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Do extreme weather events damage the German economy?

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Inhalt

1 INTRODUCTION

Worldwide economic losses resulting from extreme weather events have increased in recent years. Climate change is often perceived as driving force behind this development but no conclusive evidence exists, since it cannot be ruled out that changes in socio-economic conditions (settlement of flood-prone regions, accumulation of wealth) lead to major losses (Barredo 2009, Feyen et al. 2009, Elmer et al. 2012). However, climate modeling results suggest climate change to become a determining factor in future changes of precipitation patterns (Christensen & Christensen 2007, van der Linden & Mitchell 2009) and temperature extremes (IPCC 2012). Due to rising economic losses caused by extreme events, the vulnerability of countries and economic sectors to climate change increasingly comes into focus.

In the last two decades since the Rio conference, much work has been done in the context of quantifying economic effects of climate change. Integrated Assessment Models (IAM), combining earth system and economic models via damage functions, have been (further) developed and applied (Kemfert 2007, Anthoff & Tol 2013, Nordhaus & Sztorc 2013). However, IAM usually focus on effects resulting from a gradual increase in the global average surface temperature. They do not consider effects resulting from extreme weather events (Patt et al. 2010)[1]. For this purpose Disaster Impact Models (DIM) have been developed, providing a basis for analyzing economic effects of extreme weather events such as floods, hurricanes or earthquakes on a regional level (e.g. Hallegatte et al. 2011, Crawford-Brown et al. 2013, Rose & Liao 2005). A third category comprises flood damage assessment methods. Albeit, unlike IAM and DIM they cannot be characterized as "economic models", as their focus is on a detailed modeling of flood risks. The various methodological approaches differ markedly to some extent, but they have in common that damages are estimated by using damage functions (Rojas et al. 2013, Feyen et al. 2012, Lugeri et al. 2010). To the authors' knowledge there exists no literature on estimations of (possible) tangible damages or direct and indirect economic effects of heat waves in the past or in the future for Germany.

Climate change in Germany primarily becomes visible through a rising number of extreme weather events which may influence Germany's economic development (Rahmstorf & Schellnhuber 2006). To quantify economic damages and the responses of the economy to such a shock, we have to implement these events in the economic model's functions. In this paper an INFORUM[2]-type econometric input-output model PANTA RHEI (e.g. Lehr

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[1] FUND 3.17 for example is one of the few models dealing with this topic (Anthoff & Tol 2013).

[2] The INFORUM philosophy is characterized by the construction principles (1) "bottom up" and (2) "full integration", meaning that (1) each of the industries of the German economy on the two-digit level is modeled in detail. Macroeconomic variables are then formed by aggregation within the model interrelations. (2) The construction principle "full integration" means a complex and simultaneous modeling, describing inter-industry interdependencies, generation and use of income and other components determining a country's economic performance.

et al. 2012) is further developed to answer the questions (a) if extreme weather events do harm the German economy, and (b) which economic sectors are mainly affected by these events, especially after taking into account direct and indirect economic effects resulting from input-output linkages. Because Germany will be threatened by an increasing number of these events in the future, estimation of the economic impacts of these events is relevant for decision makers. In this paper we contribute to the discussion with an answer to the question if and how extreme weather events can be modeled in a macro-econometric input-output model. In the analysis we are focusing on river floods and extreme heat waves.

Our approach differs from others in that damages resulting from heat waves and river floods are integrated as shocks into our macro-econometric model. Moreover, instead of focusing on single events, impacts of recurring events are estimated.

Only few authors have dealt with economic effects of future river floods focusing on Germany, yet. Most of the floods-related research analyzes damages on a basin, European or global scale. Detailed direct and indirect overall economic effects are not considered in those studies. The same is true for economic costs resulting from these events.

De Kok and Grossmann (2009) present a flood risk assessment methodology and analyze damages of a flood event along the river Elbe on the basis of damage functions describing flood damages as a function of the inundation depth. Results indicate damages amounting to between 2.5 bn. and 6.6 bn. Euros, depending on the damage assessment methodology. Te Linde et al. (2011) estimate on the basis of scenario analysis the future fluvial flood risk for the Rhine basin and find potential damages amounting to 142 bn. Euros in Germany in the year 2030. Indirect effects are comprised implicitly in the damage model as a surcharge on direct damages of five percent. This share is intended to reflect turnover losses of businesses resulting from flood events. The scenario analysis considers changes in socio-economic and climate conditions. In the light of these changes, Rojas et al. (2013) estimate socio-economic effects of a river flood with and without adaptation in the European Union until 2080. The combination of flood inundation maps and information on the exposure and vulnerability of assets enables the analysis of socio-economic effects, which comprise annual damages and the number of people affected. The expected annual damages for Germany until 2050 amount to 1.1 bn. Euros by imposing a protection level of a 100-year event and 2.2 bn. Euros of a protection level of a 50-year river flood.

To the authors' knowledge there exist no literature on estimations of (possible) tangible damages or direct and indirect economic effects of heat waves in Germany, albeit the EM-DAT database[1] reports damages of 1.2 bn. Euros, resulting from the 2003 heat wave (EM-DAT 2014).

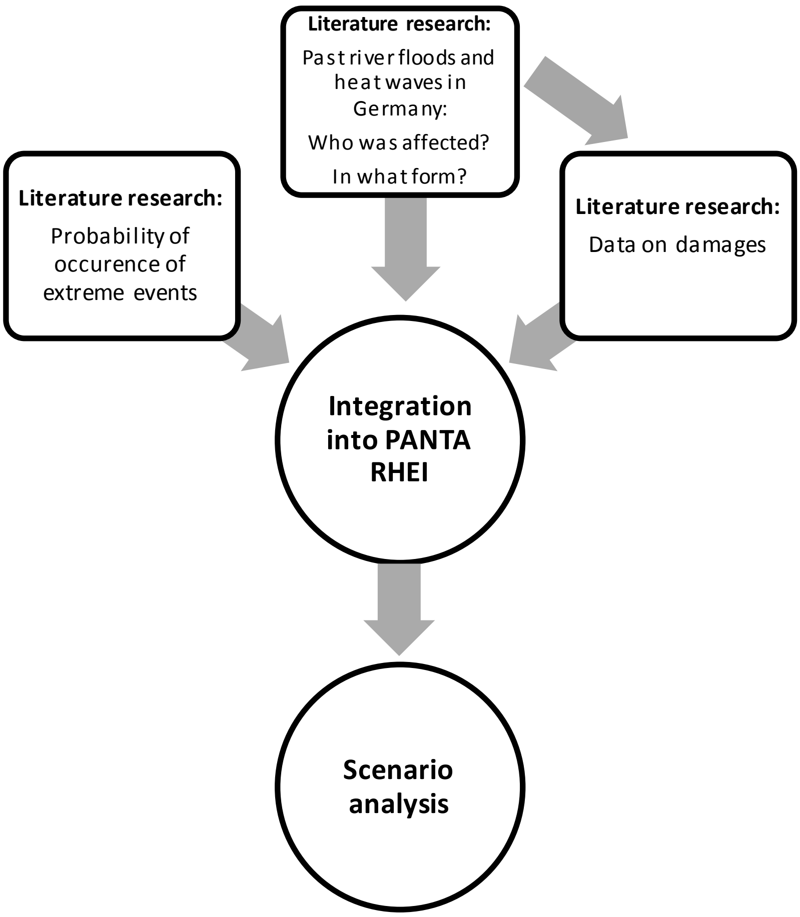
The next section describes the methodological framework, used to estimate economic impacts of flood events and heat waves. The results are reported in section 3, whereas a conclusion of this work can be found in section 4.

