Energy Research & Social Science 80 (2021) 102240

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Pulling up the carbon ladder? Decarbonization, dependence, and third-country risks from the European carbon border adjustment mechanism

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ARTICLE INFO

Keywords:
European Green Deal
EU
Carbon leakage
Border carbon adjustment
Global South
MRV
CBAM

ABSTRACT

Since the EU Commission announced the introduction of a carbon border adjustment mechanism (CBAM) within the European Green Deal, debates intensified on its effectiveness for climate action, adhering to WTO regulations, and potential trade wars with China and the US. We argue that the implications of the EU CBAM for affected countries, especially in the Global South, have been underrepresented so far. We assess countries' relative risk levels in two scenarios: i) CBAM addressing only emissions-intensive sectors and ii) CBAM targeting the whole economy. The paper maps relative risks in these two scenarios using a risk index encompassing the export structure of countries, their emissions intensity, emissions reduction targets, and institutional capacities to monitor and report product-based emissions. The quantitative analysis reveals that the impacts of CBAM are distributed unevenly across the globe. The spectrum of impacted nations varies between the two analysed scenarios, but in both cases most countries at relatively high risk are located in Africa. Three qualitative case studies covering Mozambique, Bosnia and Herzegovina, and Morocco evaluate the countries' trade relations, their carbon intensity, energy and climate policies, and institutional capacities, with a special focus on monitoring, reporting and verification (MRV) of carbon emissions. The analysis sheds light on different patterns of vulnerability and policy options to increase resilience.

1. Introduction

Central to the European Union's plans to link climate action and trade policies in the European Green Deal is a carbon border adjustment mechanism (CBAM). These levies on goods entering the EU are intended to counteract carbon leakage, that is, the relocation of business activities to countries with less ambitious climate policies [1]. So far, policy debates have paid limited attention to the impacts of the policy beyond the EU's borders, apart from the emphasis placed on compatibility with WTO rules. Yet, this policy may impact countries differently; and countries for which exports to the EU are an important part of the economy risk seeing certain sectors contract in the event of a CBAM. The extent of this risk depends not only on policy *exposure* (a country's exports to the EU), but also country *vulnerability*, defined as the inability to adapt by, for example, shifting trade flows, or decarbonizing and verifying a product's carbon content.

While there is a significant body of research on CBAM, it largely looks at impacts within the implementing country or region, and major world players such as China or the United States. The way in which such a policy might impact developing countries[2] is not yet clear (see section 2 for further details). However, other bodies of research on decarbonization processes indicate that Global South countries may be unable to 'go green' at the pace required to remain competitive in global markets. Climate finance flows remain more focused on emerging economies, and

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[2] The country classification as "developing country" differs among institutions (e.g., UNCTAD, UNFCCC, WTO, UNDP, World Bank), and self-reported categories of countries, as this term sometimes 'reflects historically formed common interests and identities of economies' [2] and sometimes refers to a ranking in macroeconomic or social indicators (often GNI or HDI). In this paper, we use the term to refer to Low- and lower-middle-income countries, with a GNI per capita below $4,036, based the World Bank's classification system.

https://doi.org/10.1016/j.erss.2021.102240
Received 6 January 2021; Received in revised form 9 July 2021; Accepted 5 August 2021
Available online 6 September 2021
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the needs indicated by developing countries for financial and technical support far outstrip the currently available finance [3]. In some regions, rapidly increasing energy demand and a lack of financial and technical resources are leading to a high degree of carbon lock-in in energy systems [4]. Such emissions-intensive energy systems would increase the carbon footprint of any product made in these countries, leading to disadvantages on the global market under a CBAM. Escaping carbon lock-in is additionally complex for energy-intensive industrial sectors, where a long investment cycle means that assets installed today need to comply with 2030 and 2040 emissions reduction targets [5]. This process is costly and difficult, requiring policy consistency and support instruments such as subsidies and investments [6]. So far, efforts to decarbonize these industries have been concentrated in Europe and to a lesser extent the United States, China, and Brazil, as this is a particular challenge for developing countries [7]. Finally, the complexities and administrative costs of reporting carbon content pose additional difficulties for countries of the Global South [8,9]. Given these obstacles, a CBAM might limit trade options for the developing world, rather than acting as an incentive to decarbonize.

The scholarly case to research the distribution of risks lies in exploring the implications of such policies at a global level, mapping out a fuller picture beyond the 'key players' which have hitherto been the focus of research. In addition, the paper links the body of CBAM literature to streams of research on the complexity of carbon lock-in and the particular challenges faced by developing countries in decarbonizing their energy systems [10]. The normative case has been raised by other authors, in that a CBAM that disadvantages developing countries would violate the principles of historical responsibility for emissions and respective capacities [11]. However, such policies may also be a first step in reallocating responsbility for emissions to the consumer and countering what Baker [12] calls 'ecologically unequal exchange', where the consumption of the world's richest 10% generates half of the world's emissions. Balancing these imperatives will require a better understanding of a CBAM's impacts outside the EU.

We examine potential implications of the EU CBAM on countries worldwide by assessing not only countries' exposure but also their vulnerability in two scenarios. In a first scenario, depicting the most likely short-term EU plans, CBAM only targets the emissions-intensive and trade-exposed (EITE) goods cement, steel and aluminium. In the second scenario, CBAM is applied to all goods imported to the EU in accordance with EC President von der Leyen's plans to expand a CBAM to more sectors in the long term [13]. Each scenario maps relative national risk levels using an index representing a country's export structure and the importance of trade relations with the EU, emissions intensity, climate targets and institutional statistical capacity. Additionally, we assess different drivers of exposure and of the ability to adapt to a CBAM for three countries identified as relatively high-risk. Here it is important to note that the paper looks at *relative* risk and does not assess impacts. It shows that exposure and vulnerability associated with the EU CBAM are distributed unevenly across the globe; they vary between the two scenarios but are generally higher in the Global South and non-EU Eastern Europe. Our findings on different patterns of vulnerability highlight the need to consider countries' differing adaptive capacity to an EU CBAM. With this, the paper adds a new and timely perspective to the current discussions on CBAM policy design.

The paper begins with a review of the scholarly literature on CBAM and potential aspects of an EU policy design in section 2. Section 3 describes the risk framework and methods and data for the index. Section 4 presents the results of our analysis, including a global map of relative risk levels for the two different scenarios and three in-depth country case-studies. Finally, we discuss different risk patterns and conclude with how these could be integrated into the CBAM policy design.

