Publizierbarer Endbericht

Gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
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Projekt- und KooperationspartnerIn (inkl. Bundesland):	JOANNEUM RESEARCH Forschungsgesellschaft mbH (ST/W) University of Graz, Wegener Center for Climate and Global Change, Regional Climate Research Group (ST)
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Allgemeines zum Projekt	
Klimafonds-Nr:	B670197
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B) Projektübersicht

1 Kurzfassung

Die weltweiten Auswirkungen des Klimawandels können sich über den Handel bis nach Österreich übertragen. Beispiele für solche Risiken sind großräumige Ernteausfälle, Meeresspiegelanstieg, Veränderungen der Wasserverfügbarkeit oder der Arbeitsproduktivität. Die Folgen des weltweiten Klimawandels stellen somit ein potenzielles Risiko für Österreichs Volkswirtschaft dar. Das Ziel des Projekts COIN-INT war es daher, diese indirekten handelsinduzierten Klimawandelfolgekosten für Österreich zu beurteilen und mit den direkten Klimawandelfolgekosten, die innerhalb Österreichs entstehen, zu vergleichen.

Das Projekt COIN-INT behandelte folgende Forschungsfragen:

1. Wie unterscheiden sich Länder bzw. Weltregionen hinsichtlich der Vulnerabilität gegenüber dem Klimawandel?
2. Welche Folgen ergeben sich daraus für Österreichs Handelsströme und den Ressourcenverbrauch enthalten im Konsum?
3. Welche volkswirtschaftlichen Kosten entstehen dadurch im Inland, auch im Vergleich zu den inländischen Kosten des Klimawandels?
4. Wie können sich österreichische Unternehmen und die politischen Entscheidungsträger auf diese Risiken vorbereiten?

Die zentralen Ergebnisse des Forschungsprojekts sind:

- Viele der wichtigsten Handelspartner Österreichs, beispielsweise China, Brasilien und die USA, sind von Extremwetterereignissen und Klimawandelfolgen deutlich stärker betroffen als Österreich, insbesondere unter einer starken globalen Erwärmung. Die Handelsverflechtungen haben sich zudem weltweit in den letzten 10 Jahren deutlich intensiviert und dies gilt insbesondere für eine kleine offene Volkswirtschaft wie Österreich. Grenzüberschreitende Klimawandelfolgen sind somit von zunehmender Relevanz für Österreich.
- Österreichs Konsum basiert auf zahlreichen Ressourcen, welche zu einem erheblichen Anteil über den Handel mit anderen Ländern bereitgestellt werden. Für die in diesem Projekt untersuchten Ressourcen (Wasserverbrauch, Getreideproduktion, Veränderungen der Arbeitsproduktivität durch Hitze und Malaria Risiko) ist Österreich, wie auch andere europäische Länder, ein Netto-Importeur. Das Beispiel Wasser verdeutlicht die globale Verflechtung: rund ¾ der virtuellen Wasser-Importe Österreichs stammen von Regionen außerhalb Europas.
- Ein Ignorieren grenzüberschreitender Klimawandelfolgen unterschätzt die Auswirkungen des Klimawandels auf den Ressourcenverbrauch deutlich: Eine durch günstige klimatische Bedingungen mögliche Ausweitung des

Getreidekonsums in Österreich im mittleren Szenario von 2.3% ist zu Zwei-Drittel auf einen Anstieg der Getreideproduktion in anderen Ländern zurückzuführen. Deutlicher zeigt sich dieser Einfluss am Beispiel Wasser, wo ein leichter Rückgang des heimischen Konsums (-0.2%) durch positive, grenzüberschreitende Wirkungen kompensiert wird (+1.9%). Der Effekt von sinkender Arbeitsproduktivität, einerseits hitzebedingt und andererseits durch Ausbreitung des Malariarisikos, ist beinahe zur Gänze transnational: der Konsum von Arbeitskraft, welches als Malaria gefährdet einzustufen ist, steigt um 22% an und betrifft v.a. die Importe von elektronischen und optischen Produkten, Bekleidung, und Autozubehör.

- Innerhalb der EU liegt Österreich beim Anteil der indirekten, grenzüberschreitenden Wirkungen im ersten Drittel und gehört daher zu den exponierten Ländern. Europas Ressourcenabhängigkeit wird durch Klimawandel verschärft, es entstehen aber auch Chancen, wie im Bereich Getreide oder auch durch Rückverlagerung arbeitsintensiver Schritte.
- Obwohl Österreichs primäre Handelspartner derzeit innerhalb Europas liegen, ist Österreichs Volkswirtschaft von grenzüberschreitenden Klimawandelfolgen in den Bereichen Meeresspiegelanstieg, hitzebedingte Einbußen in der Arbeitsproduktivität und Ernteausfälle in der Landwirtschaft mit rund 1.5-2 Mrd. Euro um 2050 betroffen; dies entspricht 15-30% der volkswirtschaftlichen Kosten durch Klimawandelfolgen im Inland. Die stärksten Rückgänge entstehen bei Importen von Textilien, Dienstleistungen, Lebensmittel, Maschinen und Fahrzeuge. Importe aus Europa steigen leicht, können aber den starken Rückgang der Importe aus dem Rest der Welt nicht kompensieren. Exportseitig kann sich Österreich leicht verbessern, obwohl die Exporte in den Rest der Welt aufgrund der sinkenden Nachfrage rückläufig sind.
- Unternehmen berücksichtigen grenzüberschreitende Klimawandelfolgen zu wenig in ihren Entscheidungen. Unternehmen können das Risiko reduzieren, indem sie Klimarisiken entlang ihrer Lieferketten in das unternehmerische Risikomanagement aufnehmen, Zulieferer diversifizieren, die Lagerhaltung ausbauen oder ihre Versicherungen erweitern. Auch potenzielle Chancen könnten sich für den Standort Österreich und Europa ergeben – dies hängt jedoch auch von der globalen Nachfrage abhängig.
- Einige Länder wie Großbritannien und Deutschland inkludieren grenzüberschreitende Klimawandelfolgen in ihren Klimarisikoabschätzungen sowie in ihren Anpassungsstrategien und -plänen. Dies ist ein erster wichtiger Schritt, um das Bewusstsein für Anpassungsmaßnahmen in diesem Bereich zu schärfen. Weiters kann der Staat durch Anpassungsfinanzierung vulnerable Herkunftsländer unterstützen. Dies untermauert, dass reine nationale Maßnahmen und Bemühungen zu kurz greifen und Europa nur mithilfe internationaler Kooperationen grenzüberschreitende Klimawandelauswirkungen dämpfen kann.

2 Executive Summary

The global effects of climate change can be transferred to Austria via trade. Examples of such transnational risks of climate change are large-scale crop failures, sea-level rise, changes in water availability or in labor productivity to increased heat and malaria risk. The consequences of global climate change thus represent a potential risk for Austria's economy. The goal of the COIN-INT project was therefore to assess these transnational costs of climate change for Austria and to compare them with the costs that arise within Austria.

The COIN-INT project addressed the following research questions:

1. How do countries or world regions differ in their vulnerability to climate change?
2. What are the consequences for Austria's trade flows and the use of resources embodied in consumption?
3. What economic costs are incurred domestically, also in comparison to the domestic costs of climate change?
4. How can Austrian companies and political decision makers prepare for these risks?

The key results of the research project are:

- Many of Austria's most important trading partners, for example China, Brazil and the USA, are affected more strongly by extreme weather events and climate change impacts than Austria, especially under conditions of strong global warming. Moreover, trade interdependencies have intensified significantly worldwide in the last 10 years, especially for a small open economy like Austria. Transnational climate change impacts are therefore of increasing relevance for Austria.
- Austria's consumption is based on various resources that are provided to a significant extent by trade with other countries. For the resources studied in this project, i.e. water consumption, grain production, changes in labor productivity due to heat and malaria risk, Austria is a net importer like other European countries. The example of water illustrates the global interdependence: about ¾ of Austria's virtual water imports originate in regions outside Europe.
- Ignoring transnational climate change impacts clearly underestimates the effects of climate change on resource consumption: Two-thirds of the 2.3% increase in cereal consumption in Austria (according to an intermediate scenario), which is enabled by favorable climatic conditions, is due to an increase in cereal production in other countries. This influence can be seen more clearly in the example of water, where a slight decrease in domestic consumption (-0.2%) is compensated by positive transnational effects (+1.9%). The effect of declining labor productivity, due to both heat and the spread of malaria risk, is almost entirely transnational: the consumption

of labor, which is classified as being at risk of malaria, increases by 22%, which primarily affects imports of electronic and optical products, clothing, and car parts.

- Within the EU, Austria is in the top third in terms of the share of transnational effects and is therefore one of the most exposed countries to transnational climate risks embodied in resource consumption. Europe's resource dependency is exacerbated by climate change, but opportunities also arise, such as in the crop sector or by shifting back labor-intensive steps to Europe.
- Although Austria's primary trading partners are currently located within Europe, Austria's economy is affected by transnational climate change impacts in the areas of sea-level rise, heat-related losses in labor productivity and crop failures in agriculture with around 1.5-2 billion euros by mid-century; this corresponds to 15-30% of the economic costs of climate change impacts within Austria. The sharpest declines are in imports of textiles, services, food, machinery and vehicles. Imports from Europe are rising slightly, but cannot compensate for the sharp decline in imports from the rest of the world. On the export side, Austria can improve slightly, although exports to the rest of the world are declining due to falling demand.
- Companies currently take too little account of transnational climate change impacts in their decisions. Companies can reduce the risk by including climate change risks in corporate risk management along their supply chains, diversifying suppliers, expanding storage capacities or extending their insurance coverage. Potential opportunities could also arise for Austria and Europe as a business location - but this also depends on global demand.
- Some countries, such as the UK and Germany, include transnational climate change impacts in their climate risk assessments and in their adaptation strategies and plans. This is an important first step towards raising awareness of adaptation needs in this area. Furthermore, public authorities can support vulnerable countries of origin through adaptation finance. This underscores the fact that purely national measures and efforts fall short and that Europe can only mitigate transboundary climate change impacts with the help of international cooperation.

3 Hintergrund und Zielsetzung / Background and Research Goal

The number of national, regional, and global studies on the aggregate costs of climate change impacts and adaptation has increased substantially over the last years. For Austria, the most comprehensive study on the aggregate costs of climate change is the COIN project which assessed climate change impacts for 12 impact fields from a macroeconomic perspective. One serious limitation of most of these impact assessment studies, including the COIN study, is that they ignore the international trade or transnational spillover effects of climate change. This lack of academic literature on climate change vulnerability transmitted by international supply chains is also reflected in the IPCC's AR5 Working Group II synthesis of hundreds of studies on climate change impacts where the international trade dimension of climate change impacts is mentioned cursory (Oppenheimer et al. 2014; Hewitson et al. 2014).