[1] The data are reported by governments, organizations and others.

2 How to model extreme weather events?

The literature, as pointed out above, gives only an incomplete picture of potential economic impacts of extreme weather events. To answer the question if and how a rising number of extreme weather events in the future may influence Germany's economic development, we estimate economic effects with the macro-econometric model PANTA RHEI. Figure 1 shows the methodological approach. In a first step, an extensive literature research has been conducted regarding the question in what form, respectively through which channels, different institutional sectors (here: companies, insurance companies, governments, private households) were directly affected by river floods or heat waves in the past. The most vulnerable economic sectors determining a country's economic performance were identified. Furthermore, an extensive literature research was undertaken to find data on damages and costs resulting from river floods and heat waves in the past and to identify damages and costs for the identified sectors in the future. Literature on the expected impact of climate change on the frequency and intensity of extreme weather events in Germany in the future has been reviewed in a third step. Subsequently, all useful information was integrated into the macro-economic model PANTA RHEI via a climate module. Finally, scenario analysis has been undertaken, comparing a "climate change scenario" with a "reference scenario". In the following sections data and methods are described in more detail.

Figure 1: **Schematic overview of the methodological approach. The focus is on heat waves and river floods in Germany**



2.1 Data

To effectively integrate floods and heat waves into the model PANTA RHEI, it was essential to firstly identify economic sectors most severely affected by these events in the past in Germany. An overview is given in Table 1. Where possible, the Elbe flood of the year 2002 and the heat wave of the year 2003 were chosen as reference events, which means that, where available, information on damages and costs of these events was used to model extreme events. In some cases other data had to be used. Real estate and infrastructure located in a flood zone are generally directly and most severely affected by an inundation. They include production sites, dwellings and transport infrastructure such as roads and railways. Detailed data on damages of past flooding of production sites, dwellings and transport infrastructure are available at Munich Re (Münchner Rück 2003). Who is in charge of the repairs? In the following, we assume that the responsibilities remain distributed similar to today's distribution. A discussion on the results for alternative cost sharing patterns is found at the end of this paper. The existing cost sharing means in the case of production sites, incurring costs have to be borne by companies. Private households have to meet costs for damages to (residential) buildings. A part of the costs is usually met by insurance companies or governments. In particular, costs for damages of (public) transport infrastructure have first and foremost to be borne by governments.

Indirectly affected by these damages are companies of the transport sector (road, rail, ship), since they may be forced to reduce or stop their logistics services for a certain period. The resulting supply shortages even affect companies of other economic sectors or those which are located outside the inundated region by causing a decline in production. The flooding of farm land may lead to massive losses of agricultural production.

Table 1: Cost bearing institutional sectors, economic sectors and further components affected directly by extreme weather events

Event/Effects	Institutional sectors			
Effects of a river flood on:	companies	insurance companies	government	private households
production sites	X	X	X	
dwellings		X	X	X
transport infrastructure	X		X	
Production (industry/agriculture)	X			
disaster management			X	
tourism	X			
Effects of a heat wave on:				
agriculture	X			
energy sector	X			
labor productivity	X			
ship traffic	X			

There is little information on costs for transport companies caused by the Elbe flood. Therefore, the analysis is based upon data from the EU FP7 EWENT project (Extreme Weather Impacts on European Networks of Transport project) (Nokkala 2012). In this context, present and future costs of extreme weather events for “freight and logistics” (among others) were estimated on EU-27 level. The costs for Germany were calculated according to the ratio of Germany’s road length to total European road length. Estimation results of the decline in total production in the East of Germany in the aftermath of the 2003 flood are available by the Halle Institute for Economic Research (Ludwig & Brautzsch 2002). Since, to the authors’ knowledge, no information on losses in agricultural production resulting from the Elbe flood in 2002 is available, data referring to the Elbe flood in 2013 were used. These data were published by the German Ministry of the Interior (BMI 2013), which coordinates the missions of disaster relief forces. During flood events disaster relief forces are required to protect local residents and villages against threats and further damages. In the aftermath of the event, help is needed to remedy damages. Consequently, public expenditures for disaster management in a year with a flood event are higher than in other years. BMI (2013) also contains data on additional expenditures resulting from the Elbe flood in 2013. Directly affected by a flood event is the tourism sector with water damaging hotels, restaurants, natural landscapes and cultural institutions. Albeit it is undisputed that the consequences for tourist facilities in regions affected were serious in the past, effects of a river flood on the tourism sector are not included in the following. This is due to the fact that, firstly, no detailed data on specific costs for tourist providers or damages of tourist facilities are available. Secondly, in our analysis, Germany-wide economic effects are analyzed. Since flood events in the past triggered evasive reactions and increased travels to other (drier) regions, the Germany-wide effects of a flood on the tourism sector could be neutral.