2. Assessing the impacts of CBAM: The state of the debate

The literature on 'carbon leakage' most often describes the relocation of investment and production from countries with ambitious climate policies, such as a carbon tax or environmental standards, to countries with lower ambitions. Goods differ in their exposure to carbon leakage; researchers find that energy-intensive, trade-exposed sectors such as cement, steel and aluminium are the most likely to be impacted [14]. Although different factors have influenced the offshoring of production to more emissions-intensive regions in the past, especially labour costs [12], the increased climate ambition within the European Green Deal could become an additional driver for carbon leakage.[3]

Going forward, this paper focuses on an EU CBAM as the most likely mechanism to be used to address carbon leakage in the future.[4] Unlike climate clubs, the goal of CBAM is not to sanction free riders, but "to level the playing field among competing producers, and to create political leverage for more ambitious climate action across countries" [20], and ensure that the EU does not lose its industrial competetiveness [21]. If designed poorly, a CBAM could increase administrative costs, raise prices for basic products, spur international trade conflicts and undermine the multilateral rules-based system.

The proposed EU legislation is scheduled to be adopted in 2021. The Inception Impact Assessment, published on the Commission's website, lays out its reasoning:

"As long as many international partners do not share the same climate ambition as the EU, there is a risk of carbon leakage… If this risk materialises, there will be no reduction in global emissions, and this will frustrate the efforts of the EU and its industries to meet the global climate objectives of the Paris Agreement. In this context, a carbon border adjustment mechanism would ensure that the price of imports reflect more accurately their carbon content." [1]

The design of the policy is currently up for debate, and it is beyond the scope of this paper to track the discussions taking place in different EU institutions. However, the Commission's Inception Impact Assessment establishes three aspects we expect to be a part of the CBAM design. First, any measures will be WTO-compatible and comply with "international obligations". Second, the CBAM will at least apply to highly leakage-exposed imported products; options include "a carbon tax on selected products (both on imported and domestic products), a new carbon customs duty or tax on imports, or the extension of the EU ETS to imports" [1]. Third, an evaluation of a product's carbon content will be necessary, whether this is certified by exporters as above or below an EU benchmark, or by "defining carbon content of products, taking into account their interaction with existing and future climate policies" [1]. Given these three guiding points–WTO compatibility, coverage of at least the most leakage-prone sectors, and the necessity of tracking carbon content–we turn to the literature to see how such a CBAM might impact developing countries.

Extensive research has assessed the possible impacts of CBAM on global emissions and competitiveness as well as the implications for international trade since the 2000s [11,22]. Impacts depend on the different elements of policy design, such as scope and coverage, how emissions are calculated, and compatibility of CBAM regulations with existing national emissions monitoring systems; see Mehling et al. [20] for a comprehensive overview, or Rocchi et al. [23] for a proposal on a CBAM based on avoided emissions.

If an EU CBAM applies to imports, as seems likely from the

[3] Similar concerns around the increased risk of carbon leakage for energy-intensive industries were raised at the implementation of the EU Emissions Trading System (ETS); however, actual carbon leakage rates from this policy remained low [15,16]. As a preventive measure, the so-called 'carbon leakage list' grants most exposed sectors special treatment to support their international competitiveness; this will be phased out gradually until 2030 [17].

[4] While it is outside of the scope of this paper, there is a significant body of research on whether a CBAM is indeed the most effective mechanism to address carbon leakage; the dynamics of trade and on carbon leakage more generally (see for example [18]); and the implications of a global carbon price (see [19]).

Commission's impact analysis, models of anti-leakage policies suggest that consumption of home goods will grow and imports will decrease; this would also be the case in a 'full border adjustment scenario' [24]. As for sectoral coverage, the literature shows a preliminary consensus that applying border adjustments to the most vulnerable EITE sectors would already significantly reduce carbon leakage [14,25 26,27], and could increase the international competitiveness of domestic EITE industries [28]. While this can address a significant amount of carbon leakage, studies that include other sectors such as agriculture find further coverage reduces leakage [29]; and a meta-analysis of different studies confirms that despite its complicated political feasibility, full sectoral coverage would reduce leakage [30]. The EU Commission Guidelines therefore envision that the CBAM "will start with a number of selected sectors and be gradually extended" [13], similar to a gradual sectoral expansion of the EU ETS. Such an approach would also be more in line with calls to counter 'ecologically unequal exchange' [12], if the responsibility for emissions becomes tied to consumption of goods rather than only their production.

While it has been argued that CBAM can be designed to be WTO compatible [20,27,31,32], it could still spur a political backlash, retaliatory trade responses, and a breakdown of international climate negotiations and cooperation [33–35]. CBAM has also been critiqued as a form of 'green protectionism', and some have raised the concern that such policies may shift the burden of mitigation to developing countries [11,36,37]. This is especially relevant for energy-intensive sectors which are costly and complex to decarbonize [5]. Some authors have suggested that the principle of common but differentiated responsibility means that developed countries should invest in and take the main responsibility for the development and diffusion of the technologies needed to transform energy-intensive industries [7]. Another way to lessen risks for developing countries would be by exempting selected countries from CBAM, although this could potentially create 'carbon havens' [38] or come into conflict with WTO regulations [20,39].

While some authors have invoked the importance of common but differentiated responsibility, there are few empirical examinations of how developing countries in particular may be affected by a CBAM. Most analyses so far have focused on major trading partners, especially China [40–44]. Mattoo et al. [45] model the possible impacts for different country groups and major trading partners, finding that most policy design options would have a negative impact on developing country exports and economic welfare. The economic impacts from such measures for developing countries can be somewhat mitigated if the revenues from a CBAM are used to fund clean development and tech transfer, but welfare losses remain [46]. However, assessments consider macro-level welfare impacts, most often on single countries or on country categories; and do not evaluate the differences in national capacities to respond to such policies. We argue that these differences in countries' vulnerability need to be considered in addition to countries' economic exposure, in order to evaluate relative risk levels from an EU CBAM. So far, the literature on CBAM largely does not consider the administrative burden of tracking carbon content [30], although associated capacities greatly differ across the globe [47]. This process may be more difficult in developing countries [9] which are given less stringent reporting obligations due to these limitations at the UNFCCC [48]. Monitoring, reporting, and verifying (MRV) of carbon content will require significant statistical capacities from exporters, regardless of whether producers certify a product's carbon content compared to an EU-average benchmark or use a more product-specific approach. Using benchmark values might simplify carbon accounting, as only those producers with emissions below this value would see a benefit in tracking carbon. However, this approach would decrease the importance of gradual emissions reductions if they do not bring carbon intensity below the threshold [49]. Such benchmarks may also ease the path towards WTO compatibility if a CBAM is applied to imported goods; but, as Fischer and Fox point out, this is rather counter-productive in the end, as "one would *want* to discriminate against more emissions-intensive imports" [24]. In other words, there are likely trade-offs between simplifying carbon accounting by using benchmark values and decreasing incentives for climate policies for incremental emissions reductions [50].

