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Too late, too sudden: Transition to a low-carbon economy and systemic risk

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Executive Summary

Keeping global warming below 2°C will require substantial reductions in global greenhouse gas emissions over the next few decades. To reduce emissions, economies must reduce their carbon intensity; given current technology, this implies a decisive shift away from fossil-fuel energy and related physical capital.

In a benign scenario, the transition to a low-carbon economy occurs gradually: adjustment costs are manageable, and the repricing of carbon assets probably does not entail systemic risk. Nevertheless, in the absence of additional policy intervention or technological breakthroughs, it is likely that the stock of greenhouse gases in the atmosphere would continue to grow over the medium term.

In an adverse scenario, the transition to a low-carbon economy occurs late and abruptly. Belated awareness about the importance of controlling emissions could result in an abrupt implementation of quantity constraints on the use of carbon-intensive energy sources. The costs of the transition will be correspondingly higher.

This adverse scenario could affect systemic risk via three main channels: (i) the macroeconomic impact of sudden changes in energy use; (ii) the revaluation of carbon-intensive assets; and (iii) a rise in the incidence of natural catastrophes. First, a sudden transition away from fossil-fuel energy could harm GDP, as alternative sources of energy would be restricted in supply and more expensive at the margin. Second, there could be a sudden repricing of carbon-intensive assets, which are financed in large part by debt. Third, there could be a concomitant rise in the incidence of natural catastrophes related to climate change, raising general insurers' and reinsurers' liabilities.

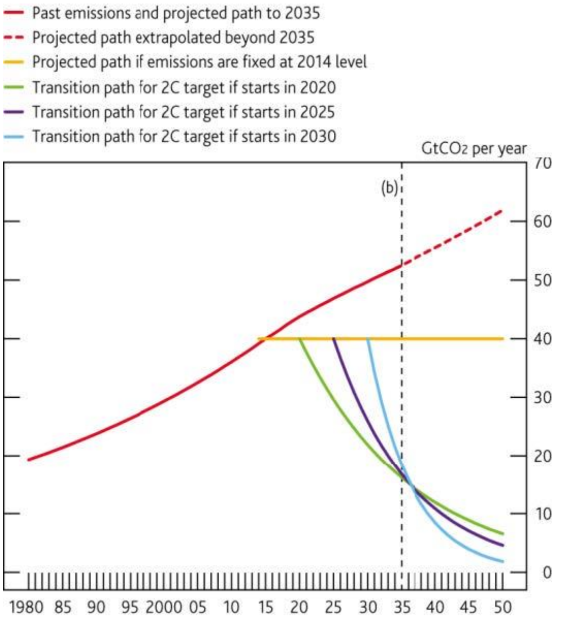
To quantify the importance of these channels, policymakers could aim for enhanced disclosure of the carbon intensity of non-financial firms. The related exposures of financial firms could then be stress-tested under the adverse scenario of a late and sudden transition. In the short-term, joint research efforts of energy experts and macroeconomists could help to better quantify macroeconomic risks and inform the design of scenarios for stress testing. In the medium-term, the availability of granular data and dedicated low-frequency stress tests will provide information about the impact of the adverse scenario on the financial system.

Section 1
The adverse scenario of a late and sudden low-carbon transition

There is broad acknowledgement of the need for decisive policy action on climate change. The United Nations Framework Convention on Climate Change (UNFCCC) has established the target of limiting the rise in average global temperatures (relative to those prevailing before the Industrial Revolution) to 2°C, with the UN climate change conference in Paris in November 2015 putting forward an even more ambitious limit of 1.5°C. Such targets are intended to limit the risk that the environment reaches a tipping point, beyond which the consequences of climate change may prove catastrophic and irreversible. Keeping global warming below 1.5-2°C requires that the stock of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere is kept below a critical limit. The speed at which this threshold is reached depends on the future trajectory of yearly emissions. If policymakers do not intervene and technological breakthroughs do not occur, the flow of emissions will continue to increase (see Figure 1), as will the stock of greenhouse gases in the atmosphere.[1]

Figure 1

Possible trajectories of carbon emissions, modelled on basis of using global '2°C carbon budget' by 2100 (>66% of less than 2°C, emissions shown until 2050)



Source: Prudential Regulation Authority (PRA) (2015).
Note: The historical growth rate in carbon emission is inferred from its 1970-2013 average; forward growth rates are based on PRA calculations using International Energy Agency (IEA) World Energy Outlook (WEO) 2013 projections and fixed at their 2035 level thereafter. The vertical line at (b) refers to the estimated date at which the carbon budget is expected to be exhausted if the flow of emissions were fixed at the current level (shown by the orange line). This estimate assumes that CO2 emissions from fossil fuels, industrial processes and land use remain fixed.

[1] For example, significant advances in carbon capture and storage that could reduce the emissions of fossil-fuel combustion. Given the nascent state of the technology and high operating costs, current predictions suggest that in the near future their large-scale deployment would be costlier than switching to renewable energy (Caldecott, Lomax and Workman, 2015; IEA, 2014b).