To model heat waves in PANTA RHEI, we have identified four fields as being particularly vulnerable to extremely high temperatures which are the agricultural sector, power generation, labor productivity and transport by boats. Impacts of heat and drought on the agricultural sector were massive in the past in Germany. In the following, data on agricultural production losses and costs of the 2003 heat wave from Bräuer et al. (2009) were used. In the scientific debate, effects of climate change on electric power generation, its transmission and distribution have been increasingly discussed (Rübbelke & Vögele 2011, Rademaekers et al. 2011, Schaeffer et al. 2012, van Vliet et al. 2012). In 2003 energy providers were forced to curtail their thermal power plants temporarily, as the temperature of cooling water had exceeded the allowable maximum temperature. Information on losses in power generation by all kind of power plants has been obtained from Rademaekers et al. (2011). They estimated the possible future percentage losses in power generation per 1°C increase in surface temperature during a heat wave. Moreover, according to literature temperatures of more than 25°C lead to a decrease in labor productivity. The extent of this reduction was estimated in several studies (Bosello et al. 2006, Hübler et al. 2008, Ziebarth et al. 2013). A summarizing overview can be found in Bux (2006). For the analysis presented here, data from Hübler et al. (2007) with respect to a reduction in labor productivity in the case of temperatures higher than 30°C were used. Information on the expected number of hot days (> 30°C) in the future in Germany come from PIK (2014). Transport infrastructure is largely vulnerable not only to flood events but to extreme heat as well – above all with regard to transport by boats. Data concerning absolute losses of transported volumes by inland waterways in the river Rhine area due to low water levels have been obtained from Jonkeren et al. (2011).

2.2 Modeling damages from extreme weather events with PANTA RHEI

Extreme events are integrated into the macro-econometric model PANTA RHEI in the form of shocks. PANTA RHEI is an environmentally extended version of the macro-econometric simulation and forecasting model INFORGE for the German economy. INFORGE describes the annual inter-industry flows between economic sectors, their contributions to private consumption, government, equipment investment, construction, inventory investment, exports as well as prices, wages, output, imports, employment, labor compensation, profits, taxes, etc. consistently for each sector as well as for the whole economy (Ahlert et al. 2009). The input-output based modeling is often deemed suitable only for short- to mid-term analysis, because of the constant production structure in the IO tables. To make the model fit for the analysis until 2050, a part of the input coefficients is estimated on the basis of prices and a time trend. These coefficients are variable and reflect technological change. All other coefficients are constant in the forecast horizon.

In addition to the economic core, PANTA RHEI captures land use, resource use (Meyer et al. 2012) as well as dwellings, transport, energy consumption and air pollutants in detail. Besides the economic core the energy module plays a prominent role, as it is fully integrated into the economic part of PANTA RHEI. The individual model components are closely related to each other and consistently linked via prices and volumes. PANTA RHEI has been used in various ways during the last years to assess e.g. economic impacts of renewable energy with a focus on the labor market (Lehr & Ulrich 2014), of energy efficiency (Lutz & Lehr 2014) or of the energy scenarios for the German energy concept (Prognos, EWI & GWS 2014).

A general overview of damages resulting from extreme weather events, target variables in the model and main expected economic effects is given in Table 2. Flood damages to productions sites, dwellings and transport infrastructure are modeled in PANTA RHEI by reducing capital stocks of machinery, real estate and public administration by the amounts that have been identified within the previous literature research. What can happen to the different sectors in the wake of a large flood?

The flooding of production sites has several outcomes: firstly, buildings and the production machines are damaged, products are wet and damaged beyond repair. One example is the machinery sector. Machinery is the most important industrial sector in Germany and a great number of manufacturing bases is located close to river basins for historical reasons such as transport (see the analysis of DAX 30 below). This means that the economic sector is extremely vulnerable to flood events and due to its size and its contribution to the overall economy, regional flooding will be felt in the overall economy. Flood events can cause production losses in agriculture and industry, which means that less (intermediate) goods are produced than needed. This can be expressed in PANTA RHEI by increasing the extent of imported intermediate goods, because missing intermediate goods have to be replaced by imports. However, not all production sites of the manufacturing industry are located close to rivers. For a reasonable approximation, it was analyzed which of the DAX 30 companies own productions sites close to rivers and to which industry these companies belong. Five sectors were identified, whose imported intermediate goods were then increased to a certain extent: chemicals, machinery, metals and semi-finished products, basic metals and automobiles and parts.

To integrate damages to dwellings into the model, the capital stock of the real estate sector is reduced. Furthermore, damages of dwellings may force private households to take additional loans, if savings are not sufficient to pay for remedying the damages incurred. Interest and payback reduce a household's real disposable income. Public administration comprises – among others – public infrastructure, therefore damages to infrastructure can be modeled by reducing the capital stock of this sector.

Table 2 Overview of damages, target variables and expected main economic effects

Damages	Target variables	Expected main effects
Damages of a river flood on:		
production sites	- Capital stock of: *Machinery* - Other current transfers	Increase in buildings investment and investment in plant and equipment, increase in real gross domestic product (GDP)
dwellings	- Capital stock of: *Real estate* - Other current transfers - Disposable income	Increase in buildings investment and investment in plant and equipment, increase in real GDP
transport infrastructure	- Capital stock of: *Public administration* - Other current transfers - Production output	Increase in buildings investment, unit costs and depreciation, increase in real GDP
production	- Imported intermediate goods: *Chemicals*, *Machinery*, *Metals and semi-finished products*, *Basic metals*, *Automobiles and parts*, *Agriculture*	Increase in imports and prices and decrease in real GDP
disaster management	- Government spending: *Defense*, *Public order and safety*	Increase in real GDP
Damages of a heat wave on:		
agriculture	- Imported intermediate goods: *Agriculture*	Increase in imports and prices and decrease in production value and real GDP
energy sector	- Electricity imports	Increase in imports and prices and decrease in production value and real GDP
labor productivity	- Labor productivity	Decrease in average wages per hour, increase in employment
transport by boat	- Input coefficients of ship and land transport services - Imported intermediate goods: *All*	Increase in imports and prices and decrease in real GDP

Who bears the costs? In case of companies and private households insurance companies have to bear a part of the costs, if they are insured against flood damages. For the model, this means that we have to increase the amount of other current transfers[1] of financial companies with respect to the average rate of national hazard insurance in the most affected federal states.

When streets are flooded, it is a nuisance to the average commuter. But valuation of commuting time is difficult, because most of us are not facing the neo-classical work-leisure choice and therefore valuation of longer commuting with wages is not very realistic. However, transport companies suffer from street damages and have to shift to other routes or even other means of transportation. Translated to modelling variables, this means that production output of the sector land transport is reduced by the amount of damages found in the literature. As a result unit costs rise.

For the public budget, one of the largest impact stems from disaster management, which directly translates to a modelling variable: public expenditures in the sectors defense and public order and safety.

Flood events as well as extreme high temperatures and drought may cause a massive loss in agricultural production. To model this, imported intermediate goods of the agricultural sector were changed in the climate scenario according to the findings from the literature review. Changes in the extent of imports directly influence Germany's gross domestic product. Germany is an open economy and exports as well as imports coin overall GDP. However, in the last years, exports exceeded imports by far causing the trade balance to be an issue of much debate. Some experts would argue that increasing imports might actually improve the trade balance. This is an obvious example that indicators cannot be interpreted out of context.

