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KUWAIT PROGRAMME

THE CLIMATE CHANGE RISK REDUCTION TRAP

LOW CARBON SPATIAL ECONOMIC RESTRUCTURING AND DISASTER RISK IN KUWAIT

Viktor Rözer,
Sara Mehryar and
Mohammad M. Alsahli

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Abstract

The risks of climate change to economies are typically separated into physical risks and transition risks. Physical risks are the damages and losses that come from extreme weather events due to unmitigated climate change, while transition risks stem from the process of rapidly reducing carbon emissions and its potential disruptions to economies and society, such as stranded assets and shifts in production and the labour market. Combining the literature on spatial economic restructuring and climate disaster risk, we show that physical and transition risk can increase at the same time. We call this dynamic the climate change risk reduction trap, which occurs when new assets that are built as part of the low carbon transition become highly exposed and vulnerable to extreme weather and climate events. The paper provides an empirical illustration of this trap using the example of flash flood risk in Kuwait, a wealthy petroleum-based economy in the Middle East, and shows how decisions on urban planning and economic restructuring have increased flash flood risk. The analysis highlights the importance of considering climate disaster risk and environmental impact assessments in low carbon transition planning to avoid falling into the climate change risk reduction trap.

Introduction

The measures required to tackle climate change will have profound impacts on how we organise our economies and societies.[1] A large part of these changes originate in the need to decarbonise economies to avoid the worst impacts of climate change,[2] while bracing for more frequent extreme weather events and sea level rise as a result of the climate change already underway.[3]

The transition to a low carbon economy can be understood as spatial economic restructuring, which will likely result in an uneven spatial distribution of risks and opportunities in labour, production, service provision and assets.[4] Spatial low carbon economic restructuring requires stranding infrastructure and assets directly or indirectly linked to fossil fuels,[5] while at the same time new infrastructure and assets for the low carbon economy need to be built elsewhere.[6]

The risks associated with low carbon economic restructuring can be understood through different conceptualisations or 'lenses' of risk, including technical, economic and financial, psychological and social science perspectives.[7] This paper extends the financial and economic risk perspective of spatial economic restructuring with the technical perspective of disaster risk, focusing on its direct (damages to assets) and indirect (labour market and incomes) impacts. As a starting point we use a popular financial and economic climate change risk framework, which separates between transition and physical risks from climate change.[8] Transition risks describe the uncertainty around the economic

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[1] Timothy J. Foxon, 'A Coevolutionary Framework for Analysing a Transition to a Sustainable Low Carbon Economy', *Ecological Economics* 70/12 (2011), pp. 2258–67; Leila Niamir et al., 'Transition To Low-carbon Economy: Assessing Cumulative Impacts Of Individual Behavioral Change', *Energy Policy* 118 (2018), pp. 325–45.

[2] Samuel Hitz and Joel Smith, 'Estimating Global Impacts from Climate Change', *Global Environmental Change* 14/3 (2004), pp. 201–18; Johan Rockström et al., 'Planetary Boundaries: Exploring the Safe Operating space for Humanity', *Ecology and Society* 14/2 (2009).

[3] Peter Stott, 'How Climate Change Affects Extreme Weather Events, *Science* 352/6293 (2016), pp. 1517–8; Gary Griggs and Borja G. Reguero, 'Coastal Adaptation to Climate Change and Sea-Level Rise', *Water* 13/16 (2021), p. 2151.

[4] Ray Hudson, 'Uneven Development in Capitalist Societies: Changing Spatial Divisions of Labour, Forms of Spatial Organization of Rroduction and Service Provision, and their Impacts on Localities', *Transactions of the Institute of British Geographers* (1988), pp. 484–96; Aidan While and Will Eadson, 'Zero Carbon as Economic Restructuring: A Spatial Divisions of Labour and Just Transition', *New Political Economy* 27/3 (2022), pp. 385–402.

[5] Frederick Van der Ploeg and Armon Rezai, 'Stranded Assets in the Transition to a Carbon-Free Economy', *Annual Review of Resource Economics* 12 (2020), pp. 281–98; Gregor Semieniuk et al., 'Stranded Fossil-Fuel Assets Translate to Major Losses for Investors in Advanced Economies', *Nature Climate Change* (2022), pp. 1–7.

