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An energy transition risk stress test for the financial system of the Netherlands

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Authors
Robert Vermeulen, Edo Schets, Melanie Lohuis, Barbara Kölbl, David-Jan Jansen and Willem Heeringa

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Robert Vermeulen, Edo Schets, Melanie Lohuis,
Barbara Kölbl, David-Jan Jansen and Willem Heeringa[1]

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[1] Corresponding author: Robert Vermeulen (r.j.g.vermeulen@dnb.nl). This study benefited from contributions by Thomas Hebbink and Lievijne Neuteboom and statistical support from Jack Bekooij, Jasper de Boer and René de Sousa van Stralen (all DNB). Special thanks go out to Dr. Nina Seega (University of Cambridge Institute for Sustainability Leadership) for commenting extensively on an earlier draft of this study. We also thank experts affiliated with the Netherlands Environmental Assessment Agency (PBL), the University of Cambridge Institute for Sustainability Leadership and Utrecht University for feedback on the scenarios used in this study. Lastly, we are grateful for the many helpful comments and suggestions we received from our colleagues at DNB. Any remaining errors are our own.

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1 Introduction

Almost 200 countries have signed the Paris Agreement: a pledge to keep the global temperature rise well below 2 degrees Celsius. To realize this pledge, global greenhouse gas emissions will need to be reduced substantially. This, in turn, requires a global transition to a low-carbon economy and energy system. Such an energy transition may give rise to shocks that could be disruptive for the financial system. This Occasional Study investigates the potential financial stability impact of a disruptive energy transition for the financial sector of the Netherlands by conducting a stress test.

Several organizations have recommended the use of stress tests in relation to climate-related risks. The European Systemic Risk Board (2016), for example, recommends European Supervisory Authorities to include a disruptive energy transition scenario into their stress test exercises. Similarly, the Financial Stability Board's Task Force on Climate-related Financial Disclosures (2017a) has recommended firms to use scenario analysis and stress testing in the context of climate-related risks. To date, however, practical experience with stress testing climate-related risks is still limited. In addition to shedding light on the financial stability risks for the Netherlands associated with the transition to a low-carbon economy, therefore, this study attempts to make a contribution to energy transition risk stress testing.

1.1 Energy transition risks and the financial system of the Netherlands

In the transition to a low-carbon economy, risks to financial institutions and financial stability may arise. At present, fossil fuels still hold a central place in the production and consumption of energy. Economist Nicholas Stern has pointed out that because of this, the necessary reduction in CO_2

emissions will require drastic changes to the global economy and energy systems (Stern, 2008, especially pp.7-8). In a speech to the UK insurance sector in 2015, Bank of England governor Mark Carney warned that this energy transition could give rise to financial risks (Carney, 2015). In particular, technological breakthroughs or abrupt changes in government policy may trigger a reassessment of asset values which could affect financial institutions' balance sheets. If this were to happen on a large scale, there could be an impact on financial stability.

Although the transition to a low-carbon economy is a long-term process, energy transition risks can materialize in the short term. Energy transition risks can materialize in the short term through various channels. If governments decide to implement carbon taxes or restrictions on CO_2 emissions (as they are currently considering, see Box 1.1), this could lead to large cost increases for firms with high CO_2 emissions. This is especially the case if such measures are implemented abruptly, as this would leave little time for firms to adapt to the new policy.[2] Energy transition risks may also materialize in case of a sudden technological breakthrough which would allow a rapid reduction in emissions. As noted by the Task Force on Climate-related Financial Disclosures (2017a, p.6) such new technologies may require old systems to be displaced, which could then disrupt parts of the economic system through a process of creative destruction. Lastly, energy transition risks may materialize in the short term if consumers, firms or financial markets suddenly change their expectations regarding future policies, technologies or other relevant factors. Even before any government action has been taken or a technological breakthrough has occurred, such a drop in confidence can cause large fluctuations in asset values.[3]

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[2] The European Systemic Risk Board (2016) explicitly warns of the financial stability risks of an abrupt energy transition.

[3] Cf. University of Cambridge Institute for Sustainability Leadership (2015); they describe how such a sentiment shift can be a trigger for transition risks.

Box 1.1 Climate policy in the Netherlands

This year, the parliament of the Netherlands proposed a climate law which targets a reduction in greenhouse gas emission emissions of 95 percent as compared to 1990 levels by 2050. As an intermediate step, the climate law aims to reduce emissions by 49 percent by 2030. The climate law further stipulates that by 2050, all energy generation in the Netherlands should be carbon-neutral in the sense that the net emissions should be zero. A group of (semi-)governmental and private organizations (the "Klimaattafels") is currently working on a proposal for concrete policy measures to achieve these goals. Potential measures include financial support for renewable energy, implementing a higher carbon price and converting residential real estate to reduce the dependence of households on natural gas.

Energy transition risks can affect financial institutions in the Netherlands through both their domestic and foreign exposures. Box 1.1 summarizes the current state-of-play with respect to climate policy in the Netherlands. However, the Paris Agreement is a multilateral agreement that aims to mobilize global action against climate change. This makes the transition to a low-carbon economy an international policy event. This is relevant for financial institutions in the Netherlands because their exposures are largely international.[4] Hence, it will be global political and technological developments, as well as consumer, firm and investor expectations regarding these global developments, that determine whether the transition to a low-carbon economy will be disruptive for the financial sector of the Netherlands.

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[4] Roughly about 50 percent of the exposures of Dutch banks and insurers is on foreign counterparties. For pension funds, 86 percent of the exposures are on foreign counterparties.

Previous research by DNB showed that the exposures of financial institutions in the Netherlands to energy transition risks could be sizable.[5] Previous work looked particularly at exposures of financial institutions in the Netherlands to industries with high CO_2 emissions. This study expands on this work by taking a macro-economic perspective beyond only high CO_2-emission industries, and by subjecting financial institutions' exposures to an energy transition risk stress test.

1.2 Energy transition risks and stress testing

Climate change and the transition to a low-carbon economy are subject to fundamental uncertainty. Predictions regarding the pace and extent of global warming vary widely (see, e.g., IPCC, 2014, p.60). In addition, it is uncertain to what extent the Paris Agreement will translate into concrete policy measures that support the transition to a low-carbon economy. Similarly, it is unknown how technologies will develop and how that development will impact the energy transition. Consequently, many different energy transition scenarios can be conceived of and their relative plausibility is difficult to gauge.

In light of this uncertainty, stress testing is a useful way to quantify energy transition risks. By focusing on scenarios that are "severe but plausible," a stress test is able to assess tail risks: the losses financial institutions may suffer in a type of worst-case scenarios.[6] By definition, the probability that a severe but plausible scenario will actually materialize is small.

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[5] See Schotten et al. (2016) and De Nederlandsche Bank (2017a).
[6] Cf. De Nederlandsche Bank (2017b).

The literature on stress testing energy transition risks displays a variety of possible methodologies. To date, a limited number of organizations has conducted a stress test of energy transition risk. In the banking sector there are some examples of stress tests of loan portfolios based on scenarios where the carbon price increases.[7] The University of Cambridge Institute for Sustainability Leadership (2015) combines macroeconomic simulations of energy transition scenarios with industry-specific risk factors to gauge the potential losses for investment portfolios. Thomä et al. (2017) analyze the exposures of Swiss asset managers to a selected set of industries that are vulnerable to energy transition risk, and consider how these industries may be affected under various energy transition scenarios. The Cambridge Centre for Sustainable Finance (2016) surveys fourteen case studies of individual financial institutions that have conducted stress tests, scenario analysis or related exercises with respect to climate-related risks. Battiston et al. (2017) assess the exposure of the EU financial system to energy transition risks by analyzing financial institutions' equity and bond exposures to selected industries that are considered particularly vulnerable to energy transition risk. In addition, a network analysis is used to gauge potential spillover effects between financial institutions in the case of a disruptive energy transition scenario. Lastly, the Task Force on Climate-related Financial Disclosures (2017b) provides a number of pointers to help firms to conduct their own scenario analysis for climate-related risks.

This study attempts to address several key challenges for energy transition stress tests. Campiglio et al. (2018) outline three main challenges for researchers and central banks with respect to the analysis of climate-related financial risks. First, sufficiently detailed data to study climate-related risks is not available. For our stress test, however, we were able to

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[7] See, for instance, BNP Paribas (2016) and ICBC (2016).

use detailed data on the bond and equity holdings (at the level of individual securities) of Dutch banks, insurers and pension funds, which allowed us to construct a detailed picture of the exposures to different industries. These data were further complemented by a survey of banks' corporate loan exposures disaggregated by risk classes and industries. Second, it is difficult to identify which assets are exposed to climate-related risks. We address this issue by calculating a transition risk vulnerability factor for each industry in the economy on the basis of its CO_2 emissions, with adjustments to reflect the risk factors in each specific scenario. This approach is based on an input-output analysis that is closely related to Hebbink et al. (2018). Third, an evaluation of climate-related risks requires the modelling of dynamic interactions between the macroeconomy, the financial system, climate change and environmental policies. In this study we take account of such interactions by first modelling the effects of environmental policies on the macroeconomy and then translating these effects into an impact on the financial system. The impact of policies on climate change itself is, however, beyond the scope of this study.

1.3 Overview of approach

The stress test is conducted by analyzing four severe but plausible energy transition scenarios. Given the uncertainty surrounding the transition to a low-carbon economy, various disruptive energy transition scenarios can be conceived of. We therefore consider four scenarios, which revolve around the two risk factors that emerge from the literature as the main drivers of energy transition risk: government policy and technological developments. In addition, we consider a drop in consumer and investor confidence in a scenario where the energy transition is postponed and technological breakthroughs are absent. Furthermore, the scenarios are defined in such a way that they materialize within five years, thus ensuring that the stress test results are relevant to financial institutions, decision makers and other stakeholders, today. Physical risks that may be brought about by climate change, such as floods, tornados and earthquakes, are not included in the scenarios. This allows us to isolate the potential losses that result from energy transition risks. Nonetheless, the impact of physical risks could be relevant for financial institutions. Previous work by DNB has estimated, for example, that flood risk could lead to several billion euros of losses for the financial system of the Netherlands (De Nederlandsche Bank, 2017a). The energy transition scenarios are described in detail in Chapter 2.