Power plants and grid operators are vulnerable to extreme weather events in several regards. They face difficulties in cooling during heat waves and difficulties in generation and distribution during flooding. A reduction in power generation was integrated into the model by increasing electricity imports corresponding to the literature. Decreases in production and outages are assumed to be replaced by imports.

Turning in full to heat waves, labor productivity is assumed to decrease. To determine the appropriate extent of this reduction, the average number of days with extremely high temperatures (> 30°C) in the future in Germany, the possible average daily reduction in labor productivity resulting from high temperatures and the average number of working days in Germany need to be known. On the basis of these data labor productivity during heat was estimated. The next feature of heat waves is low water levels. Though not as destructive as high tides, low levels affect several sectors negatively, too. Low river water levels challenge transport by boat, since shipping companies may be forced to reduce or

[1] "Other current transfers" are part of the German national account system and comprise – among others – payments of insurance companies for the settlement of claims.

temporarily cease their service entirely. To model this, transport of goods will temporarily be shifted from ship to land transport. In terms of modeling, modal shifts are always a problem. For the sectors using transport as an input, the modal shift translates into a shift in the input coefficients for both modes. This means that the input coefficients of shipping and land transport services were de- respectively increased. Furthermore, the already described effect of an increase in imports may take place, which means that the extent of imported intermediate goods increases according to the data on the possible loss of transported volume, found in the literature.

In a first run the “shocks” reflecting flood events were modeled in the form of ten-year events, which means that until 2050 every ten years the processes described above took place. An exception is the decade between 2041 and 2050 in which two flood events occur. It has to be stressed that we do not make a point regarding the likelihood of occurrence of flood events or heat waves. The occurrence in ten or four-year intervals is merely an assumption in accordance with estimations of climate experts concerning an increase in frequency and intensity of extreme weather events. The “shocks” reflecting heat waves are modeled in the form of four-year events. The frequency of these events can be varied in further runs. According to our modeling assumption, in the first decade between 2011 and 2020 only one event occurs, from 2021 to 2030 four events, followed by a decade with three events, and finally five events occur from 2041 to 2050. Table 3 gives an overview of the years in which extreme weather events occur.

Table 3: Occurrence of extreme weather events in PANTA RHEI

year	flood event	heat wave
2013	x	
2021		x
2023	x	
2025		x
2029		x
2033	x	x
2037		x
2041		x
2043	x	
2045		x
2048	x	x

3 Economic impacts of river flood events and heat waves in Germany until 2050

The aim of this paper is to investigate if and how recurring heat waves and river flood events affect the German economy, i.e. if an increasing number of these events leads to a change of Germany’s economic performance until 2050. For the analysis we have chosen eleven important economic indicators to estimate the impacts of extreme weather events on the German economy, which are (1) consumption of private households, (2) production, (3) capital stock, (4) investments, (5) exports, (6) imports, (7) available income, (8) employment, price indices of (9) production and (10) private consumption and finally (11) gross domestic product (GDP). Two scenarios present the economic development of Germany with (climate scenario) and without (reference scenario) considering extreme weather events. A comparison of the two scenarios shows the impact of flood events and heat waves on the German economy. Differences in the model variables show economic effects, since they reflect economic impulses triggered by the modeled shocks representing extreme weather events. When presenting results, it has to be stressed that the accuracy of the simulation results of PANTA RHEI is diminishing the longer the simulation period is, meaning that the simulation results for the first decade are more precise than for the last one. Simulation results are only intended to give an idea of possible extreme weather effects in Germany, with the main conclusions from the signs and direction of the effects observed.

Table 4 and Table 5 give an overview of the absolute (in bn. Euros, respectively in thousand people in the case of employment) and relative (in percent) impacts of extreme weather events on the selected economic indicators.

Table 4: Differences in bn. Euros (in thousands of employees in the case of employment), climate vs. reference scenario, decade averages

economic indicators	2011-2020	2021-2030	2031-2040	2041-2050
consumption of private households	-3.4	-12.2	-16.7	-23.5
production	-36.4	-92.6	-115.4	-165.7
capital stock	-70.3	-85.5	-71.9	-95.8
investments in building and facilities	-2.4	-4.7	-5.9	-11.0
exports	-6.6	-15.9	-24.0	-33.7
imports	1.2	12.2	12.0	17.8
employment	605.3	215.9	126.4	36.0
disposable income	0.0	-0.2	-0.2	-0.3

Table 5: Average deviation per decade in %, climate vs. reference scenario

economic indicators	2011-2020	2021-2030	2031-2040	2041-2050
consumption of private households	-0.02%	-0.08%	-0.11%	-0.14%
production	-0.08%	-0.18%	-0.20%	-0.26%
capital stock	-0.05%	-0.06%	-0.04%	-0.05%
investments in building and facilities	-0.05%	-0.09%	-0.11%	-0.18%
exports	-0.05%	-0.09%	-0.10%	-0.11%
imports	0.01%	0.08%	0.06%	0.06%
employment	0.15%	0.06%	0.04%	0.01%
available income	-0.02%	-0.10%	-0.12%	-0.17%
price index consumption of private households	0.04%	0.10%	0.13%	0.14%
price index production	0.09%	0.16%	0.19%	0.21%

The periodical occurrence of the shocks leads to heavily fluctuating deviations from the reference scenario for several indicators. For reasons of clarity, the deviations of the climate scenario in comparison to the reference run are accumulated in intervals of ten years for flow variables. For capital and employment, however, the differences in changes of stock averages with respect to previous decades are considered. The relative changes presented in Table 5 reflect the average deviation per decade of the climate scenario in comparison to the reference run. Thus, values in Table 4 and Table 5 reflect the total deviations of the respective decades, without adding up over the decades. The values of the period from 2031-2040, for example, only represent total deviations in this decade and do not contain the deviations of the previous periods.

The simulation results reveal that the effects regarding single components are rather low. However, they also show that, firstly, the overall economic effect of occurring extreme weather events is slightly negative and, secondly, that the deviations from the reference run are in most cases increasing over time. This indicates that recurring events tend to weaken Germany's economic performance, albeit on a very low level.