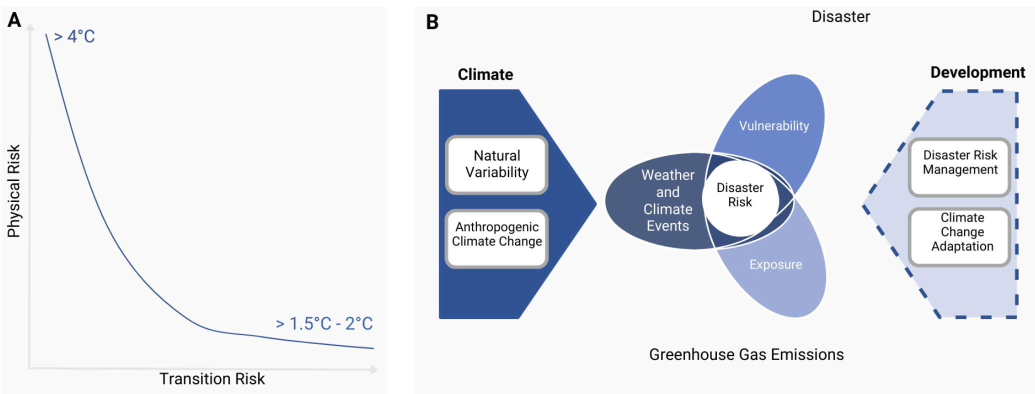
[6] Christopher Kennedy and Jan Corfee-Morlot', 'Past Performance and Future Needs for Low Carbon Climate Resilient Infrastructure – An Investment Perspective', *Energy Policy* 59 (2013), pp. 773–83; Wei Pan, 'Briefing: Delivering Buildings and Infrastructure Towards Zero Carbon', *Infrastructure Asset Management* 1/3 (2014), pp. 60–5; Dimitra Ioannidou, Guido Sonnemann, and Sangwon Suh, 'Do We Have Enough Natural Sand for Low-Carbon Infrastructure?', *Journal of Industrial Ecology* 24/5 (2020), pp. 1004–15.

[7] Terje Aven and Ortwin Renn, 'Risk Management and Governance: Concepts, Guidelines and Applications', *Springer Science & Business Media* 16 (2010).

[8] Stefano Carattini, Garth Heutel, and Givi Melkadze, 'Climate Policy, Financial Frictions, and Tran-

and financial impacts of a low-carbon transition in regard to assets (stranding of 'brown' assets and investment into 'green' assets) and the labour market (transition from 'brown' to 'green' jobs). Transition risks are considered higher the more rapid and extensive an economy needs to be restructured in order to transition to a low carbon economy within the time frames or carbon budgets set in international and national climate change mitigation plans.[9] Physical risks on the other hand, describe the increased probability of the direct impacts of climate change in the shape of losses and damages to humans, the natural and built environment from acute (extreme weather) and chronic (sea level rise, droughts) climate events.[10] Both in the academic literature on climate change risks as well as in regulatory frameworks for the finance industry such as the Task Force on Climate-related Financial Disclosures (TCFD), the relationship between transition risk and physical risk is conceptualised as a trade-off:[11] Fast and ambitious decarbonisation of economies bears high transition risks, due to a high probability of stranded assets and a disruption of the labour market, but lower physical risks as faster reductions in greenhouse gas emissions lower the probability of escalating direct impacts such as extreme weather events and sea-level rise. On the other hand, a slow transition requires less drastic steps to restructure economies but will lead to higher emissions and consequently leads to higher physical risks due to higher costs for adaptation and from losses and damages (see Figure 1A).

Figure 1: Conceptual Illustration of the Trade-off Between Transition Risk and Physical Riskin a Financial/Economic Framework (A) and Conceptual Illustration of Disaster Risk in a Technological Framework (B)



sition Risk', *National Bureau of Economic Research* (2021); Sandra Batten, Rhiannon Sowerbutts and Misa Tanaka, 'Let's Talk About the Weather: The Impact of Climate Change on Central Banks', *Bank of England* (2016), pp 1–37.