Each scenario is first translated into an impact on key macroeconomic variables and then disaggregated to a meso level (Figure 1.1). Defining a stress test scenario in terms of macroeconomic variables is standard practice in macroprudential stress testing. To translate each scenario into a set of macroeconomic impacts we used NiGEM, a multi-country macroeconometric model.[8] NiGEM and similar models are often used for scenario analysis by organizations and financial institutions, specifically when scenarios call for an international macroeconomic scope.[9]

Using a multi-country macroeconometric model provides several advantages. First, using a macroeconometric model allows us to simulate a mutually consistent set of macroeconomic impacts that can serve as input to our top-down stress test models. Second, using a multi-country model allows us to take account of the fact that energy transition risks can have global impacts. Given the international exposures of financial institutions in the Netherlands, global simulations are more relevant than simulations from a model that considers only the Dutch economy. Macroeconometric

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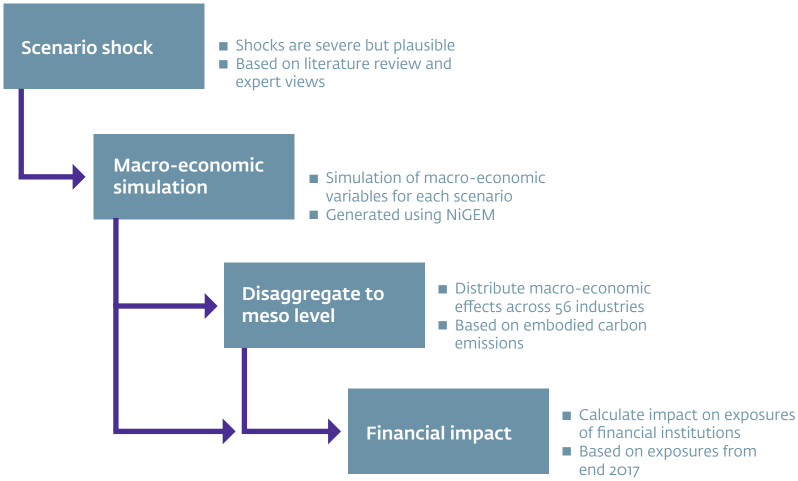
[8] Details on NiGEM are available at https://nimodel.niesr.ac.uk.

[9] Many climate science researchers use Integrated Assessment Models (IAMs) to model economic effects, but these typically contain less detail with respect to the variables that are relevant for stress testing. See Nordhaus (2017) for a description of climate change IAMs.

Figure 1.1 Overview of approach in steps



models such as NiGEM also have limitations. In particular, they are not really designed to simulate the type of structural economic shifts that may follow from the transition to a low-carbon economy. These models generally assume that economic relationships are stable over time and use estimated coefficients, which are based on historical data.

The stress test discriminates between exposures to 56 industries based on each industry's relative vulnerability to energy transition risks. Intuitively, energy transition risks will be more impactful for industries that rely heavily on fossil fuels. Hence, financial institutions may be more or less vulnerable to energy transition risks depending on their exposure to more or less vulnerable industries.[10] In this study, this effect is captured by calculating

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[10] Cf. Schotten et al. (2016), Battiston et al. (2016), De Nederlandsche Bank (2017a) and Thomä et al. (2017).

a transition vulnerability factor for each industry. This transition vulnerability factor is based on the amount of CO_2 emitted to produce the final goods and services of each industry. It takes into account both each industry's own emissions and the emissions of its suppliers, yielding so-called "embodied CO_2 emissions".[11] Since the risk channels are different in each scenario, the transition vulnerability factors vary across the scenarios as well. The total impact on financial institutions' exposures thus depends on the combined effect of the macroeconomic impact in each scenario and the industry-specific vulnerability factors. Chapter 3 presents the vulnerability factors for each industry.

The impact of each scenario on Dutch financial institutions is calculated using data of slightly more than half of the total aggregate exposures of Dutch banks, insurers and pension funds. DNB has access to detailed information on the securities holdings of financial institutions in the Netherlands through its Securities Holdings Statistics. Based on this information we were able to construct a database of the majority of the equity and bond exposures of Dutch banks, insurers and pension funds, classified according to the industry of the issuer. In addition, we have conducted a targeted survey of the corporate loan exposures of the largest Dutch banks (ABN AMRO, ING Bank and Rabobank), which contains detailed information on the probability of default, loss given default, maturity and industry classification. Note that this stress test does not take mortgage or commercial real estate exposures into account. Although energy transition risks could affect property values and thus real estate exposures, significant data gaps in measuring the energy efficiency of real estate prevent us from properly accounting for these risks. We therefore exclude these exposures

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[11] See, e.g., Wiebe and Yamano (2016) and Owen (2017) for an overview of methodologies for calculating embodied CO_2 emissions. Firm level emissions as used by e.g. Boermans and Galema (2017) to study Dutch pension funds' carbon footprint provide more detail at the firm level, but are not able to capture all emissions in the production chain.

from the stress test. For all exposures, the reporting date is December 31st, 2017. The industries classifications are based on double-digit NACE Rev. 2 definitions.[12]

Stress testing energy transition risks is a relatively new field of study and as such the results of this stress test should be interpreted carefully. As stress testing energy transition risks is novel terrain, this study necessarily has limitations. This stress test should be seen, therefore, as a first attempt to gauge the potential financial stability impact of a disruptive energy transition for the Netherlands, to be refined as methodologies develop and more data becomes available.

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[12] Details on NACE Rev. 2 can be found at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Statistical_classification_of_economic_activities_in_the_European_Community_(NACE).

2 Four scenarios

In this stress test we analyze four global scenarios in which the energy transition is disruptive, meaning that the transition creates short-run economic losses. The economic losses are brought about by policy measures, technological breakthroughs, or a drop in consumer and investor confidence.

Two factors emerge from the literature as the main drivers of energy transition risk: (1) the abrupt implementation of stringent policy measures that aim to mitigate the adverse impact of climate change, and (2) technological breakthroughs that lower CO_2 emissions but also disrupt parts of the economic system through a process of creative destruction.[13] The four scenarios in this study center around these two factors, including one scenario where the absence of both factors triggers a drop in the confidence of consumers, businesses and investors. The key assumptions of each scenario are summarized in Figure 2.1. The probability that the stress test scenarios will materialize in practice is small, as they are designed to represent tail risks. The scenarios have been discussed with experts to obtain a good sense of the plausibility of each scenario.[14]

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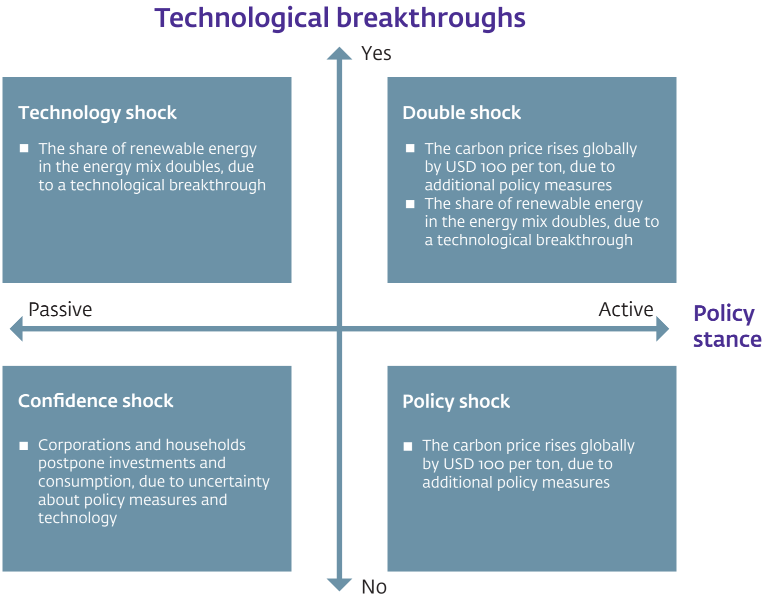
[13] Cf. the European Systemic Risk Board (2016, p.4) and the Task Force on Climate-related Financial Disclosures (2017a, pp.5-6). The latter also lists legal, market and reputation risks as potential transition risks. In our study, legal risks are grouped in with policy risks and market risk is used as a risk driver in the confidence shock scenario. Reputation risk is left out of scope here.

[14] Discussants included experts from the Netherlands Environmental Assessment Agency (PBL), the University of Cambridge Institute for Sustainability Leadership and Utrecht University.

Figure 2.1 Four disruptive energy transition scenarios



Technology shock

- The share of renewable energy in the energy mix doubles, due to a technological breakthrough

Double shock

- The carbon price rises globally by USD 100 per ton, due to additional policy measures
- The share of renewable energy in the energy mix doubles, due to a technological breakthrough

Confidence shock

- Corporations and households postpone investments and consumption, due to uncertainty about policy measures and technology

Policy shock

- The carbon price rises globally by USD 100 per ton, due to additional policy measures

Reflecting the fact that both energy transition risks and Dutch financial institutions' exposures are international in nature, the scenarios are defined with a global scope. This means that we assume policy actions to be globally coordinated and technological breakthroughs to be globally accessible. The scenarios are furthermore defined in such a way that they could plausibly materialize in the short-term, thus ensuring immediate relevance of the stress test results to financial institutions, decision makers and other stakeholders. The short-term focus is also reflected in the scenario timeframe, which spans five years. A detailed description of each scenario follows below.[15]

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[15] The full NiGEM scenario simulations are included in the web-appendix: https://www.dnb.nl/binaries/Web-Appendix%20-%20Transition%20risk%20stress%20test%20versie%202018-10-08%20voor%20web_tcm46-379400.pdf.

2.1 The policy shock scenario

In the policy shock scenario, a set of policies designed to reduce CO_2 emissions is abruptly implemented, leading to a large increase in the carbon price. An important policy instrument to support the reduction in CO_2 emissions is to price these (either directly or through a trading scheme).[16] There are, however, also other ways in which emissions can be made relatively more expensive. For example, subsidies on the use of low-emission technologies could increase the opportunity cost of emissions, and taxes or restrictions (such as performance standards) on high-emission technologies could further drive up the effective price of carbon emissions.[17] In this scenario it is assumed that a set of policies pushes the effective global carbon price up by USD 100 per ton of CO_2 emissions. The resulting cost increase leads to a general economic slowdown, while interest rates rise as the central bank attempts to curb inflation.

Although policy makers will generally aim to implement climate policies in a gradual and predictable manner, an abrupt implementation of policies can be triggered in various ways. Policy makers are typically reluctant to cause severe short-term economic disruptions. As this is a stress test, however, the interest here lies precisely in scenarios where abrupt disruptions do occur. Examples of triggers that could bring about the abrupt implementation of impactful policies are:

- **Materialization of physical climate risks increasing the sense of urgency to take action against climate change.** Environmental risks can have a profound influence on public sentiment and in policy. In the Netherlands, for example, the production of natural gas in the Groningen province is causing earthquakes, prompting the government to phase

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[16] Cf. Stern (2008), IPCC (2014).

[17] Presently, a number of policies exist that lead to an effective carbon price. In the European Union, firms can trade emissions rights within the European Emissions trading scheme (ETS). The current price within the ETS is roughly EUR 25 per ton of CO_2-emissions.

out natural gas production by 2030. Climate change can also invoke environmental risks on a large scale, so-called physical risks (IPCC, 2014). If such risks materialize, the impact on public sentiment can reach far beyond the affected region. Consider, for example, when Japan was hit by a tsunami in 2011, which caused a subsequent nuclear disaster in Fukushima. Related in part to this event, the German government abruptly decided to phase out its own nuclear power. Similarly, if a natural disaster occurs that is perceived to be a direct consequence of climate change, it may well prompt an abrupt implementation of stringent climate policies.