Uncertainty regarding the timing and speed of the required emissions reductions is high. Many authorities have made pledges to significantly reduce carbon emissions over the coming decades. These pledges require substitution of fossil fuels with renewable energy, and may imply a costly transition for the global economy. For example, the EU has pledged to reduce emissions (relative to 1990 levels) by at least 40% before 2030 and at least 60% before 2050. Historically, such pledges have been revised sequentially upwards, and the five-year review mechanism agreed in November 2015 following the UN climate change conference in Paris will encourage countries to increase their pledges periodically.[2] Some environmental models suggest that even bigger reductions may need to be targeted in the future.[3]

If governments make an early start in implementing existing pledges, a "soft landing" is likely. The transition to a low-carbon economy would be gradual, allowing adequate time for the physical capital stock to be replenished and for technological progress to keep energy costs at reasonable levels.[4] However, the credibility of some existing pledges is in doubt, owing to the long time horizons over which reductions are promised combined with the short-term costs of immediate action. As a result, there is considerable uncertainty about whether the shift to a low-carbon economy will be slow, gradual and benign – or late, abrupt and costly (see Box).

The adverse scenario for the EU financial system is one of late adjustment, resulting in a "hard landing". In this scenario, the underlying political economy – i.e. the short-term political costs of low-carbon transition, combined with the need for (and difficulty of) global coordination of emission cuts – leads to belated and sudden implementation of constraints on the use of carbon-intensive energy. Back-loaded policy intervention implies more severe reductions in the flow of emissions, as the stock of GHGs in the atmosphere would be close to the critical limit owing the cumulated flow of past emissions.

The "hard landing" would be exacerbated by a lack of technological progress. The development of promising technologies – such as carbon capture, renewables and batteries – could transform how energy is produced and stored, providing a boost to real economic activity. However, the future of technological innovation is inherently uncertain. Current levels of R&D in renewable energy are relatively low, in part owing to uncertainty regarding governments' long-term environmental policies.

A late transition to a low-carbon economy would exacerbate the physical costs of climate change. Global warming, and its implications for the frequency and severity of natural catastrophes, is increasing with the stock of greenhouse gases in the atmosphere. As such, a late transition to a low-carbon economy will aggravate the costs of transition for, among others, general insurers, reinsurers and governments.

Box

Climate policies and emissions pathways

Previous and current emission reduction pledges suggest a highly uncertain environment regarding the speed and timing of the transition to a low-carbon economy. Despite the increasing frequency of declarations about the importance of climate change and the growing

[2] See **http://ec.europa.eu/clima/policies/international/negotiations/future/index_en.htm**

[3] For example, recent integrated environmental economic models point to the need for much more severe reductions in emissions than had previously been estimated (Dietz and Stern, 2015).

[4] See Stern (2005) for an early defence of the virtues of an early and gradual transition. Acemoglu et al (2012) reinforce the argument for an early intervention alluding to its virtuous dynamic effects on endogenous technical change and growth, especially if carbon taxes are accompanied with subsidies to relevant R&D activities.

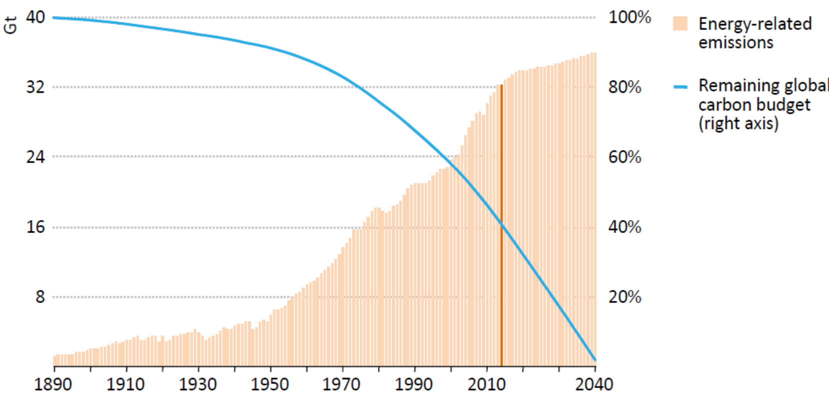
consensus around a new agreement under the United Nations Framework Convention on Climate Change (UNFCCC), global emissions continue to grow. It is therefore hard to forecast the true speed at which emissions might be abated.

Extrapolating from existing emissions pledges and the targets consistent with limiting global warming to 2°C suggests that a late and sudden transition to a low-carbon economy is a plausible scenario. Using country-level emissions pledges and global climate targets, the International Energy Agency (IEA) calculates that, following current trends, the so-called "carbon budget" (i.e. the stock of greenhouse gases in the atmosphere compatible with a rise in average global temperatures of less than 2°C) would be exhausted by 2040. Under those projections, emissions would need to drop below zero beyond that date. Alternatively, if the abatement of emissions were to start earlier, the transition to a low-carbon economy can be more gradual. The later the transition starts, the more likely it is that either the targeted limit will be revised (at the risk of catastrophic physical implications) or the transition to the low-carbon economy will be late and abrupt (see Figure B1).

Future policy is likely to involve a combination of price-based and quantity-based interventions to reduce the use of carbon-intensive energy sources (e.g. carbon taxation, trading schemes for emission rights, or constraints on energy consumption). Around 12% of global emissions are currently covered by carbon pricing, with emissions trading being the most popular pricing mechanism (Kossoy, 2015). This figure rises to about 50% in the EU (Ellerman, 2008).