Several recent reports and papers conclude that transnational risks of climate change (also called international, transboundary or borderless risks) might pose a similar or even greater threat for the economy than the domestic climate change impacts (PricewaterhouseCoopers 2013; Persson 2019, Challinor et al. 2017, Hedlund et al. 2018, Benzie et al. 2019). At least five channels for the global transmission of climate risks can be distinguished: biophysical (e.g. shared river basins and other ecosystems); flows of people (e.g. migration), international trade in goods and services, investment and capital flows, and health related channels (e.g. spread of diseases).

In the last decade, a substantial internationalization of supply chains has occurred due to multilateral trade agreements, lower trade tariffs and investment barriers, declining transport costs, technological change in information and communication systems as well as internationalization of R&D activities. Considering these developments in international trade, there is a higher potential for disruption or unfavorable effects of bottlenecks to the supply chain, particularly due to global climate change impacts. For instance, reduced agricultural productivity in specific world regions may trigger higher world market prices and decrease food security. More frequent extreme weather events and disasters may disrupt transport systems and therefore supply and demand chains of manufacturing and service sectors. The high level of global interconnectedness is of special importance for small open economies, such as Austria, as they source relatively more inputs from abroad and produce relatively more inputs for use in global value chains than large economies.

Ignoring spillover effects of climate change via international trade and global supply chains may therefore systematically misjudge the true costs of climate change for Austria, and systematically underestimate both the risks and potentials of climate change for Austria. In this research project, we therefore assessed the transnational risks of climate change for Austria, by focusing specifically on the trade channel. The following research questions were addressed:

1. How do countries or world regions differ in their vulnerability to climate change?
2. What are the consequences for Austria's trade flows and the use of resources embodied in consumption?
3. What economic costs are incurred domestically, also in comparison to the domestic costs of climate change?
4. How can Austrian companies and political decision makers prepare for these risks?

4 Projektinhalt und Ergebnis(se) / Project Content and Results

This section is structured along the four main research questions. For details on methodologies and project structure, see section C.

1) How do countries or world regions differ in their vulnerability to climate change?

We identified projections from the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP, Warzawski et al. 2014) Fast Track as the best state of the art information on global climate change vulnerabilities. Within ISIMIP global climate change data from five global climate models (GCMs) participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5, Taylor et al. 2012) have been bias corrected and subsequently were used to drive multiple impact models (IMs) for multiple impact fields.

We used ISIMIP IM data to estimate changes for the impact fields (variables) agriculture (crop production and crop potential irrigation water withdrawal), water (available blue water), health (potential population at risk of malaria transmission) and coastal infrastructure (expected annual seaflood costs and expected annual people flooded) as well as CMIP5 GCM data to estimate changes in work ability for three different work intensities (light, moderate and heavy) as well as two different work environments (indoor and outdoor; Kjellstrom et al., 2009; Bröde et al., 2017).

Figure 1 shows changes of selected variables for all impact fields on the grid point level of the three selected model combinations of CMIP5-GCMs and ISIMIP-IMs under the emission scenario RCP8.5 until the end of the century. While the single model combinations show regional differences, projected vulnerabilities are especially high in South and Southeast Asia (agriculture and work ability), Africa (agriculture, water availability and work ability), and Central and South America (agriculture, water, work ability and health). For other regions general tendencies are not identifiable, while virtually all countries suffer from higher annual seaflood costs in projections of future climate change.

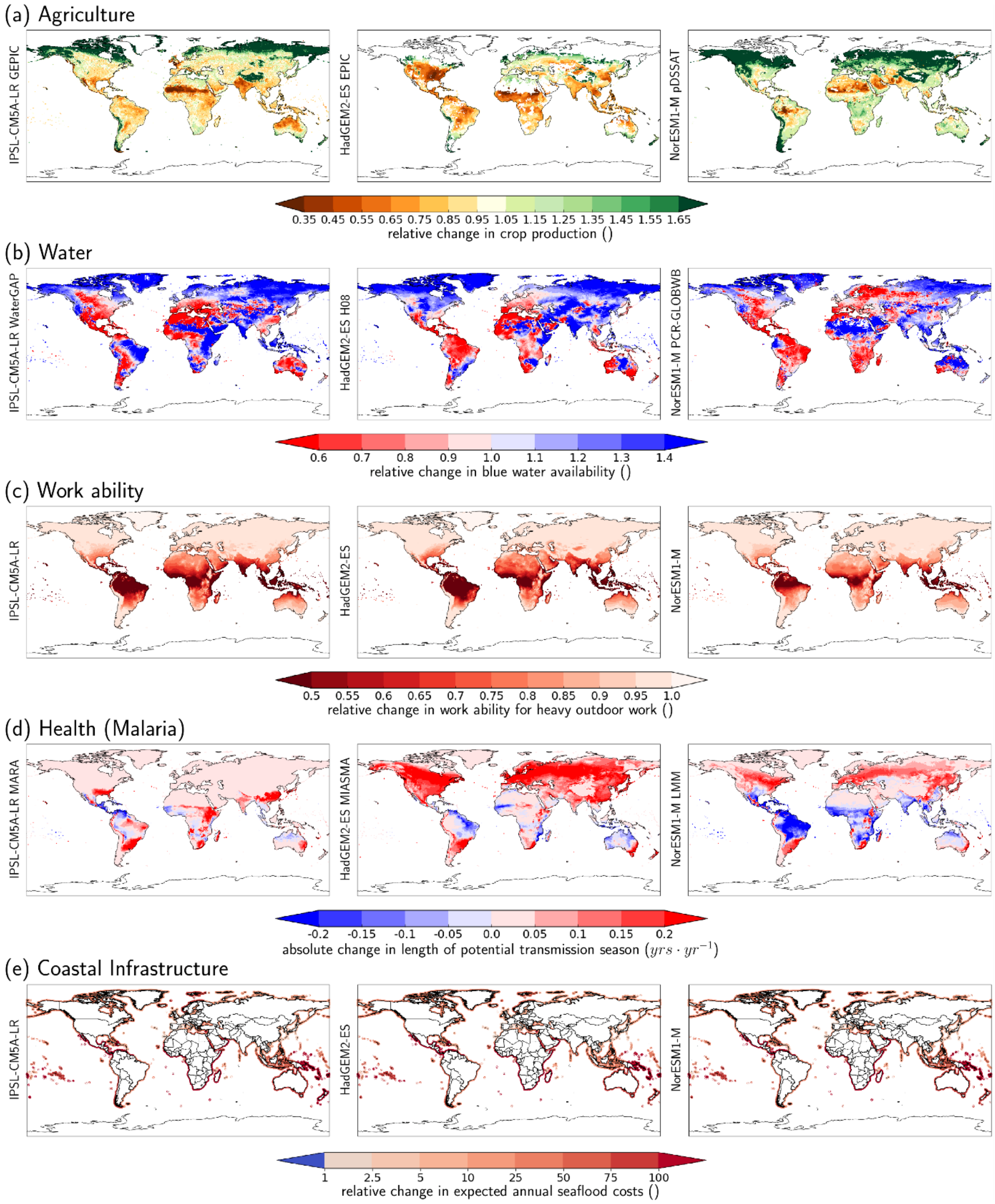

Figure 1: Changes in (a) agricultural crop production, (b) blue water availability, (c) heavy outdoor work ability, (d) health (malaria) and (e) expected annual seaflood costs as projected by three selected model combinations of CMIP5-GCMs and ISIMIP-IMs under the emission scenario RCP8.5 until the end of the century (Jury and Maraun, 2020)

The assessment of vulnerability along trade flows based on the three different indices results in a broad picture of how climate change may affect Austria's trading partners and thus Austria (see Rohrer et al. 2018a for details). The Climate Risk Index, which depicts the degree to which countries are affected by past extreme weather events, shows a much greater vulnerability among European countries as compared to the other two indices, which account for future impacts. Among relevant trading partners for Austria, the TCI as well as the ND-GAIN project much larger vulnerabilities in Southeast Asia for example. The map illustrates Austria’s foreign trade flows and how impacts of global climate change are characterized by strong regional differences represented on an exemplary basis by the ND-GAIN.

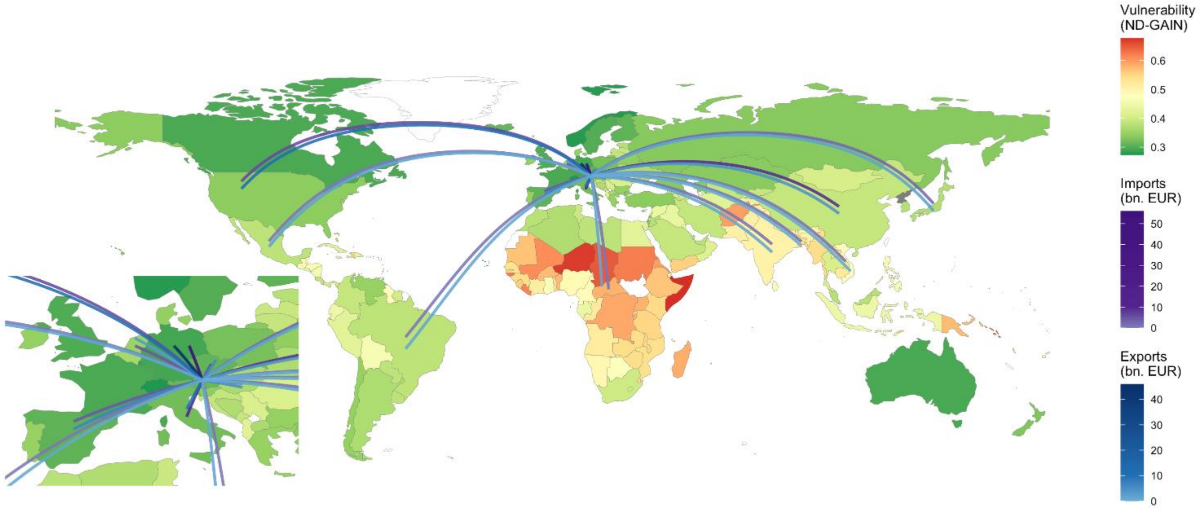

Figure 2: Vulnerability of individual countries, based on ND-GAIN (Chen et al. 2015), and important Austrian trade flows within and outside Europe, based on trade data for 2018 (Statistik Austria 2020).

Overall, two groups of relevant trading partners and trading sectors were identified: On the one hand, those countries that stand out due to their large volume of trade with Austria and, on the other hand, countries or sectors that are particularly affected by climate change and climate change impacts.

Due to their large volume of trade with Austria, Germany, the United States and Italy are in the first group of particularly relevant trading partners of Austria. India, Bangladesh, Thailand and Singapore stand out as particularly vulnerable on the export and import side, as they are among the group with the highest exposure in more than one index (CRI, TCI or ND-GAIN) and are thus in the second group.

