**Testimony to the Senate Budget Committee**
**Hearing on "Left Holding the Bag: The Cost of Oil Dependence in a Low-Carbon World"**

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Chairman Whitehouse, Ranking Member Grassley, and Members of the Senate Budget Committee,

Thank you for inviting me to testify. My name is Gregor Semieniuk. I am an assistant research professor of economics at the University of Massachusetts Amherst. I research the economic drivers and consequences of structural change in the energy transition. Recent publications of my team in *Nature Energy* and *Nature Climate Change* analyze the macroeconomic and financial risks of global oil and gas asset stranding due to uncertainty about the pace at which energy demand is shifting to low-carbon alternatives.

The US economy is a major oil and gas producer and therefore exposed to these risks. A key problem is that final investment decisions today have to be made for projects that require returns years into the future. And financial investors must make decisions today about how to value companies based on their ability to deliver shareholder distributions years into the future. The energy transition creates major uncertainty about future fossil fuel demand. Here I focus on reasons for downside risk, that is, demand for fossil fuels that turns out to be lower than was expected at the time of investment. That can lead to a stranding of the invested asset.

There are 3 key causes for such downside risk that depend on the actions of the whole world, not just the US.

First, importers of oil and gas have always had the energy security incentive to wean themselves off fossil fuel imports. Thanks to the fast decline in costs of low-carbon alternatives, there is now also an economic incentive to substitute fossil fuel imports. Cost declines and deployment of renewables continue to outpace even bullish projections.

Since Russia's invasion of Ukraine, transition efforts in importing countries have only intensified with global record investments into renewables in 2022. Thanks to the robust negative correlation between cumulative investment and the price of various renewable technologies, called Wright's law, these efforts will lead to even stronger economic incentives for a fast transition in a self-reinforcing cycle. That is advantageous for fossil fuel importers but creates stranded asset risks for exporters.

Second, the United States does not produce the lowest-cost product in the world. If other, lower-cost producers expect fossil fuel demand to decline, they are incentivized to attempt to capture as much of the remaining market as they can. They would do this by flooding the market to lower prices. We find that this is the dominant strategy for low-cost producers to play, which leaves a diminished market share for US producers.

We calculate that these two causes of downside risk combined could lead to revenue losses in the US fossil fuel sector of $1.6 trillion over 15 years. That in turn would spell a GDP loss of $1.8 trillion over 15 years. Both figures are discounted to present values. These losses do not account for medium-term lower competitiveness in low-carbon sectors if the US economy remains specialized in fossil-fuel compatible technologies longer than its competitors.

Third, US investors are globally active, thereby exposed to stranded fossil-fuel assets not just in the US. We calculate that $400 billion in potentially stranded assets are sitting on US balance sheets, a third more than the value of stranded US-based production assets, and 30% of the global total. In light of the interconnectedness of financial markets and herd behavior, such financial risks could have systemic implications.

The current undersupply of fossil fuels may suggest that stranded assets are just an illusion. But it is precisely the uncertainty about future demand for their product that makes oil and gas companies more reluctant to proceed with new projects. Capitalist economies are unrivalled in their ability to supply an expanding market. The same cannot be said of a declining one. Energy security in the short and long-run must consider a robust diversification away from relying mainly on fossil fuels whose prices will only become more volatile in a declining global market.

In the following, I expand on these key points.

**Stranded asset risk as a result of large uncertainty**

One of the problems of the transition to a low-carbon economy is that while demand for fossil fuels is set to decline, it is uncertain how fast and by how much. Fossil-fuel asset stranding (in short: asset stranding) refers to a sudden decline in market value of fossil fuel-related assets. For this to happen, expectations about demand for the product that the asset produces, e.g. crude oil, must decline after the investment decision has been made. The causes may be faster than expected technological improvements in and diffusion of low-carbon energy supply and end-use devices: unexpected stringent climate policy or changes in consumer preferences (Semieniuk et al., 2021). All have the effect of an unanticipated decline in expected future profitability of fossil fuel-related assets, which cannot be cheaply repurposed for other uses (van der Ploeg and Rezai, 2020).

Asset stranding is relevant to the current energy transition because assets must be paid for upfront in the hope of earning returns often many years in the future. That is true both of fossil-fuel producing industries and of those that rely on them as inputs, such as fossil fuel-based utilities, manufacturers of fossil fuel-compatible end-use devices (e.g. internal combustion engine vehicle manufacturers), and petrochemical manufacturers. Since there is uncertainty about the pace and nature of the energy transition, investments that may have been made in the expectations of sufficient future returns to justify the upfront expenditure may eventually turn out not to pay back, as the actual future course of events disappoints expectations (see also Caldecott, 2017).