- **Legal action against governments forcing governments to take action.** Governments worldwide are increasingly facing lawsuits for taking insufficient action against climate change.[18] Notably, a court ruling in the Netherlands in 2015 established that the government of the Netherlands has to step up its efforts in limiting greenhouse gas emissions.[19]
- **The realization that "time is running out" could lead to a strong reaction by governments.** Delaying mitigation action today is associated with sharper emission reduction efforts in the future (IPCC, 2014, p.23). Moreover, the belief as to what is needed in terms of policy actions evolves continuously as new scientific evidence is brought to light. Consequently, policy makers may suddenly realize that much more policy action is needed. For example, if technologies that support a reduction in emissions cannot be deployed as expected, the cost of climate change mitigation can increases significantly (IPCC, 2014, p.23). This could be the

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[18] Currently, the number of cases related to climate change is around 900 globally (retrieved from http://climatecasechart.com/search/ on 27 September 2018).

[19] https://www.rechtspraak.nl/Uitspraken-en-nieuws/Bekende- cyclones in the North Atlantic has increased since the 1970s".rechtszaken/klimaatzaak-urgenda. This case is currently being challenged in the Court of Appeal of The Hague.

case if, say, Carbon Capture and Storage (CCS) technology will not be deployable on a large scale.[20]

A carbon price increase by USD 100 per ton of CO_2 emissions is severe, but not implausible. The High-Level Commission on Carbon Prices (HLCCP, 2017) recommends the implementation of a carbon price in the range of 40 to 80 dollars per ton of CO_2 emitted by 2020. This range is consistent with some of the carbon prices that firms already use internally as part of their business planning and considerably higher than the current ETS price of about 25 euros.[21] As this scenario represents a severe case, the price on emissions should, at a minimum, be at the higher end of this range. Moreover, as the scenario considers an effective price (rather than merely a direct price) on emissions, the price in this scenario can plausibly be higher than the upper bound suggested by the HLCCP.[22] The price increase of USD 100 per ton of CO_2 emissions captures, in our view, a severe but plausible case. Table 2.1 presents an overview of carbon prices used in other energy transition risk stress tests for comparison.

The macroeconomic impacts of this scenario are modelled by imposing a shock on fossil fuel prices in NiGEM in a manner that is consistent with a carbon price increase of USD 100 per ton of emissions. NiGEM contains separate prices for the fossil fuels coal, oil and natural gas. Assuming a price increase of USD 100 per ton of emissions, we calculate the CO_2 cost per (burnt) barrel of oil and its equivalents for coal and natural gas. This cost is then added to the current price of each fossil fuel in NiGEM. As coal is both

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[20] CCS installations are often met with public resistance, which has already led to the postponement and cancellation of several CCS projects, including in the Netherlands (GCCSI, 2009). Moreover, there is uncertainty whether Bioenergy with CCS can in practice be widely used on a large scale (IPCC, 2014, p.81).

[21] See CDP (2017) for a survey of internal carbon prices.

[22] Formal climate models such as Limits-450 and EMF 27 display a wide range of possible carbon prices (roughly USD 0 - USD 500 per ton of CO_2 emissions by 2020) that could be consistent with the objectives in the Paris Agreement, depending on the assumptions in a particular model.

the cheapest and most polluting fuel, it receives the largest relative price increase (870%), while oil and gas receive milder shocks (80% and 58%, respectively).[23]

Table 2.1 Carbon prices in energy transition stress tests

	Carbon price	Timing
BNP Paribas (2016)	50-75 USD/tCO_2	By 2025
University of Cambridge Institute for Sustainability Leadership (2015)	100 USD/tCO_2	2015-2020
Optrust/Mercer (2017)	40 USD/tCO_2	By 2020

In terms of the macroeconomic impact, this scenario yields lower GDP growth, higher inflation, a decrease in stock prices and higher interest rates. Higher energy costs increase the cost of production, resulting in lower profitability. This in turn brings down investment and equity prices. Firms increase the prices they charge to consumers, which causes household disposable income to decrease and therewith lowers consumption. The combination of less consumption and fewer investments leads to a GDP decrease. The increase in the price level leads the central bank to tighten the monetary policy stance, while higher inflation expectations lead to higher long-term interest rates. On the whole, the short-term economic effects in this scenario bear a resemblance to the 1970s stagflation episode. However, in the current scenario the economy already begins to recover within the five-year horizon of the scenario because inflation pressures decrease and interest rates start to return to baseline values, which increases demand.

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[23] The CO_2 emissions from burning a barrel of oil or an oil-barrel equivalent of coal and gas are 432 kilograms, 653 kilograms and 316 kilograms, respectively. Hence, the price of oil increases by USD 43.20 (from a baseline level of USD 59.10), and the prices of an oil-barrel equivalent of coal and gas increase by USD 65.20 (baseline USD 8.27) and USD 31.60 (baseline USD 59.56), respectively.

Box 2.1 The policy shock scenario at a glance

Policy stance: active | Technological breakthroughs: no

What: Sudden implementation of a set of policies that aim to reduce CO_2 emissions leading to an increase in the effective carbon price of USD 100 per ton.

Why: Policy makers are pressured into taking abrupt, stringent measures against climate change, triggered by, for example, (i) a natural disaster, (ii) legal action holding policy makers accountable for climate change, or (iii) a strong reaction by policy makers in response to the realization that the time to act is running out.

How: The carbon price is modelled as a shock on prices of coal, oil, and gas.

Macroeconomic impact (relative to baseline level)

Year	GDP (level)	HICP (level)	10Y interest rate (level)	Global stock price index (level)
1	-1.3%	+2.1%	+1.0 p.p.	-5.3%
2	-3.2%	+2.3%	+0.6 p.p.	-5.4%
3	-2.8%	+2.2%	-0.0 p.p.	-2.6%
4	-1.3%	+2.7%	-0.2 p.p.	-0.8%
5	-0.5%	+3.5%	-0.0 p.p.	-0.3%

Numbers refer to the Netherlands, with the exception of the global stock price index.

Effects stemming from tax policy and government spending in case the increase in the carbon price is achieved by means of a carbon tax, are left out of scope in this study. If the increase in the carbon price in this scenario would be a result of carbon taxes, the macroeconomic impact could potentially be made less severe by returning carbon tax revenues to households and firms. Policy makers can potentially mitigate the adverse macroeconomic consequences of an increase in the carbon price by returning the receipts, either by reducing non-carbon taxes or by increasing government subsidies (e.g., to renewable energy industries). The effects on GDP, inflation and interest rates will differ depending on how the carbon tax receipts are returned to the economy.

2.2 The technology shock scenario

In the technology shock scenario, unanticipated technological breakthroughs allow the share of renewable energy in the energy mix to double in five years. The share of renewables in the energy mix is expected to grow,[24] but currently technological bottlenecks in the generation and especially the storage of renewable energy constrain the potential. In this scenario, technological breakthroughs help to lift these bottlenecks, giving way to a steep decline in the cost of renewable energy (Figure 2.2) and allowing the share of renewable energy to double in five years already. As a result, production becomes less fossil fuel intensive. In addition, the new technologies spark a process of creative destruction whereby old, fossil-fuel dependent technologies are gradually replaced by “clean” alternatives. Concretely, this means that a large chunk of equipment used to mine and process fossil fuels will be written off and, additionally, equipment that requires fossil fuels as an input (e.g., combustion engines) will to some

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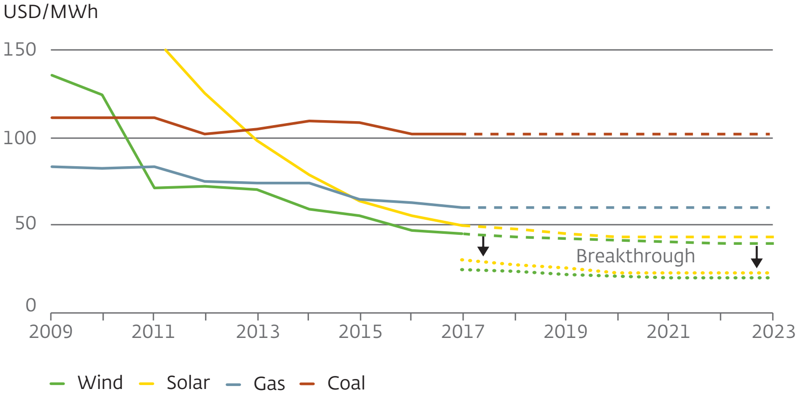
[24] In 2015, the share of renewable energy in the energy mix was 19 percent. Most energy experts believe that by 2050, that share will be more than 50% (REN21, 2017, p.32).

Figure 2.2 Historical levelized cost of energy estimates and the effect of a technological breakthrough



Notes: The levelized cost of energy (LCOE) is defined as the net present value of the unit-cost of electricity over the lifetime of an energy-generating asset (e.g., a windmill or a coal plant). It includes initial investment costs, as well as the cost of capital and the cost of operations and maintenance. In the graph, solid lines show actual (unsubsidized) cost estimates (Lazard, 2018); bar-lines show cost projections, loosely based on International Energy Agency (2016); dotted lines illustrate (hypothetically) the effect of a technological breakthrough.

extent be replaced by equipment that can take advantage of the cheaper energy (e.g., batteries). The lower cost of energy, which is assumed to be accessible worldwide, increases the potential output of the economy. In the short run, however, losses for fossil fuel producers and adjustment costs incurred by firms that need to replace equipment lead to an economic slowdown. Only once the economy has fully incorporated the new technology will a higher GDP level be achieved.

Against the background of record-breaking expenditures on the production and storage of renewable energy, short-term technological breakthroughs seem conceivable. Global new investment in renewable energy generation is at all-time highs, with approximately USD 300 bn invested in 2017 (International Energy Agency, 2018). Expenditures on relevant R&D are also high, with worldwide public spending on low-carbon energy R&D passing USD 20 billion in 2017 (low-carbon energy technologies now account for 80% of total public R&D, p.193). In addition, the investments seem to be paying off. Wind and solar energy, for example, are in some places already able to compete with traditional energy sources without government subsidies (Lazard, 2017). Indeed, the International Energy Agency (2017) predicts that wind power will likely be the primary source of electricity in the EU by the 2030s, and Creutzig et al. (2017) even predict that by then, half of all global energy production might come from renewable sources. For the Netherlands, Schoots et al. (2017, pp. 82-83) predict that the share of renewable energy will more than double in the period up to 2020.

An important driver of the possibility to use renewable energy is the ability to store it. A growing amount of investment is geared towards energy storage. Electrochemical (i.e. battery) storage, in particular, has received a lot of new investment as electric vehicles are rapidly growing more popular.[25] In fact, the sudden popularity of electric vehicles demonstrates how changing consumer preferences can have a profound influence on energy markets. According to BNEF (2017), the costs of battery storage will fall by more than 50% in the next decade, and D'Aprile et al. (2016) think that the cost of energy storage might already half by 2020.