At the sectoral level, due to the volume of trade, goods and sectors in the areas of machinery and electronic equipment, vehicles and plastic products are particularly relevant, while more vulnerable sectors are found in beverages and tobacco products, as well as in textiles and leather goods.

At the sectoral level, the exposure to climate change is greatly reduced by the diversification of trading partners as compared to the assessment at the level of trading partners only. This is due to the fact, that a trade flow of a specific sector is composed of both vulnerable and less vulnerable sources or destinations.

Eventually, the Austrian case exhibits a special feature: Germany is by far Austria's most important trading partner on both the import and export side. Although Germany is not considered to be severely affected by the future-oriented climate risks according to the two indices ND-GAIN and TCI, it is also embedded in international trade networks and is thus also reliant on the purchase of intermediate goods from potentially vulnerable regions.

2) What are the consequences for Austria's trade flows and the use of resources embodied in consumption?

WP3 investigated how global climate change impacts affect the consumption of resources, namely water, labor, malaria risk and crops, across world regions. We quantified both impact channels, direct comprising domestic effects and indirect, subsuming cross-border effects. For reasons of brevity we illustrate results for the EU member states and for the global median projection describing average impacts. Impacts for the remaining world regions and the bandwidth of possible impacts from lower bound projections (5th percentile of all GCM-IM projected relative global changes) to global max (95th percentile) are provided by Kulmer et al. 2020. Austrian specific insights, e.g. on sectoral level, are available as factsheet on the project website (https://coin-int.ccca.ac.at/ergebnisse).

Resources under investigation

The selection of which resource to quantify is key, and to do so, we follow the advice in the literature concerning the impacts of climate change on resources. The IPCC AR5 listed agriculture, water, and human health among the most vulnerable sectors towards climate change (IPCC 2014a, IPCC 2014b). Simultaneously, the role of these sectors in the displacement of environmental pressure through trade is frequently discussed (Steen-Olson et al. 2012, Lenzen et al. 2012, Schewe et al. 2014). Out of these sectors, the selection of a representative resource that meets the objectives of this study is based on two criteria: (i) High and regionally diverse vulnerability towards climate change (IPCC 2014a) and (ii) High intensity and fragmentation of trade (Challinor et al. 2017):

- The impacts of climate change on labor supply and how they unfold via international trade have yet to be studied carefully. In this context **Malaria** is a well suited example; a dangerous disease with a global distribution and significant health burden, whose spatiotemporal potential transmission patterns are sensitive to climate factors. Another example in the context of human health highly relevant to trade is the impact of a climate change-induced rise in temperatures on productivity. **Heat related fall of labor productivity** is of key economic concern and may severely challenge fragmented global supply chains where numerous countries participate by adding labor input.
- Numerous agricultural studies highlight that changes in temperature, precipitation, length of growing season, and timing of extreme events severely stress the production of food and fiber, hence affecting yields and productivity in numerous ways. The supply of **key agricultural crop**s (maize, soy, rice and wheat) is highly concentrated, compared to that of other commodities (e.g. metal, minerals and petroleum) and thus climatic conditions in certain Asian countries, North America and South America dictate resource availability.

- Climate change severely threatens **water security** and thus challenges food security and economic prosperity in numerous countries. The number of trade connections and the volume of water associated with global food trade has more than doubled in the last two decades alone. Table 1 reports the definition of each selected resource.

Table 1. Description of resources under investigations and the corresponding climate change signal

Sector	Specification	Unit	Climate Change Signal
Agriculture	Crop production	tons	%-Change in crop production
Human Health	Labor at risk of malaria Transmission	USD	%-Change in population at risk of malaria transmission
	Labor supply	USD	%-Change in labor productivity
Water	Blue and gray Water	m^3	%-Change in annual mean blue water resource

Effects on EU member states

On a country level the diversity of international spillover of resource pressure are particularly visible for the EU28 member states. Our results reveal a contrasting picture regarding stringency and direction of impacts on resource consumption between north and south as well as east and west member states. Consequently, there is a great potential that existing tensions due to differences in degree of prosperity and economic development between the member states are widened as disparities of impacts related to resource consumption kick-in.

The geographic and economic heterogeneity of the EU member states is already underscored by the impacts on labor consumption. In the median scenario (IPSL-CM5A-LR) labor consumption of continental European countries, e.g. Austria, Germany, France, and Hungary, is affected to a modest degree, while effects on south and south-east member states are severe. As illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.**, Cyprus experiences a stark fall in domestic consumption, followed by Malta, Greece, and Spain, where the decrease is above the average of the EU28. The impact channel is also quite different: the south and south east member states face predominantly domestic impacts, while the impacts on continental European states are to a vast extent transmitted via trade from abroad (50% to 70% root in territories outside of Europe). Austria is affected to a modest degree (-0.2%), however a large part (-0.13%) of the impact stems from abroad. Tracing the virtual trade flows of labor from the EU28 underpins that the fall in labor consumption originates predominantly in Thailand, Indonesia, China, Brazil, and Venezuela. Regarding uncertainty, we find that the upper and lower bound projections mirror the results regarding direction and pattern of impacts of the median projection (The uncertainty bandwidth for the EU28 member states is reported in Kulmer et al. 2020; for all resources).

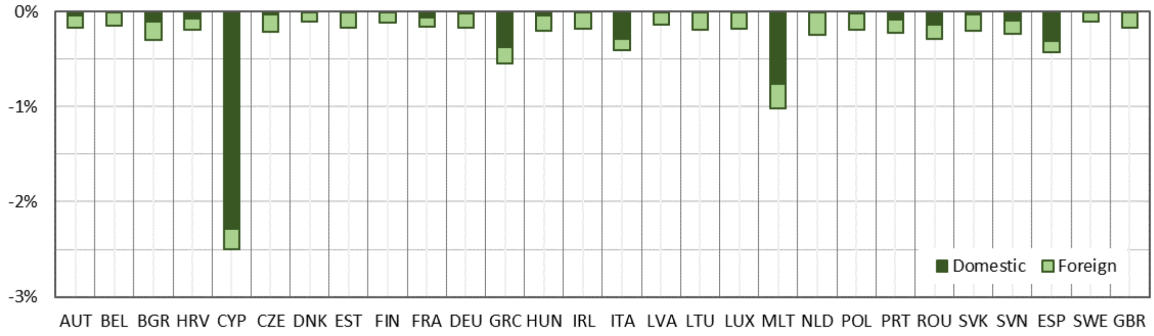

Figure 3: %-changes in direct and indirect consumption of labor by EU member states for the median scenario (Kulmer et al. 2020)

In the median projection, in South and Southeast member states water consumption declines strongly (5% to 10%), while for those in Continental Europe water consumption rises. As illustrated in Figure 4 in all member states, water imports rise due to higher water availability in other world regions, however in South and Southeast Europe this increase is offset by a strong decrease in domestic water availability. Austria is less affected by the fall in domestic water use (-0.2%), still this small decline is offset strongly by imports from abroad (+1.9%). The ensemble of scenario projections underscores the EU's dependency on water imports, which will be much stronger in the near future. In all scenario projections (global mix, global median and global max) domestic water availability falls, the strongest in the upper bound projection. Although in the upper bound projection, globally water availability rises considerably, Europe faces sharp reductions. In contrast, the lower bound projection favors the EU, where water availability decreases to a smaller extend, while water availability increases for main trade partners. Thus, EU consumption benefits the most in case of the lower bound projection. All projections reflect the regional disparity in the EU's vulnerability, change in water consumption, between southern as well as southeastern member states and member states in continental as well as northern Europe.

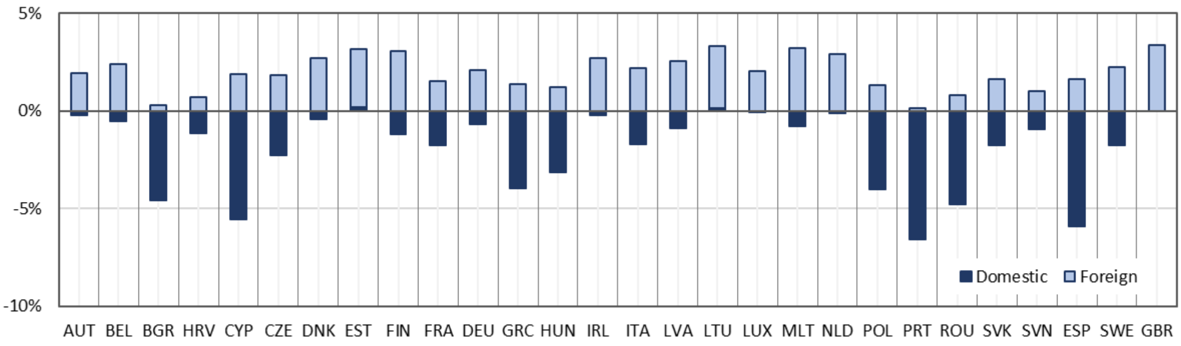

Figure 4: %-changes in direct and indirect consumption of blue & gray water by EU member states for the median scenario (Kulmer et al. 2020)

Regarding climate change impacts on crops, most of the EU28 member states benefit and crop consumption is able to increase, (i) directly due to enhancing domestic production possibilities and (ii) indirectly via rising imports from abroad. As reported in Figure 5, there is a large spread in impacts between north and south Europe. Since crop production increases in higher latitudes and higher altitudes and the impact channel is predominantly domestic, northern and northeastern member states experience strong increases in consumption while southern member states show negligible, even negative impacts. Consumption increases by over 10% in numerous member states, in particular Sweden, Great Britain, Latvia, and Lithuania. On the opposite side, consumption falls in Greece, Croatia, Spain, Cyprus, and Italy. For most member states, domestic impacts are the dominant factor, however Estonia, Finland, Ireland, and Austria benefit from imports more than domestic increases. In particular, Austria's increase in consumption of 2.3% stems to two-thirds (1.5%) from abroad. Regarding uncertainty, the upper bound projections show a stark increase in crop consumption, directly due to higher production possibilities but also indirectly, mainly in northern Europa, via imports from abroad. The indirect impact channel is particularly visible in case of northern member states, pointing to an import share of 40% to 50%. In contrast to the lower bound and median projection, reflecting a similar pattern of impacts on resource consumption, the upper bound projection shows very strong increases for north and northeast member states, ranging between 35% and 65%.