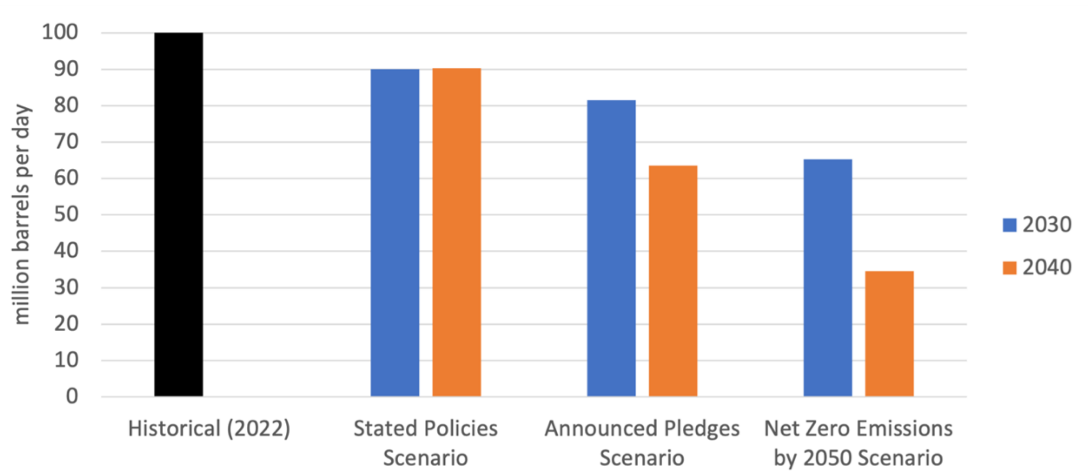


**Figure 1: Variation in oil demand across IEA scenarios.** Global demand for oil in 2030 and 2040 according to three scenarios from the IEA's 2022 World Energy Outlook (variable Total Energy Supply). Data for 2022 is from the IEA's December 2022 Oil Market Report.

Uncertainty about just how demand evolves going forward is documented in scenarios of the future global energy system. The International Energy Agency (IEA) publishes one of the most widely used set of global energy scenarios in its annually appearing World Economic Outlook. The most recent 2022 version contains three scenarios that report on global energy demand, including for oil. One is called Stated Policies, that projects what governments are currently doing to reach stated targets (which may be insufficient to meet them). The next one, the Announced Pledges Scenario, projects demand conditional on governments reaching their self-set climate policy targets. Finally, the Net Zero Emissions by 2050 Scenario is a normative scenario that calculates what would need to happen for the global economy to emit net-zero CO2 emissions in 2050 (IEA, 2022). Figure 1 reports each scenario's demand for oil in 2030 and 2040. Oil demand in the Stated Policies Scenario is projected to stagnate at about 90 million barrels per day through 2040, down only slightly from the 100 million barrels per day demand in

2022. In the Announced Pledges Scenario, demand is 10% and 30% lower respectively in 2030 and 2040 than in the Stated Policies Scenario. If there were additional pledges that governments would make and fulfill, such as updated Nationally Determined Contributions under the Paris Agreement in 2025, demand would decline even faster, narrowing the gap with the Net Zero by 2050 Scenario. Oil producers weighing investments and looking at these scenarios must make up their mind about what they believe to be true. If producers make investment decisions under Stated Policy Scenario expectations that are not borne out by subsequent events, this will lead to stranded assets for a share of the global production fleet. Thus, stranded assets are the result of downside risks for fossil fuel demand in the energy transition.

**Fossil fuel importers: two reasons to substitute fossil fuels**

One cause of downside risk to global fossil fuel demand are the incentives faced by importers. Many important economies are net fossil fuel-importers, notably in the European Union and East Asia. These countries have always had an energy security rationale for trying to substitute fossil-fuel imports with domestic non-fossil energy sources. Until recently, such substitution would have come at a hefty price tag. However, this may no longer be the case; low-carbon energy and economic advantage go hand in hand, at least for importing countries (Aklin and Mildenberger, 2020; Ansari and Holz, 2020; Goldthau et al., 2019; Mercure et al., 2021). Not only are low-carbon alternatives becoming cheaper. They also improve the balance of payments as precious foreign currency need not be spent on fuel purchases anymore. Importers thus have every incentive to decarbonize and may be doing so faster than previously expected.