Here, it is important to note that an EU CBAM would not be the only instance of influential trade players linking trade and climate; in the United States, proposals for a 'green deal' involve border adjustments [50], and President-elect Biden's climate plan includes similar measures.[5] Therefore, the larger question of developing country vulnerability in the event of linked climate and trade policies merits further examination.

Going forward, both the academic literature and policy planning process would benefit from understanding the risks arising from a CBAM for non-EU countries. Our study addresses this gap by both assessing how relative risk is distributed at a global level and providing an in-depth analysis of three relatively high-risk countries with diverse geographical backgrounds and development contexts.

3. Methodology

Countries with limited abilities to adapt to a lower-carbon paradigm may face a higher risk of economic consequences from an EU CBAM. We draw from the literature on risk to consider the dynamics of impacts from a CBAM on developing countries, where risk refers to "uncertainty about and severity of the consequences (or outcomes) of an activity with respect to something that humans value" [52]. Risk depends on both exposure to a risk agent, and vulnerability, that is, the extent to which an 'absorbing system' reacts to stressors. The 'absorbing system' of the country and its institutions might be less able to react to a CBAM in a way that minimizes risk, depending on characteristics such as level of decarbonisation, climate policies, and capacities to deal with the administrative burden of tracking carbon content. For example, two countries may have similar exposure to a CBAM, but a country with a high degree of carbon lock-in will be more vulnerable than one which is on a clean pathway. Similarly, exporters in a country with an effective emissions tracking system already in place might be better prepared to measure, report and verify the carbon content of their products.

We use the concepts of exposure and vulnerability to construct a relative risk index in two different scenarios. In the first scenario, only EITE exports to the EU would be subject to a CBAM. In the second scenario, all exports to the EU would be subject to a CBAM. Scenario 2 would more thoroughly address all carbon leakage but would also increase complexity; it is unlikely to be introduced in the short term but could represent a longer-term option. Scenario 1 is more likely to be used in the short term, as the EU Commission has stated its intent to focus at least on the highest-leakage sectors. The index combines exposure (how important trade with the EU is for a country's economy) and vulnerability (potential reaction to stressors). The composition of the risk index is visualized in Fig. 1.

In Scenario 1, exposure to a CBAM is measured by EITE-sector exports of cement, steel and aluminium to the EU as a proportion of a country's GDP [53]. In Scenario 2, country exposure to a CBAM is measured by its total exports to the EU as a proportion of national GDP [54][6]. Both indices increase the extent to which a country is exposed to a CBAM, and therefore the overall risk of severe economic consequences.

We consider the (in)ability to adapt as a combination of three dimensions of vulnerability:

Firstly, countries could adapt by trade diversification. In the first scenario, some countries may try to diversify their exports of EITE products. To measure the prospects for this strategy, we take UN data on EITE goods as a percentage of total exports [55] as a proxy; high shares

[5] See for example [51]

[6] Trade data for most countries covers 2018. We also included countries without data for 2018 with the latest available data, going no further back than 2012.

Framework	Scenario 1: Risk Indicator	Scenario 2: Risk Indicator
Exposure		
Importance of trade with the EU for the national economy	EITE exports to the EU as proportion of country GDP	Exports to the EU as proportion of country GDP
Vulnerability		
Reliance on trade with the EU	Diversification of exports : EITE exports as a proportion of total exports	Diversification of partners: Exports to the EU as a proportion of total exports
Emissions, current and planned	Carbon intensity of total final energy consumption & Emissions Reduction Targets	
Capacity to measure and report emissions	National statistical system and data quality	

Fig. 1. Framework and operationalization of the risk index.

indicate low trade diversification, adding to vulnerability. In the second scenario, covering all goods, some countries may seek new trading partners. Overall risk is therefore increased by a higher reliance on the EU; we take the share of exports to the EU relative to total exports as a proxy [54].

Secondly, a high carbon intensity of energy systems increases a country's vulnerability, as it is difficult and expensive to break away from carbon-intensive systems [56]. As a proxy for carbon intensity, we use the carbon intensity of the total final energy consumption (TFEC)[7], which is calculated by taking national emissions [57] divided by TFEC [58]. The use of this proxy entails some limitations, as different levels of energy efficiency within production processes or the direct use of renewable energy sources within production processes are not captured. Furthermore, the carbon intensity of the EITE sector can be expected to be higher than of TFEC; however, as sector-specific data are not available for a large number of countries, we rely on the carbon intensity of TFEC as a proxy in both scenarios.[8] The limitations in the data on carbon content of products and the complexity of accounting in a world of global production has been noted by other authors [12]. However, despite this limitation the carbon intensity of TFEC remains a good proxy for the carbon intensity of the EITE sector as the main drivers behind the carbon intensity of the different sectors within the economy are energy efficiency and the fuel mix which are strongly linked to the carbon intensity of the energy sector overall.

In addition, we look at whether national emissions are likely to fall in the future, which could be a further strategy for adaptation to the EU CBAM. As a proxy, we take data from Pauw et al.'s NDC Explorer project [62], creating a binary variable where 0 is aiming to reduce total emissions, and 1 encompasses countries without targets as well as those with emissions reductions in line with 'Business as Usual' scenarios.[9] Having no emissions reduction target increases vulnerability. This binary proxy entails some limitations, as it is unable to capture different degrees of ambition and differences between the two scenarios. As an indicator measuring specific plans for emissions reductions in the EITE sector has been missing at a global scale, we relied on this proxy for both scenarios.