Figure B1

Carbon budget and CO2 emissions



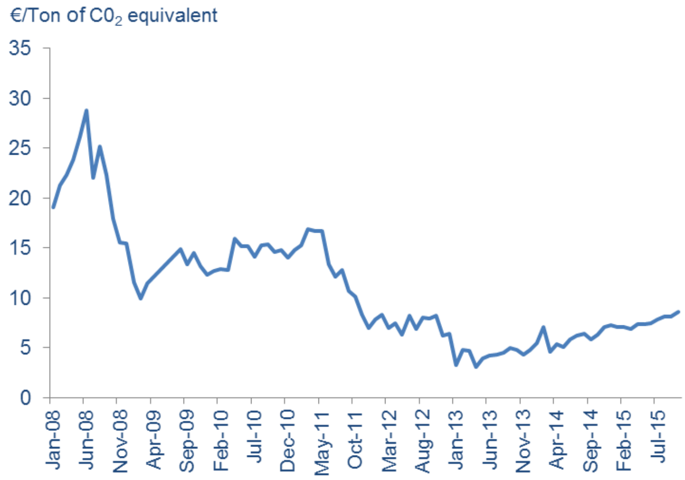
Source: IEA (2015). Global energy-related CO_2 emissions extrapolating from current national emissions pledges under the UNFCC, compared to remaining carbon budget for a less than 50% chance of keeping to 2°C.

In the soft-landing scenario, carbon pricing and the higher marginal cost of renewable energy might result in short-term energy price increases. Policy innovations – e.g. adding a carbon tax to fossil fuels – would incentivise a shift to consumption of renewable energy; the transition would be gradual enough such that energy supply would not be significantly constrained and turnover in the physical capital stock would be orderly. Though there might be some energy price increases in the short-term, energy prices would likely decrease in the medium- to long-term as the production of renewable energy becomes more efficient.

Under a soft landing, the low-carbon transition could have an overall positive effect on the economy, given timely investment in alternative energy and infrastructure. The development of new technology and increased energy efficiency could stimulate innovation, create new jobs and lower production costs – depending on the pace of innovation, the mobility of labour, the energy intensity of the country's main sectors, and the speed and type of transition.[5] **This soft landing would require a significant but feasible increase in investment and infrastructure. Though renewables as a category are currently the fastest growing energy subsector, roughly 70% of new energy investment is related to fossil fuels (IEA, 2015).** The OECD estimates that investment would still need to increase by $1tn annually in order to decarbonise the economy while maintaining sufficient energy supply (Kaminker, 2012). This investment and R&D activity could be partially financed by revenues from carbon taxes.

The implementation of emissions regulation thus far has shown considerable variability and volatility in establishing a price for carbon emissions, dampening investment in clean energy sources. Globally, carbon prices vary from less than $1 per ton of CO2 equivalent (tCO2e) to $130 per tCO2e, with 85% of emissions priced at less than $10, which is significantly below the price that economic models estimate is necessary for remaining under 2°C (Kossoy, 2015) (see Figure B2).[6]

Figure B2
Carbon futures price under the EU Emissions Trading System, 2008-14



Source: Investing.com.

In the absence of stable price signals and decisive global political commitment to limit climate change, a hard landing is more likely. The economies of scale and path dependency associated with energy production suggest that technological adaptation to the low-carbon economy requires time, particularly given the speed of turnover for the relevant infrastructure (Unruh, 2000): fossil-fuelled power plants, for example, can operate for thirty to forty years (IEA, 2015). Investment in alternative energy has been dampened by uncertainty surrounding its regulatory framework and its long-run returns (Masini and Menichetti, 2011; IEA, 2014b).

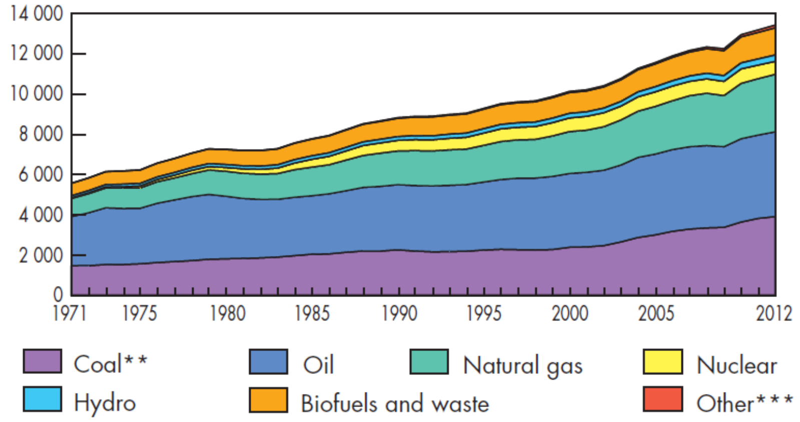
In a hard-landing scenario, the increase in the cost of energy will likely reflect the effect of both higher carbon taxes and direct quantity constraints on the use of fossil fuels. Globally,

5 See e.g. Acemoglu et al (2012), Stern (2008), Wei (2010), Fankhaeser (2010).

6 Estimates of the so-called "social price of carbon" (the price required to efficiently contain emissions) vary quite widely, from $50 per tCO2 to more than $300 per tCO2 (see CISL, 2015).

13% of energy comes from renewable energy, and 82% from fossil-fuel-based sources (see Figure A3).[7] Achieving a drastic reduction in the use of fossil fuel in such a short interval of time would significantly curtail energy supply during a transitional period, especially given the rate of turnover of the capital stock involved in energy generation and energy usage.

Figure A3
World* total primary energy supply from 1971 to 2012 by fuel (Mtoe)



Source: IEA (2014a)
Notes: *World includes international aviation and international marine bunkers. **In these graphs, peat and oil shale are aggregated with coal. ***Includes geothermal, solar, wind, heat, etc.