The capital stock plays an essential role in the determination of an economy's production potential. To model damages to buildings and production sites resulting from a flood event, the capital stock of some economic sectors is reduced (see section 2). The decline, representing damages to buildings and facilities, amounts to 0.05% until 2020, slightly increases in the following decade (0.06%) and decreases in the third decade (0.04%). In the last period between 2041 and 2050 the capital stock in the climate scenario is 0.05% percent lower in comparison to the reference. This seems to be quite low but expressed in bn. Euros, the "loss" of the capital stock until 2050 amounts to more than 320 bn. Euros (accumulated over the four periods), which may reduce Germany's production potential substantially. Reductions in the capital stock usually trigger additional investments in buildings and facilities, since a "loss" in capital stock requires (replacement) investments to provide the same production conditions as before an event. Simulation results indicate, however, that investments decrease and are between 0.05% (until 2020) and almost 0.2% (2041-2050) lower than in the reference. Expressed in bn. Euros the reductions amount to between 2.4 and 11.0 bn. Euros. This is because investments are not only determined by capital stock but by other demand components as well, which in turn is determined – among other components – by consumption of private households. Sectors whose products are less demanded than in the reference scenario may forego replacement investments. Obviously, this is the case in most economic sectors. Furthermore, investments as well as capital losses in turn determine capital stock. This also explains the negative effect on total capital stock, since a reduction in investments, as can be observed in the climate scenario, influences the capital stock negatively.

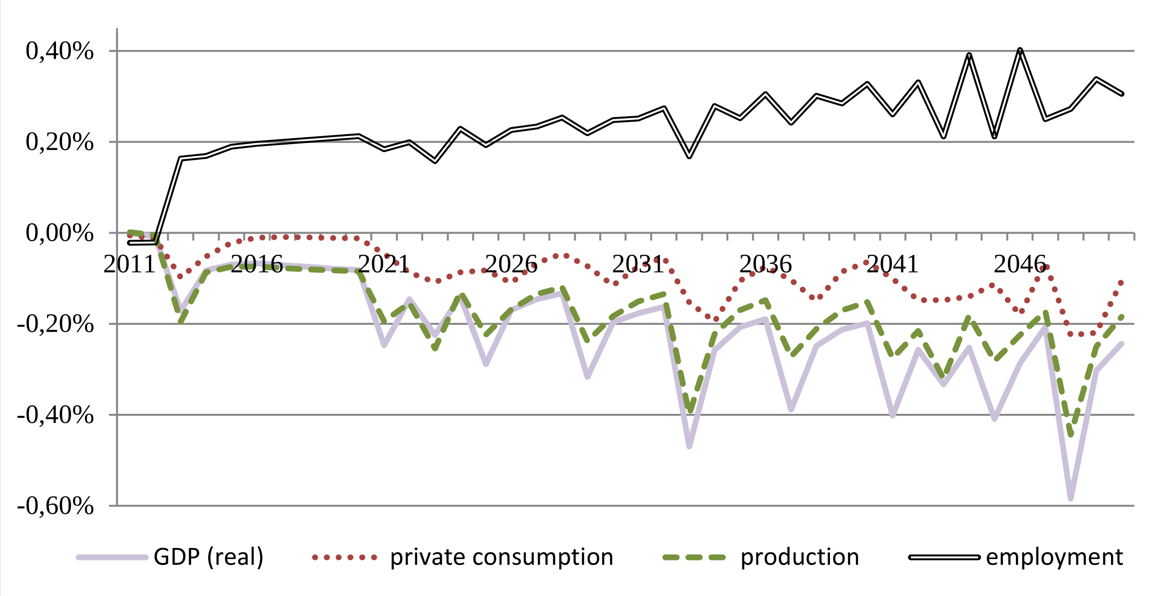
In the aftermath of an extreme weather event, businesses are confronted with rising unit costs, resulting – among others – from rising depreciation and labor costs. The latter is a consequence of a reduction in labor productivity. Since unit costs determine prices, production prices as well as consumer prices increase. Overall, the price level in the climate scenario increases faster than in the reference scenario. Production prices are between 0.09% (until 2020) and 0.21% (2041-2050) higher than in the reference, consumer prices between 0.04% and 0.14%. A higher price level in combination with lower wages leads to a lower disposable income of private households in real terms in comparison to the reference. Additionally, a minor part of the effect is attributable to the reduction of disposable income by annuity payments, which was an exogenous model assumption. These payments have to be made by households, who were forced to take out a loan to remedy flood damages to dwellings. According to the simulation results, a single flood event only has a rather small effect on disposable income. This is the case until 2020, when the average deviation from the reference run only amounts to -0.02%. Only in the later periods, in which several events take place, small effects are observable. Between 2021 and 2030 the disposable income is almost 0.1% (0.2 bn. Euros) lower than in the reference. In the years between 2041 and 2050 the deviation amounts to 0.17% which represents a reduction of 0.3 bn. Euros in comparison to the reference.

Less income clearly leads to a reduction in consumption. Simulation results reveal that private consumption is between 0.02% (3.4 bn. Euros) and 0.14% (23.5 bn. Euros) lower than in the reference, which has a dampening effect on Germany's production. Germany's produced output decreases between 0.08% (2011-2020) and 0.26% (2041-2050) which means that in the climate scenario it is between 36 bn. and 166 bn. Euros lower than in the reference scenario. This explains why Germany's exports slightly decrease (between 0.05% and 0.11%) in comparison to the reference scenario. Imports however increase due to the reduction in domestic production, i.e. final as well as intermediate goods which are required for further processing have to be obtained from abroad. The strongest percentage deviation from the reference run of about 0.08% is observable in the years between 2021 and 2030, the strongest total deviation in the years between 2041 and 2050, amounting to 17.8 bn. Euros.

The development of the economic indicators presented here indicates a slightly negative impact of recurring extreme weather events on the German economy. Nevertheless, simulation results reveal a positive development of employment. In the climate scenario, employment increases in the first decade by 0.15%. However, the extent of the deviation per decade diminishes over time, amounting to only 0.01% on average in the last decade. The principally positive (> 0) development can be explained by the increase in the number of very hot days in the climate scenario, which has been modeled as a reduction in labor productivity. More employees are hence required to generate the same output. The diminishing trend can be explained by demographic change. The reduction in labor productivity actually pushes demand for additional labor but this effect is counteracted by a decreasing labor force potential.

Overall economic effects of recurring river floods (every ten years) and heat waves (every four years) are rather moderate in Germany until 2050. Despite strongly fluctuating deviations it becomes clear that the overall effect is negative (an exception is rising total employment in Germany), albeit on a very low level. Moreover, the effect is slightly intensifying over time, irrespective of the number of extreme weather events that are modeled in a given decade. This can be seen in Figure 2 where the deviation per year of important economic indicators from the reference is presented. The number of events occurring during a decade may certainly have a small impact on the deviations from the reference scenario, since for example the smallest effects are observable in the first decade when only a flood event occurs. However, Table 4 and Table 5 reveal that deviations in the decade from 2031 to 2040 (three events) are higher than those in the previous decade (four events) even if less events occur. This may answer the question if the more frequent occurrence of extreme weather events weakens the German economy. The simulation results show that the strength of the effects is very low. However, effects seem to be lasting, which means that the predicted increase in frequency and intensity of extreme weather events may challenge Germany's economy in the future. Maximal values of (negative) changes for all indicators are observable in the years 2033 and 2048, two years in which a heat wave and a flood event co-occur. The GDP is in these years about 0.5%, respectively 0.6% lower than in the reference, which is a decrease of 14 bn., respectively 20 bn. Euros.