One reason why the pace at which this happens may surprise fossil-fuel investors is that low-carbon energy has a history of surpassing expectations. Past scenario projections tend to lag systematically behind actual subsequent deployment as well as cost declines (Creutzig et al., 2017; Mohn, 2020; Way et al., 2022; Wilson et al., 2013). One way to illustrate this phenomenon is to compare how successive Stated Policies Scenarios (or their predecessors) from the above-introduced IEA project cumulative solar PV capacity with the actual subsequent deployment. The result is shown in Figure 2 left panel.[1] And the right panel of Figure 2 reports a similar process for scenarios of the cost of producing electricity with solar PV. Clearly, every scenario overestimates subsequent cost and underestimates subsequent capacity, and the discrepancy can grow large after only a few years. A similar process is unfolding with electric vehicles (Haensel and Naughton, 2021; Lam and Mercure, 2022).

[1] See also a plot of annual additions and discussion of underlying model mechanisms at Carbon Brief: https://www.carbonbrief.org/profound-shifts-underway-in-energy-system-says-iea-world-energy-outlook/

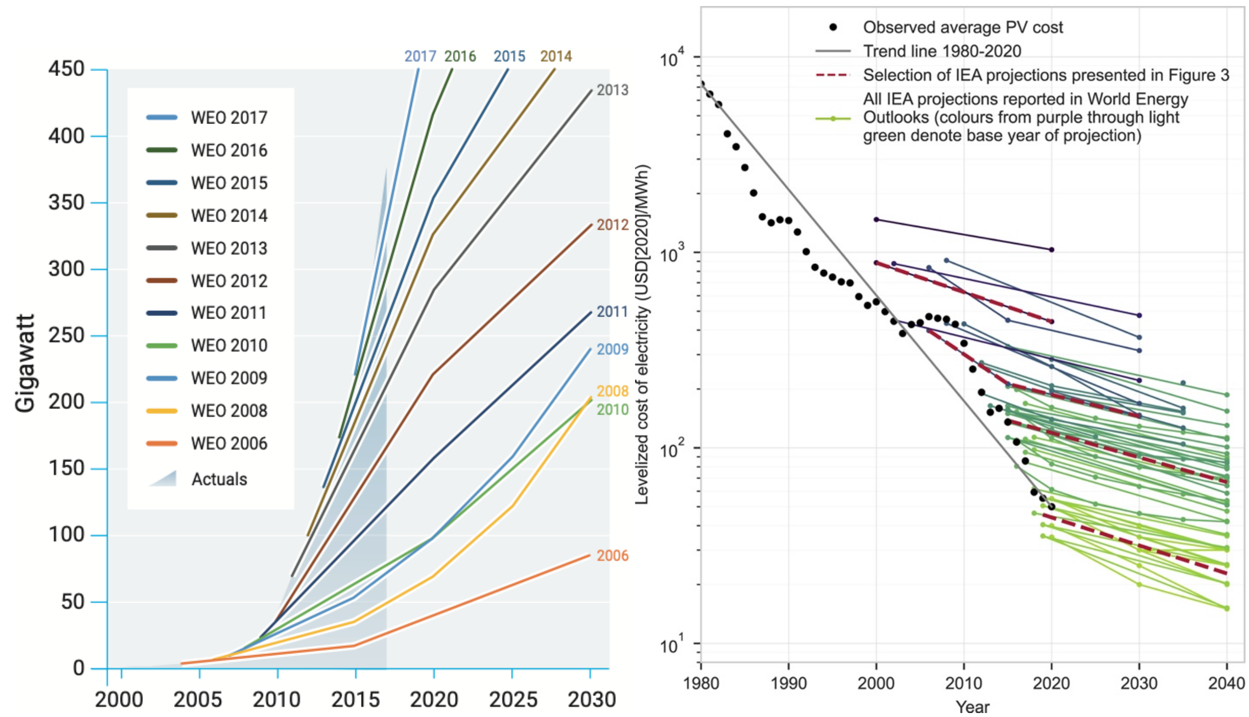


**Figure 2: Empirical version scenario evolution of solar PV.** Left panel: Cumulative solar PV capacity installed compared to Stated Policies-type scenarios from successive IEA World Energy Outlooks. Reproduced from (Mazzucato et al., 2018). Right panel: Evolution of the levelized cost of electricity from solar PV compared to all IEA World Energy Outlook scenarios, y-axis on log scale. Reproduced from (Way et al., 2022).