[9] Sandra Batten, 'Climate Change and the Macro-Economy: A Critical Review', *Bank of England* (2018), pp. 1-48; Christophe McGlade and Paul Ekins, 'The Geographical Distribution of Fossil Fuels Unused when Limiting Global Warming to 2C', *Nature* 517/7533 (2015), pp. 187–90.

[10] Simon Dietz et al., 'Climate Value at Risk of Global Financial Assets', *Nature Climate Change* 6/7 (2016), pp. 676–9.

[11] Timothy M Lenton and Juan-Carlos Ciscar, 'Integrating Tipping Points Into Climate Impact Assessments', *Climatic Change* 117/3 (2013), pp. 585–97; TCFD, 'The Use of Scenario Analysis in Disclosure of Climate-Related Risks and Opportunities - Technical Supplement', *Task Force on Climate-Related Financial Disclosures* (2017).

In this paper, we extend the conceptualisation of this trade-off established in the climate change risk literature by combining evidence from the economic restructuring literature[12] with the traditional understanding of climate-related disaster risk. The latter is defined as a function of hazard, exposure and vulnerability by the IPCC and others.[13] The IPCC defines the hazard as the severity and frequency of extreme weather and climate events directly influenced by climate change, the exposure as the assets and people that are harmed in an extreme weather or climate event and the vulnerability as how susceptible the exposed assets and people are to such an event. Both exposure and vulnerability are primarily influenced by socio-economic developments, choices about the location of human activities and how well those are protected from and/or adapted to extreme weather and climate events[14] (Figure 1B).

We hypothesise that the interaction between physical and transition risk might actually not be a trade-off and both risks can increase at the same time as a result of low-carbon economic restructuring. In this case new assets, infrastructure and labour markets as a result of the low carbon spatial economic restructuring increase the exposure and vulnerability to a degree that cannot be offset by limiting the increase in physical hazard when emissions and subsequent increases in global mean temperature are curtailed.[15] By disentangling it in its three components – hazard, vulnerability, exposure – we analyse how changes in exposure and vulnerability from low carbon spatial economic restructuring shape the overall risk from climate change (i.e. the sum of physical and transition risks over time). We discuss that the actual trade-offs between physical and transition risk largely depend on the ability to geographically organise the low-carbon economic restructuring in a way that does not lead to a significant increase in exposure and vulnerability of people and assets to physical hazards such as floods, heat or drought.

For cases where the climate change risk is increasing as a result of growing exposure and vulnerability from low-carbon economic restructuring, we coin the term climate change risk reduction trap. We illustrate this climate change risk reduction trap through the example of Kuwait, a wealthy petroleum-based economy and one of the largest global exporters of petroleum products. Kuwait is currently at the beginning of a major shift in diversifying their economy away from the production and export of oil and gas products,[16] while at the same time facing an increase in climate and weather related events such as flash floods, sea level rise and extreme heat.[17] Based on empirical data of Kuwait's urban

[12] Ray Hudson, 'Uneven Development in Capitalist Societies'; Doreen Massey, *Spatial Divisions of Labour: Social Structures and the Geography of Production* (New York: Routledge, 1995); Aiden While and Will Eadson, 'Zero Carbon as Economic Restructuring: A Spatial Divisions of Labour and Just Transition', *New Political Economy* 27/3 (2022), pp. 385–402.

[13] Susan L. Cutter, 'Vulnerability to Environmental Hazards', *Progress in Human Geography* 20/4 (1996), pp. 529–39; Christopher B. Field et al., *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2012).

[14] Christopher B. Field et al., *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.*

[15] Nicholas P. Simpson et al., 'A Framework for Complex Climate Change Risk Assessment', *One Earth* 4/4 (2021), pp. 489–501.

[16] Manal Shehabi, 'Diversification Effects of Energy Subsidy Reform in Oil Exporters: Illustrations from Kuwait', *Energy Policy* 138 (2020), p. 110966.