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[25] The share of investment in electrochemical storage relative to other types of electricity storage has risen from around 5% in 2013 to nearly 30% in 2017 (International Energy Agency, 2018, p.65).

The macroeconomic effects of the technological breakthrough are modelled by increasing the share of renewable energy and writing-off part of the existing capital stock. The economy's production function in NiGEM contains energy use in addition to capital and labor, but energy use is not explicitly split between renewables and non-renewables. We therefore approximate the technological breakthrough by adjusting the production function such that the amount of fossil fuels that is needed to produce a unit of output gradually falls by up to 25 percent during the five year scenario horizon. This adjustment should be interpreted as being equivalent to a doubling of the share of renewable energy in the global energy mix. As the demand for fossil fuels falls in this scenario, fossil fuel prices decrease. In addition, the technological breakthrough sparks a process of creative destruction, which leads to write-offs on existing assets. Specifically, 6 percent of the capital stock is written off in the first year and 4 percent in the second year.[26]

In terms of the macroeconomic impact, this scenario yields short-term losses but medium-term gains. Higher investment demand initially boosts GDP, but by the end of the second year, GDP growth slows down due to the capital stock write-offs that result from creative destruction and a reallocation of production factors in the economy. At the same time, potential output increases because energy has become cheaper, and this gradually pushes up GDP growth. Because of this, GDP is up (relative to the benchmark) by the end of the fourth year. The stock market initially suffers as firms that rely on old technologies face write-offs, but after a few years

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[26] The magnitude of the shock is calibrated on the basis of the current share of capital goods used in a number of fossil fuel-intensive industries in the US (mining, utilities and oil refining). According to the Bureau of Economic Analysis, this share is around 15 percent of the total capital stock. We assume that some 40 percent of these capital goods need to be written-off. Furthermore, since the technological breakthrough has an impact across the economy, we assume that a further 5 percent of the remaining capital stock (i.e. 85 percent of the total) needs to be written off as well. In sum, 10 percent of the total capital stock will be written-off.

Box 2.2 The technology shock scenario at a glance

Policy stance: Passive | Technological breakthroughs: yes

What: Unanticipated technological breakthroughs allow the share of renewable energy in the energy mix to double in five years.

Why: Investment in the R&D of renewable energy generation and storage is higher than ever, boosting the share of renewable energy in the energy mix and creating the potential for technological breakthroughs.

How: Technological breakthroughs in the generation and storage of renewable energy are assumed to alter the economy's production function, making energy cheaper and less fossil fuel intensive. The new technology sparks a process of creative destruction whereby old, fossil-fuel dependent technologies are gradually replaced by "clean" alternatives, thus resulting initially in capital stock write-offs.

Macroeconomic impact (relative to baseline level)

Year	GDP (level)	HICP (level)	10Y interest rate (level)	Global stock price index (level)
1	+1.6%	+0.2%	+0.2 p.p.	-2.8%
2	-0.3%	+0.1%	+0.1 p.p.	-2.5%
3	-1.0%	-0.6%	-0.4 p.p.	+0.5%
4	+0.8%	-1.3%	-0.7 p.p.	+0.3%
5	+2.0%	-1.5%	-0.6 p.p.	-1.4%

Numbers refer to the Netherlands, with the exception of the global stock price index.

it benefits from the increase in GDP. Interest rates do not react strongly in this scenario. Initially, they increase somewhat due to the higher demand for capital goods and higher inflation. Interest rates then fall, however, as energy costs decrease, which drives prices down.

2.3 The double shock scenario

In the double shock scenario, strong climate change mitigation policies are abruptly implemented while simultaneous unanticipated technological breakthroughs allow the share of renewable energy in the energy mix to grow faster than expected. This is a combination of the policy and technology shock scenarios, which means that the carbon price increases by USD 100 per ton while at the same time, the cost of energy falls and a process of creative destruction takes place.

The double shock scenario is especially plausible if climate change mitigation policies and progress in renewable energy technology are mutually reinforcing. In *The Theory of Wages*, John Hicks (1932) argues that changes in the relative prices of production inputs can redirect research and development efforts and thereby have an influence on innovation. The implementation of a carbon tax, for example, may induce producers to invest in less carbon-intensive technologies. It is in fact partially because of this effect that the OECD (2016, p.33) calls carbon pricing “an effective policy.” Similarly, innovation may have an effect on policies; when innovation reduces the economic impact of policies that increase the cost of CO_2 emissions, such policies will become more politically attractive.

The empirical evidence for the mutually reinforcing relationship between policy and innovation is mixed. A survey conducted by Kemp and Pontoglio (2011) reveals that the effect of climate policy on green innovation depends heavily on the specific features of the policy measure. A possible explanation for this is given by Acemoglu et al. (2012), who show that the effect of a carbon tax on innovation is driven by the relative substitutability of carbon-intensive and carbon-neutral technologies. There is also some evidence that a carbon tax may actually be detrimental to innovation, as it may reduce the amount of funds available for research and development. For the purpose of this stress test we do not take an explicit stance on this debate. In fact, we will assume that both policy and innovation occur simultaneously and independently of one another.

Box 2.3 The double shock scenario at a glance

Policy stance: Active | Technological breakthroughs: yes
What: Strong climate change mitigation policies are abruptly implemented while simultaneous unanticipated technological breakthroughs allow the share of renewable energy in the energy mix to grow faster than expected.
Why: Climate change mitigation policies and progress in renewable energy technology turn out to be mutually reinforcing. In particular, policy measures that increase the cost of traditional energy technologies stimulate innovation, and/ or innovations in energy technology inspire the implementation of policy measures.
How: The carbon price increases by USD 100 per ton of CO_2 emissions and simultaneously technological breakthroughs in the generation and storage of renewable energy decrease the costs of energy production. The new technology sparks a process of creative destruction whereby old, fossil-fuel dependent technologies are gradually replaced by "clean" alternatives, thus resulting initially in capital stock write-offs.

Macroeconomic impact (relative to baseline level)

Year	GDP (level)	HICP (level)	10Y interest rate (level)	Global stock price index (level)
1	+0.4%	+2.3%	+1.3 p.p.	-8.0%
2	-3.5%	+2.5%	+0.7 p.p.	-8.4%
3	-4.0%	+1.9%	-0.3 p.p.	-3.3%
4	-1.1%	+1.8%	-0.7 p.p.	-1.8%
5	+0.9%	+2.5%	-0.5 p.p.	-2.8%

Numbers refer to the Netherlands, with the exception of the global stock price index.

In terms of the macroeconomic impact, this scenario combines the impacts of the policy and technology shock scenarios. As in the technology shock scenario, higher investment demand initially boosts GDP. GDP then rapidly starts to fall, however, due to the combined effect of higher fossil fuel prices and capital stock write-offs. The economy starts recovering by the end of the fourth year as it begins to reap the benefits of lower energy prices, leading to an increase in GDP by the end of the fifth year. Lower energy prices also dominate the effect on interest rates, which are below their benchmark levels for most of the five year period. Stock prices initially decrease, but exhibit some volatility during the five year period. This volatility can be explained by the adjustment process the economy faces following the double shock.

2.4 The confidence shock scenario

In the confidence shock scenario, uncertainty regarding government policies to combat climate change causes a sudden drop in the confidence of consumers, producers and investors. Although the Paris Agreement has been ratified by almost 200 countries, it remains uncertain whether it will actually translate into concrete policy measures that support the transition to a low-carbon economy. In this scenario, it is assumed that policy uncertainty triggers a sudden drop in confidence, such that consumers delay their purchases, producers invest more cautiously and investors demand higher risk premiums. As a result, there is a setback in GDP, stock prices fall and lower inflation leads to lower interest rates.

A confidence shock is conceivable against the background of a growing discrepancy between international ambitions to combat climate change and the actual progress to date. According to Climate Action Tracker, only a handful of countries worldwide are on track to meet the climate goals set out in the Paris Agreement.[27] The Federal Government of the United States has even decided to withdraw from the Paris Agreement, potentially delaying progress with regard to climate ambitions further.[28] There are several reasons why this discrepancy between ambition and practice is likely to enhance uncertainty among consumers, producers and investors:

- **If policy action is delayed, the risk that drastic policy measures need to be implemented in the future increases.** Risks from climate change are driven by cumulative greenhouse gas emissions. Hence, if we emit more today, a larger future reduction in emissions will be necessary to combat climate change. This means that if policy makers postpone action

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[27] https://climateactiontracker.org, accessed on 27 September 2018.

[28] A number of individual U.S. states have stated that, notwithstanding a withdrawal from the Paris Agreement by the Federal Government, they intend to uphold the Paris Agreement. Detailed information can be found on https://www.usclimatealliance.org/.

now, there will likely be a need for sudden and drastic policy measures later on. According to the European Systemic Risk Board (2016), such a scenario would lead to constrained energy supply and increased costs of production for the whole economy, resulting in an impact similar to "a large and persistent negative macroeconomic shock" (p.9).

- **Policy uncertainty may deter technological development.** Policies can support the development of low-carbon technologies. Either directly through subsidies, or indirectly by making CO_2 emissions more costly. Policy uncertainty, on the other hand, can deter investment in low-carbon technologies.[29] In fact, some authors (such as Fuss et al., 2009) have claimed that uncertainty over the carbon price has already slowed down the transition to less fossil fuel-intensive technologies.
- **If policy action is insufficient, the world will be exposed to the adverse consequences of climate change, i.e. physical risks.** According to IPCC (2014, pp.65-73), key risks from climate change include (i) bodily harm and disrupted livelihoods due to storm surges, sea level rise, flooding and extreme heat; (ii) breakdown of infrastructure and critical services due to extreme weather events; (iii) food and water insecurity; (iv) loss of ecosystems and biodiversity. Clearly, the economic consequences of such a scenario could be very severe. Note that potential losses resulting from physical risks are not in scope of this stress test.

The short-term macroeconomic consequences of this scenario are modelled as a drop in consumption and an increase in the cost of capital for businesses and the risk premium demanded by investors. A drop in confidence can lead consumers to delay their spending and increase their precautionary savings, especially with regards to durable goods (see, e.g.,

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[29] Several authors have researched the effect of policy uncertainty on investment, e.g., Barradale (2010) and Kang et al. (2014).

Box 2.4 The confidence shock scenario at a glance

Policy stance: passive | Technological breakthroughs: no

What: Uncertainty regarding government policies to combat climate change triggers a drop in the confidence of consumers, producers and investors.

Why: The discrepancy between international ambitions to combat climate change and the actual progress to date is growing, increasing the risk of (i) abrupt and drastic policy interventions, (ii) slow technological development and (iii) physical climate risks.

How: Consumers delay their purchases, businesses invest more cautiously and investors demand higher risk premiums.