Since Russia's invasion of Ukraine, transition efforts in importing countries have only intensified. 2022 was a record year for investment in clean energy at $1.3 trillion, up 19% from 2021 and 50% from 2019 (IRENA and CPI, 2023). These scaled up investments may create path-dependencies that steer to an even faster low-carbon transition. There is a robust negative correlation between cumulative investment or experience in making and deploying a manufactured low-carbon technology and its price. In Figure 3, both axes are on logarithmic scales, which means a straight downward facing pattern correlates a given percentage cost decline with a 1 percent deployment increase. In other words, for every doubling of deployed capacity, costs come down by a certain fraction of what they were before, leading to powerful cumulative cost declines. In economics, this phenomenon has long been known as 'learning by doing' (Arrow, 1962), and recognized as leading to path-dependencies (Arthur, 1994). These robust patterns are also known as Wright's law (Nagy et al., 2013). To the extent that Wright's law continues to hold for low-carbon technologies, the upscaled investment efforts will lead to even lower cost. That in turn will create stronger economic incentives for a fast transition resulting in yet more investment in a self-reinforcing cycle.

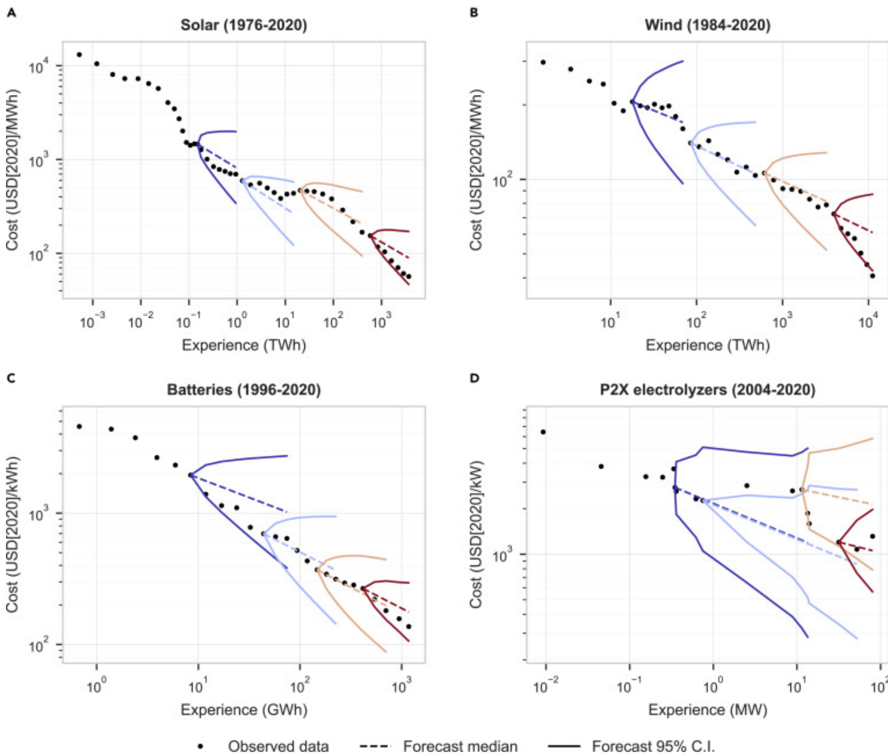


**Figure 3: Unit cost vs. deployment in four low-carbon technologies.** Dots are historical data. Lines report forecast and uncertainty from a model. Both x and y-axes on log scale. Reproduced from Way et al. (2022).

**Low-cost producers: flood the market**

If low-cost fossil fuel producers expect that the market for their product will shrink, not least as a result of the above-described dynamic, they may decide to try and capture as much of the remaining market as they can before demand for the resource underneath their territory dries up. Estimates of scenarios that project 2ºC global warming by 2100 (and are consistent with importers moving away fast from fossil fuels) calculate that one third of oil reserves and one half of gas reserves have to be left untapped between 2010 and 2050 (McGlade and Ekins, 2015). Reserves are resources of fossil fuels that are recoverable under current economic conditions. Flooding the market with low-cost fossil-fuels will likely drive down the price thereby making it uneconomic for higher-cost producers to supply.