[17] Ahmed Hassan, Jasem A. Albanai and Andrew Goudie, 'Modeling and Managing Flash Flood Hazards

development since the discovery of oil in the 1950s and Kuwait's urban development plan up to the 2040s, in combination with existing evidence on climate change impacts, we demonstrate how the transition to a low carbon economy drives the creation of new assets as well as people vulnerable and exposed to the physical impacts of climate change.

Background and Setting

Actions to reduce the negative impacts of climate change can be distinguished between climate change mitigation and adaption. Climate change mitigation is described as actions to mitigate global warming by reducing greenhouse gas (GHG) emission, while adaptation aims to reduce the negative consequences of climate change to humans and the environment by reducing their exposure and vulnerability to impacts such as extreme weather events.[18] Especially in developed and emerging economies with high GHG emissions, climate change adaptation and mitigation need to be integrated in order to meet internationally agreed targets on both emissions under the Paris Agreement and disaster risk reduction under the Sendai Framework.[19] However, in many cases mitigation and adaptation targets are in conflict with each other or come with significant trade-offs.[20] These conflicts and trade-offs depend on several factors including infrastructure[21] and labour demand[22] in a low carbon economy compared to its current state and the availability of geographical locations for new developments that are both suitable and safe from climate related hazards.[23]

There are a number of studies that have looked at these factors individually. Several studies, for example, look at the vulnerability to climate-related hazards of low-carbon

in the State of Kuwait', *Preprints* (2021); Subramaniam Neelamani et al., 'Assessment of Coastal Inundation Cost Due to Future Sea Level Rise: A Case Study for Kuwait', *Marine Georesources & Geotechnology* 40/5 (2022), pp. 523–37; Barrak Alahmad et al., 'Climate Change and Health in Kuwait: Temperature and Mortality Projections Under Different Climatic Scenarios', *Environmental Research Letters* 17/7 (2022), p. 074001.

[18] Richard J.T. Klein et al., *Climate Change 2007 - Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Fourth Assessment Report of the IPCC* (Cambride: Cambridge University Press, 2007).

[19] Alexandra Lesnikowski et al., 'What Does the Paris Agreement Mean for Adaptation?', *Climate Policy* 17/7 (2017), pp. 825–31; Reinhard Mechler and Stefan Hochrainer-Stigler, 'Generating Multiple Resilience Dividends from Managing Unnatural Disasters in Asia: Opportunities for Measurement and Policy', *Asian Development Bank Economics Working Paper Series* 601 (2019); Anna Hurlimann, Sareh Moosavi and Geoffrey R. Browne, 'Urban Planning Policy Must do More to Integrate Climate Change Adaptation and Mitigation Actions', *Land Use Policy* 101 (2021), p. 105188.

[20] Ayyoob Sharifi, 'Trade-Offs and Conflicts Between Urban Climate Change Mitigation and Adaptation Measures: A Literature Review', *Journal of Cleaner Production* 276 (2020), p. 122813.

[21] Vivien Fisch-Romito and Céline Guivarch, 'Transportation Infrastructures in a Low Carbon World: An Evaluation of Investment Needs and Their Determinants', *Transportation Research Part D: Transport and Environment* 72 (2019), pp. 203–19; Christopher Kennedy and Jan Corfee-Morlot, 'Past Performance and Future Needs for Low Carbon Climate Resilient Infrastructure – An Investment Perspective', *Energy Policy* 59 (2013), pp. 773-83.

[22] Pablo Garcia-Garcia, Oscar Carpintero and Luis Buend, 'Just Energy Transitions to Low Carbon Economies: A Review of the Concept and its Effects on Labour and Income', *Energy Research & Social Science* 70 (2020), p. 101664.