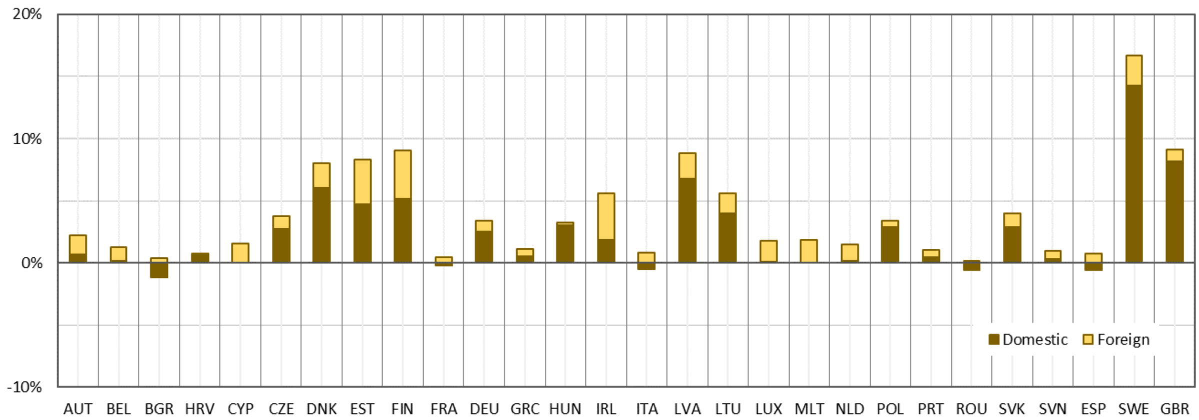

Figure 5: %-changes in direct and indirect consumption of agricultural crops by EU member states for the median scenario (Kulmer et al. 2020)

Figure 6 takes a closer look at the risk channels of the EU28 member states of labor at risk of malaria transmission. This figure reports for the median scenario (IPSL-CM5A-LR_MARA) high vulnerabilities for South European countries, where the risk rises by 20% to 30%, while northern member states are affected modestly. While the risk of Malta, Spain, Portugal, France, and Italy roots in domestic impacts, the other member states are mostly affected indirectly, via imports of high-risk labor. Austria's risk rises by 22%, and stems from abroad. On a regional level, the uncertainty analysis of labor at risk of malaria transmission revealed high volatilities in direction and characteristics of impacts for Western and Other Europe. Regarding the EU28, the upper and lower bound projections show a doubling of the risks and, in contrast to the median impacts, are driven domestically. Despite these developments, in absolute terms the share of labor affected is still modest, compared to high-risk countries. On average, the share of labor-at-risk is 25% in the EU28 in the upper bound projection.

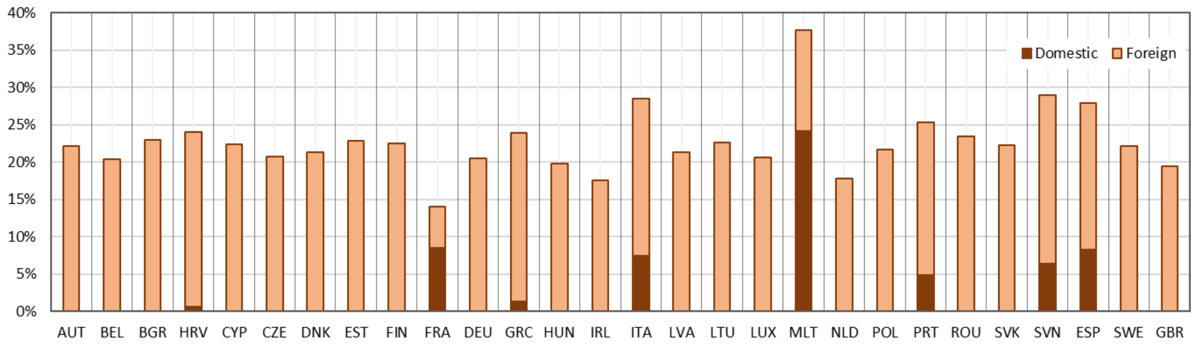

Figure 6: %-changes in direct and indirect consumption of labor at risk of malaria transmission by EU member states for the median scenario (Kulmer et al. 2020)

3) What macroeconomic costs are incurred domestically, also in comparison to the domestic costs of climate change?

Effects of transnational costs on Austria's trade balance, GDP and welfare

In Figure 7 we show how changes in sea level rise, labor productivity and agricultural yields affect imports and exports as well as Austrian GDP and welfare. The bars indicate median values of socioeconomic development scenarios (SSPs) combined with climate models (GCMs) and separately for the two emission scenarios RCP4.5 (blue) and RCP8.5 (orange). The results are again given for 2050 in relative terms, which indicate a %-deviation from the baseline scenario without climate change. Overall, the GDP and welfare effects are strongly driven by the effects on labor productivity, with slightly compensating or reinforcing effects from agriculture. Relative to the other impact chains, sea level rise has only a marginal influence on the overall results (assuming that adaptation to the impacts of sea level rise is performed).

Trade with EU+ regions increases in a world with climate change: Imports from other EU+ regions increase slightly by +0.05% with RCP4.5 and +0.08% with RCP8.5, while exports to EU+ regions are higher by +0.49% with RCP4.5 and +0.7% with RCP8.5. Trade with non-EU+ regions decreases more strongly: Imports decrease by -1.54% with RCP4.5 and by -2.25% with RCP8.5 and exports by -0.64% with RCP4.5 and -0.9% with RCP8.5. Although the Austrian trade surplus increases, the effects on Austria's GDP and welfare are clearly negative (for Austria but also every other model region). Hence, the exploitation of comparative advantages cannot prevent welfare losses. In RCP4.5 the reduction in domestic GDP ranges is lower by -0.32% with RCP4.5 and by -0.43% in the stronger emission scenario RCP8.5. The reduction in welfare amounts to -0.26% in RCP4.5 and to -0.37% in RCP8.5. Thus, the effects are stronger with a higher emission scenario (RCP8.5 as compared to RCP4.5).

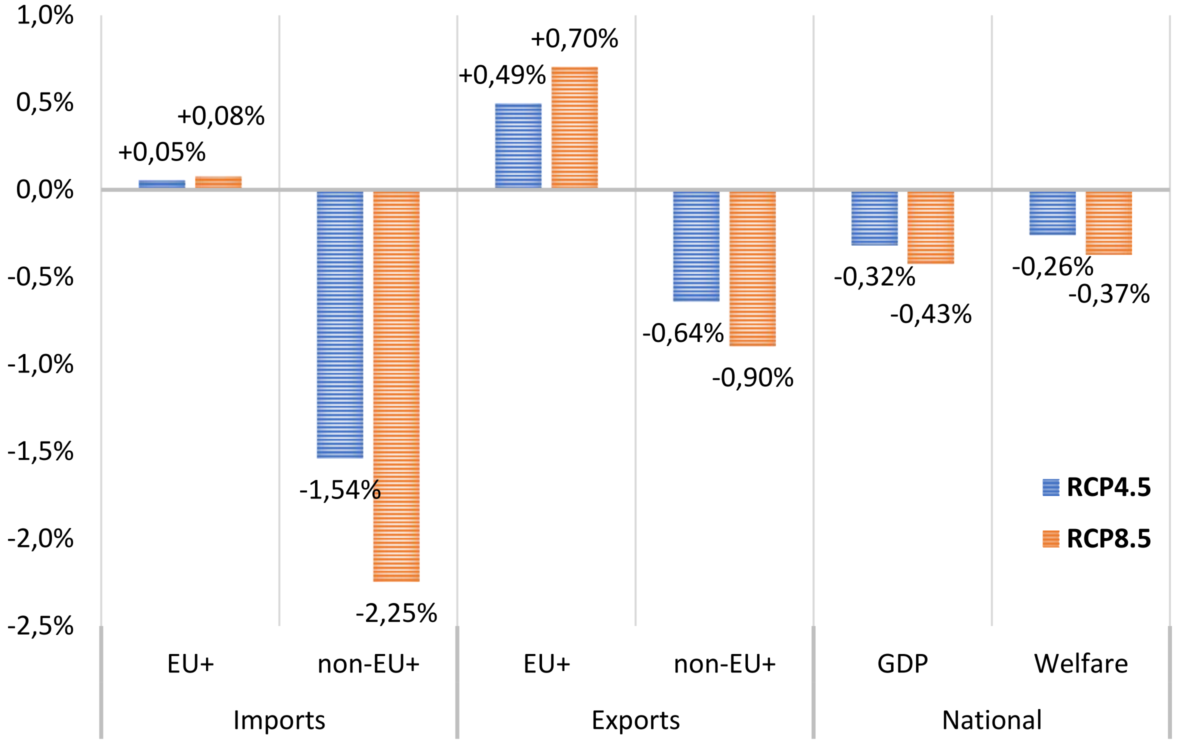

Figure 7: Relative change in Austrian imports, exports, GDP and welfare in 2050 due to climate change for the climatic period 2050 (Ø2036-2065) relative to the baseline; median values of socioeconomic development scenarios (SSPs) and climate models (GCMs) combinations for RCP4.5 (blue) and RCP8.5 (orange). (Knittel et al. 2020b) EU+ regions: EU-28 plus rest of Europe; non-EU+ : rest of the world.

Comparison of transnational to domestic effects

To set the macroeconomic costs of transnational climate change effects on Austria into context, we first aimed at disentangling how strongly effects outside Europe drive the direction and magnitude of the effects to Austria's trade balance, and second, we compared national costs identified in the comprehensive cost of inaction (COIN) study performed by Steininger et al. (2015) with the results of the present study.

We first performed a scenario, where we assumed that climate change would occur only outside Europe but would leave European countries unharmed. We find that there are no substantial changes in the results, which is mainly driven by the fact that the direct climate impact in the most prominent impact category labour productivity losses is relatively small in Europe. While reductions of work ability mainly vary around 1% in EU regions (up to 4% in Italy with the stronger emission scenario RCP8.5), reductions in the rest of the world can reach up to 30% for Southeast Asian countries. Thus, despite Austria having (currently) its main trading partners within Europe, its economy would still be strongly affected by spill-over effects triggered by climate change impacts occurring outside Europe. This is also driven by the fact that some of Austria's key trading partners outside Europe, such as China and Eurasian countries, are strongly affected by climate change impacts on particularly labour productivity, but also agricultural yields.

For the recent study RE-COIN (Steininger et al. 2020), all results from COIN and COIN-INT were converted into Euro at 2019 prices to allow for a comparison. For the international spill-over effects, Figure 8 shows the median value across SSP and GCM combinations for the RCP4.5 emission scenario in order to be compatible with the assumptions in the COIN study. While the spill-over effects cover the three described impact chains sea level rise, change in labor productivity and change in agricultural yields on a global level, the results from COIN cover 12 different impact fields on a very detailed level but for Austria only.

In total, the spill-over effects amount to annually € 1.4 billion on average for the period around 2050. Thus, although the considered impact chains are to a large extent not directly relevant for Austria as there is no coast to be affected by sea level rise, changes in labor productivity are very low and changes in crop yields can even be positive, spill-over effects constitute a significant share of the overall sum of macroeconomic costs for Austria.