Figure 4 shows that the United States is not the lowest cost producer, especially of oil. As such, a decline in the price of oil and gas could curtail the market for US producers. In Mercure et al. (2021) we calculate that when importers move away from fossil fuels quickly, flooding the market is indeed a dominant strategy for low-cost producers, chiefly OPEC countries. Dominant strategy is here used in the game-theoretic sense: it is economically beneficial for OPEC to flood the market, regardless of whether high-cost exporters of fossil fuels decarbonize quickly or not.

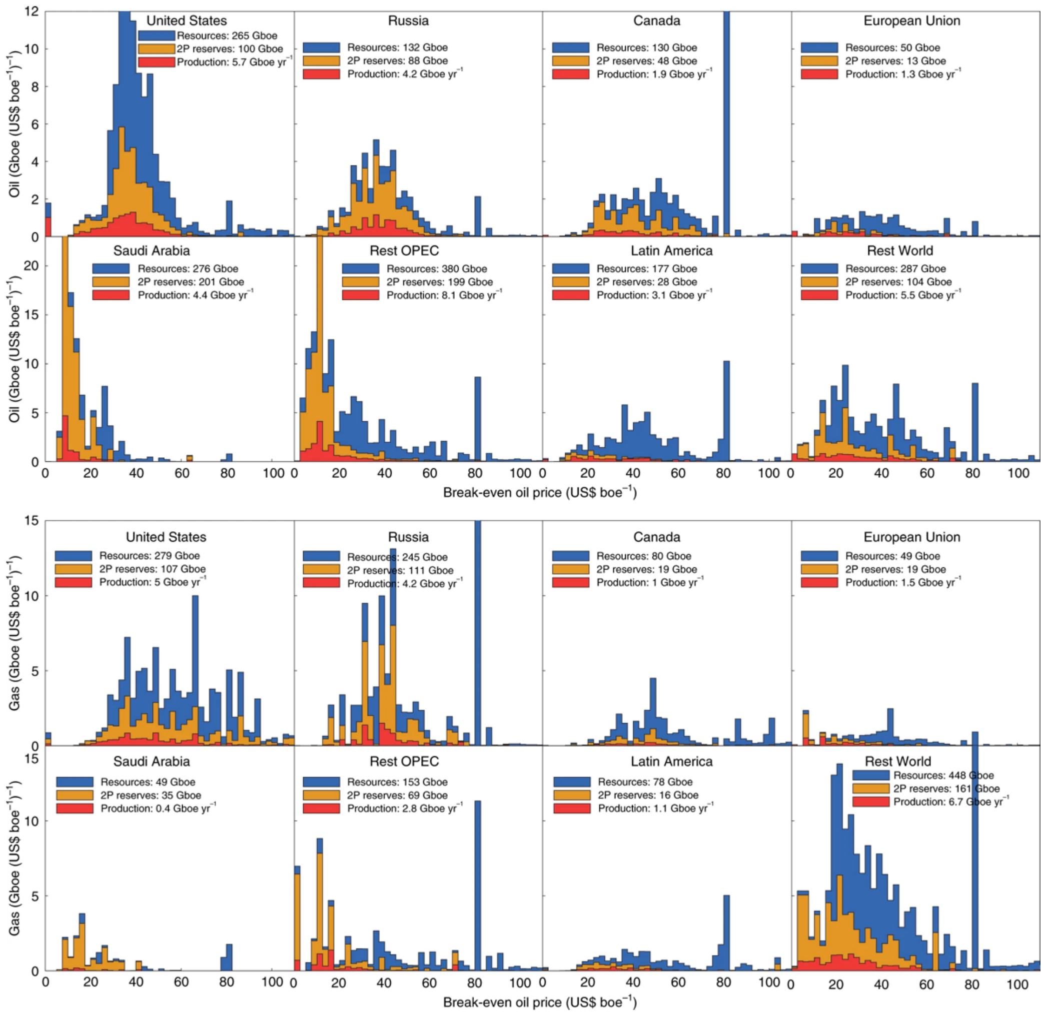


**Figure 4: Frequency distribution of global oil and gas reserves and resources by production cost and region.** Oil and gas world resources, reserves and production distributed along their break-even oil and gas prices, prices at which they are profitable to extract. Production bar heights are scaled up by a factor of five to be visible in the graphs. Vertical axes have units of energy quantities per unit cost range, such that their integral between two limits yields energy quantities. Legends indicate totals. Reproduced from Mercure et al. (2021).