Macroeconomic impact (relative to baseline level)

Year	GDP (level)	HICP (level)	10Y interest rate (level)	Global stock price index (level)
1	-1.4%	-0.1%	-0.0 p.p.	-11.3%
2	-2.7%	-0.8%	-0.0 p.p.	-3.7%
3	-2.3%	-1.8%	-0.4 p.p.	+0.8%
4	-1.4%	-2.4%	-0.8 p.p.	+0.8%
5	-0.6%	-2.7%	-1.1 p.p.	-0.9%

Numbers refer to the Netherlands, with the exception of the global stock price index.

Bloom, 2014, and Bansal and Yaron, 2004). As consumer confidence is not a variable in NiGEM, this effect is modelled by negative consumption shocks which amount to 1 percentage point per year relative to the baseline during the five year horizon. Similarly, the drop in producer confidence will lead to lower investment by businesses.[30] This business conservatism is modeled by increasing the cost of capital for firms by 1 percentage point relative to the baseline. Lastly, it is assumed that financial markets become more risk averse and thus demand a higher compensation for risk. This effect is modelled by increasing the equity risk premium by 1 percentage point.

In terms of the macroeconomic impact, this scenario yields relatively large losses. The shocks to consumer demand and corporate investment lead to a drop in GDP and stock prices. GDP and stock prices gradually recover over the scenario horizon of five years, although GDP remains below baseline by the end of the five year period.[31] The initial economic setback creates deflationary pressures, which leads to lower interest rates.

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[30] See Stokey (2016) for an analysis of the effects of policy uncertainty on investment.

[31] Note that we assume that no further shocks hit the economy during the five year period. Arguably, this is a conservative assumption as further confidence shocks may arise if there are no technological breakthroughs and government policy remains passive.

3 Transition vulnerability factors

The transition to a low-carbon economy is likely to affect industries that emit a lot of CO_2 more than industries that emit little. To capture this heterogeneity between industries, a transition vulnerability factor is determined for each industry in the economy. The transition vulnerability factors vary by scenario to reflect the different risk factors that are at play, and allow us to translate the macroeconomic conditions in each scenario to industry-specific losses.

To determine the transition vulnerability of each industry, this study exploits insights from an input-output analysis that is closely related to the approach used in Hebbink et al. (2018). The input-output table provides insight into each industry's suppliers and customers and the total CO_2 emitted in the production process.[32] This allows us to calculate the embodied CO_2 emissions in the final goods and services of each industry. The transition vulnerability factors reflect these embodied CO_2 emissions, such that an industry which sells products that contain twice as much CO_2 as the economy average, will be hit twice as hard.

3.1 Constructing the transition vulnerability factors

Our method for constructing the transition vulnerability factors is derived from the Capital Asset Pricing Model (CAPM). In CAPM, each stock's return is determined by a stock specific excess return and loading on the excess market return, where the excess market return is given by the gross market return minus the risk free interest rate.[33] The loading on the excess market return is typically represented by a *beta* (β) and implies that,

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[32] To be consistent with the scenario storylines, the transition vulnerability factors are based on CO_2 emissions rather than all greenhouse gas emissions. Taking all greenhouse gas emissions into account would result in a significantly higher vulnerability factor for the agricultural sector as it emits a lot of methane, but it does not significantly alter the final results of the stress test.

[33] Fama and French (2004) provide an overview of the theory and evidence regarding CAPM.

if the excess market return is X, the return of a particular stock (R) can be calculated as $R = a + \beta * X$ (where α is the stock specific excess return). The transition vulnerability factors are similar to the *betas* in CAPM in the sense that they determine a stock specific return given a certain excess market return. However, whereas the *betas* in CAPM capture a relationship between a stock and its market risk, the transition vulnerability factors in this stress test capture a relationship between a stock and its energy transition risk. Consider the example of the policy shock scenario, which is modeled as an increase in the effective carbon price by USD 100 per ton of CO_2 emissions. The transition vulnerability factors and excess market return in that scenario then jointly determine how the equity of a firm in a given industry is affected as a result of the carbon price increase.[34]

The transition vulnerability factors are based on the embodied emissions of the final goods and services in each industry. Embodied emissions account not only for the emissions by the producer of the final goods and services, but also for emissions by firms upstream in the value chain (Figure 3.1). Thus, by using embodied CO_2 emissions as the basis for the transition vulnerability factors, industries with final goods and services that require a lot of CO_2 emissions in the production process will be hit harder in the stress test. To transform the embodied CO_2 emissions into transition vulnerability factors, the embodied CO_2 of the final goods and services of a particular industry is weighted by the share of those final goods and services in the GDP of the economy. This weighted embodied CO_2 is then normalized, such that the weighted average transition vulnerability factor for the global economy is equal to 1, which ensures that the transition vulnerability factors

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[34] A similar approach is used by the University of Cambridge Institute for Sustainability Leadership (2015). Instead of on CO_2 emissions, however, they base the transition vulnerability factors (or *betas*) on the historical volatilities between industry returns and the market return, adjusted by a risk factor that depends on the geographical location of a firm.

Figure 3.1 Embodied CO_2 emissions per car

Total CO_2 emission
to produce 1 car
17 ton

=

0.7 ton	Car production

+

6.3 ton	Metal production
4.3 ton	Utilities
2.8 ton	Other industries
2.4 ton	Rubber & plastic
0.5 ton	Transport

Notes: Numbers are fictional and for illustrative purposes only.

are consistent with the aggregate stock market return in each scenario (assuming that the composition of the stock market index matches the industry composition in the real economy). The web-appendix provides technical details.

The transition vulnerability factors vary across scenarios to reflect the particular risk factors that are at play in each scenario. The transition vulnerability factors for each scenario are calculated as follows:

- **Policy shock:** As the policy shock scenario revolves around an increase in the carbon price, the transition vulnerability factors for this scenario reflect the fact that industries producing goods and services that require more emissions will be more vulnerable to the carbon price increase. The transition vulnerability factors for this scenario are therefore calculated on the basis of all embodied CO_2 emissions in the final goods and services of each industry.
- **Technology shock:** In the technology shock scenario, industries face costs as a result of a process of creative destruction. We assume that these costs are higher for industries that produce final goods and services which have a more carbon-intensive production process (e.g. steel production) and lower for industries which rely on electricity for their energy use (e.g. telecommunications). This "creative destruction effect" can be approximated with the transition vulnerability factors from the policy shock scenario, as in both scenarios losses are likely to become larger when the amount of embodied CO_2 emissions in the final goods and services of an industry increase. However, the technology shock scenario yields additional costs for industries that mine and process fossil fuels, because fossil fuels are assumed to lose market share to renewables. To capture this additional "substitution effect," we perform a correction on the transition vulnerability factors from the policy shock scenario. Specifically, we allocate the CO_2 emissions that have been

emitted by energy producers to produce energy that is used in the production process of other industries to three industries that mine and process fossil fuels: 50 percent of these emissions are allocated to the mining industry and 25 percent to both the petrochemical industry and utilities industry. In the context of the example in Figure 3.1 this would mean that the embodied CO_2 emissions per car would decrease by 4.3 tons. In general, the embodied CO_2 emissions of industries that mine and process fossil fuels increase, while the embodied CO_2 emissions of industries that consume energy from the energy producers decrease. As a result, industries that mine and process fossil fuels receive higher transition vulnerability factors than other industries in this scenario.

- **Double shock:** In the double shock scenario, the shocks from the policy and technology shock scenarios occur simultaneously. Due to this combination of shocks, losses in this scenario are higher than in the policy or technology shock scenario alone. The distribution of these losses, however, is likely to be identical to the distribution of losses in the technology shock scenario. Consider the transition vulnerability factors from the technology shock scenario, which account for both a creative destruction and a substitution effect. These transition vulnerability factors rank industries according to the embodied CO_2 emissions in their final goods and services, with an additional penalty for industries that mine and process fossil fuels. In the double shock scenario, the losses that industries face due to the technology shock are augmented further by an increase in the carbon price of USD 100 per ton of CO_2 emissions. This carbon price increase will affect industries more as the amount of embodied CO_2 emissions in the final goods and services of an industry is higher, which thus amplifies the creative destruction effect. In addition, the carbon price increase makes renewables a more attractive source of energy, which amplifies the aforementioned substitution effect. Taking these effects together, the distribution of losses in the double shock scenario is likely to be roughly similar to the distribution of losses in the technology shock scenario. We therefore use the same transition vulnerability factors in both.

- **Confidence shock:** In the confidence shock scenario, policy uncertainty triggers a general decline in consumption and investment. We assume that this general economic slowdown affects all industries equally. This implies that the transition vulnerability factor for every industry is equal to 1 in this scenario.

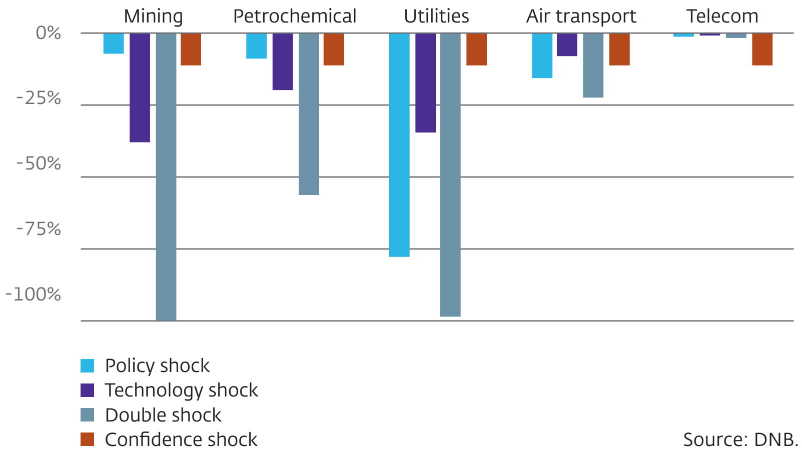
By constructing transition vulnerability factors in this way, the mining, petrochemical and utilities industries turn out as most vulnerable to energy transition risk. The appendix displays the transition vulnerability factors for all 56 industries. The transition vulnerability factors for the mining and petrochemical industries are larger in the technology shock scenario than in the policy shock scenario, but for the utilities industry the transition vulnerability factor is smaller in the technology scenario. This reflects that firms in the utilities industry can potentially switch to renewable energy while firms in the mining and petrochemical industries cannot. Note that the transition vulnerability factors do not account for the CO_2 emitted in the consumption of the final goods and services of each industry. That is, while the transition vulnerability factors reflect the emissions from *producing* a car, they do not reflect the emissions from *driving* a car. This shortcoming could potentially be addressed by including the CO_2 emissions during the use of final goods and services in their embodied CO_2. Presently, however, we do not possess the required data for such an exercise.