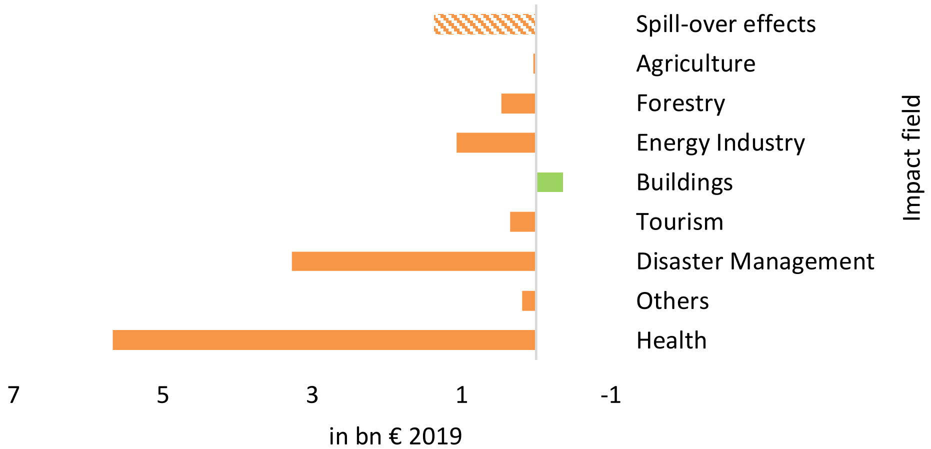

Figure 8: Macroeconomic costs of transnational climate change impacts and national impacts (by key impact fields for the climatic period 2050 (Ø2036-2065) and the emission scenario RCP4.5 relative to the baseline. Spill-over effects (=transnational impacts) are the results of the COIN-INT project (Knittel et al. 2020b), while results for other impact fields are taken from the COIN project (Steininger et al. 2015).

4) How can Austrian companies and political decision makers prepare for these risks?

In general, we find that ignoring cross-border climate change impacts considerably underestimates the true effects and hence costs of climate change and therefore require consideration alongside national impacts. Companies can pursue different strategies ranging from diversifying supply chains to expanding transport infrastructure or capturing opportunities of a changing market. National and supranational, i.e. EU or other international institutions, could increase coordination in managing climate change impacts.

With a focus on the sectoral results, Austrian policy-makers may seize the potential of competitiveness gains by supporting key industries of the Austrian economy, such as machinery, iron and steel and the motor vehicles industry. Yet, potential synergies and trade-offs exist with the transition to a low-carbon economy.

According to the case studies that have been performed in this research project, actors in the different areas have already identified several options to address the international dimension of climate change. Detailed results are shown in Table 2.

Table 2: Summary of risks, adaptation options and chances identified by the case studies (Rohrer et al. 2018b)

	Thailand flood	Lithium as raw material	Imports of soy bean	Textiles
Risks	– Lack of preparation by enterprises – Unidimensional view of the supply chains – Suppliers from a single region	– Bottlenecks due to increased demand – Lack of substitutability of the resource	– Droughts in Europe – Lack of substitutability in the pig farming sector – High and low flows on the Danube	– Higher prices due to heat-related reductions in labor productivity – Increase in industrial work accidents due to higher temperatures
Adaptation	– Diversification of supply chains – Business Continuity Management – Annual risk evaluation	– Diversification of supply chains – Mining of Lithium within Europe – Maintaining the location of the steel industry in Europe – Increased rate of recycling of Lithium	– Conversion of the feedstock – more domestic cultivation areas – Increase in yield of feed crops – Expansion of the rail network (to ensure delivery)	– Improvement of working conditions in heat exposed locations of production – Sustainable supply chains – Small production plants
Chances	– Preparedness for similar events	– World market leader in niche markets – Market potential for recycling companies	– Lack of preparation on the part of the companies – Marketing of know-how on seeds for pig feed	– First-mover advantage for sustainable companies – Focus on domestic production of textiles

In addition, stakeholder workshops and exchanges pointed to some essential prerequisites for action among Austrian companies. Insufficient information and lack of awareness at the level of companies regarding the risks of climate change and extreme weather events results in no action. Due to this lack of awareness, there is very little ambition from the practical side to reduce risks and identify possible opportunities. It even seems to some degree that the topic of adaptation and diversification of supply chains has not yet arrived in the companies, while the topic of climate change is predominantly associated with the issue of emissions and related policies. Exceptions in that respect are companies that trade with raw materials such as coffee and cocoa, as well as the insurance sector.

To increase the awareness for this topic, sensibilization and education can be carried out by interest groups, such as the industrial association (IV) or the chamber of economics (WKO). However, as international dimensions of climate change are not yet a priority of companies, members will likely not choose this topic. Thus, a major problem consists in the lack of public information about risks and opportunities. In addition, the transition to a more transparent supply chain is expensive and complex. Especially in countries of origin, the awareness of climate risk is often perceived to be very low. Companies claim that there is insufficient financial and in-kind support from the government. In contrast, information often remains stuck at the company level and public decision-makers have little information about existing strategies at company level and potential gaps and vulnerabilities, which in turn makes support difficult.

Approaches to point out climate management in companies have been undertaken for example by the Financial Market Authority (FMA), that has developed a climate risk guide. A similar document might be helpful for other sectors too. For such a document, it is important to address the heterogeneity of companies, especially with regard to SMEs. The differences in vulnerability and adaptive capacity are for instance considerably large between SMEs and multinationals.

5 Schlussfolgerungen und Empfehlungen / Conclusions and Recommendations

Both companies and the state currently take too little account of cross-border climate change impacts in their decisions. Some countries, such as the UK and Germany, include transnational climate change impacts in their climate risk assessments and in their adaptation strategies and plans. This is an important first step towards raising awareness of adaptation measures in this area. Furthermore, public authorities can support vulnerable countries of origin through adaptation finance. This underscores the fact that purely national measures and efforts fall short and that Europe can only mitigate transboundary climate change impacts with the help of international cooperation. Companies can reduce the risk by including climate change risks in corporate risk management along their supply chains, diversifying suppliers, expanding storage capacities or extending their insurance coverage. Potential opportunities could also arise for Austria and Europe as a business location - but this also depends on global demand.

In the context of climate change adaptation, the magnitude of impacts transferred via trade suggests that the focus on national impacts is not sufficient to be optimally prepared for changed climatic conditions. Thus, the National Adaptation Strategy requires taking account of global climate change impacts, either as an additional activity field or across all existing activity fields. The results additionally call for climate mitigation to reduce climate impacts in vulnerable areas as a primary goal, and to reduce the spillover effects for the Austrian economy as a secondary goal. A combination of these two goals can also be achieved by increasing or investing in international climate finance to support developing countries to tackle climate change challenges. By reducing vulnerability of important trading partners, the effects on the Austrian economy decrease as well. An example is found in the textile industry, where improved working conditions at the production site in the exporting countries, can substantially dampen the consequences of increased temperature. Furthermore, Austria might at the same time be able to achieve some targets of the Sustainable Development Goals.

On the example of four resources, namely water, labor productivity, labor at risk of malaria-transmission and crop yield, we demonstrate how future climate change impacts alter the virtual trade of resources and quantify the changes in direct and indirect resource consumption of world regions and countries. We find that ignoring cross-border climate change impacts considerably underestimates the true effects and hence costs of climate change. Depending on the investigated resource, for a large number of countries (30% to 60% of countries around the world) total climate change impacts on resource consumption are predominantly transmitted from abroad. This dominance of the indirect impact channel is particularly pronounced for the EU28 member states, where the imported impacts are five to ten times higher than the domestic ones. Consequently, Europe’s already relatively high dependency on resource imports is further enlarged by climate change.

Our study offers some policy implications for the EU. Resource consumption depends on availability. Climate change may have negative impacts on resource availability in vulnerable countries from where the EU sources in needed net resource consumption. That is, when resource consumption is not available from production within the EU, it can be imported, and when imported, the EU – as net consumer of resources from those vulnerable regions – may need to take some actions. For instance: (a) find regions that produce the amount of resources needed, among those being less vulnerable; or (b) produce within the EU, if the respective resources is available; or (c) shift consumption towards less resource intensive products; or, (d) help the vulnerable regions providing the required resources. Indeed, strategies for the EU and other large industrialized nations to cope with high indirect vulnerabilities could comprise investment in adaptation measures in other parts of the world, by e.g. promoting technological change to improve the resource efficiency of crucial supply chains. In the context of coping measures and economic development, the results on heat related productivity loss are of special interest. On the domestic impact side, Western European countries are affected the least by falling labor productivity, and hence, incentives to relocate labor-intensive production back to Europe could arise.

C) Projektdetails / Project Details

6 Methodik / Methodology

The project pursued a multi method approach, with different methods applied for each research question. Figure 9 gives an overview of the 6 Work Packages in COIN-INT and its key goals. To address the international climate change vulnerability assessment, data from multiple impact models for multiple impact fields and different climate models were retrieved and processed. A quantitative assessments of vulnerability indices mapped to Austrian trade data complemented the analysis of current and future vulnerabilities of countries and sectors (WP2). The impacts on Austrian trade flows were assessed by means of a multiregional input-output (MRIO) analysis (WP3), while the macroeconomic effects were analyzed in a global multi-regional and multi-sectoral computable general equilibrium (CGE) model (WP5). For the intermediate step of identifying hotspots and case studies, the method consisted of a combination of literature search and stakeholder interviews (WP4). The project conducted two expert workshops, released 4 factsheets and an infographic (see section 8 for details on these and other dissemination activities).

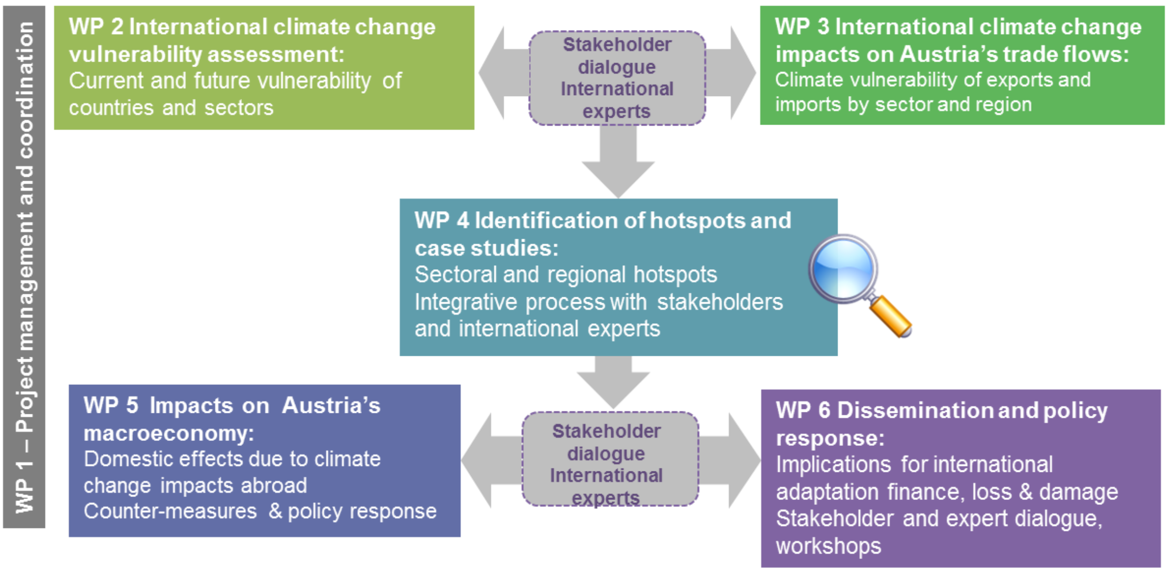

Figure 9: Project structure of COIN-INT.