Figure 2: Economic development, difference (in %) climate vs. reference scenario, price adjusted



For reaching a more profound final conclusion it is essential not only to assess overall economic effects, but also to include effects in different economic sectors, since these effects may otherwise be underestimated. The sectoral effects are discussed for ten economic sectors, resulting from an aggregation of 59 more detailed sectors from the System of National Accounts (see Table 6). Thus, rather than a detailed description of the single effects of extreme weather events on the economic sectors, an overview of the most and least affected industries is given.

Table 6: Aggregated economic sectors

economic sectors	
agriculture, forestry and fishery	trade; maintenance and repair of motor vehicles
mining and quarrying	hotel and restaurant industry
manufacturing	transport and communication services
energy and water supply	financial intermediation
construction	other services

To get a first idea, which sectors are the most affected by extreme weather events, the development of two important economic indicators – gross value added (GVA) and employment – in the climate versus the reference scenario are presented on a sectoral basis. Regarding gross value added Table 7 gives an overview of the deviations of the climate scenario in comparison to the reference scenario in bn. Euros, accumulated in intervals of ten years. According to the simulation results some sectors benefit whereas others appear to suffer from extreme weather events. In monetary values the sectors manufacturing and other services are most negatively affected. The latter comprises – among others – real estate activities, public administration, social security, education, health and social work. Whereas the deviation from the reference run is only about -3.6 bn. respectively -2.5 bn. Euros in the period until 2020, the deviation amounts to -22.2 bn. and -25.2 bn. Euros in the last decade from 2041 to 2050. The reduction in manufacturing can be explained by damages to production sites that force businesses to interrupt production temporarily until these damages are remedied. The reinforcing development is the result of increasing depreciations and labor costs which reduce the net operating surplus and thus gross value added.

Table 7: Gross value added, deviations in bn. Euros, climate vs. reference scenario, decade averages

economic sectors	2011-2020	2021-2030	2031-2040	2041-2050
agriculture, forestry and fishery	0.1	0.0	0.4	0.3
mining and quarrying	-0.1	-0.3	-0.3	-0.3
manufacturing	-3.6	-14.0	-13.6	-22.2
energy and water supply	-0.3	-0.6	-0.8	-1.0
construction	1.7	3.1	5.0	5.4
trade; maintenance and repair of motor vehicles	2.0	3.8	6.6	7.8
hotel and restaurant industry	-0.2	-0.7	-0.9	-1.3
transport and communication services	6.5	9.1	10.3	10.7
financial intermediation	0.6	0.8	1.3	1.3
other services	-2.5	-12.6	-16.5	-25.2

The sectors trade, construction and transport services are developing differently, since they grow stronger after an extreme weather event. In monetary values the transport sector benefits the most, as the deviation from the reference amounts to, in total, 6.5 bn. Euros between 2011 and 2020 and increases in the following years. Between 2041 and 2050 the deviation in gross value added amounts to almost 11 bn. Euros. The trade sector follows with 2 bn. to 7.8 bn. Euros and the construction sector deviating between 1.7 bn. and 5.4 bn. Euros from the reference. The transport sector benefits from the positive development in the trade and construction sector. Not only demand for construction material and for the disposal of rubble increases, implicating an increased need for transport services, but also demand for machinery and other equipment in affected regions rises after an extreme weather event. The monetary values give indeed a first insight into the extent of changes in gross value added resulting from extreme weather events, but they do not fully answer the question which sectors probably are the most affected. Relative deviations, summarized in Table 8, give more information on this issue. Most striking are the rather small deviations from the reference run which are between (-) 0.1% and (-) 0.3%, with the transport sector as an exception with percentage changes between 0.4 and 0.5. Furthermore, despite the relatively strong deviations in monetary terms, relative deviations show that the sector of Other Services is hardly affected by extreme weather events. The manufacturing sector, being the second most negatively affected sector in monetary values, is less negatively affected than the sector mining and quarrying. Gross value added of the manufacturing sector decreases by 0.1% (2011-2020) to 0.3% (2041-2050) and 0.2% in the decades in between, whereas the reduction in the sector mining and quarrying amounts to 0.2% (2011-2020) and 0.3% in the remaining three decades. This development is due to the negative development in the manufacturing sector since the mining and quarrying industry requires a range of intermediate products from the manufacturing sector for the production. However, the sector mining and quarrying only contributes little to total gross value added. The response of the sector mining and quarrying to the reduction in produced output of the manufacturing sector reflects a weakness of the model. It can be assumed that the imports of equipment required by the mining and quarrying sector rise after an extreme event if supply shortages in Germany exist. However, intermediate input linkages of the sector mining and quarrying are, to a large extent, constant in the future which means that an adaptation to the consequences of an extreme weather event e.g. by sourcing abroad cannot be expressed by PANTA RHEI. Considering relative deviations, the sector transport and communication services is still the sector most positively affected with an increase in gross value added of 0.5% in the period between 2021 and 2030 and 0.4% in the other decades. The construction sector follows with deviations amounting to values between 0.1% and 0.3%.