3.2 Impact on stock and bond prices by industry

The transition vulnerability factors allow us to calculate equity returns by industry. The excess market return in each scenario is based on the NiGEM simulations presented in Chapter 2. This market return can be disaggregated to the industry level by multiplying it with each industry’s transition vulnerability factor. As is customary in stress tests, the return on tradeable assets such as equities and bonds is calculated on impact. That is, we look at the equity losses that are incurred at the start of each scenario by using the excess market return of the first year. Due to the variation in the transition vulnerability factors, the industry returns display considerable heterogeneity (Figure 3.2). In the policy shock scenario, the Utilities industry is hit particularly hard (-78%), while in the technology shock scenario the Mining industry takes a big hit (-38%). In the double shock scenario, the Mining and Utilities industries are rendered completely unprofitable, as virtually all their equity value is wiped out. The Air transport industry is hit relatively hard in the policy shock scenario (-15%), while in the technology and double shock scenarios the impact is relatively small (-8% and -22%, respectively). The intuition behind this result is that airlines benefit from lower fossil fuel prices in these scenarios. Industries with low embodied CO_2 emissions, such as Telecommunications, are hit hardest in the confidence shock scenario because of the general economic slowdown (see the Appendix for a complete overview of equity returns by industry and scenario).

An important driver of bond prices is the change in the risk free interest rate. When the risk free rate increases, investors demand a higher return on their bonds, which results in a drop in the bond price. We use the projected changes in 10 year government bond yields as a proxy for the change in the risks free rate at all maturities. That is, we assume a linear shift in the risk free yield curve corresponding to the shift in the yields of 10 year government bonds. Note that the impact of a shift in the risk free interest rate on bond prices is larger for bonds that have a longer duration. In the stress test, this impact is the largest in the policy shock and double shock scenarios, with the price of a bond with a duration of five years falling by 5 percent and 7 percent, respectively (Figure 3.3).

Figure 3.2 Equity price changes for selected industries



Source: DNB.

Bond prices are also affected by changes in the credit risk spread. When the credit risk for a particular bond increases, investors demand a higher return on that bond, which increases the credit risk spread and leads to a drop in the bond price. The change in the credit risk spread of a bond is calculated by industry, as more vulnerable industries will likely have a larger increase in credit risk than less vulnerable industries. To make the calculation, we adapted the corporate credit risk module from DNB's top down stress test model for the Dutch banking sector.[35] This module calculates the probability of default for a bond based on changes in GDP (which we know from NiGEM) and equity returns (which we have calculated for each industry), taking into account the rating and remaining maturity of the bond. The financial impact is largest for bonds with a remaining maturity of five years or more, as we assume that after five years the economy returns to baseline.

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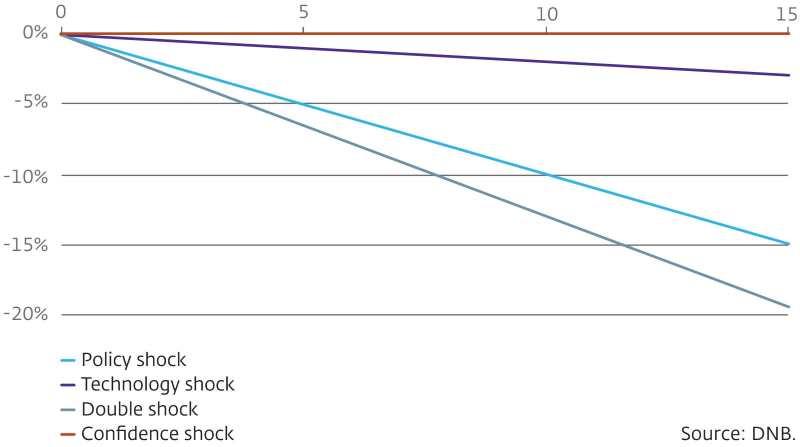
[35] See Daniëls et al. (2017) for a detailed description of the top down stress test model.

Figure 3.3 Bond price changes due to a shift in the risk free rate

Bond duration in years



Source: DNB.

Note that the same module is also used to project the losses on corporate loans over a five year horizon.[36] As shown in Figure 3.4, prices of bonds from the Mining industry are hit relatively hard by changes in the credit risk spread (especially for maturities of five years or more), even if the bonds have a relatively good initial credit rating. The prices of bonds of industries with low embodied CO_2 emissions, such as Telecommunications, are predominantly affected if the initial credit rating is low.

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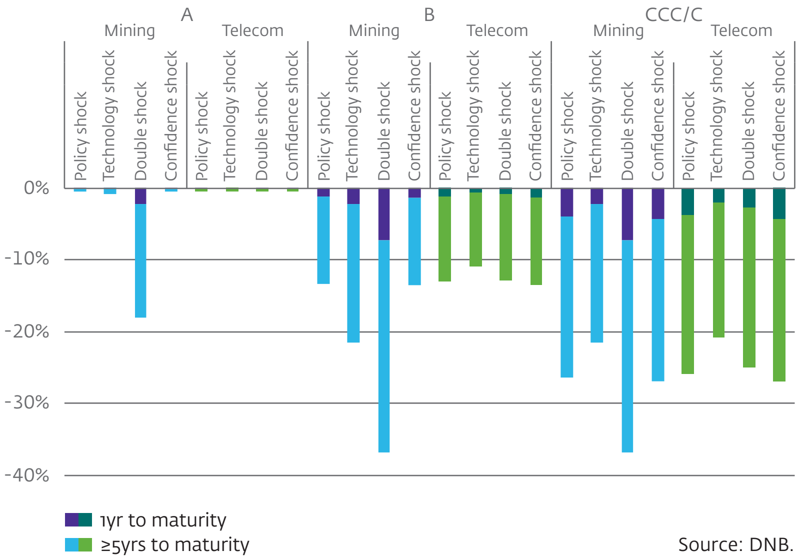
[36] Details on how the credit risk spread was calculated are included in the web-appendix.

Figure 3.4 Bond price changes due to changes in the credit risk spread, by credit rating and industry



Source: DNB.

4 Financial impact

The data that are analyzed in this study show that aggregate exposures on carbon-intensive industries are limited. However, the disruptive energy transition scenarios affect not only the carbon-intensive industries, but also the economy at large. Thus, the total losses for financial institutions could be sizeable: up to 3 percent of the stressed assets for banks, 11 percent for insurers and 10 percent for pension funds. Despite these losses, the impact on supervisory ratios seems manageable.

To calculate the financial impact of the stress scenarios, we combine the macroeconomic scenario simulations from Chapter 2 with the transition vulnerability factors from Chapter 3. The impact on corporate loans is calculated with DNB's top down stress test model for the Dutch banking sector. For bank loans, the losses are calculated as the cumulative additional losses on the loan portfolio relative to baseline expected losses over the five year scenario horizon. The main reason for this is that bonds and stocks are priced and held at market values, while loans are valued in accordance with accounting rules. Since bonds and stocks can generally be sold quickly on the market and bond and equity portfolios can be rebalanced relatively easily, the losses on impact are the most relevant for these portfolios. Bank loans are held in accordance with IFRS9 accounting rules, which require banks to increase the provisions of loans when the probability of default of the loans increases. The stress test approximates this increase in loan loss provisions by calculating the expected defaults over the five year scenario horizon assuming a static balance sheet.[37]

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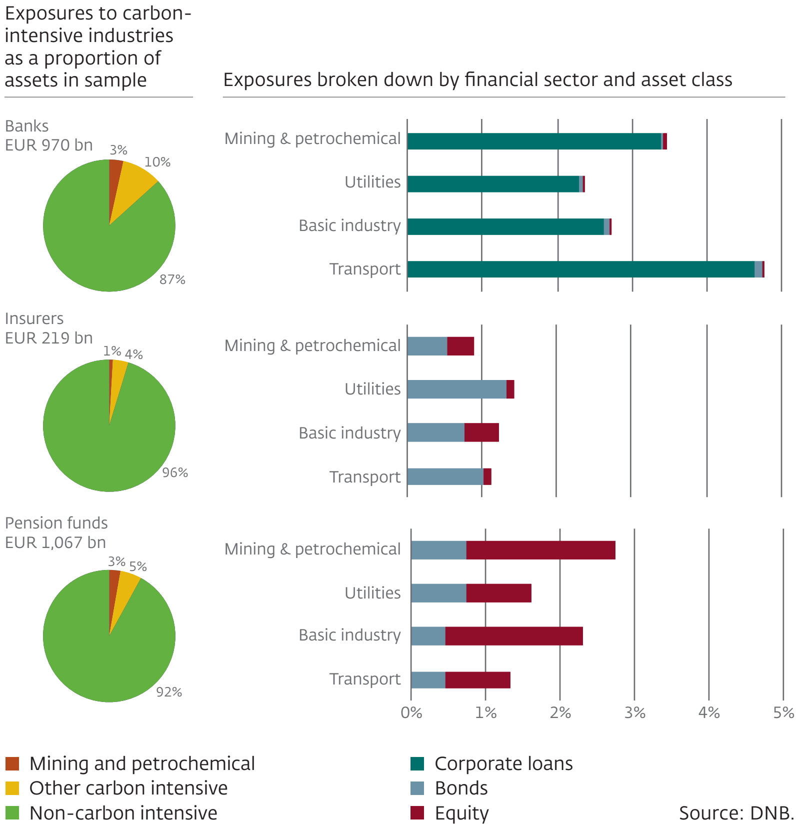
[37] Note that the European Banking Authority also uses a static balance sheet assumption in its stress tests for the European banking system (see, e.g., European Banking Authority, 2018).

4.1 Data and exposures

The stress test is conducted for EUR 2,256 bn of assets held by banks, insurers and pension funds located in the Netherlands. The majority of the assets in our sample are held by banks (EUR 970 bn) and pension funds (EUR 1,067 bn). The assets of banks are mainly made up out of loans to large, medium and small non-financial corporates (69%). For insurers, the assets consist mainly out of bonds (78%) while for pension funds, equities (55%) account for the largest share.

The bond holdings in our sample are highly concentrated, while corporate loans and equity portfolios are more diversified. The banks, insurers and pension funds in our sample all hold a large share of government bonds, which for the most part are euro dominated government bonds with a high credit rating. They also hold a large share of bonds of other financial institutions (in the case of banks, these bonds are mostly AAA-rated Residential Mortgage Backed Securities). In total, over 80 percent of the bond holdings in our sample are exposures to governments and financials. The corporate loan portfolios of the banks in our sample are more diversified, with the largest exposures on Wholesale trade (13% of all corporate loans in the sample), Real estate (11%) and Agriculture (10%). In the equity portfolios, banks and insurers have a large concentration on Financial institutions (around 40% of the total equity portfolio of each sector), while the remaining part of the portfolio is diversified across industries. The pension fund equity holdings are the most diversified, with the largest exposure on Legal and consulting services (10%), followed by Financial institutions (9%) and Real Estate (7%).

Figure 4.1 Exposures to carbon-intensive industries



Source: DNB.

Notes: Other carbon-intensive industries include Utilities, Basic industry and Transport.

About a quarter of the equity holdings in our sample could not be allocated to a specific industry. The equities for which an industry code is missing are mainly exposures to investment funds outside of the Netherlands. We do not have detailed information on the holdings of investment funds outside of the Netherlands and therefore we cannot determine which industries these exposures are ultimately on. In our calculations we treat these unclassified exposures as if they have a transition vulnerability factor of 1, which is equivalent to the assumption that together, these exposures roughly reflect the market portfolio.