Together, these two downside risks – a fast transition in importers to net zero emissions in accordance with their policy pledges and fossil-fuel market flooding by low-cost producers – could substantially affect the US economy if they materialize. In our research on this subject reported in Mercure et al. (2021), we call this scenario the European Union-East Asia Net Zero Selloff (EUEA Net Zero SO). If the US invested in its fossil energy industry as if the world was on a trajectory like the IEA's Stated Policies Scenario, expecting 'business as usual', but demand materialized according to EUEA Net Zero SO, this could lead to revenue losses in the upstream US fossil fuel sector of $1.6 trillion over 15 years relative to the States Policies Scenario. That in turn would spell a GDP loss of $1.8 trillion over 15 years.[2] Both of these figures discount future

[2] Results for different time spans, discount rates, scenarios and other countries can be found in the supplementary information accompanying Mercure et al. (2021).

losses back to the present with a 6% discount rate. Key here is that whether or not these downside risks materialize lies in the hand of countries other than the US. The health of the US fossil energy sector depends substantially on what happens in the world as a whole, not just in the domestic economy. Figure 5 reports these figures for the US and also for other countries. The considerable upside opportunity for fossil fuel importers is evident in the positive bars, underscoring these economic incentives.

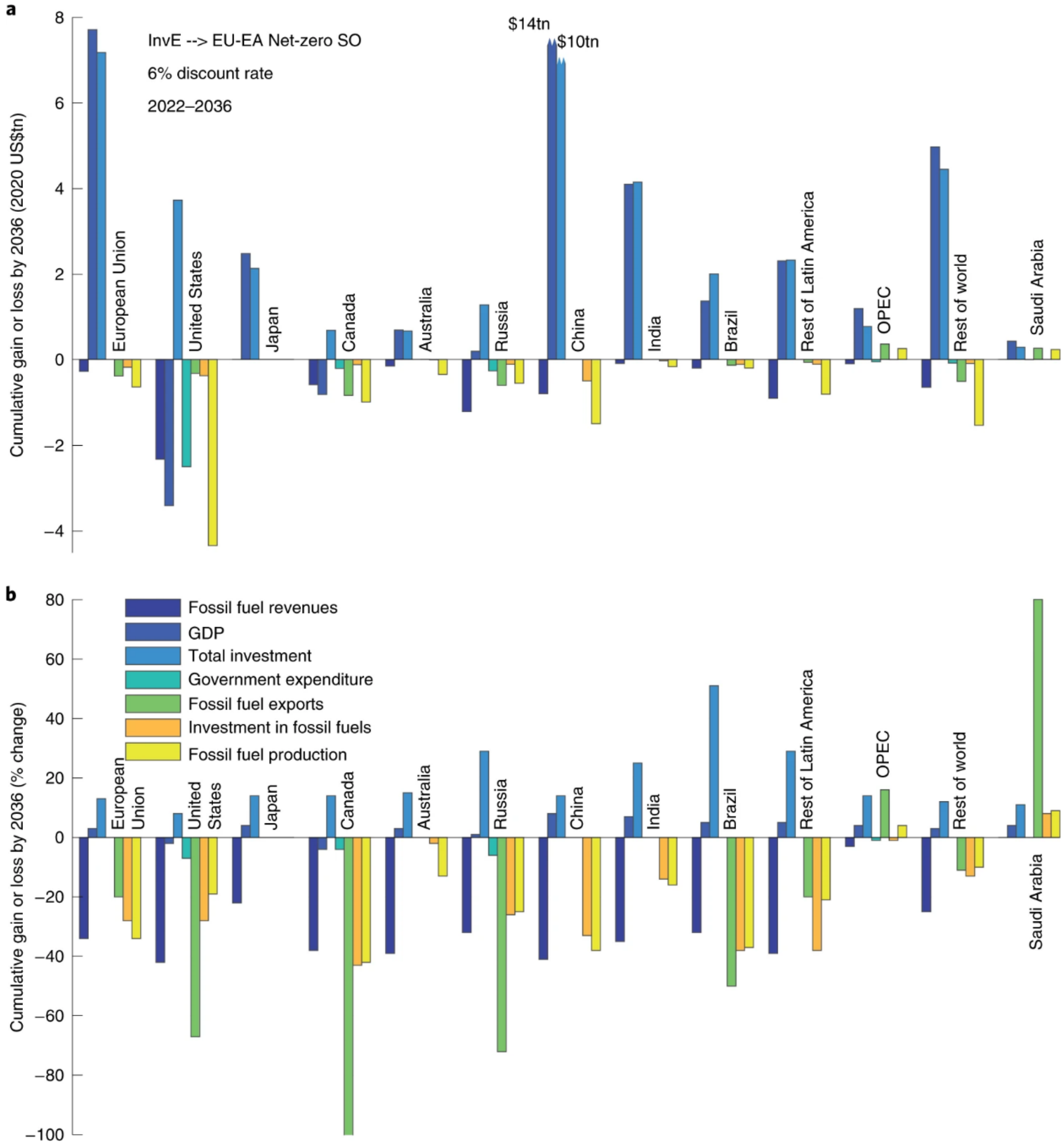


**Figure 5: Regional macroeconomic consequences of a fast transition.** Changes in the value of fossil fuel assets, GDP, investment, and fossil fuel production across chosen economies for the EUEA Net Zero SO scenario, relative to a high fossil-fuel Stated Policies-type demand scenario, expressed in absolute terms (**a**) and as percentage change (**b**). Gains are positive and losses negative. Values are cumulated over 15 years, between 2022 and 2036, using a 6% discount rate. Note that stranded fossil fuel assets are stocks of financial value, whereas GDP and investment are cumulated economic flows, and thus are not to be compared or added. Reproduced from Mercure et al. (2021).