Global warming greater than 2°C would expose the global economy to greater physical risks. Some negative physical effects of global warming (e.g. a greater incidence of natural disasters) have already manifested themselves (Lloyd's, 2014; IPCC, 2014). In the absence of a decisive abatement of greenhouse gas emissions, global warming will likely exceed 2°C. Extrapolating from current policy and energy demand, the IEA predicts that average warming will exceed 2.6°C by 2100 and 3.5°C by 2200 (IEA, 2015).

The severity of physical impacts will depend on the degree of global warming. Given the current stock of greenhouse gases in the atmosphere and current emissions pathways, IPCC (2014) estimates that physical effects will begin to manifest noticeably over the next ten to fifteen years and increase thereafter. The value at risk varies depending on the degree of warming. The Economist Intelligence Unit calculates the average (mean) expected loss across scenarios as $4.2tn in financial assets. Under the extreme scenario of 5-6°C of global warming,[8] $13.8tn of financial assets would be destroyed (Economist Intelligence Unit, 2015).

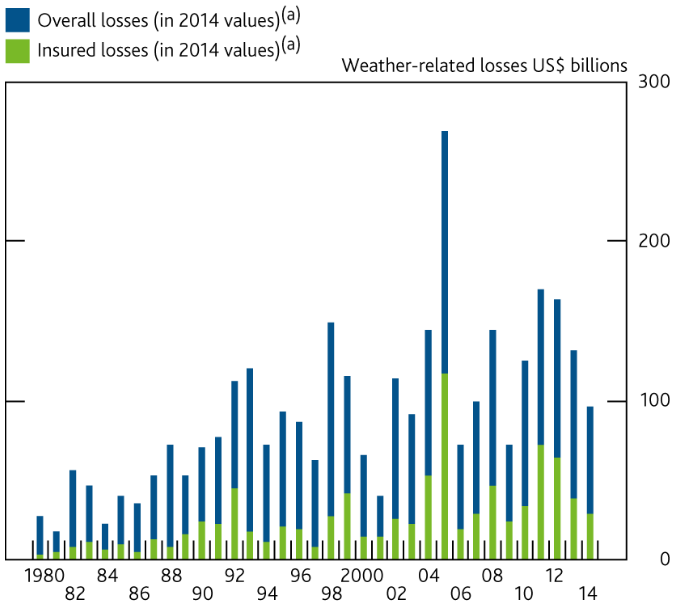
The increase in natural disasters will likely affect the insurance industry in particular. Losses from natural disasters have increased fourfold over the past thirty years (see Figure B4), particularly uninsured losses. In the short term, insured losses pose challenges for the profitability and resilience of the insurance industry, while the costs of the large and increasing share of uninsured losses will be borne by the larger economy. Disruptions due to natural disasters may impact negatively the capital stock, productivity and output, as well as public finances.

[7] Approximately 25% of EU-28 energy production comes from renewable sources, but only accounts for 11.8% of energy consumption; the difference is made up by energy imports, primarily oil and gas (see Eurostat, "Consumption of Energy" and "Energy Production and Imports"; data is as of 2013).

[8] Since climate modelling is based on probability distributions, an emissions pathway with mean warming of 3.7°C by 2100 encompasses a "likely" (5 to 95% probability) range of 2.0 to 5.4°C (IPCC, 2014).

The insurance industry might also face losses due to liability risks. As the physical implications of climate change materialise, some firms (e.g. in the carbon-intensive energy sector) might face liability claims for their contribution to such change. The insurance industry might be affected in their role as insurer of third-party liability claims (see PRA, 2015). In the medium- to long-term, these losses – both from natural disasters and from liability claims – might shift even more to the household and non-financial sectors as more risks become uninsurable.

Figure B4
Weather-related loss events worldwide (1980-2014)



Source: PRA (2015) and Munich Re.
Note: a) Values as at 2014 adjusted to inflation based on Country Consumer Price Index.

Section 2
Systemic risk in the adverse scenario

The adverse scenario described in Section 1 could affect systemic risk via two main channels:

- first, reduced energy supply and increased energy costs would impair macroeconomic activity;
- second, financial institutions would be affected by their exposure to carbon-intensive assets (i.e. real and financial assets whose value depends on the extraction or usage of fossil fuels and other carbon-intensive resources).

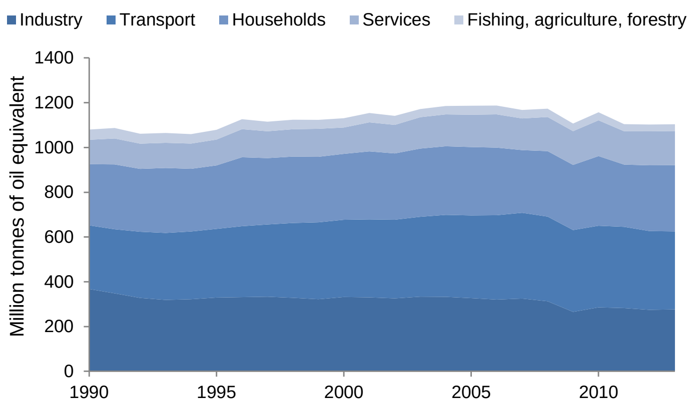
These two channels could generate contagion in the broader financial system by interacting with other financial frictions. They might further interact with a third channel: the impact of physical shocks (e.g. natural catastrophes) associated with climate change, which become more likely as the stock of greenhouse gases accumulates in the atmosphere.

2.1 Macroeconomic impacts of energy price shocks

A “hard landing” transition to a low-carbon economy implies constrained energy supply and increased costs of production for the whole economy, with effects equivalent to a large and persistent negative macroeconomic shock.