Thirdly, regardless of emissions levels, exporters will need to be able to monitor, report, and verify emissions; an inability to do so would increase vulnerability. The ability to measure emissions is relevant whether a CBAM evaluates carbon content using benchmarking or a more product-specific approach. While the tracking of embedded carbon would be done by exporting firms rather than countries in the event of a CBAM, comparable data on the statistical capacity at the firm level on a global scale is lacking. Therefore, we employ national statistical capacity as a proxy, measuring the statistical system and the quality of data [57]. The ability of local firms to measure, report and verify the carbon content of their products will to some extent depend on the existing national infrastructure and the level of statistical skills and knowledge in a given country. The national statistical capacity has influence on the national "data ecosystem" [63], in terms of skills of locally trained personnel and established reporting procedures and infrastructures [64]. This impacts both private companies' carbon labelling practices and national companies in the EITE sector [65], which, for example, accounted for at least 32% of global crude steel output in 2016 with growing presence over the past years [66]. Thus, national statistical capacity is considered to be of key importance for economic growth and sustainable development [67]. In countries with effective emissions reporting schemes, standards and publicly available data on sectoral emissions, firms will not need to build such systems from the ground up, which would be an "administratively complex, burdensome and costly task" [68,69] that could "exclude most companies in developing

[7] We chose this measure over carbon intensity of GDP because the latter varies more based on the sectoral composition and it is therefore less comparable across countries.

[8] It should be noted that we explored the use of the EORA Global Supply Chain Database [59,60], which was the only database we found to cover sectoral emissions for a larger number of countries. However, this database has certain limitations. Firstly, the years covered are only until 2015. Secondly, the database is not fully publicly available. Finally, the computational approach is based on a multi-region input–output table model which also relies on a number of assumptions [59,61]. Future work could incorporate this database as a robustness check for the chosen vulnerability measures. However, we believe that this is beyond the scope of this paper.

[9] While this is a simplistic measure, it captures whether the carbon in products is likely to fall in the long term; other indicators of national ambition (e.g. RISE) are more precise, but would result in large case losses of developing countries.

Table 1
Summary statistics and description of the relative risk indices.

	Formula	N	Mean	Standard deviation	Values range
Scenario 1	Sectoral_Exports_GDP + 0.25×(RelativeExports_Sectoral + LowStatisticalCapacity + CarbonIntensity_FinalEnergyConsumption + LackingEmissionReductionTargets)	95	−0.03	1.07	−1.3 6.67
Scenario 2	Exports_GDP + 0.25×(RelativeExports_EU + LowStatisticalCapacity + CarbonIntensity_FinalEnergyConsumption + LackingEmissionReductionTargets)	106	0.05	1.23	−1.58 6.28

The standardized values of all relevant variables were used in the formulas. A small number of outliers were removed. Namely, observations with CarbonIntensity_FinalEnergyConsumption > 2.6 as well as those with LowStatisticalCapacity > 1.93.

countries" [70]. Higher national statistical capacities would allow for a quicker, less cost-intensive adaptation to the new EU CBAM requirements and make exporters less vulnerable.

In order to construct the relative risk index, we consider exposure and vulnerability as equally important and therefore give them equal weights. Recognising that exposure is necessary for vulnerability to be relevant, countries with zero or close to zero exposure (<0.000001) were excluded. The relevant variables were standardized to be comparable across different scales; therefore, the indices indicate a country's risk level *relative* to others.[10] Table 1 provides an overview of the summary statistics and description of the relative risk indices. Further details on the variables used and the summary statistics of the constructed indices can be found in the appendix (see Table A1 and Table A2).

Countries with missing data for at least one of the variables comprising the risk indices were removed from the analysis. This also includes a number of high-income countries like the United States, Canada, Japan, and Australia, as we did not have data on their statistical capacity. Although we could assume that the statistical capacity of all these countries is high, we do not consider their exclusion from the analysis problematic as our main aim was to examine the relative impacts of middle-income and developing countries.

To obtain a more nuanced understanding of country-specific exposure and vulnerability in the two presented scenarios, we conduct case studies for three countries: Morocco, Bosnia and Herzegovina, and Mozambique. These countries were selected because they all have a high score on the relative risk index in at least one scenario, are varied geographically and in terms of economic development, and represent different facets of exposure and vulnerability. We compare these countries along three main aspects: trading structure and trade relations with the EU; carbon intensity, energy and climate policies; and institutional capacities, with a focus on monitoring, reporting and verification (MRV) of carbon emissions. The case studies add a more nuanced and comprehensive picture of countries' energy policies, climate goals, and relevant statistical capacities beyond the limitations of the proxies used within the index. The comparative analysis thereby adds to the understanding of relative risk by identifying potentially different drivers of higher risk levels among these countries and associated contextual conditions. Due to the differing contextual conditions, there are nevertheless limitations regarding the generalizability of the results from these case studies [71].

4. Results

4.1. Mapping relative risk levels

We employ the relative risk index to map at-risk countries for the two scenarios. To facilitate interpretation, the global map depicts countries' relative risk in quintiles of the risk index. The values of the risk index for countries that ranked in the two highest quintiles in both scenarios are shown in the appendix (see Table A3).

In Scenario 1, a CBAM on EITE goods entering the EU would impact North-Western and Southern African countries as well as South-Eastern European countries most (see Fig. 2). However, differences in relative risk levels among African countries are generally smaller than in the second scenario. The countries most affected in this scenario include Bosnia and Herzegovina, Algeria, Namibia, Madagascar, Cambodia, and Vietnam (5th quintile) (see Table A3).

In Scenario 2, which might become relevant in the long term when the scope of CBAM will likely be broadened, the countries with the highest relative risk from an EU CBAM are located in Northern Africa, non-EU Eastern Europe and Southeast Asia (see Fig. 3). Strong differences in risk levels are visible, even among neighbouring countries in Africa. Most at risk are the Northern African countries of Tunisia, Algeria and Morocco, along with South Africa, Zimbabwe, Lesotho, and Mozambique (5th quintile of the risk index). Other African countries like Egypt face relatively low risk levels (1st quintile). Furthermore, a diverse range of countries including Jamaica, Saint Lucia, Serbia, Trinidad and Tobago, Bhutan, and Montenegro also rank relatively high (5th quintile).