Assessment of physical vulnerabilities on a global scale

To identify, assess and validate international climate change vulnerabilities, we examined the impact of future climate change for two time periods (until 2031–2060 and 2070–2099) and two emission scenarios (RCP4.5 and RCP8.5) with respect to the historical period (1981–2010). In doing so we obtained data (i) from multiple impact models (IMs) for multiple impact fields (i.e. agriculture, health (malaria), water and coastal infrastructure) participating in the Inter-Sectoral

Impact Model Intercomparison Project (ISIMIP) Fast Track framework, and (ii) from five global climate models (GCMs) that were bias corrected within ISIMIP. A pre-processing ensured to meet the needs of MRIO (WP3) and CGE modelers (WP5). This pre-processing included the mapping of data on grid point scale to means (health and work ability) or sums (agriculture and water) over economic regions (e.g. countries), an additional weighting in terms of within-country population distribution (health and work ability), as well as the calculation of relative climate change signals. Depending on the impact field a different number of IMs driven by the same five GCMs was disposable, which led to a total of up to 45 different model combinations (GCM-IM). We excluded single models either due to inconsistency in their output or because they were inappropriate for the purpose. From the remaining models three model combinations were subsequently selected to sample the spectrum of possible future climate vulnerabilities for every impact field. Figure 10 illustrates the global climate change signals for the different impact fields for RCP4.5 until the mid and RCP8.5 until the end of the century and the three selected GCM-IM combinations.

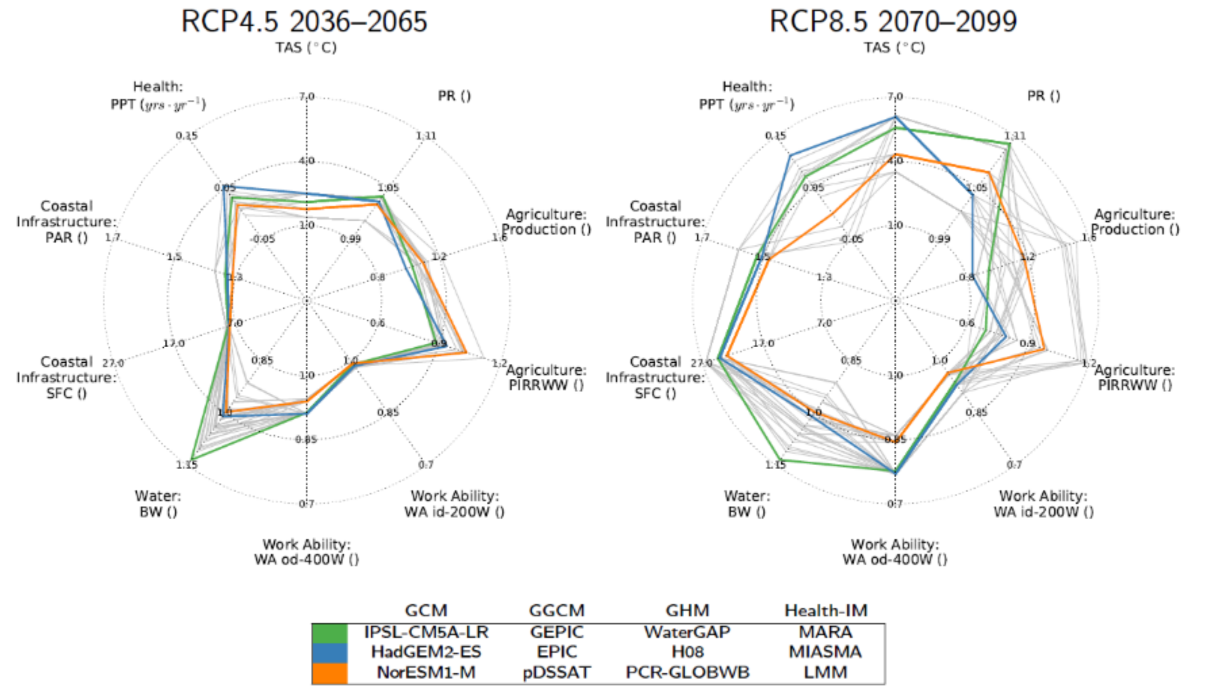

Figure 10: Projected changes under RCP4.5 (until 2036-2065, left) and RCP8.5 (until 2070-2099, right) for the GCM ensemble (2-meter air temperature (TAS) and precipitation rate (PR)) and considered impact fields (Agriculture: production and potential irrigation water withdrawal (PIRRWW); Work Ability: light indoor work (id-200W) and heavy outdoor work (od-400W); Water: blue water (BW); Coastal infrastructure: Expected Annual Seaflood Costs (SFC) and Expected Annual People Flooded (PAR); and Health: potential population at risk of transmission (PPT)). Selected GCMs and IMs are shown in color. (Jury and Maraun, 2020)

Mapping Austrian trade flows with international vulnerability indices

The mapping of Austria's foreign trade to different indices describing certain aspects of climate vulnerability allowed for a first quantitative assessment of the vulnerability of Austrian trade flows with respect to the divergence of global climate impacts. The method applied was a quantitative comparison of Austrian foreign trade data, using both data from Statistik Austria (Statistik Austria 2018) and data from the Global Trade Analysis Project (GTAP) (Aguiar et al. 2015) with the following three indices: The Climate Risk Index (CRI) of Germanwatch, which represents past exposure to extreme weather events (Eckstein et al. 2018), the ND-GAIN Exposure Score, a subset of the ND-GAIN Vulnerability Score of the Notre Dame Global Adaptation Initiative (Chen et al. 2015), which projects exposure to climate change in 2050, and the Transnational Climate Impact Index (TCI) of the Stockholm Environmental Institute, which also considers vulnerability to international trade (Benzie et al. 2016). For an assessment of the vulnerability on the sectoral level, we calculated a sector-specific score based on the ND-GAIN Exposure Score and the composition of the import and export countries for each sector.

Environmentally extended multiregional input-output analysis

In order to analyze how regional climate change impacts affect consumption and trade of resources we adopt a multistep approach. *First*, the current situation of trade induced net displacements of the investigated resources is studied. In particular, by means of environmentally-extended multi-regional input-output analysis we calculate today's resource consumption and net trade balance of resources. These results serve as "the Baseline", to which climate change impact scenarios are compared to. *Second*, we construct counterfactual scenarios which depict a new satellite account where resource entries are multiplied with the climate change signal (percentage change in resource availability compared to the Baseline) provided by the selected ISIMIP projections. More precisely, each impact scenario depicts a new row-vector of resource coefficients $q^{CC\ Secnario}$, by means of which we then calculate scenario-specific resource consumption and net trade balances. For each of the investigated resources, these scenarios describe the bandwidth of possible global climate change impacts from lower bound via median to upper bound projections. *Third*, by comparing the Baseline and the climate change impact scenario we study how future climate change projections alter the current situation of trade induced net displacements of resource indicators. Therein, we decompose the change in a countries' or regions' resource consumption in direct (domestic) and indirect (transnational) impacts.

The system of equations in (1) represents the core identity of the EE-MRIO model and describes how the total output of the global economy is either used by industries as intermediate inputs or to satisfy final demand (to enhance readability and clarity for the reader we abstract in the mathematical formulation from a sector disaggregation):

$$\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_R \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1R} \\ A_{21} & A_{21} & \cdots & A_{2R} \\ \vdots & \vdots & \ddots & \vdots \\ A_{R1} & A_{R2} & \cdots & A_{RR} \end{bmatrix} * \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_R \end{bmatrix} + \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_R \end{bmatrix} \qquad (1)$$

X_i denotes the column vector of total output by economic sector in country *i* $(i, j \in R)$, *A* is a coefficient matrix describing input per output ratios in the production of these sectors with A_{ij} denoting inputs from sectors in country *i* required to produce one unit of output from each sector in country j. Y_i is, a column vector of total final demand for the output of country *i*.

This equation can be transformed into $X = (I - A)^{-1}Y$, where $(I - A)^{-1}$ describes the inverse Leontief matrix. Given any final demand, the total output needed to meet that demand is simply the product of the inverse Leontief matrix and the final demand.

The Leontief matrix can then be extended by a row-vector of resource coefficients q in order to illustrate how these indicators are distributed over sectors and countries. Thereby $q^* = [q^1, \quad q^2 \quad , \ldots , \quad q^R]$ is a row vector of resource coefficients by sector and region denoting the physical (e.g. water in m³, crops in tons) or monetary (labor in USD) units per unit of output.

This row vector of resource coefficients times the total output needed to meet any final demand yields embodied resources, Q, in final demand ($\mathrm{Q} = q^*(I - A^*)^{-1}Y^*$; Q is a R x R matrix). Thus, for instance focusing on final demand in country j, we are able to measure the embodied resource flows from each country to country j (Gasim 2014):

$$\begin{bmatrix} Q_{1j} \\ Q_2 j \\ \vdots \\ Q_n j \end{bmatrix} = q(I - A)^{-1} \begin{bmatrix} Y_{1j} \\ Y_2 j \\ \vdots \\ Y_n j \end{bmatrix} \qquad (2)$$

Therein, total direct (*i* = *j*) and indirect (*i* ≠ *j*) consumption of resources in country j is $f_j^{RC} = \sum_i Q_{ij}$. In other words, the sum of each column vector of the matrix Q represents the resource consumption of a country j (RC_j).

Consequently, total resources embodied in exports of country i (QEX_i) can be obtained by $\mathrm{QEX}_i = \sum_{j \neq i} Q_{ij}$ (row sum of matrix Q by abstracting self-consumption). Similarly total resources embodied in imports of country j (QIM_j), can be obtained by $\mathrm{QIM}_j = \sum_{i \neq j} Q_{ij}$; (column sum of matrix Q by abstracting self-consumption) (Ewing et al. 2012, Gasim et al. 2015). A frequent discussed quantity is the virtual resource net trade balance ($\mathrm{QVTB} = \mathrm{QEX}_i - \mathrm{QIM}_i$), which presents the net trade flows of a country.