[23] Giovanni Marin and Marco Modica, 'Socio-Economic Exposure to Natural Disasters', *Environmental Impact Assessment Review* 64 (2017), pp. 57–66.

built assets, including low energy buildings[24] or wind farms.[25] Susan E. Hanson and Robert J. Nicholls[26] analyse how ports need to change by 2050 in response to both sea-level rise and changes to global trade volume and patterns in a low-carbon economy. For the labour market, review studies often find an increase in net employment through a shift to a low-carbon economy, which can result in a higher number of people exposed to the impacts of climate change.[27] A study on coal miners in Poland, for example, finds that 50% of coal miners could not find a job in another sector and left the labour market, while new workers came in for the green jobs that were created, resulting in a net increase in population in the region.[28] In case of an area exposed to impacts from climate change, labour-market driven migration can further increase the exposure and vulnerability to climate-related hazards.[29]

Petroleum economies are particularly affected by the low carbon transition. To be aligned with the Paris Agreement's 2°C objective more than 80% of the proven global fossil fuel reserves need to remain in the ground.[30] With 38% of their known oil and 61% of their gas reserves, petroleum economies of the Middle East have the highest share of fossil fuel resources that would need to be stranded under the Paris Agreement.[31] In addition, increased global oil production from other sources affects the petroleum revenues in the region. Several visions for low carbon economic restructuring are proposed for petroleum economies including climate tech, tourism and green energy, which all require a far-reaching economic restructuring, including changes to the build environment and the labour market. Dawud Ansari and Franziska Holz[32] analyse four potential scenarios for the Middle East, including a climate tech and green cooperation scenario, of which all project an increasing energy demand and population growth from labour-market driven immigration. This represents a continuation of a trend since the discovery of oil in the region, where most of the demand in skilled and unskilled labour is met through immigration.[33]

[24] Ali Tighnavard Balasbaneh, Abdul Kadir Bin Marsono and Adel Gohari, 'Sustainable Materials Selection Based on Flood Damage Assessment for a Building Using LCA and LCC', *Journal of Cleaner Production* 222 (2019), pp. 844–55.

[25] Di Zhang et al., 'Economic and Sustainability Promises of Wind Energy Considering the Impacts of Climate Change and Vulnerabilities to Extreme Conditions', *The Electricity Journal* 32/6 (2019), pp. 7–12.

[26] Susan E. Hanson and Robert J. Nicholls, 'Demand for Ports to 2050: Climate Policy, Growing Trade and the Impacts of Sea-Level Rise', *Earth's Future* 8/8 (2020.

[27] Pablo Garcia-Garcia, Oscar Carpintero and Luis Buendia, 'Just Energy Transitions to Low Carbon Economies: A Review of the Concept and its Effects on Labour and Income', *Elsevier* 70 (2020), pp. 1–16.

[28] Jan Baran, Aleksander Szpor and Jan Witajewski-Baltvilks, 'Low-Carbon Transition in a Coal-Producing Country: A Labour Market Perspective', *Energy Policy* 147 (2020), p. 111878.

[29] Giovannin Marin and Marco Modica, 'Socio-Economic Exposure to Natural Disasters', *Environmental Impact Assessment Review* 64 (2017), p. 57–66.

[30] Kyra Bos and Joyeeta Gupta, 'Stranded Assets and Stranded Resources: Implications for Climate Change Mitigation and Global Sustainable Development', *Energy Research & Social Science* 56 (2019), p. 101215.

[31] Christopher McGlade and Paul Ekins, 'The Geographical Distribution of Fossil Fuels Unused When Limiting Global Warming to 2C', *Nature* 517 (2015), pp.187-90; Tokhir N. Mirzoev et al., 'The Future of Oil and Fiscal Sustainability in the GCC Region' *International Monetary Fund* (2020).

[32] Dawud Ansari and Franziska Holz, 'Between Stranded Assets and Green Transformation: Fossil-Fuel-Producing Developing Countries Towards 2055', *World Development* 130 (2020), p. 104947.

[33] Hélène Thiollet, 'Managing Migrant Labour in the Gulf: Transnational Dynamics of Migration Politics Since the 1930s', *IMI Working Papers Series* 131 (2016), pp. 1–25.

The combination of more frequent and intense extreme weather events as a result of climate change, growing demand for housing and other built assets due to spatial low-carbon economic restructuring has the potential to significantly increase climate related disaster risk in the region. Future sea level rise is threatening residential areas along the urbanised coastline,[34] a number of extreme rainfall events in recent years have caused significant damage[35] and heat-related mortality in the Gulf region is projected to increase by between 5.1% and 11.7% by 2100.[36] Building on the theoretical work by Eli D. Lazarus[37]on the disaster trap and the R&D trap,[38] we conceptually and empirically explore flash flood and other climate-related risks in Kuwait, looking at how disaster risk in the region has developed and is likely going to change in the future as a function of low carbon spatial economic restructuring and its associated demand for labour and housing.