Relative to the insurers and pension funds, the banks in our sample are the most exposed to carbon intensive industries. Figure 4.1 displays each sector's exposure to selected carbon intensive industries in a style similar to Schotten et al. (2016). Although the relative exposure of banks (13%) to carbon- intensive industries is larger than the relative exposure of insurers (5%) and pension funds (8%), the exposure to individual carbon intensive industries is always less than 5%. Note that some of the categories in Figure 4.1 comprise multiple industries, which are here combined for ease of reference.[38] In our calculations, however, each of the underlying industries receives a separate transition vulnerability factor.

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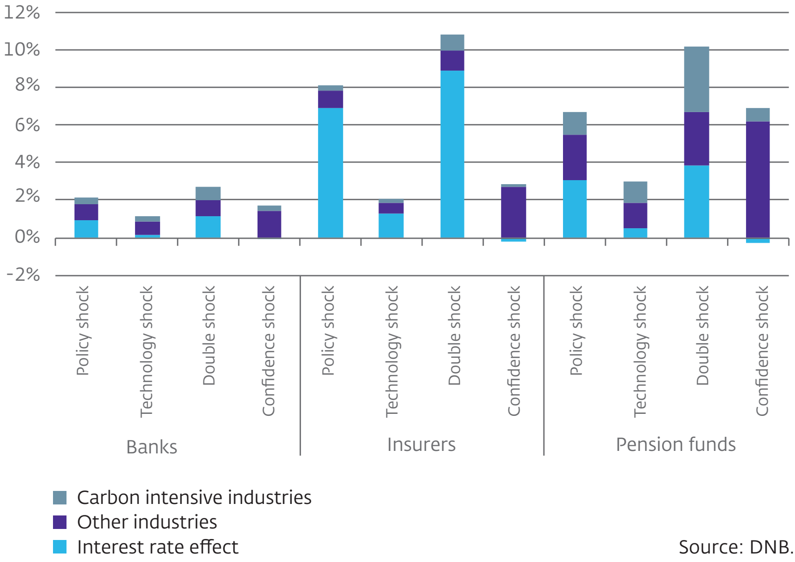
[38] Specifically (NACE Rev.2 code between brackets): Mining & petrochemical comprises Mining (B) and Petrochemical industry (C19); Basic industry comprises various manufacturing industries (C16, C17, C20, C22, C23, C24) and Transport comprises various transport sectors (H49, H50, H51, H52, H53). Utilities is defined as a single industry (D35).

4.2 Impact on assets

The impact on financial institutions' assets in each scenario can be attributed to three risk drivers: (1) exposures to selected carbon intensive industries, (2) exposures to other industries and (3) changes in the risk free interest rate. Figure 4.2 visualizes the losses for each sector and for each scenario, relative to the total assets of each sector accounted for in this study ("total stressed assets"). Losses that are due to a change in the risk free interest rate are shown as the "interest rate effect." Losses due to exposures to carbon intensive industries are defined as the losses on the exposures on Mining and petrochemical, Utilities, Basic industry and Transport.

Figure 4.2 Impact on assets as a percentage of total stressed assets per sector, disaggregated by risk driver



Source: DNB.

Losses for banks range between 1 percent of total stressed assets in the technology shock scenario and 3 percent in the double shock scenario. In both the policy shock and double shock scenario, a substantial part of losses is due to the interest rate effect. This effect is mainly due to holdings in government bonds with a long residual maturity and therefore a high duration. In the double shock scenario the interest rate effect accounts for roughly 40% of total losses, while the remaining losses are spread evenly between holdings in carbon-intensive industries and holdings in non-carbon-intensive industries. Losses on exposures to carbon-intensive industries account for between 20 (confidence shock scenario) and 50 (double shock scenario) percent of total non-interest rate losses.

Losses for insurers range between 2 percent of total stressed assets in the technology shock scenario and 11 percent in the double shock scenario, with the interest rate effect driving the majority of losses in three out the four scenarios. The bond portfolio of insurers is characterized by a high duration, which leads to large decreases in asset values when interest rates increase. In the double shock scenario, for example, insurers face losses of 11 percent of their total stressed assets, 9 percentage points of which are driven by the interest rate effect. In the confidence shock scenario insurers obtain a small benefit, since interest rates outside the euro area slightly decrease which leads to a small increase in bond values. In the confidence shock scenario, insurers are hit relatively hard on their exposures to non-carbon intensive industries, with total losses amounting to nearly 3 percent of total stressed assets.

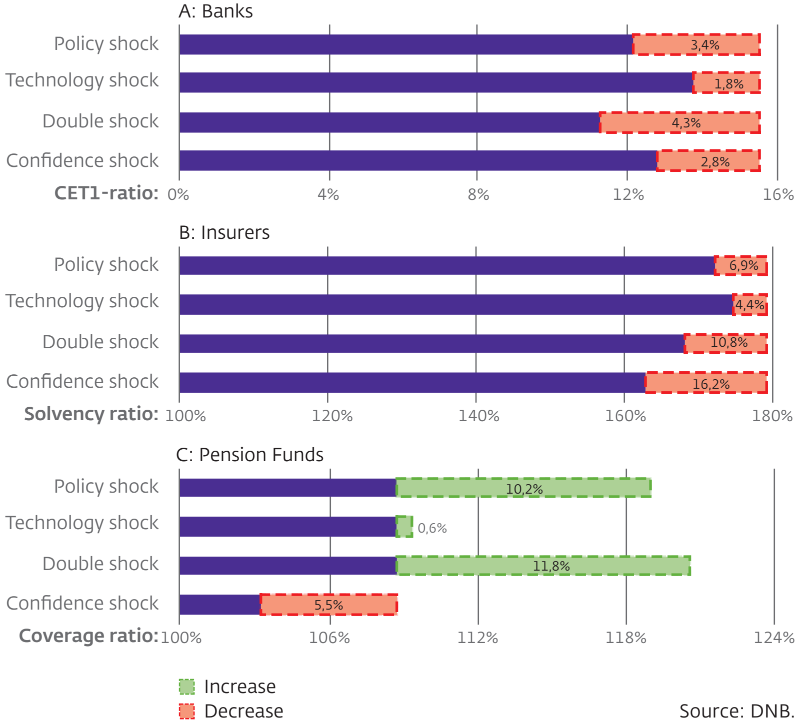
Losses for pension funds range between 7 percent of total stressed assets in the policy shock and confidence shock scenarios and 10 percent in the double shock scenario. The interest rate effect drives about half of the losses in the policy shock scenario and some two-fifths of the losses in the double shock scenario. This effect is thus less important for pension funds than for insurers, which can be explained by the relatively larger equity portfolios of pension funds. Losses on exposures to carbon-intensive industries account for over one third of the losses in the double shock scenario, which is notable as these industries account for only 8 percent of total exposures. The losses in the confidence shock scenario are significantly larger for pension funds than for banks and insurers, which is primarily driven by pension funds' large equity positions (recall that losses are spread evenly across all industries in this scenario).

4.3 Impact on supervisory ratios

It is possible to translate the losses on financial institutions' assets to an impact on supervisory ratios (Figure 4.3), but this requires making a number of strict assumptions. Although the primary focus of this stress test is on the impact of the energy transition scenarios on financial institutions' assets, institutions and supervisors are ultimately concerned with the impact on supervisory ratios. These ratios determine, from a regulatory perspective, whether an institution's assets are sufficient to meet its obligations. The impact on ratios should be interpreted carefully, however, because they hinge crucially on underlying assumptions.

The regulatory capital (CET1) ratio of Dutch banks can decrease by slightly more than 4 percentage points in the double shock scenario. The capital ratio impact can be calculated by taking the current level of CET1-capital of the banks in our sample and subtracting the losses in each scenario. The new CET1-ratio is calculated by dividing the new CET1-capital by the original Risk Exposure Amount (REA). Whether the REA increases or decreases in the scenarios is ambiguous. On the one hand, the REA increases when the riskiness of loans in general increases. On the other hand, the REA decreases when the riskiest assets are written off. We therefore make the simplifying assumption that the REA remains constant. There could be factors that mitigate the impact on banks, such as reduced tax payments, which we do not consider here. An additional mitigating factor is that, in practice, banks are often allowed to gradually build up the capital required to cover an increase in expected future losses on corporate loans. Here we assume that banks need to meet these capital requirements immediately.

Figure 4.3 Impact on supervisory ratios by sector



Source: DNB.

The regulatory solvency ratio of Dutch insurers could decrease by up to 16 percentage points in the confidence shock scenario. On average, insurers in the Netherlands have a solvency ratio of about 179%. Since the minimum capital requirement is 100%, a loss of 16 percentage points is relatively small and manageable. To calculate the impact on the solvency ratio, we start from the current level of capital that insurers in the Netherlands have available to cover the regulatory Solvency Capital Requirement (SCR). Since insurers face both a negative interest rate effect on the asset side of their balance sheets and a positive interest rate effect on the liabilities side, we make the simplifying assumption that losses due to interest rate changes are fully hedged. Note that a fraction of the losses of insurers is incurred directly by the insurers' clients, due to so-called unit linked products. We assume, therefore, that insurers incur only 79 percent of the non-interest rate effect losses in each scenario.[39] Lastly, we assume that the SCR remains constant.[40]

The regulatory coverage ratio of Dutch pension funds can decrease by up to 6 percentage points in the confidence shock scenario, but it can also improve in the policy shock and double shock scenarios. To determine the impact on the coverage ratio, we calculate the new value of the liabilities by discounting the future cash flows based on the scenario specific market interest rates while retaining the current Ultimate Forward Rate. Based on DNB statistics we assume that pension funds hedge 38% of the interest rate risk. Note that the stress test covers 73% of the total assets of Dutch pension funds; we assume that the remaining portion of assets retains its full value in each of the scenarios (except for price decreases due to interest rate hedging).

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[39] DNB statistics show that the share of assets linked to unit linked products is 21%.

[40] In general, the SCR will be recalculated after a shock hits an insurer's assets. Calculating these new requirements is beyond the scope of this study, as it would require a bottom up calculation on the basis of the risk profile of both the assets and liabilities of each insurer.

We then divide the after-stress value of assets in each scenario by the after-stress value of liabilities to obtain the new coverage ratios. Note that the increase in the coverage ratio in the policy and double shock scenarios will be smaller if pensions are indexed to match inflation.

5 Conclusion

The stress test results suggest that the losses for financial institutions in the event of a disruptive energy transition could be sizeable, but also manageable. Individual financial institutions can mitigate the risks for their portfolio by taking energy transition risks into account. In addition, policy makers can help to avoid unnecessary losses by implementing timely, reliable and effective climate policies. As stress testing energy transition risks is a relatively new field of study, future work could help to further refine the results.