The analysis shows that economic risks related to an EU CBAM are distributed unequally across the globe. The relative risks for countries differ depending on whether a CBAM is applied to only EITE sector goods (Scenario 1), or all goods (Scenario 2). Kazakhstan, for example, is among the countries with the highest relative risk levels in Scenario 1 (within the 5th quintile) but is at lower risk in Scenario 2 (1st quintile). In turn, Zimbabwe and Bhutan rank among the countries with the highest relative risk levels in Scenario 2 (5th quintile) but would be at low risk in Scenario 1 (2nd and 1st quintile). Several countries including Turkey, North Macedonia, Sao Tome and Principe, and Saint Lucia are relatively high-risk in both scenarios.

A number of robustness tests were conducted to see how relative risks change when exposure is given a higher weight than vulnerability. More specifically, this was done for a 60%, 80% and 90% weight of the exposure indicator. The general conclusion that the Global South and non-EU Eastern Europe face higher relative risks holds for both scenarios.

4.2. Patterns of vulnerability

We conducted comparative case studies of three relatively high-risk countries in order to enhance understanding on different patterns of vulnerability. These case studies evaluate countries' exposure based on their trade relations with the EU, and their vulnerability based on trade diversification, carbon intensity, energy and climate policies, and the institutional capacities for MRV. The selected countries cover different world regions and exemplify specific drivers of vulnerability. Fig. 4 demonstrates countries' relative performance in deciles of the risk index's components. The case studies draw a more nuanced picture of how Morocco's relatively high risk is strongly influenced by carbon lock-in, Mozambique's risk level is driven by a low statistical capacity to prove emissions, and Bosnia and Herzegovina's low diversification of trading partners and goods decreases adaptive capacity. Understanding these patterns of vulnerability within the two scenarios sheds light on entry points for reducing relative risk levels.

4.2.1. Low emissions and low statistical capacity – The case of Mozambique

Mozambique's ability to adapt to an EU CBAM mostly depends on the ability to monitor, report, and verify the currently comparatively low emissions intensity of its products. Its TFEC is 64% less carbon-intensive

[10] Standardisation here indicates subtracting the mean and dividing the results by the standard deviation.

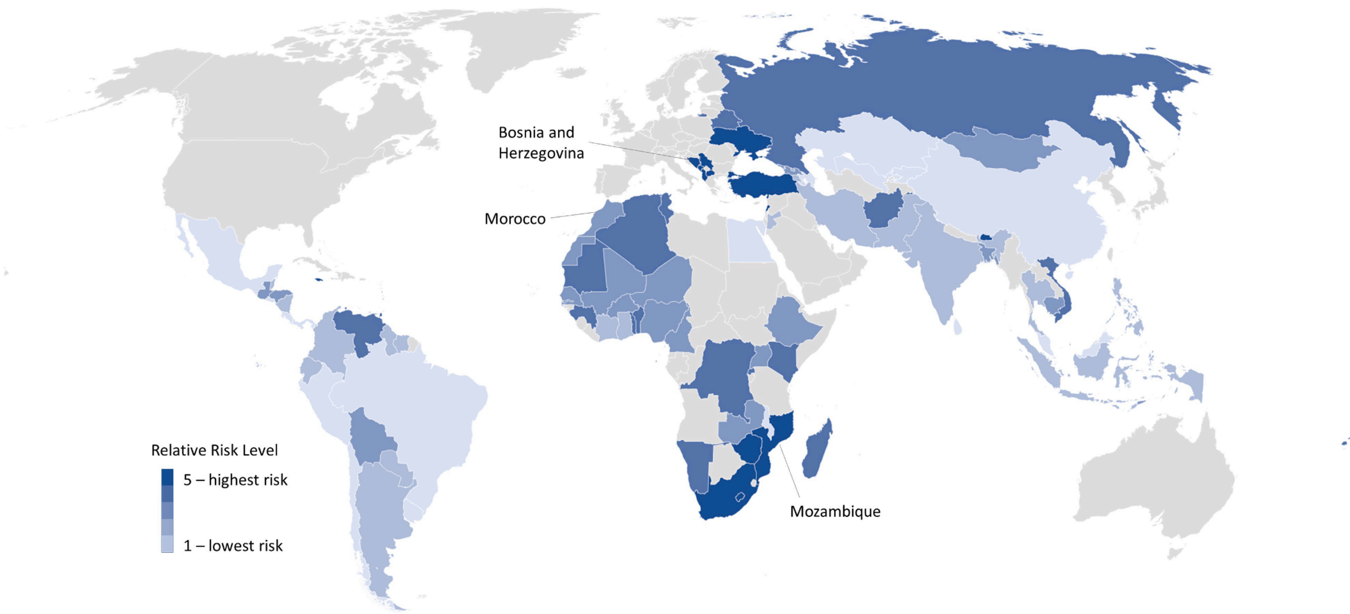

Fig. 2. Global map displaying quintiles of country relative risk levels for an EU CBAM on EITE imports (Scenario 1).