The calculations above only include the losses in the upstream fossil fuel sector incurred directly from the lack of demand for US fossil fuels, especially oil and gas. Additional losses could arise from other sectors, which depend for the use of their capital stock on fossil fuels to varying degrees (Cahen-Fourot et al., 2021). Furthermore, a more subtle consequence must also be considered. To the extent that the US maintains substantial domestic demand for fossil fuels to take off a high level of domestic production, there could be an additional longer-term economic cost. If the US relies longer on less-and-less competitive fossil-fuel powered technologies than its international competitors, those competitors will gain the experience and expertise in the new low-carbon sectors faster than the United States. This could leave the US in the medium term with diminished competitiveness in the low-carbon economy, as it would have been slow to develop the capabilities associated with low-carbon manufacturing and these industries would have agglomerated elsewhere.

**Financial markets: importing stranded asset risks**

US investors are globally active, thereby exposed to stranded fossil-fuel assets not just in the US. In Semieniuk et al. (2022) we calculate that in the same scenario as above – with investment undertaken based on expectations about a stated policies world that subsequently realign to those of a EUEA Net Zero SO scenario – $400 billion in potentially stranded assets are sitting on US balance sheets. Only $300 billion stem from assets producing on US territory. The rest is imported either by US listed oil and gas companies operating globally, or US-based financial investors holding shares in oil and gas companies abroad. Figure 5 shows how the stranded assets shift across institutional and geographical boundaries as their financial ownership is traced through a network of shareholding relations to the ultimate owners. In light of the interconnectedness of financial markets and herd behavior, such financial risks could have systemic implications (Battiston et al., 2021, 2017; Bolton et al., 2020; Vermeulen et al., 2021). These are the 'transition risks' that can materialize when the structural change toward the low-carbon economy is disorderly. Uncertainty about whether investments could turn into stranded (financial) assets contribute to the potential for disorder (Alvarez et al., 2020; Campiglio et al., 2022; Semieniuk et al., 2021).