The Climate Change Risk Reduction Trap Framework

Figure 2 shows how disaster risk from climate change is shaped by hazard (i.e., weather and climate events), exposure and vulnerability.[39] The future disaster risk from climate change depends on the intensity and frequency of extreme weather and climate events and is a function of natural variability and anthropogenic climate change, i.e., global action to reduce GHG emissions by decarbonising national economies. Failing to decarbonise and reduce GHG emissions leads to increasing impacts and costs from extreme weather and climate events both in terms of losses and damages and increased spending on climate change adaptation (CCA).[40] While areas with the highest current and cumulative GHG emissions do not necessarily geographically overlap with the areas that will see the highest increases in climate related impacts,[41] countries of the Gulf region have both rapidly increasing per capita GHG emissions (surpassing those of for example the

[34] Mohammad M. Alsahli and Ahmed M. AlHasem, 'Vulnerability of Kuwait Coast to Sea Level Rise', *Geografisk Tidsskrift-Danish Journal of Geography* 116/1 (2016), pp. 56–70; Ahmed Hassan and Mahmoud A Hassaan, 'Potential Impact of Sea Level Rise on the Geomorphology of Kuwait State Coastline', *Arabian Journal of Geosciences* 13/21 (2020), pp. 1–16.

[35] Farah Al-Nakib, *Kuwait Transformed: A History of Oil and Urban Life* (Stanford: Red Wood City, 2016); Ahmed Hassan, Jasem Albanai and Andrew Goudie, 'Modeling and Managing Flash Flood Hazards in the State of Kuwait'.

[36] Barrak Alahmad et al., 'Climate Change and Health in Kuwait: Temperature and Mortality Projections Under Different Climatic Scenarios', *Environmental Research* 17/7 (2022), pp.1–8.

[37] Eli D. Lazarus, 'The Disaster Trap: Cyclones, Tourism, Colonial Legacies, and the Systemic Feedbacks Exacerbating Disaster Risk', *Transactions of the Institute of British Geographers* 47/2 (2022), pp. 577–88.

[38] Husam Arman et al., 'Systems of Innovation, Diversification, and the R&D Trap: A Case Study of Kuwait', *Science and Public Policy* 49/2 (2022), pp. 179–90.

[39] Field et al., *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*.

[40] Samuel Fankhauser, 'The Costs of Adaptation', *Wiley Interdisciplinary Reviews: Climate Change* 1/1 (2010), pp. 23–30; Stott, 'How Climate Change Affects Extreme Weather Events'; Sonia I. Seneviratne and Xuebin Zhang, 'Weather and Climate Extreme Events in a Changing Climate', *IPCC* (2021). Available at: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter11.pdf (accessed 20 April 2024).

[41] Richard S.J. Tol et al, 'Distributional Aspects of Climate Change Impacts', *Global Environmental Change* 14/3 (2004), pp. 259–72.

European Union) and are also warming significantly faster than other inhabited regions leading to an intensification of the water cycle and an increase in extreme events such as extreme heat, droughts and floods.[42] In addition, countries of the Gulf region are among the largest single contributors to upstream GHG emissions with oil and gas exported from the region being responsible for 8% of the total cumulative GHG emissions between 1854 and 2010 and keep contributing to global GHG emissions through the export of oil & gas products.[43] We refer to this increase in climate change disaster risk by failing to reduce GHG emissions and the subsequent increase in extreme weather and climate events as the delayed decarbonisation trap.

A fast and ambitious decarbonisation to meet globally agreed GHG emission reduction targets and to curtail a further increase in extreme weather and climate events, requires stranding existing 'brown' assets and infrastructure linked to the oil and gas production consumption, while creating new 'green' assets and infrastructure for a decarbonised economy.[44]

Low carbon economic restructuring is driving change in three areas: population change through changing labour demands, land-use change by changing demand in built assets and infrastructure as well as fiscal changes by changing revenue streams to become independent from oil rents.[45] These fundamental changes to the demographic, spatial and fiscal structure of a country opens a number of channels for an increase in climate disaster risk through exposure and vulnerability.