The EE-MRIO model is calibrated to the Eora global Multi-Region Input–output database of the year 2013 (Lenzen et al. 2012, Lenzen et al. 2013) which comprises of 26 economic sectors, 189 countries, one aggregate for the rest of the world, and a satellite account with 35 types of resources, environmental and economic indicators. This serves as Baseline scenario for the present study.

Computable General Equilibrium model

The macroeconomic effects for Austria due to climate change arising in other world regions were assessed by means of a CGE model. For the purpose of the present research project, the national scale COIN model (Bednar-Friedl et al. 2012), which covers trade only by means of bilateral trade tables, was extended towards a full global version and updated to the GTAP9 database (Global Trade Analysis Project, V9, base year 2011, Aguiar et al., 2016). This COIN-INT model distinguishes 24 world regions and 23 sectors according to their importance in terms of Austrian trade and differences in climate vulnerability. Regarding international trade, the model is calibrated to real world bilateral trade flows under current trade policies and costs as provided by GTAP (Aguiar et al. 2016). Concerning the flexibility of changing trade partners (import sources) we apply the Armington (1969) assumption: imports and domestically produced goods are imperfect substitutes.

As for the Input-Output analysis, we distinguish baseline and climate change scenarios. The baseline scenarios entail the general regional socioeconomic development, but do not include any climatic changes. In particular, we differentiate between two Shared Socio-Economic Pathways (SSPs; O'Neill et al. 2014; Riahi et al. 2017): SSP2, characterized by intermediate challenges for mitigation and adaptation, represents a middle-of-the-road scenario with trends that are not very different from historical patterns. SSP3, characterized by high challenges for mitigation and adaptation, represents a world in which regional rivalry dominates and environmental issues are neglected.

The climate change scenarios include the same assumptions as the baseline and additionally climate change induced sea level rise, labor productivity changes and agricultural yield changes (see Table 2 for details).

Table 3: Impacts of global climate change covered in the COIN-INT model

Risk channel	Description of the covered effects	Calculation of the (bio)physical effects
Sea level rise	Impact of sea level rise on coastal assets (land, capital); damage caused by flooding; costs of constructing/adapting protective structures (investments and maintenance costs)	Calculation of damage with or without additional adjustment (coastal protection): – Coastal infrastructure: expected annual flood costs – Costs of dikes and other flood protection structures Data basis: DIVA (Hinkel et al. 2014)
Change in labor productivity	Decreases in labor productivity due to increasing heat and absolute humidity.	Calculation of the change in work ability as a function of the Wet Bulb Globe Temperature Index (WBGT), differentiating between work intensity and indoor and outdoor activities (Bröde et al. 2017). Data basis: ISIMIP (Warszawski et al., 2014)
Change in agricultural yields	Yield changes of the four main crops (wheat, maize, soy, rice) due to changing temperature minima and maxima, precipitation, radiation, relative humidity, wind speed	Changes in yields per ha of cultivated area; calculation based on 3 agricultural impact models (GEPIC, EPIC, pDSSAT) Data basis: ISIMIP (Warszawski et al. 2014)

7 Arbeits- und Zeitplan / Work and Time plan

The work and time plan is visualized below.

		2017			2018				2019				2020	
		Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
WP1	**Project management and coordination**													
Task 1.1	Project management	X	X	X	X	X	X	X	X	X	X	X	X	X
Task 1.2	Reporting to funding agency												X	X
Task 1.3	Publication strategy						X	X		X	X	X	X	X
Task 1.4	Engagement of scientific advisory board		X			X					X			X
WP2	**International climate change vulnerability assessment**													
Task 2.1	Climate trends and weather variability	X	X											
Task 2.2	Socioeconomic trends		X	X										
Task 2.3	Vulnerability assessment for each country				X	X								
WP3	**Assessment of international climate change impacts on Austria's trade flows**													
Task 3.1	Data processing and mapping		X	X										
Task 3.2	Multi-regional input-output analysis		X	X	X									
Task 3.3	Results and visualization				X	X								
WP4	**Derivation of Scenarios**													
Task 4.1	Identification of hotspots			X	X	X								
Task 4.2	Case studies on selected supply chains					X	X							
Task 4.3	Definition/quantification of scenarios					X	X							
Task 4.4	Defining key sensitivities						X	X						
WP5	**Comparison of domestic and international climate change impacts for Austria's economy**													
Task 5.1	Data					X								
Task 5.2	Model refinement					X	X							
Task 5.3	Scenario simulation						X	X						
Task 5.4	Results & publications								X	X	X	X		
WP6	**Dissemination and policy response**													
Task 6.1	Homepage and corporate design	X												
Task 6.2	Compilation of fact sheets							X						X
Task 6.3	Stakeholder engagement		X			X	X	X					X	X
Task 6.4	Conclusions for policy makers		X					X					X	X

8 Publikationen und Disseminierungsaktivitäten / Publications and Dissemination

Tabellarische Angabe von wissenschaftlichen Publikationen, die aus dem Projekt entstanden sind, sowie sonstiger relevanter Disseminierungsaktivitäten.

	Journal	Other	Dissemi-nation	Presen-tation
1. Kulmer V., Jury M.W., Wong S., Kortschak D. 2020. Global resource consumption effects of borderless climate change: EU's indirect vulnerability. Environmental and Sustainability Indicators, DOI 10.1016/j.indic.2020.100071.	x			
2. Knittel N., Jury M.W., Bednar-Friedl B., Bachner G., and Steiner A.K. 2020. A Global Analysis of Heat-Related Labour Productivity Losses under Climate Change—Implications for Germany's Foreign Trade. Climatic Change DOI 10.1007/s10584-020-02661-1.	x			
3. Borsky S., Jury M.W. 2020 The role of global supply chains in the transmission of weather induced production shocks. Under review (Working paper version: Graz Economics Papers 2020-13).	x			
4. Bednar-Friedl B., Knittel N., Preinfalk, E., Borsky S., Troeltsch J. (2020), Climate change adaptation in the manufacturing industry. A systematic literature review of the current state of adaptation, its drivers and barriers. Under review.	x			
5. Knittel N., Bachner G., Bednar-Friedl B., Jury M.W., Lincke D., Hinkel J., (2020), The effects of global climate change on foreign trade patterns – Insights from a cross-sectoral impact assessment for Austria. Unpublished manuscript.	x			
6. Bednar-Friedl B., Raich J., Knittel N., Adams, K. (2020), Adaptation to transboundary climate risks: Investigating actors and strategies for an emerging challenge in global environmental governance. In preparation.	x			
7. Rohrer A.V., Bednar-Friedl, B., Knittel N., 2018. Vulnerabilität der wichtigsten österreichischen Handelspartner gegenüber dem Klimawandel. COIN-INT Report #1, Wegener Center, Universität Graz.		x		
8. Rohrer A.V., Jury M.W., Preinfalk E., Bednar-Friedl, B. 2018. Grenzüberschreitende Auswirkungen des Klimawandels auf Österreichs Außenhandel. Fallstudien zu „Thailandflut", „Weakest Link – Lithium", „Soja" und „Textil- und Bekleidungsindustrie". COIN-INT Report #2. Wegener Center, Universität Graz.		x		
9. Steininger K.W., Bednar-Friedl B., Knittel N., Kirchengast G., Nabernegg S., Williges K.,		x		

Mestel R., Hutter H.-P., Kenner L. (2020), Klimapolitik in Österreich: Innovationschance Coronakrise und die Kosten des Nicht-Handelns, Wegener Center Research Briefs 1-2020, Wegener Center Verlag, Universität Graz, Austria, Juni 2020. DOI 10.25364/23.2020.1				
10. Jury M., Maraun D. (2020) International Climate Change Vulnerability Assessment, COIN-INT WP2 Report, 76 p.		x		
11. Infographic: Grenzüberschreitender Klimawandel am Beispiel der Textilindustrie			x	
12. Factsheet 1: Landwirtschaft (Klimarisiken durch internationalen Handel von landwirtschaftlichen Gütern)			x	
13. Factsheet 2: Wasser (Klimarisiken durch internationalen Handel von Wasser)			x	
14. Factsheet 3: Arbeit (Klimarisiken durch internationalen Handel von Arbeit)			x	
15. Factsheet 4: Volkswirtschaftliche Wirkungen der Klimarisiken durch internationalen Handel			x	
16. Bednar-Friedl B., Knittel, N. (2020) Die Auswirkungen des Klimawandels kennen keine Grenzen Die Presse, Leitartikel & Blog „Der ökonomische Blick", 14.9.2020.			x	
17. Bednar-Friedl B. (2018) Warum bezahlen wir für den Klimawandel?; Plakatkampagne „We Work for Tomorrow" der Uni Graz als CityLights, November 2018			x	
18. Bednar-Friedl B., Kulmer V. (2017) Die Kosten des Nicht-Handelns für Österreich: Übertragung von Klimawandelfolgen über den Außenhandel, Federal Ministry of Agriculture, Forestry, Water and Environment, 18.12.2017				x
19. Bednar-Friedl B. (2018) Climate change impacts transmitted by international trade, Research Seminar of the School of Economics and Social Sciences, University of Graz, Austria, 25.01.2018				X
20. Bednar-Friedl B. (2018) Die Kosten des Nicht-Handelns für Österreich: Übertragung von Klimawandelfolgen über den Außenhandel, Klimatag 2018, Salzburg, Poster Präsentation (ACRP Special Session), April 25, 2018				x
21. Kulmer V., Kernitzkyi M. (2018), Klimarisiko durch internationalen Handel, Zukunftskonferenz der JOANNEUM RESEARCH Forschungsgesellschaftmbh, March 7, 2018, Graz				x
22. Kulmer V., Kernitzkyi M., Jury M.W., Kortschak D. (2018), How climate change shapes international trade flows of embodied resources, Conference of Economic Modelling, Venice, July 4-6, 2018				
23. Kulmer V., Kernitzkyi M., Jury M.W., Kortschak D. (2018), How climate change shapes international trade flows of embodied resources, International Energy Workshop, Gothenburg, June 19-21, 2018				

24. Borsky S., Jury M. (2019), Supply Chain Shocks and Countries' Exports. Annual Meeting of the Regional Science Association, June 06, 2019, Santiago de Compostela, Spain.				
25. Kulmer V., Kernitzky M., Jury M.W., Kortschak D. (2019), Klimarisiko durch internationalen Handel, Dialogveranstaltung Junge Industrie, 16. September 2019, Wien (cancelled due to illness)			x	x
26. Steininger K.W., Knittel N. (2020), Klimapolitik in Österreich: Innovationschance Coronakrise und die Kosten des Nicht-Handelns. Pressekonferenz mit BM Gewessler, Klimaschutzministerium, Wien, June 25, 2020.			x	x
27. Knittel N. (2020), The Effects of Global Climate Change on Foreign Trade Patterns – Insights from a Cross-Sectoral Impact Assessment for Austria'. Annual Conference of the European Association of Environmental and Resource Economists, Berlin, Germany, June 25, 2020.			x	x
28. Knittel N. (2020), Volkswirtschaftliche Auswirkungen grenzüberschreitender Klima-wandelfolgen für Österreich und Fallstudien ausgewählter Hotspots, INFRAS Webinar, 3. September 2020			X	X
29. Knittel N. (2020), Klimawandel: Die Kosten des Nicht-Handelns und der Nutzen von Anpassung. Lernwerkstatt Klimawandel, Environmental Agency Austria, October 7, 2020.			x	x
30. Knittel N. (2020), The Effects of Global Climate Change on Foreign Trade Patterns – Insights from a Cross-Sectoral Impact Assessment for Austria'. Sustainable Resource Use and Economic Development (SURED) Conference, Ascona, Switzerland, October 20, 2020.			x	
31. Kulmer V. (2020) Interview zu Klimapolitik, Ressourcenverbrauch und Konsum, Radio FM4 (im Rahmen der FM4 Klimatalks), Sendung FM4 connected, 18.9.2020.			x	x

References

Aguiar, A., Narayanan, B., McDougall, R. (2016), An Overview of the GTAP 9 Data Base. *Journal of Global Economic Analysis* 1 (1): 181–208.