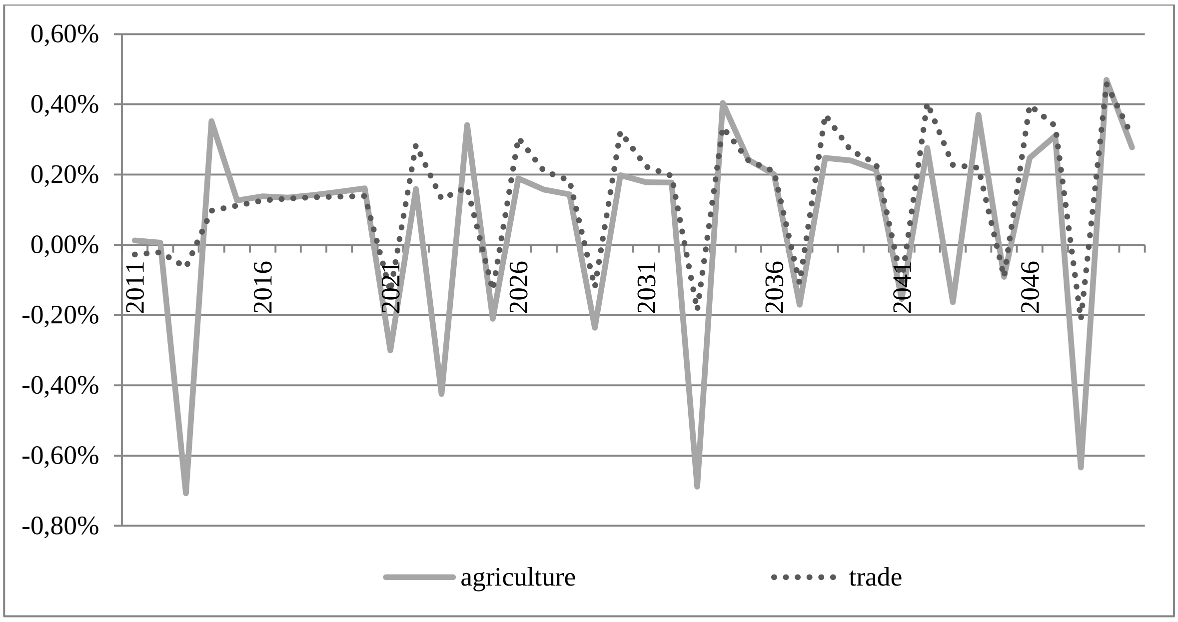
Table 8: Gross value added, average deviations per decade, climate vs. reference scenario, in percent

economic sectors	2011-2020	2021-2030	2031-2040	2041-2050
agriculture, forestry and fishery	0.1%	0.0%	0.1%	0.1%
mining and quarrying	-0.2%	-0.3%	-0.3%	-0.3%
manufacturing	-0.1%	-0.2%	-0.2%	-0.3%
energy and water supply	0.0%	-0.1%	-0.1%	-0.2%
construction	0.1%	0.2%	0.3%	0.3%
trade; maintenance and repair of motor vehicles	0.1%	0.1%	0.2%	0.2%
hotel and restaurant industry	0.0%	-0.1%	-0.1%	-0.2%
transport and communication services	0.4%	0.5%	0.4%	0.4%
financial intermediation	0.1%	0.1%	0.1%	0.1%
other services	0.0%	-0.1%	-0.1%	-0.1%

Simulation results indicate a slightly positive effect on agriculture – if considering average deviations per decade. However, it is hard to explain why an industry that is particularly challenged by inundation, heat and drought may not lose or even “benefit” from these events. This argument reveals the “weakness” of both Table 7 and Table 8. Both give an overview of the extent to which an economic sector is affected, but they do not give information on the heavily fluctuating annual deviations. Figure 3 shows annual deviations from the reference scenario in the sectors agriculture and trade (in percent). The total effect on these sectors, positive in both cases, does not reflect the vulnerability of a sector. Simulation results indicate years with negative as well as years with positive effects. Even if the negative effect on gross value added in the agricultural sector is quite strong (-0.71%) on an annual basis in comparison to the other sectors, the overall effect on the sector is positive, meaning that negative impacts in the years in which extreme events occur are overcompensated by positive effects in the years in between. The same is true for the trade sector: negative effects are observable but positive effects predominate.

The stronger the impact, the stronger is the counter-reaction in the years following extreme weather events. Even if gross value added in both sectors has a slightly positive overall effect, it should be stressed that particularly the agricultural sector may be challenged by an increasing number of extreme events. The relatively “strong” counter-reactions can be explained by the fact that prices increase in the aftermath of an extreme weather event due to the likely massive crop loss. Higher prices in years following an extreme event may compensate farmers for the losses in the previous, thus lead to an increase in gross value added.

Figure 3: Gross value added, deviations from the reference scenario of the sectors trade and agriculture, in percent



Agriculture and trade are not the only sectors characterized by fluctuating deviations from the reference run. Similar analysis can be applied to the other sectors as well. To give an idea of the fluctuations, Table 9 summarizes the standard deviations of the industries in intervals of ten years. Additional to the agricultural and the trade sector, also deviations in gross value added of the manufacturing sector are strongly fluctuating. Furthermore, fluctuations are increasing over time, which could be the consequence of a missing price adjustment.

Overall, the most striking developments take place in the sectors agriculture, manufacturing, construction, trade and transport, where the strongest deviations from the reference and the strongest fluctuations of the deviations are observable.

Besides gross value added, employment typically is an important indicator of Germany’s economic performance. The analysis of damages from extreme weather teaches us to treat this indicator carefully: The higher number of employees is mainly due to the reduction in labor productivity during heat waves which causes a higher demand for additional labor force. More people are employed, albeit to lower wages. Therefore, higher employment levels are not so much a result of economic success. For the last decade, however, several extremes come together and the overall employment is negative for most sectors.

Only in four sectors employment is still higher than in the reference (trade, hotel and restaurant industry, transport and other services), because they only get the impact of lower productivity and no additional damages in the case of hotels etc. or they even benefit from other people's damages in the case of transport. Employment in all other sectors starts to suffer from extreme events in the last decade, being at a lower level in comparison to the reference run.

Table 9: Standard deviation of sectoral gross value added

economic sectors	2011-2020	2021-2030	2031-2040	2041-2050
agriculture, forestry and fishery	0.27%	0.25%	0.30%	0.32%
mining and quarrying	0.05%	0.14%	0.14%	0.14%
manufacturing	0.07%	0.21%	0.26%	0.30%
energy and water supply	0.02%	0.03%	0.05%	0.07%
construction	0.10%	0.05%	0.07%	0.06%
trade; maintenance and repair of motor vehicles	0.08%	0.17%	0.17%	0.23%
hotel and restaurant industry	0.03%	0.03%	0.07%	0.07%
transport and communication services	0.02%	0.15%	0.12%	0.16%
financial intermediation	0.05%	0.03%	0.04%	0.05%
other services	0.02%	0.02%	0.04%	0.03%

In contrast to the overall economic effects represented in Figure 2 and Table 4 and Table 5, the sector effects reveal the already mentioned constraints resulting from a reduction in labor force potential resulting from demographic change. The sector specific development of employment is presented in Table 10.