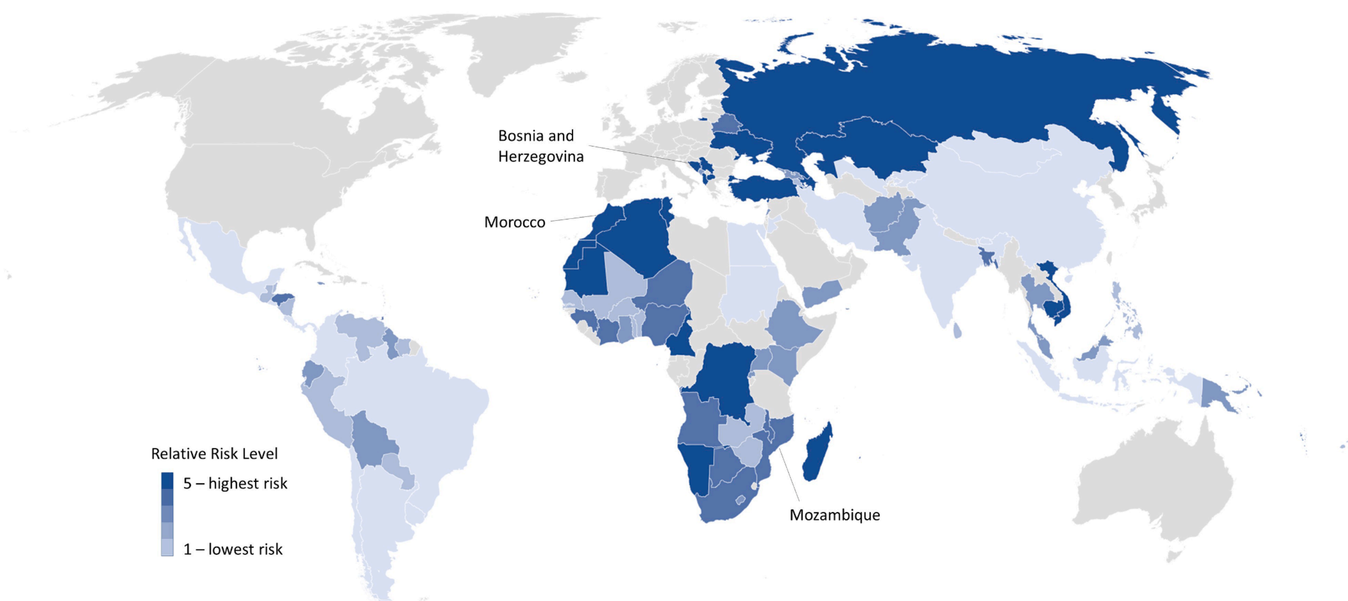

Fig. 3. Global map displaying quintiles of country relative risk levels for an EU CBAM on all imports (Scenario 2).

than the EU average; this value is most likely significantly higher for the EITE sector alone, for which data is lacking. However, this picture might change in the future, as Mozambique has vast offshore gas reserves [72] and a large share of the population without access to the power grid (70%) or without the means to afford the relatively high electricity prices [73]. Mozambique does not plan to reduce carbon emissions, but to mitigate carbon in relation to BAU [72]. High shares (62%) of the primary energy supply originate from biofuels and waste, and 70% of its electricity comes from hydropower [74]. New installations of wind and solar energy could help the country avoid future carbon lock-in; first support policies include a feed-in tariff (since 2014) and plans for auctions in 2021 [75].

Thus, currently, the low statistical capacity can be considered the strongest driver of Mozambique's vulnerability. The country missed several submission deadlines for reports to the UNFCCC [53] and indicated the need for capacity building [62]. Several international initiatives support Mozambique, but mostly do not tackle the decarbonisation of aluminium production (its key EITE export), or MRV in particular [76].

Whether payments under a CBAM are based on benchmarking or embodied emissions, a lack of statistical capacity to prove its lower carbon intensity could have severe economic consequences. Mozambique would be exposed to additional CBAM costs in both scenarios but would face greater economic consequences in Scenario 2. The EITE sector accounts for 26% of Mozambique's total exports, and, besides raw cane sugar, it accounts for the majority of exports to the EU. In the case of a CBAM covering all imports, export diversification would remain a driver of vulnerability: 30% of Mozambique's total exports target the EU, making up 11% of its GDP.

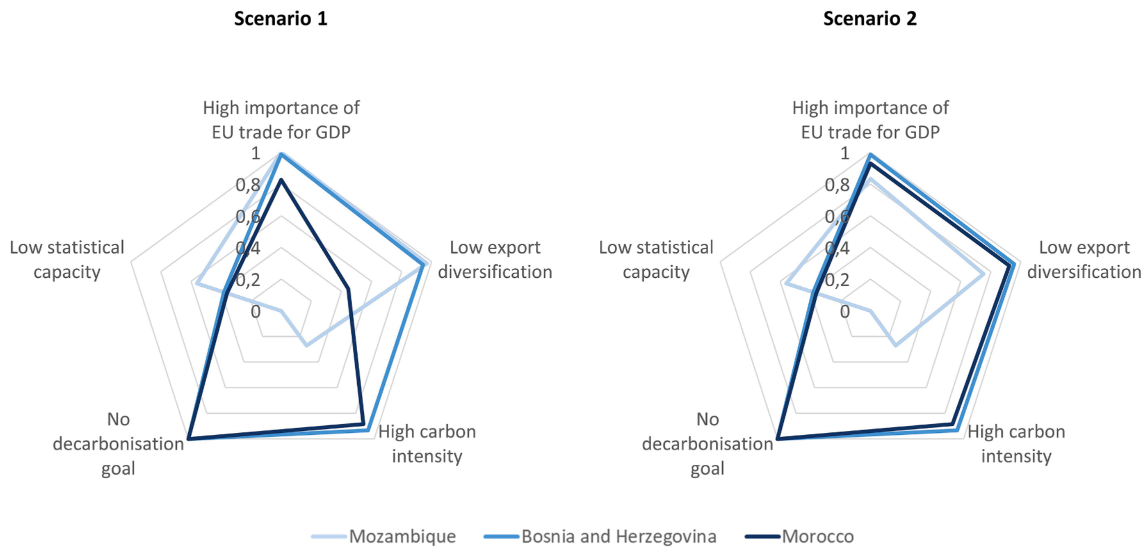

Fig. 4. Relative risk levels of selected countries in Scenarios 1 and 2.

4.2.2. *High emissions and carbon lock-in – The case of Morocco*

Morocco's vulnerability is driven not only by a high level of current emissions, but also by a long-term carbon lock-in until 2050. The carbon intensity of industrial energy consumption is 60% and the intensity of its TFEC is 50% higher than the European average. The country's power sector strongly relies on fossil fuels; two thirds of the energy supply stem from oil and almost a quarter from coal [74]. Despite its import dependency, the country will further expand coal powered generation; long-term power purchase agreements would increase the costs for a decarbonisation process of the national electricity system [77]. Morocco plans to further increase its emissions and only to reduce them compared to BAU [78].

Nevertheless, a low-carbon development strategy aims to increase the share of renewables to 52% especially by the expansion of solar power and reduce energy consumption by 15% by 2030 [79]. Additionally, Morocco identified cement production and phosphate processing as target areas to achieve emissions mitigation [78]. Whether Morocco would be able to measure and report sectoral emissions remains open, as the country currently lacks an operational sectoral MRV system, increasing the country's vulnerability in Scenario 1. However, a pilot in each sector is planned [80] as preparation for the establishment of a future carbon market, with international support [81]. These processes open two options to decrease Morocco's vulnerability vis-à-vis a CBAM. One relates to a currently discussed CBAM design option, in which "comparable mitigation efforts" and especially national carbon pricing systems could lead to an exemption from the CBAM. The second option relates to a targeted decarbonisation of single export-oriented plants based on the installation of renewable energy, to 'green' exports despite the national's electricity system's carbon lock-in. A first pilot of solar thermal power use in cement plants in Morocco started in 2014 [82]. Furthermore, Morocco's plans to export green hydrogen to the EU point in this direction.