In the event of a hard landing, a rapid transition away from fossil-fuel-based energy production would be necessary. This could trigger a downward shift in the supply of energy and an upward shock to energy prices. Depending on advances in renewable energy technology and energy efficiency, substituting low-carbon for fossil-fuel energy would be expensive at the margin. Additionally, the time-intensive adaptation of infrastructures and generation capacity may imply energy shortages and abnormally high energy costs in a transitional period (see Box).

Figure 2
Final energy consumption by sector, EU-28

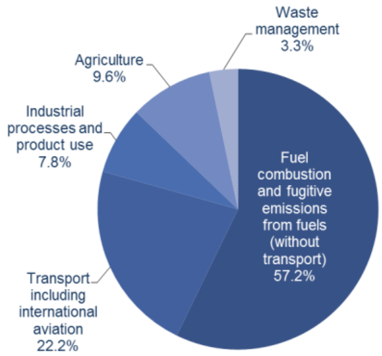


Source: European Environment Agency (EEA).9

[9] See http://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-9/assessment

Increased energy costs would impair economic growth both on the supply and demand side. Energy-intensive sectors, particularly transport and manufacturing, would see their production processes disrupted as input prices increase. In the shorter term, a rapid transition could result in constrained energy supply if demand outstrips the productive capacity of renewable energy (see Box). At the same time, households' disposable income would be hit by the effect of increased energy costs on the price of consumption goods (most notably, electricity and transport) (Figure 2).

Figure 3
Greenhouse gas emissions by sector (EU-28, 2013)



Source: Eurostat[10].

Economic output depends upon the reliable supply of energy. Carbon restrictions would severely affect not only energy production industries, but also emissions-intensive industries more generally, and other industries relying on energy or other carbon-intensive inputs.[11] Energy, transport, agriculture, and industrial processes are particularly emissions intensive (see Figure 3). According to Stern (2008), the energy sector will need to be at least 60% decarbonised by 2050 in order to stabilize emissions at the targeted level;[12] the overall costs of mitigation have been estimated in a range of -2% to 5% of global GDP by 2050 (Stern, 2008; see also Box), with considerable variation by industry (see Figure 4). Though these estimates should be treated with caution given uncertainties involved in modelling,[13] historical analysis of oil price shocks support the view that even small shocks to the cost of energy have substantial effects on real GDP (Kilian, 2014).

10 See http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics

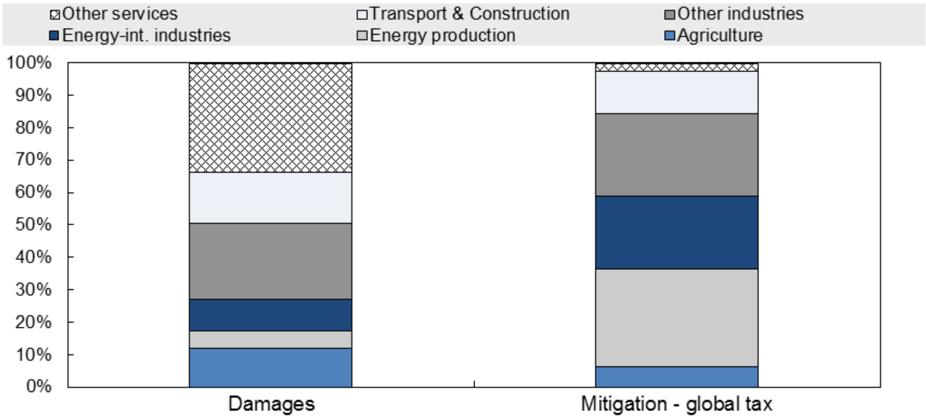
11 See Schoenmaker et al (2015).

12 i.e., 550 parts per million (ppm) of CO2 equivalent in the atmosphere. A more ambitious target of 350 ppm would entail even larger reductions. See http://www.eea.europa.eu/highlights/climate-change-targets-350-ppm-and-the-eu-2-degree-target.

13 See for example Rosen (2015) on the significant challenges involved in macroeconomic modelling of mitigation costs, including uncertainty about technological development and changes in production and consumption patterns.

Figure 4

Shares of sectors in global GDP loss in 2060 (percentage of total GDP loss)



Source: OECD (2015, showing how industries would be relatively affected by climate change damages compared to increased costs from a global carbon tax – for example, energy production would be relatively more affected by mitigation, whereas agriculture would make up a larger share of the overall GDP losses if exposed to the physical effects of unmitigated climate change.

2.2 Financial system exposure to stranded assets

The transition to a low-carbon economy implies that a wide range of carbon-intensive assets would become "stranded" (i.e. unusable). In a gradual transition to renewable energy and replenishment of the physical capital stock, these assets would slowly become obsolete. Carbon-intensive technologies would gradually become unprofitable due to a combination of regulation (such as carbon taxes) and technological development (i.e. economies of scale that drive down the costs of renewable energy). In the case of a "hard landing", the sudden arrival of obsolescence caused by a rapid change in environmental policy might precipitate a more radical and not fully anticipated repricing of carbon-intensive assets, including fossil-fuel reserves and other assets dependent on cheap fossil fuels.[14] This section discusses two types of assets that could become stranded: fossil-fuel reserves (2.2.1) and other assets (2.2.2).