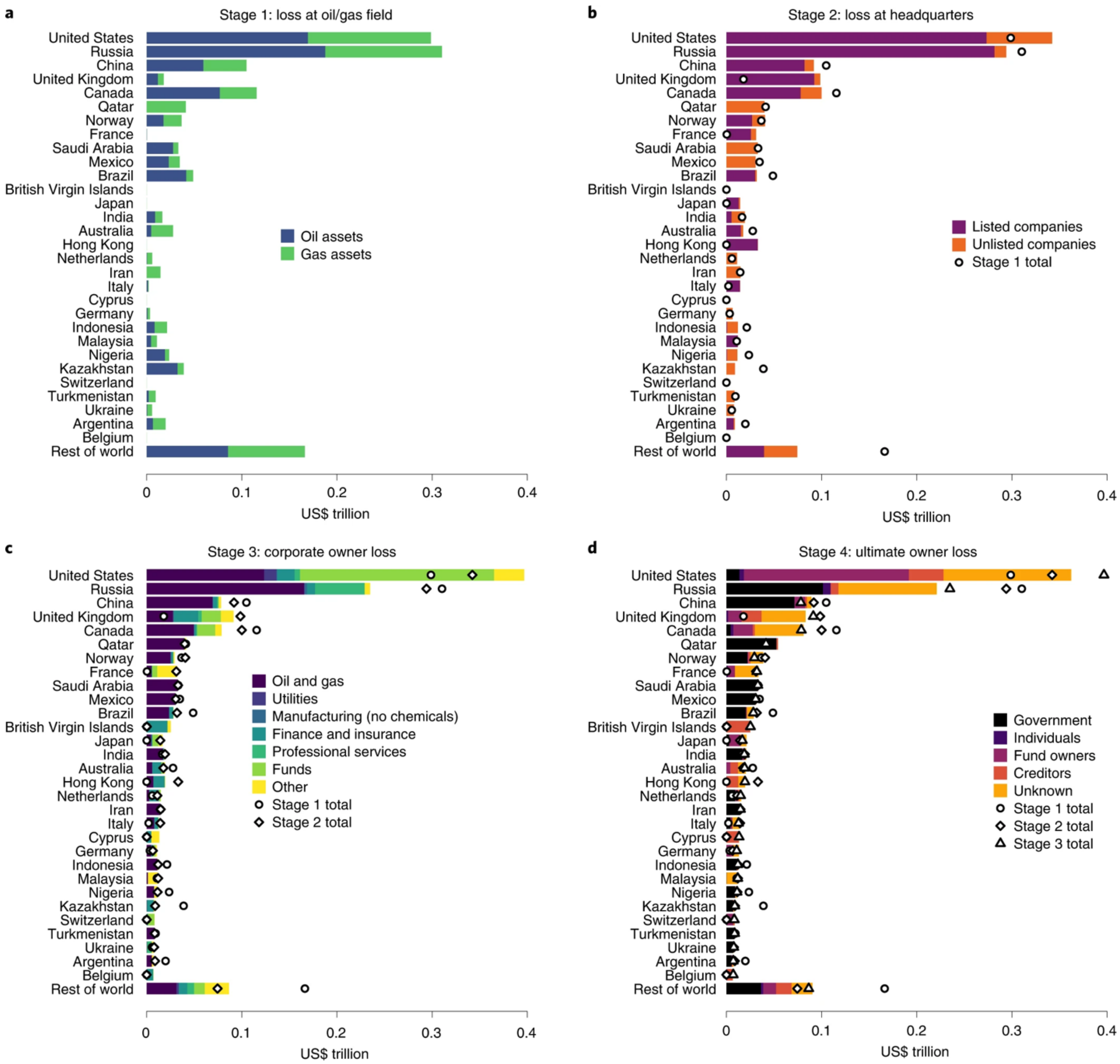


**Figure 5: Ownership chain of stranded assets by country and institutional category.** Distribution of stranded assets at 4 stages of the ownership chain as expectations realign to a scenario with importers moving away from fossil fuels and low-cost producers flooding the market. Reproduced from Semieniuk et al. (2022).

## Short term requirements and energy security

The current undersupply of fossil fuels may suggest that stranded assets are just an illusion. At the time of this testimony there are fears of an ‘energy crunch’ as underinvestment in the energy sector portends demand-supply mismatches (Jacobs et al., 2023). But it is precisely the uncertainty about future demand for their product that makes oil and gas companies more reluctant to proceed with new projects, with one estimate suggesting the oil and gas sector’s investment is consistent with that needed for a Net Zero in 2050 scenario (Jain and Palacios, 2023). Capitalist economies are unrivalled in their ability to supply an expanding market. The same cannot be said of a declining one. Moreover, as the world emerges from the COVID-19 pandemic and its disruptions to economies, it grapples with a war in Europe while the effects of climate change are set to become more and more disruptive. These 'overlapping emergencies' have the potential to continue disrupting economies and induce volatility into fossil fuel prices, which can lead to wider inflationary pressures when prices are high (Weber et al., 2022) and economic losses to producers like the US when they are low. Here it is important to realize that oil prices are determined globally and gas prices increasingly, too, as LNG exports are becoming more important. Energy security and economic resilience in the short and long-run both suggest a robust diversification away from relying mainly on fossil fuels.

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