Morocco's high exposure is also due to its close economic relations with Europe: Morocco is part of the Euro-Mediterranean Partnership, signed an Association Agreement in 1996 and currently is negotiating a Deep and Comprehensive Free Trade Area with the EU [83]. The EU is Morocco's largest trading partner and target of 64% of its exports, which constitute 16% of the country's GDP. Whereas Morocco's main exports to the EU are relatively easier to decarbonise products, such as machinery, transport equipment, agricultural products and textiles, the EITE sector makes up only 2% of Morocco's exports and 0.2% of the country's GDP [83]. Therefore, Morocco would be more exposed in the second scenario.

4.2.3. *High emissions and low trade diversification – The case of Bosnia and Herzegovina*

Bosnia and Herzegovina's vulnerability is driven by a high emissions intensity paired with low trade diversification. The carbon intensity of its TFEC and of industrial consumption is almost double that of the EU average. Significant emissions reductions are not within reach, as the country's climate targets see emissions increasing until 2030. With large lignite reserves available at a reserve-to-production ratio of almost 200 years, most energy stems from coal (60%), followed by oil and gas [74]. The share of renewables in electricity production reached 42% in 2018; 96% of renewable electricity stems from hydropower, leaving potential for wind and solar energy untapped [84]. Although the Energy Community provides technical support and advice on renewables and energy efficiency, the EITE sector is not targeted in particular [84]. The introduction of carbon pricing is also not planned. However, if emissions reductions were achieved, the country would be able to provide detailed information on sector specific emissions levels [53].

A low trade diversification leads to high exposure for Bosnia and Herzegovina in both scenarios and makes high additional payments likely. As of 2020, 72% of the country's exports go to the EU, making up 26% of its GDP. The main exports are machinery and appliances, followed by metals, including iron, steel and aluminium; these EITE sector exports to the EU are the basis for over 5% of the country's GDP. The country has close political and economic relations with the EU and applied for membership in 2016. In 2019, the EU Commission confirmed support, but identified key reform areas before entering accession talks [85]. These prospects make a re-orientation towards alternative trading partners, which could reduce the country's risk levels, rather unlikely; rapid decarbonization is the only way the country could increase its resilience.

5. Discussion

Whereas other studies have calculated the potential economic impacts of border carbon adjustment mechanisms on major trade partners [41,43] our paper does not assess impacts but rather looks at *relative* risks, in order to give an overall picture of their global distribution. It differs from previous work in assessing not only exposure, but also the potential for countries to adapt to a CBAM. This special emphasis on vulnerability stems from the considerations around historical responsibility and justice raised also in this journal [12,86]; and the understanding that carbon lock-in is a pervasive problem for both the energy sector [4] and energy-intensive industries [7].

The analysis reveals that relative risk is highest in the Global South and non-EU Eastern Europe, and points toward different patterns of exposure and vulnerability. Carbon lock-in and trade patterns play a key role for Eastern Europe, while statistical capacities become relevant for developing countries. Overall, the highest relative risks in both scenarios are found on the African continent.

In the South-Eastern European region, risk is relatively high in both Scenarios 1 and 2 due to high-emissions energy systems and low export diversification. The case of Bosnia and Herzegovina shows that an export strategy with a strong EU orientation becomes a problem if it is heavily based on EITE sector goods. Similar pattens of vulnerability are visible in other countries in the region such as Albania, Montenegro, North Macedonia, Serbia, and Ukraine. As the literature on low-carbon transitions in energy-intensive industries shows, the longevity of the investment cycle [5] means that these will quickly become stranded assets in the case of an EU CBAM. Competing with European producers by going zero-carbon is unlikely here, as this requires mobilizing investment and subsidizing the transition, which has already begun in the EU [6,7].

A similar problem arises for Mozambique in Scenario 1, due to the key importance of EITE sector goods for its GDP and overall exports. This risk could be mitigated if producers in Mozambique were able to monitor, report, and verify emissions from EITE production, as the carbon content of products is likely lower than the EU average. However, the case studies reveal that the complexity of sector-specific MRV already poses serious challenges to countries that have MRV capacities for emissions in place. Therefore, countries with low-carbon production and low statistical capacities such as Mozambique still risk being impacted by a CBAM. This paradox might intensify ongoing discussions on climate justice and historical responsibility, as countries need time as well as financial and technical support to establish procedures for a sector-specific emissions inventory. A differentiation in reporting obligations based on country capabilities, in which least developed countries report less frequently and with less details has been practiced under the UNFCCC [48]; this could be a promising approach to ensure that a lack of MRV capacities does not increase risk.

In contrast, countries like Morocco with a high carbon intensity and high share of GDP from (non-EITE) EU trade would face more difficulties in Scenario 2, as any of their exports to the EU might be subject to a CBAM. The difficulties of escaping carbon lock-in and addressing growing energy demand leave little room for a phase-out of fossil energy sources at the necessary pace to stay at or below EU emissions levels. While many countries focus their emissions mitigation policies on increasing the share of renewables in the electricity system, which is likely beneficial across both scenarios, this is insufficient to decarbonise the EITE sector which needs specific measures and support [6]. Very few countries have introduced policies that tackle the EITE sector specifically that could reduce their vulnerability in Scenario 1. In Morocco, first pilot projects in the cement sector have been implemented; a targeted decarbonisation of export-dedicated EITE production could be in line with the country's plans for a strategic partnership on green hydrogen production with the EU and decrease Morocco's vulnerability vis-à-vis CBAM in Scenario 1. This case study highlights a potential risk of Scenario 1, in which countries or companies could "reshuffle" their renewable energy capacity, devoting clean energy to supply just EU-export-oriented production sites without major changes in the domestic energy systems, rendering the EU CBAM's goal to lead global emissions reductions less effective [49].

Here it is worth highlighting the finding that smaller developing countries face higher relative risks than the emerging economies of Chile, Brazil, China, or India. Larger countries may be less exposed because of stronger internal markets that decrease the importance of EU trade relative to GDP. Their vulnerability is also lower due to the higher average statistical capacity which could enable monitoring, tracking and verifying carbon content; and the existence of climate targets which may mean decreased carbon content of products in the future. Although this is not depicted within our index, large economies may be even less vulnerable because have higher chances to negotiate political tit-for-tat agreements; and because their overall prospects for rapid decarbonization are better due to the fact that they receive more resources for low-carbon transitions such as 'green' finance and technology transfer [87].

