assets under management of Aegon, Lloyd's Corporation, Bank J. Safra Sarasin, and Swiss Reinsurance Company Ltd (results shown in column 4 of Table 3.4). For Aviva—the last of the largest 14 entities with limited commitment levels—we multiplied assets under management by 0.43%, and then multiplied that result by 0.2. The reason for this adjustment in our calculations for Aviva is that Aviva did not fully divest from coal. Rather, they put 40 coal companies on notice, threatening to divest only if those companies did not show that they were accounting for climate change in their business models. Eight of those companies refused to engage with Aviva, two of which Aviva said they may divest from

[82] The nine entities include Government Pension Fund Global, AXA Investment Managers, Allianz SE, AXA SA, CalPERS, Nordea Asset Management, CalSTRS, PFZW, and University of California (see Table 3.4 for level of funds divested).

(Aviva 2017; Cadle 2016). Therefore, we assume they will divest from the eight companies they put on notice, which is 20% of the coal companies in which they invested.

The second method of estimation we considered consisted of multiplying each company's assets under management by the global coal industry's share of total value of the global stock markets. We were unable to find figures on the coal industry's share of the global bond market, so we assumed that this figure was the same share as that for the global stock market. In 2014, the market capitalization of coal was $233 billion (Bullard 2014), and the market capitalization of world stock markets was $63.3 trillion (World Bank 2018). Dividing the former by the latter results in 0.37% (i.e., the coal industry makes up 0.37% of the stock market), which is slightly less than the 0.43% we used in method one.

We chose to work with our first estimation method, in the interests of, if anything, overstating rather than understating the level of fossil fuel divestments.

Smaller Entities with Limited Divestment Commitments

As stated in the paper, we applied method one from above to the 94 smaller entities with limited divestment commitments.

Entities with Full Divestment Commitments

The largest two entities committed to full divestments are the New York City pension fund system and MP Pension Fund. By researching each of these commitments we found that they were divesting a combined $5.2 billion, or 2.5% of their $208 billion in assets under management (see Appendix 1 for references). Because these were the only two entities for which we had data on funds divested, we did not believe it was appropriate to apply the 2.5% figure to the remaining 371 entities. Ansar et al. (2013) found that educational institutions and pension funds generally hold 3-7.5% of assets under management in fossil fuels (includes both stocks and bonds). However, these are not the only types of institutions divesting. Thus, to estimate funds divested of the 371 smaller entities, we multiplied their assets under management by the global fossil fuel industry's share of world stock markets. In 2014, the market capitalization of the fossil fuel industry was \$4.9 trillion (Bullard 2014), and the market capitalization of global stock markets was \$63.3 trillion (World Bank 2018). Dividing the former by the latter, we found that the fossil fuel industry's share of global stock markets is 7.7%. Multiplying 7.7% by the assets under management of the 371 smaller entities (\$82 billion) leads to an estimate of \$6.3 billion of funds divested. This figure is, again, likely to overstate rather than understate the true level of divestment.

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