2.2.1 Financial system exposure to fossil-fuel reserves

If substantial climate change is to be avoided, a large quantity of fossil-fuel reserves and infrastructure is unusable. McGlade and Elkins (2015) estimate that if the rise in average global temperatures is to be kept below 2°C, approximately 35% of current oil reserves, 50% of gas reserves and nearly 90% of coal reserves are unusable. In addition, Lewis (2014) estimates that under a more stringent policy scenario,[15] oil, gas and coal companies could lose $28tn in revenue over the next twenty years, relative to baseline projections, due to reduced sales – an estimated 22% decrease in revenues for the oil industry alone.

The market values of the firms involved in the extraction and processing of fossil fuels may only belatedly and suddenly reflect changes in future revenues and the negligible scrap

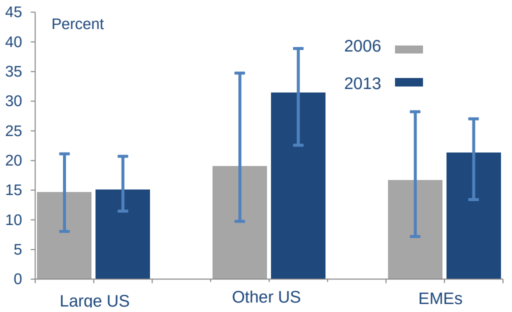
[14] In addition to changes in policy and technology, carbon-intensive assets are exposed to reputational risk and rising social pressure against their use, for example the fossil-fuel divestment movement (Bloomberg New Energy Finance, 2014). Some asset managers are already taking these risks into account – see for example Dutch pension fund service provider PPGM's commitment to halve the carbon footprint of its investments, or Allianz SE's recent announcement that it will stop financing coal-based business models and shift increased investment towards wind energy instead (Allianz SE, 2015).

[15] Namely, one consistent with limiting GHG-emissions to 450ppm of CO2 equivalent in the atmosphere.

value of stranded assets. Oil and gas companies represent a significant fraction of the non-financial corporate sector; their global market capitalisation is nearly $5tn (Bloomberg New Energy Finance, 2014). In a "hard landing" scenario, markets might suddenly reassess the value of firms' stranded assets and future profits. HSBC (2013) estimates that this could result in a 50% decrease in market capitalisation for oil and gas companies, including both the risk of stranded assets and reduced demand. Current market pricing may reflect lack of awareness of the challenges posed by climate change as well as uncertainty regarding the path of policy (see Box).[16]

Figure 5

Oil and gas producers – total debt to assets(a)



Source: Domanski *et al* (2015).
Notes: Calculations by the Bank for International Settlements based on data from Bloomberg and Thomson Reuters Worldwide. The bars show the median and the lines show the interquartile range.
(a) Integrated oil, gas and exploration/production companies. "Large US" and "EMEs" (emerging market economies) include companies with total assets in 2013 exceeding $25bn.

Fossil-fuel firms and electricity utilities are substantially debt financed, exacerbating the potential financial stability impact of a sudden revaluation of stranded assets. Fossil fuel and other carbon-intensive companies make up one-third of the $2.6tn global leveraged loan market (PRA, 2015). Oil and gas companies in particular have been significantly increasing their indebtedness (see Figure 5), with the rise largely led by the US and emerging markets and aggravated by the downward oil price shocks of 2015-2016 (Domanski et al, 2015).[17] A large swing in asset prices could lead to debt repricing and credit losses, aggravating the impact on financial stability.[18]

The EU financial system has significant direct exposure to fossil-fuel firms. Though the potential effect is difficult to quantify without better exposure data, Weyzig (2014) estimates that the exposures of European financial institutions (including banks, pension funds and insurers) to fossil-fuel firms exceed €1tn (see Table 1), and estimates potential losses of between €350bn and €400bn, even under an orderly transition scenario.[19]

Based on available information, the first-order impact of financial sector losses on carbon-intensive assets appears manageable, though the initial shock could trigger negative feedback loops. Even relatively small initial shocks can generate systemic feedback loops via the interaction of financial frictions (Clerc et al, 2016). Moreover, the repricing of carbon-intensive assets is likely to take place at the same time as general market volatility (e.g. oil prices in the commodities market).[20]

[16] See, for example, Caldecott and Rook (2015) on limitations on capex disclosure in extractive industry project portfolios, which may make it difficult for investors to fully assess risk.

[17] US regulators are already concerned about the "substandard" nature of the loans; see Tan (2015).

[18] Brunnermeier and Schnabel (2015) find that the severity of the economic crisis following the bursting of an asset price bubble is linked to the degree of debt financing of the bubble asset.

[19] Weyzig's estimates are based on extrapolating available data on banks, insurers, and pension fund portfolios; additional disclosure and AnaCredit should help to reduce data gaps.

[20] The oil price shocks of 2015-2016 give an illustrative example of the far-reaching effects such a repricing could have for both the real economy and the financial markets – see, for example, Husain (2015).

Table 1

Exposures of European financial institutions to fossil-fuel firms (in €bn)

	Equity	Debt	Total	Total as % of total assets
Banks	98	365a	463	1.3
Pension funds	196b	60	256	5.0
Insurers	109	233	342	4.4
Total				
- in €bn	403	658	1061	
- in % of total	38%	62%	100%	

Source: Weyzig et al (2014). Notes: a) sum of bonds (62) and loans (303); b) sum of equities (118) and commodities (78).