The finding that many smaller developing countries have higher relative risk has implications for the potential for the world to achieve its climate goals, and for normative questions of global justice. Many developing countries have indicated a need for international finance, technology transfer or capacity building to achieve their NDCs under the Paris Agreement [3]. Without access to these support measures, the danger emerges that countries fall behind in decarbonisation processes, which might result in higher risks of economic instability or conflict [88]. The current COVID-19 health crisis seems to further increase the gap between energy transition leaders and laggards [89]. Thus, international support seems to be important to avoid conflicts within the UNFCCC and to achieve the European Commission's goal to increase global ambition in the long run. This need for support mechanisms also links to the current EU discussion on what should be done with the revenues from a CBAM. It has been suggested to retain this revenue within the EU as a contribution to the bloc's own resources, including financing the Covid-19 recovery [13]. This use of funds would contradict recommendations that countries historically responsible for climate change fund and transfer innovations to address the sectors most difficult to decarbonise, especially the energy-intensive industry [7]. Using at least part of the CBAM revenues for climate finance may not only enhance the resilience of developing countries and reduce their climate policy risks, but also increase acceptance and compliance with the emissions reporting obligations needed for the CBAM.

This paper has two key limitations: its operationalization of risk, and the potential for scenarios to change as the EU's CBAM policy evolves.

The focus on providing as wide a picture as possible meant that the index uses proxies in place of more precise variables that would have limited the breadth of countries surveyed. For example, we relied on TFEC as a proxy, as comprehensive data on the carbon intensity of specific sectors, namely EITE, is missing. In order to measure vulnerability, we refer to the statistical capacity within countries as a proxy, as comparable data at the level of exporting firms is not available. Similarly, the use of emissions reduction targets and statistical capacity as proxies for future emissions trajectories and ability to measure emissions entails a number of limitations (discussed in detail in section 3), but still represents the best measure available for a comparative study at the global level.

In addition, the relative country risks we outline here may be subject to change as the design of the EU CBAM develops; the index cannot account for the many ways in which certain policy details could change countries' exposure and vulnerability. Here we outline three potential differences and their possible effects: which sectors will be taken into account, how carbon will be measured, and whether certain countries will be excluded from the measure. While a tax on EITE-sector goods (Scenario 1) seems most likely in the short term, the sectoral coverage could be broadened in the future [13] to include further sectors such as energy or agriculture, which will impact the relative risks. Furthermore, the use of benchmarking rather than tracking a product's emissions may change the relative importance of MRV capacities for vulnerability. If benchmarks are used, producers in relatively low-emissions countries like Mozambique would still need sufficient MRV capacities to verify that their product's emissions fall below the benchmark in order to be exempted. But for producers with emissions above the benchmark, indicating the exact emissions embodied in their exports becomes less important, thereby decreasing the importance of gradual emissions reductions targets if the carbon intensity is not brought below the benchmark's threshold. Hence, if benchmarks are used instead of product emissions, the relative weight of the different elements of vulnerability might change for high-carbon producers, with less importance placed on emissions reductions goals, carbon intensity, and MRV capacities.

Another uncertainty is whether or not developing or least developed countries would be excluded from a CBAM altogether. Such an exclusion might have consequences for the European Commission's aims to achieve WTO compatibility and to avoid carbon leakage; however, it has been argued that at least in the short-term perspective, the loss of emissions coverage might be modest [13]. Our findings on the relatively high risk for certain developing countries can inform this debate, especially when it comes to exposed countries like Mozambique, where vulnerability stems not from its emissions but a lack of MRV capacities.

6. Conclusion

Given the urgency of the climate crisis, the European Green Deal promotes novel ways to foster climate action while attempting to avoid carbon leakage. After a decade of theoretical discussions on CBAM, the EU puts the promising idea to link climate and trade policy into practice, with yet unknown consequences. Other countries, like the United States under President Biden or China might follow similar approaches. It is therefore relevant whether countries will indeed adapt to such measures by decarbonising production. Further research on implications and potential (unintended) risks of such energy transition policies, especially on countries of the Global South, could help avoid new global dividing lines [87].

This paper contributes an analysis of potential implications for non-EU countries by drawing on the concepts of country exposure and vulnerability. It compares these in two different scenarios: a CBAM covering only EITE sector imports, which is favoured as a short-term solution, versus CBAM covering all imports, which could be the result of a future expansion. Our analysis suggests that relative risks from an EU CBAM are distributed unevenly across the globe. The design of the CBAM matters, as the countries at relatively high risk vary between the two scenarios. We find that most countries with relatively high risks across both scenarios are located in Africa. Given their high trade dependence on the EU, South-Eastern European countries also face relatively high risks.

The EU would be well advised to take patterns of country exposure and vulnerability into account when designing CBAM to avoid new global dividing lines. Several options could be discussed: a part of the revenues generated could address climate justice concerns and support countries in their decarbonisation processes and the build-up of institutional capacities. The EU could offer support and capacity-building to reduce vulnerability on various ends. Possible means are training programs for MRV and best practice exchanges with emissions reductions in the EITE industries, similar to the Nitric Acid Climate Action Group (NACAG) initiative in the chemical industry.

Several countries are likely to be challenged by sector-specific emissions MRV; building CBAM on existing international emissions reporting obligations would minimize administrative burdens. A differentiation regarding reporting periods and the level of detail, reflecting institutional capabilities alike under the UNFCCC, could be one approach to increase policy acceptance and compliance.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Laima Eicke, Silvia Weko and Maria Apergi are funded by the Investigating the Systemic Impacts of the Global Energy Transition (ISIGET) project financed by the Federal Ministry of Education and Research (BMBF) under the "Make our Planet Great Again - German Research Initiative", grant number 57429628, implemented by the German Academic Exchange Service (DAAD). Adela Marian is supported with institutional funding for the Institute of Advanced Sustainability Studies (IASS) from the German Federal Ministry of Education and Research and Brandenburg's Ministry for Science, Research and Culture. The authors thank Susanne Dröge, Andreas Goldthau, Anselm Eicke, Rainer Quitzow, Grace Mbungu, Joschka Jahn and Konstantin Veit for useful comments and discussions throughout the research process.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2021.102240.

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