Armington, P.S. (1969), A Theory of Demand for Products Distinguished by Place of Production (Une Theorie de La Demande de Produits Differencies d'apres Leur Origine) (Una Teoria de La Demanda de Productos Distinguiendolos Segun El Lugar de Produccion). *Staff Papers - International Monetary Fund* 16 (1): 159. DOI 10.2307/3866403.

Bednar-Friedl, B., Schinko, T., Steininger, K.W. (2012), The Relevance of Process Emissions for Carbon Leakage: A Comparison of Unilateral Climate Policy Options with and without Border Carbon Adjustment. *Energy Economics* 34, Suppl. 2: S168–S180. DOI 10.1016/j.eneco.2012.08.038.

Benzie, M., Hedlund, J., Carlsen, H., (2016), Introducing the Transnational Climate Impacts Index: Indicators of Country-Level Exposure – Methodology Report. SEI Working Paper, 2016– 07, Stockholm Environment Institute, Stockholm, Sweden.

Benzie, M., Carter, T. R., Carlsen, H., & Taylor, R. (2019), Cross-border climate change impacts: implications for the European Union. Regional Environmental Change, 19(3), 763–776. DOI 10.1007/s10113-018-1436-1

Borsky, S., Jury, M.W. (2020), The role of global supply chains in the transmission of weather induced production shocks. Graz Economics Papers 2020-13.

Bröde, P., Fiala, D., Lemke, B., & Kjellstrom, T. (2017), Estimated work ability in warm outdoor environments depends on the chosen heat stress assessment metric. International Journal of Biometeorology, 1–15. DOI 10.1007/s00484-017-1346-9

Challinor, A. J., Adger, W. N., & Benton, T. G. (2017), Climate risks across borders and scales. Nature Climate Change, 7(9), 621–623. DOI 10.1038/nclimate3380

Chen, C., Noble, I., Hellmann, J., Coffee, J., Murillo, M., Chawla, N. (2015), Country Index Technical Report. Notre Dame Global Adaptation Index. University of Notre Dame.

Eckstein, D., Hutfils, M.-L., Winges, M. (2018), Global Climate Risk Index 2019. Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2017 and 1998 to 2017. GermanWatch, Bonn.

Ewing, B.R., Hawkins, T.R., Wiedmann, T.O., Galli, A., Ercin, A.E., Weinzettel, J., Steen-Olsen, K., (2012), Integrating ecological and water footprint accounting in a multi-regional input–output framework, Ecological Indicators 23: 1-8, DOI 10.1016/j.ecolind.2012.02.025.

Gasim, A.A. (2015), The embodied energy in trade: What role does specialization play?, Energy Policy 86: 186-197, DOI 10.1016/j.enpol.2015.06.043.

Hedlund, J., Fick, S., Carlsen, H., & Benzie, M. (2018). Quantifying transnational climate impact exposure: New perspectives on the global distribution of climate risk. Global Environmental Change, 52, 75–85. https://doi.org/10.1016/j.gloenvcha.2018.04.006

Hewitson, B. C., Janetos, A. C., Carter, T. R., Giorgi, F., Jones, R. G., Kwon, W.-T., Mearns, L. O., Schipper, E. L. F. and Aalst, M. van (2014), Regional context. In Climate Change 2014:Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. V. R. Barros,

C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, et al. (eds.). Cambridge University Press, Cambridge, UK, and New York. 1133–97. https://www.ipcc.ch/report/ar5/wg2/.

Hinkel, J., Lincke, D., Vafeidis, A.T., Perrette, M., Nicholls, R.J., Tol, R.S.J., Marzeion, B., Fettweis, X., Ionescu, C., Levermann, A. (2014), Coastal Flood Damage and Adaptation Costs under 21st Century Sea-Level Rise. *Proceedings of the National Academy of Sciences* 111 (9): 3292–97. DOI 10.1073/pnas.1222469111.

IPCC, (2014a), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

IPCC, (2014b), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

Kjellstrom, T., Holmer, I., Lemke, B. (2009), Workplace Heat Stress, Health and Productivity – an Increasing Challenge for Low and Middle-Income Countries during Climate Change. *Global Health Action* 2(1): 2047. DOI 10.3402/gha.v2i0.2047.

Knittel N., Jury M.W., Bednar-Friedl B., Bachner G., Steiner A.K. (2020a), A Global Analysis of Heat-Related Labour Productivity Losses under Climate Change—Implications for Germany's Foreign Trade. *Climatic Change* 160: 251-269. DOI 10.1007/s10584-020-02661-1.

Knittel N., Bachner G., Bednar-Friedl B., Jury M.W., Lincke D., Hinkel J. (2020b), The effects of global climate change on foreign trade patterns – Insights from a cross-sectoral impact assessment for Austria. Unpublished manuscript.

Kulmer V., Jury M.W., Wong S., Kortschak D. (2020), Global resource consumption effects of borderless climate change: EU's indirect vulnerability. *Environmental and Sustainability Indicators* 8: 100071. DOI 10.1016/j.indic.2020.100071.

Lenzen, M., Kanemoto, K., Moran, D., Geschke, A. (2012) Mapping the Structure of the World Economy, *Environmental Science & Technology* 46(15): 8374-8381.

Lenzen, M., Moran, D., Kanemoto, K., Geschke, A. (2013), Building Eora: A Global Multi-regional Input-Output Database at High Country and Sector Resolution, *Economic Systems Research* 25(1): 20-49, DOI 10.1080/09535314.2013.769 938

O'Neill, B.C., E. Kriegler, K. Riahi, K.L. Ebi, S. Hallegatte, T.R. Carter, R. Mathur, and van Vuuren, D. (2014), A New Scenario Framework for Climate Change Research: The Concept of Shared Socioeconomic Pathways. *Climatic Change* 122 (3): 387–400. DOI 10.1007/s10584-013-0905-2.

Oppenheimer, M., Campos, M., Warren, R., Birkmann, J., Luber, G., O'Neill, B. and Takahashi, K. (2014), Emergent risks and key vulnerabilities. In Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to theUK Foresight 2011, Fifth Assessment Report of the Intergovernmental Panel of Climate

Change. C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, et al. (eds.). Cambridge University Press, Cambridge, UK, and New York. 1039–99.

PricewaterhouseCoopers (PwC) (2013), International threats and opportunities of climate change for the UK. http://www.pwc.co.uk/services/sustainability-climate-change/insights/international-threats-and-opportunities-of-climate-change-to-the-uk.html

Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., et al. (2017), The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview. *Global Environmental Change* 42: 153–68. DOI 10.1016/j.gloenvcha.2016.05.009.

Rohrer, A.V., Bednar-Friedl, B., Knittel, N. (2018a), Vulnerabilität der wichtigsten österreichischen Handelspartner gegenüber dem Klimawandel. COIN-INT Report #1, Wegener Center, Universität Graz.

Rohrer, A.V., Jury, M.W., Preinfalk, E., Bednar-Friedl, B. (2018b), Grenzüberschreitende Auswirkungen des Klimawandels auf Österreichs Außenhandel. Fallstudien zu „Thailandflut", „Weakest Link – Lithium", „Soja" und „Textil- und Bekleidungsindustrie". COIN-INT Report #2. Wegener Center, Universität Graz.

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N.W., Clark, D.B., Dankers, R., Eisner, S., Fekete, B.M., Colón-González, F.J., Gosling, S.N., Kim, H., Liu, X., Masaki, Y., Portmann, F.T., Satoh, Y., Stacke, T., Tang, Q., Wada, Y., Wisser, D., Albrecht, T., Frieler, K., Piontek, F., Warszawski, L., Kabat, P. (2014), Multimodel assessment of water scarcity under climate change. *Proceedings of the National Academy of Sciences* 111: 3245–3250. DOI 10.1073/pnas.1222460110.

Statistik Austria, (2018), Der Außenhandels Österreich - Ergebnisse Im Überblick'. https://www.statistik.at/web_de/statistiken/wirtschaft/aussenhandel/hauptdaten/index.html.

Statistik Austria, (2020), Der Außenhandels Österreich - Ergebnisse Im Überblick'. https://www.statistik.at/web_de/statistiken/wirtschaft/aussenhandel/hauptdaten/index.html.

Steen-Olsen, K., Weinzettel, J., Cranston, G., Ercin, A.E., Hertwich, E.G. (2012), Carbon, land, and water footprint accounts for the European Union: consumption, production, and displacements through international trade. *Environmental Science & Technology* 46: 10883–10891.

Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Loibl, W., Prettenthaler, F. (eds.) (2015), *Economic Evaluation of Climate Change Impacts*. Springer Climate. Cham: Springer International Publishing. DOI 10.1007/978-3-319-12457-5.

Steininger, K.W., Bednar-Friedl, B., Knittel, N., Kirchengast, G., Nabernegg, S., Williges, K., Mestel, R., Hutter, H.-P., Kenner; L. (2020), *Klimapolitik in Österreich: Innovationschance Coronakrise und die Kosten des Nicht-Handelns*. Wegener Center Verlag. DOI 10.25364/23.2020.1.

Warszawski, L., Frieler, K., Huber, V., Piontek, F., Serdeczny, O., Schewe, J. (2014), The Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP): Project Framework. *Proceedings of the National Academy of Sciences* 111 (9): 3228–32. DOI 10.1073/pnas.1312330110.

Wenz, L., Levermann, A. (2016), Enhanced economic connectivity to foster heat stress–related losses. Science Advances 2(6): e1501026. DOI 10.1126/sciadv.1501026

Willner, S. N., Otto, C., Levermann, A. (2018), Global economic response to river floods. Nature *Climate Change* 8(7): 594–598. DOI 10.1038/s41558-018-0173-2