2.2.2 Financial system exposure to other carbon-intensive assets

Avoiding substantial climate change implies that assets dependent on fossil-fuel energy will become obsolete. Carbon-intensive sectors such as transportation, manufacturing, agriculture and real estate rely on a large stock of long-lived physical capital whose efficient use requires a continued supply of cheap energy and, in many cases, energy specifically derived from fossil fuels. In a “hard landing” transition to a low-carbon economy, carbon-intensive physical capital (such as conventional vehicles, electricity supply infrastructure, machinery used in manufacturing processes) would quickly become obsolete.

The sudden revaluation of carbon-intensive capital would also affect financial institutions with claims on firms that disproportionately own such capital or use it as an input in their production processes. This includes firms that own and distribute fossil fuels and those whose production processes directly generate emissions. It also includes industries with a heavy reliance on inputs whose manufacturing is emissions intensive (e.g. construction, as a user of concrete and steel), which will also find the use of their existing capital uneconomical. Recent macroeconomic modelling estimates that, under a scenario in which markets revalue assets in accordance with policy limiting warming to 2°C, major stock market indexes might fall by 15-20% (CISL, 2015).[21]

The initial shock of this revaluation could trigger systemically relevant second-round effects. Contagion could extend across the corporate bond and leveraged loan markets, partly reflecting uncertainty as to the extent to which firms of various sectors may be affected directly or indirectly by the initial shock. If some highly leveraged financial institutions were severely hit by initial losses, and exposures throughout the system were opaque and unquantified, market and funding liquidity spirals might significantly amplify the damage to the financial system (Clerc *et al*, 2016).[22]

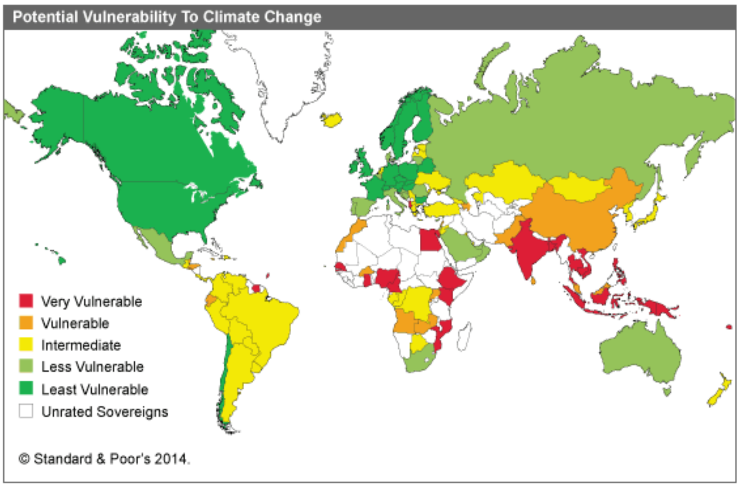
[21] Compared to a baseline “business as usual” scenario projection trajectory from Oxford Economics. Nevertheless, they find that the equity losses under this scenario are much smaller than under a “no mitigation” scenario of severe climate change.

[22] See, for example, Battiston et al (2016), who found that European investment funds in particular had a relatively high equity exposure to climate-sensitive sectors, such that losses related to climate policy changes could lead to significant second order effects.

2.3 Global risk dimensions

Systemic implications are compounded by the global nature of transitional risk. Countries that are highly dependent on oil and gas production – for both domestic consumption and export – may be particularly affected by the fall in the global use of carbon-intensive resources: they will simultaneously suffer from increased energy costs and decreased exports. State-owned oil firms in EMEs in particular are substantial contributors to government revenue and have also recently increased their debt financing (Domanski *et al*, 2015), with potential risks for publicly guaranteed debt and debt sustainability. Emerging markets are also more exposed to physical risk. A recent report by Standard & Poor's (Kraemer and Negrila, 2014) highlights climate change as a growing concern for sovereign risk, especially for countries that are highly dependent on agriculture, due to the impact on agricultural yields, productivity, GDP growth and public finances. By contrast, the EU is less vulnerable to physical risk (see Figure 6), though its financial sector is exposed to front-line countries such as China, Brazil and Turkey.

Figure 6
Global vulnerability to physical effects of climate change



Source: Kraemer (2014).

Section 3
Macroprudential policy implications

The adverse scenario for the EU financial system is a late and abrupt transition away from fossil fuels, exacerbated by relatively low investment in alternative energy infrastructure and R&D. In the adverse scenario, the underlying political economy leads to a late and sudden implementation of constraints on the use of carbon-intensive energy. This implies a sharp spike in energy costs; temporarily inadequate energy supply; sudden economic obsolescence of the capital stock; sudden revaluation of fossil fuel reserves; and revaluation of the market value of firms according to their exposure to carbon-intensive resources, inputs or technologies.

The effects of a hard landing would be amplified by macroeconomic and macro-financial channels. Precise quantification of these effects requires collaboration between macroeconomic modellers, financial economists and energy experts. The potential severity of the impact is exacerbated by the global nature of the process and the fact that a late transition increases the risk of concomitant physical effects of climate change.

Markets may not have fully priced in the risks from climate change. Climate change is seen as only possibly having effects in the long term. When combined with uncertainty about climate change and emissions abatement policies, this may have led to an underestimation of the problem and its effect on growth prospects, firms' cash flows, and asset payoffs. Meanwhile, investment in infrastructure and R&D with respect to alternative energy sources remains low.

The systemic risk implications depend on the exposure levels of entities, and highly leveraged financial institutions in particular, to carbon-intensive assets and the specific form of emission abatement policies, both of which are highly uncertain. The increased availability of exposure data, including better knowledge of the carbon intensity of firms' resources, inputs and technologies (and of the cost of replacing them with low-carbon alternatives), would help to better quantify the potential effects.