Table 10: Employment, deviations from the reference scenario, in thousands, accumulated in intervals of ten years

economic sectors	2011-2020	2021-2030	2031-2040	2041-2050
agriculture, forestry and fishery	7.1	-2.5	3.9	-0.1
mining and quarrying	1.5	0.1	-0.1	-0.3
manufacturing	151.7	18.5	17.0	-5.7
energy and water supply	6.1	2.5	0.9	-0.6
construction	32.8	10.6	7.2	-1.8
trade; maintenance and repair of motor vehicles	86.0	29.3	18.2	11.3
hotel and restaurant industry	49.4	29.0	15.0	11.0
transport and communication services	18.5	53.9	4.4	21.8
financial intermediation	23.7	8.6	3.3	-0.5
other services	236.9	65.9	56.6	0.8

Considering absolute numbers, most jobs are created in the sector Other Services, followed by the manufacturing sector and trade. In the first decade (2011-2020) more than 230,000 persons are additionally employed per decade in the sector other services in comparison to the reference. In the last decade the number amounts to 800 additional employees. In the manufacturing sector the increase in employment amounts to more than

150,000 in the first decade. Between 2014 and 2050, a total of almost 6000 less persons is employed in the manufacturing sector in the climate scenario compared to the reference. The trade sector starts with positive difference of 86,000 employees and ends up with a number with a plus of 11,000 employees. The relatively high numbers of the three sectors in the first decade are certainly attributable to their importance for Germany's economic performance. Thus, the number of employees and therefore the increase of this number are automatically higher than in other sectors. Expressed in relative deviations, it becomes clear that employment in sectors other than other services benefit the most from extreme weather events. The hotel and restaurant industry (0.24% to 0.06%), the sector energy and water supply (0.24% to -0.03%) and the transport sector (0.09% in the first, 0.27% in the second and up to 0.12% in the last decade) record the strongest positive deviations in employment in comparison to the reference scenario. Least affected in relative terms are the sectors agriculture and other services.

Table 11: Employment, deviations from the reference scenario, in percent, based on accumulated deviation in monetary values

economic sectors	2011-2020	2021-2030	2031-2040	2041-2050
agriculture, forestry and fishery	0.10%	-0.04%	0.07%	0.00%
mining and quarrying	0.26%	0.02%	-0.02%	-0.11%
manufacturing	0.22%	0.03%	0.04%	-0.01%
energy and water supply	0.24%	0.11%	0.05%	-0.03%
construction	0.14%	0.05%	0.04%	-0.01%
trade; maintenance and repair of motor vehicles	0.15%	0.06%	0.04%	0.03%
hotel and restaurant industry	0.24%	0.15%	0.08%	0.06%
transport and communication services	0.09%	0.27%	0.02%	0.12%
financial intermediation	0.21%	0.09%	0.04%	-0.01%
other services	0.12%	0.03%	0.03%	0.00%

Employment in mining and quarrying shows in the first decade a relatively strong positive impact but the development in the following decades is rather negative, which goes hand in hand with the negative development of gross value added in this sector (see Table 8). Also the development of employment on the sector specific basis confirms the already described trend of a slightly increasing intensity of the negative effects over time. In all sectors the relative deviations in the decade between 2041 and 2050 are less positive respectively more negative than in the previous decade, although one event less is modeled.

Also, deviations in sector specific employment from the reference scenario are characterized by fluctuations which, however, are significantly lower than the deviations referring to gross value added. Deviations in the sector transport and communication services fluctuate the most. Conversely, deviations from the reference scenario in employment in sectors such as agriculture, manufacturing and trade fluctuate far less than in gross value added. The sector specific results underline the importance of a disaggregation by sector when analyzing economic impacts of extreme weather events. Considering only overall economic effects one may conclude that extreme weather events stimulate employment. A disaggregation by sector, however, reveals that until 2050 employment in Germany does not benefit unrestrictedly by extreme weather events. In most of the sectors employment is in the last decade in the climate scenario lower than in the reference. The positive development in other sectors overcompensates the negative effects, which leads to the positive results shown in Table 4 and Table 5 as well as Figure 2.

Table 12: Standard deviation of sector specific employment

economic sectors	2011-2020	2021-2030	2031-2040	2041-2050
agriculture, forestry and fishery	0.12%	0.10%	0.12%	0.12%
mining and quarrying	0.14%	0.08%	0.09%	0.10%
manufacturing	0.12%	0.07%	0.10%	0.10%
energy and water supply	0.12%	0.03%	0.03%	0.01%
construction	0.08%	0.04%	0.05%	0.04%
trade; maintenance and repair of motor vehicles	0.09%	0.02%	0.03%	0.03%
hotel and restaurant industry	0.12%	0.03%	0.04%	0.04%
transport and communication services	0.11%	0.25%	0.22%	0.27%
financial intermediation	0.11%	0.03%	0.04%	0.02%
other services	0.07%	0.04%	0.06%	0.11%

4 Conclusion

The analysis has shown that extreme weather events only have a small effect on the German economy. However, despite the impression that the German economy might be quite resilient towards extreme weather events, the analysis shows an intensification of the impacts on economic sectors and the economy as a whole in the future. This means that recurring extreme weather events have the potential to weaken Germany's economic performance in the future. The analysis of the impacts on gross value added and employment on a sector specific level has revealed which sectors are mainly influenced by extreme weather events, given the set of assumptions used in the modeling. Manufacturing and mining and quarrying are the most heavily affected industries with respect to gross value added. However, in comparison to the reference scenario employment in these sectors grows stronger than in other sectors, whose gross value added is less affected by extreme weather events. The transport sector benefits the most from extreme events in terms of value added which is also reflected in the development of its employment.

Not only industries differ in their vulnerability to extreme weather events, but also the regions in Germany. Reductions in agricultural production, for example, will have stronger impacts on the economy of Schleswig-Holstein than on North Rhine-Westphalia, since agricultural production in Schleswig-Holstein plays a more important role for the value added in that region than in North Rhine-Westphalia. Regarding this issue, further research has to be undertaken to gain a more comprehensive insight into the impacts of extreme weather events in Germany. Detailed knowledge about a region's vulnerability to extreme events is decisive with respect to policy implications. Within a regional approach, the burden sharing process will gain more relevance. Although the effects spread over the whole economy, the local or regional effects on individual households might be much larger. These aspects escape a macro-modeling exercise.

Furthermore, the access to more comprehensive and more detailed data on damages and costs resulting from extreme weather events in Germany could improve simulation results. Finally, it has to be stressed that effects on Germany are analyzed without taking climate change effects on other countries into account. It can be assumed that an integration of effects abroad may intensify the effects in Germany. For example, summer temperatures and precipitation patterns in Southern Europe are expected to change to the effect that a cultivation of fruits and vegetables in Southern Europe like today would not be possible any longer. This would have impacts on Germany's international trade flows, on consumers and particularly on the manufacturing industry which may suffer from supply shortages and/or potential higher prices when being forced to obtain foodstuffs from suppliers overseas.

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