The stress test results suggest that financial institutions can mitigate their vulnerability to a disruptive energy transition by including energy transition risks in their risk management. As a first step, institutions could map their exposures to industries that are the most vulnerable to a disruptive energy transition. Institutions could also conduct their own transition risk stress test to gain a sense of their vulnerability. By taking the energy transition into account in their exposures, financial institutions can mitigate the impact of transition risks on their institution and the financial system as a whole. In addition, by explicitly accounting for energy transition risks, financial institutions may alter their investment decisions in a way that contributes to a timely energy transition and thereby decreases the probability of a disruptive scenario.

A timely implementation of effective climate policies can help to avoid unnecessary losses. The stress test results suggest that a disruptive energy transition can already affect Dutch financial institutions in the short term. Moreover, a disruptive energy transition affects the economy at large, such that losses for financial institutions are not confined to exposures to carbon-intensive industries. Postponing policy action increases the risk of abrupt action in the future. Timely, reliable and effective government policy therefore helps to prevent a disruptive energy transition and the associated economic damage as much as possible.

In many ways, this stress test is only a first step towards an assessment of the impact of a disruptive energy transition on the financial sector of the Netherlands. The outcomes of this stress test depend crucially on assumptions and methodological choices. Moreover, as energy transition risks are a relatively novel field of study, the uncertainty surrounding the assumptions seems larger than in conventional stress tests. We have attempted to make the assumptions as consistent as possible with existing stress tests and the climate change literature. Nevertheless, some different assumptions could have been made that would have led to different results. On the one hand, we excluded certain factors that would have likely resulted in larger losses for financial institutions. Examples are the impact of potential physical risks on financial institutions, energy transition risks for households, or a price increase on agriculture's methane emissions. On the other hand, changing some of our assumptions might have reduced the impact on supervisory ratios. Examples are the assumption that banks need to recognize capital losses immediately, or that insurers fully hedge their interest rate risk.

Future work on energy transition stress testing could further refine the outcomes, especially with regards to (1) data quality, (2) modelling industry returns and (3) capturing second round effects. First, although this study used highly granular data on financial institutions' holdings in individual bonds and stocks, data gaps remain. In particular the holdings in investment funds lack information on the industry classification of the ultimate exposures. Data quality can be improved by performing a detailed "look-through" of the exposures in these investment funds. Second, the microeconomic foundations of the stress test could be improved by first calculating industry returns in each scenario and then aggregating to a macroeconomic impact. Such an approach would require a detailed industry-by-industry model that is able to generate equity and bond returns for each industry. Ideally, such a model would also be able to account for potential changes in consumer behavior in response to climate change policies or technological breakthroughs. Alternatively, future energy transition risk stress tests could consider an approach based on an integrated-assessment model, agent-based model or computable general equilibrium model, each of which has advantages and disadvantages vis-à-vis the macro-econometric approach used in this study. Third, financial institutions could face further losses if the initial shock in a scenario leads them to sell large amounts of distressed assets ("fire sales"), such that the prices of these assets drop further. Insight in which assets are susceptible to this fire-sale channel will allow for better estimates of asset price decreases.

Appendix: Transition vulnerability factors (TVFs) and equity returns by industry and scenario

		TVF (equity returns)			
NACE code(s)	Industry	Policy shock	Tech shock	Double shock	Confidence shock
A01	Crop and animal production, hunting and related service activities	1 (-6%)	0.5 (-1%)	0.5 (-4%)	1 (-11%)
A02	Forestry and logging	0.9 (-5%)	0.8 (-2%)	0.8 (-6%)	1 (-11%)
A03	Fishing and aquaculture	0.9 (-5%)	0.8 (-2%)	0.8 (-6%)	1 (-11%)
B05 – B09	Mining and quarrying	1.4 (-7%)	13.5 (-38%)	13.5 (-100%)	1 (-11%)
C10 – C12	Manufacture of food products, beverages and tobacco products	0.8 (-4%)	0.5 (-2%)	0.5 (-4%)	1 (-11%)
C13 – C15	Manufacture of textiles, wearing apparel and leather products	1.1 (-6%)	0.7 (-2%)	0.7 (-6%)	1 (-11%)
C16	Manufacture of wood and of products of wood, cork, straw and plaiting, except furniture	0.9 (-5%)	0.7 (-2%)	0.7 (-6%)	1 (-11%)
C17	Manufacture of paper and paper products	1.4 (-7%)	0.9 (-3%)	0.9 (-7%)	1 (-11%)
C18	Printing and reproduction of recorded media	0.5 (-2%)	0.3 (-1%)	0.3 (-2%)	1 (-11%)
C19	Petrochemical (manufacture of coke and refined petroleum products)	1.7 (-9%)	7 (-20%)	7 (-56%)	1 (-11%)
C20	Manufacture of chemicals and chemical products	1.4 (-7%)	0.9 (-3%)	0.9 (-7%)	1 (-11%)
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	1.5 (-8%)	1 (-3%)	1 (-8%)	1 (-11%)
C22	Manufacture of rubber and plastic products	2.5 (-13%)	2 (-5%)	2 (-16%)	1 (-11%)
C23	Manufacture of other non-metallic mineral products	4.1 (-22%)	3.4 (-10%)	3.4 (-27%)	1 (-11%)

C24	Manufacture of basic metals	3 (-16%)	2.6 (-7%)	2.6 (-21%)	1 (-11%)
C25	Manufacture of fabricated metal products, except machinery and equipment	1.2 (-6%)	0.8 (-2%)	0.8 (-6%)	1 (-11%)
C26	Manufacture of computer, electronic and optical products	1 (-5%)	0.6 (-2%)	0.6 (-5%)	1 (-11%)
C27	Manufacture of electrical equipment	1.4 (-7%)	0.9 (-3%)	0.9 (-7%)	1 (-11%)
C28	Manufacture of machinery and equipment	1.4 (-7%)	0.8 (-2%)	0.8 (-7%)	1 (-11%)
C29	Manufacture of motor vehicles, trailers and semi-trailers	1.2 (-6%)	0.8 (-2%)	0.8 (-6%)	1 (-11%)
C30	Manufacture of other transport equipment	1.2 (-6%)	0.8 (-2%)	0.8 (-6%)	1 (-11%)
C31 – C32	Manufacture of furniture; other manufacturing	1.9 (-10%)	1.5 (-4%)	1.5 (-12%)	1 (-11%)
C33	Repair and installation of machinery and equipment	1.4 (-7%)	0.8 (-2%)	0.8 (-7%)	1 (-11%)
D35	Utilities (electricity, gas, steam and air conditioning supply)	14.7 (-78%)	12.4 (-35%)	12.4 (-99%)	1 (-11%)
E36	Water collection, treatment and supply	2.2 (-11%)	1 (-3%)	1 (-8%)	1 (-11%)
E37 – E39	Sewerage; waste management services, treatment and disposal activities	1.3 (-7%)	1.1 (-3%)	1.1 (-9%)	1 (-11%)
F41 – F43	Construction	1.9 (-10%)	1.6 (-4%)	1.6 (-12%)	1 (-11%)
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles	0.3 (-2%)	0.3 (-1%)	0.3 (-2%)	1 (-11%)
G46	Wholesale trade, except of motor vehicles and motorcycles	0.3 (-2%)	0.3 (-1%)	0.3 (-2%)	1 (-11%)

G47	Retail trade, except of motor vehicles and motorcycles	0.4 (-2%)	0.4 (-1%)	0.4 (-3%)	1 (-11%)
H49	Land transport and transport via pipelines	0.7 (-4%)	0.6 (-2%)	0.6 (-5%)	1 (-11%)
H50	Water transport	4.7 (-25%)	4.6 (-13%)	4.6 (-37%)	1 (-11%)
H51	Air transport	2.9 (-15%)	2.8 (-8%)	2.8 (-22%)	1 (-11%)
H52	Warehousing and support activities for transportation	0.5 (-3%)	0.4 (-1%)	0.4 (-4%)	1 (-11%)
H53	Postal and courier activities	0.2 (-1%)	0.2 (0%)	0.2 (-1%)	1 (-11%)
I55 – I56	Accommodation and food service activities	0.3 (-2%)	0.2 (-1%)	0.2 (-2%)	1 (-11%)
J58	Publishing activities	0.5 (-2%)	0.3 (-1%)	0.3 (-2%)	1 (-11%)
J59 – J60	Motion picture, television program production, sound recording and music publishing	0.4 (-2%)	0.3 (-1%)	0.3 (-2%)	1 (-11%)
J61	Telecommunications	0.2 (-1%)	0.2 (0%)	0.2 (-1%)	1 (-11%)
J62 – J63	Computer programming, consultancy and information service activities	0.3 (-2%)	0.2 (-1%)	0.2 (-2%)	1 (-11%)
K64	Financial service activities, except insurance and pension funding	0.2 (-1%)	0.2 (-1%)	0.2 (-1%)	1 (-11%)
K65	Insurance, reinsurance and pension funding, except compulsory social security	0.3 (-1%)	0.2 (-1%)	0.2 (-2%)	1 (-11%)
K66	Activities auxiliary to financial services and insurance activities	0.3 (-1%)	0.2 (-1%)	0.2 (-2%)	1 (-11%)
L68	Real estate activities	0.2 (-1%)	0.1 (0%)	0.1 (-1%)	1 (-11%)

M69 – M70	Legal and accounting activities; activities of head offices; management consultancy	0.3 (-1%)	0.2 (-1%)	0.2 (-2%)	1 (-11%)
M71	Architectural and engineering activities; technical testing and analysis	0.3 (-1%)	0.2 (-1%)	0.2 (-2%)	1 (-11%)
M72	Scientific research and development	1 (-5%)	0.7 (-2%)	0.7 (-5%)	1 (-11%)
M73	Advertising and market research	0.3 (-1%)	0.2 (-1%)	0.2 (-2%)	1 (-11%)
M74 – M75	Other professional, scientific and technical activities; veterinary activities	0.3 (-1%)	0.2 (-1%)	0.2 (-2%)	1 (-11%)
N77 – N82	Administrative and support service activities	0.4 (-2%)	0.3 (-1%)	0.3 (-3%)	1 (-11%)
O84	Public administration and defense; compulsory social security	0.6 (-3%)	0.4 (-1%)	0.4 (-3%)	1 (-11%)
P85	Education	0.4 (-2%)	0.2 (-1%)	0.2 (-2%)	1 (-11%)
Q86 – Q88	Human health and social work activities	0.5 (-3%)	0.3 (-1%)	0.3 (-2%)	1 (-11%)
R90-R93 S94-S96	Other service activities	0.5 (-3%)	0.4 (-1%)	0.4 (-3%)	1 (-11%)
T97 – T98	Activities of households as employers; production activities of households for own use	0.5 (-2%)	0.2 (-1%)	0.2 (-2%)	1 (-11%)

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Erratum

14 January 2019: Corrected values of Global stock price index in Boxes 2.1-2.4. The previous version contained annual returns. These have been corrected to level deviations.

DeNederlandscheBank

EUROSYSTEEM

De Nederlandsche Bank N.V.
PO Box 98, 1000 AB Amsterdam
+31 20 524 91 11
dnb.nl