In response to the potential systemic risk involved, macroprudential policymakers could encourage the disclosure of non-financial firms' carbon intensity. In the short-term, enhanced disclosure would help quantify financial firms' potential exposure. The ESRB could also develop relevant macroeconomic scenarios against which to stress test firms. In the medium-term, regulators could use granular AnaCredit data and dedicated "carbon stress tests" to estimate the impact of the adverse scenario on financial institutions.

3.1 Short-term policy response

In the short-term, the ESRB could support enhanced information collection and disclosure and consider incorporating climate-related prudential risks into regular stress tests. From a macroprudential perspective, these initiatives would ensure a timely assessment of potential threats to financial stability and the development of remedial macroprudential policies. Moreover, efforts from macroprudential policymakers could help to increase public awareness about the financial stability challenges posed by climate change, and thereby increase the likelihood of a "soft landing".

- **Support enhanced information collection and disclosure.** This could take the form of additional reporting requirements (e.g. along the lines of Article 173 of the French Energy

Transition Law, which enhances disclosure of climate change-related risk).[23] In an initial phase, authorities could encourage industry efforts to voluntarily adopt disclosure standards (e.g. the Financial Stability Board's industry-led Taskforce on Climate-related Financial Disclosures, which will develop voluntary, consistent climate-related financial disclosures for use by companies in providing information to lenders, insurers, investors and other stakeholders).

- **Incorporate climate-related prudential risks into regular stress test exercises.** The ESRB could incorporate risks associated with a "hard landing" into the ESRB's adverse macroeconomic scenarios used by the European Supervisory Authorities in their regular stress testing of regulated financial institutions. In particular, the ESRB macroeconomic scenario could incorporate an upward shock in the price of non-renewable energy sources, causing a negative impact on aggregate demand while at the same time "turning off" any positive balance sheet effects for energy producers and accounting for country specificities. In practice, this could be done by the ESRB in collaboration with the ECB using a large macroeconometric model.[24] This approach could be complemented by the more granular "carbon stress tests" proposed in section 3.2.

3.2 Medium-term macroprudential policy response

In the medium term, authorities could consider further policy actions – if additional data and research suggests that the financial system is indeed significantly exposed to carbon risk. In particular, regulators could run dedicated "carbon stress tests", which would help to define the most pertinent systemic risks and would be adapted to the specificities of the "hard landing" scenario (including the long time horizon over which adverse events would occur). The methodology of dedicated carbon stress testing is still under development, and will depend heavily on the assumed range of emissions pathways and could benefit from collaboration across institutions.

Work towards a "carbon stress test" will be facilitated, for euro area countries and in relation to credit exposures, by the availability of granular data within the AnaCredit project (due for completion in 2020) that could be matched with information on the carbon intensity or carbon dependence of the various sectors without implying large additional information collection costs.[25]

[23] The French Treasury is currently working on the implementation of the law; see the 2° Investing Initiative (2015) for a concise overview. Directive 2014/95/EU, coming into effect in 2017, also requires large public-interest entities to disclose relevant and useful information on their policies, main risks and outcomes on environmental matters, including "the use of renewable and/or non-renewable energy, greenhouse gas emissions, water use and air pollution".

[24] By using the National Institute Global Econometrics Model (NiGEM) to assess the impact of changes in the price of non-renewable sources of energy, the econometrician can assess how such a shock would propagate throughout the global economy. To do this, the econometrician faces a choice between shocking the price of oil, coal and gas individually or in combination. As the NiGEM system of equations is based on countries' relative competitiveness, modelling the shock would provide an insight into the countries that would be most affected by shocks to the price of non-renewables. Furthermore, the total impact on macroeconomic indicators – including GDP, inflation and unemployment – can be assessed and compared across regions. In implementing this scenario, the econometrician would need to be careful to "offset" the positive balance sheet impact of higher oil, coal and gas prices (both to the government balance sheet via higher tax revenues and to energy firms' balance sheets).

[25] AnaCredit is a European System of Central Banks (ESCB) project that aims to create a common granular credit dataset shared between Eurosystem members and comprising data from all euro area countries. The dataset will contain the credit exposures of euro area countries' deposit-taking corporations and other financial intermediaries to resident and non-resident legal entities, reported on a loan-by-loan basis with regular time frequency. After final implementation – which is expected to be completed in in 2020 – AnaCredit data could be used for the purpose of detailed assessment of sectoral exposure concentration risk of euro area banks, with particular focus on certain sectors, such as those identified as carbon-intensive.

If stress tests ultimately find that systemic risks are material, research and consultation would be necessary in order to assess which policies are best suited in light of the pre-existing prudential stance. The role of prudential policy is to mitigate excessive financial risks – both on the level of individual institutions and the financial system as a whole. It is therefore distinct from governments' climate change policies, which attempt to reconfigure the production and consumption of energy in order to reduce environmental risks (Carney, 2015). Possibilities for prudential policies include:

- building systemic capital buffers (for example, to protect against the macroeconomic and macro-financial implications of a "hard landing");
- regulatory loss absorbency requirements to, for example, encourage the issuance of "carbon risk bonds", the payoff of which would be contingent on a contractually defined critical event (e.g. the imposition of a prohibitive carbon tax);
- specific capital surcharges based on the carbon intensity of individual exposures; and
- large exposure limits applied to the overall investment in assets deemed highly vulnerable to an abrupt transition to the low-carbon economy.

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