The transition to a low-carbon economy can increase exposure through land use changes, with new assets and infrastructure being built in areas at risk.[46] Exposure to extreme weather and climate events can also increase from population growth as a result of labour immigration. In many cases re-training the existing workforce is expected not to be sufficient to meet the demand for the low carbon transition and additional immigration of skilled labour is necessary. The resulting increase in demand for housing can lead to a further increase in exposure to extreme climate and weather events.[47]

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[42] Jeremy S. Pal and Elfatih A.B. Eltahir, 'Future Temperature in Southwest Asia Projected to Exceed a Threshold for Human Adaptability', *Nature Climate Change* 6/2 (2016), pp. 197–200; G. Zittis et al., 'Climate Change and Weather Extremes in the Eastern Mediterranean and Middle East', *Reviews of Geophysics* 60/3 (2022).

[43] Richard Heede, 'Tracing Anthropogenic Carbon Dioxide and Methane Emissions to Fossil Fuel and Cement Producers, 1854–2010', *Climatic Change* 122/1 (2014), pp. 229–41.

[44] Christopher McGlade and Paul Ekins, 'The Geographical Distribution Of Fossil Fuels Unused When Limiting Global Warming To 2C', *Nature* 517/7533 (2015), pp. 187–90; While and Eadson, 'Zero Carbon as Economic Restructuring: A Spatial Divisions of Labour and Just Transition', *New Political Economy* 27/3 (2022), pp. 385–402.

[45] Li-Chen Sim, 'Low-Carbon Energy in the Gulf: Upending the Rentier Dtate?', *Energy Research & Social Science* 70 (2020), p. 101752; Sayeed Mohammed, Cheryl Desha and Ashantha Goonetilleke, 'Investigating Low-Carbon Pathways for Hydrocarbon-Dependent Rentier States: Economic Transition in Qatar', *Technological Forecasting and Social Change* 185 (2022), p. 122084.

[46] Gavin Bridge et al., 'Geographies of Energy Transition: Space, Place and the Low-Carbon Economy', *Energy Policy* 53 (2013), pp. 331–40; Thuc Han Tran and Markus Egermann, 'Land-Use Implications of Energy Transition Pathways Towards Decarbonisation–Comparing the Footprints of Vietnam, New Zealand and Finland', *Energy Policy* 166 (2022), p. 112951.

[47] Daniel B. Müller et al., 'Carbon Emissions of Infrastructure Development', *Environmental Science &*

At the same time, fiscal stability decreases during the low carbon transition, with both public and private investors having to write off investments in sunset industries and facing an increased risk of bubbles in sunrise industries.[48] Together with shrinking revenues from oil and gas, welfare spending cuts become more likely to maintain fiscal stability, increasing social vulnerability as a result of increased inequality and poverty.[49] Due to the low food production and water scarcity in the region, revenues from oil and gas as well as cheap energy play are deciding factors on how much fresh water can be produced and how much food can be imported or produced.[50] The resulting reduced water and food security can directly and/or indirectly affect people's vulnerability and resilience to the impacts from extreme weather events.[51]

We refer to the increase in climate disaster risk as a result of increasing exposure and vulnerability from low carbon development and economic restructuring as the low-carbon restructuring trap.

Chances of falling in either the delayed decarbonisation trap or the low-carbon restructuring trap depend on both global and local actions. Increases in extreme weather events and the subsequent risk of falling into the delayed decarbonisation trap as a result of failed GHG mitigation is mainly driven by actions on the international level such as countries meeting agreed targets under the Paris Agreement. However, as the world's largest exporters of oil and gas products, petroleum economies of the Gulf Cooperation Council (GCC) and elsewhere have additional leverage by leaving more of their known oil and gas reserves in the ground.[52] In this context,[53] and others recommend economic diversification as the most promising long-term strategy.[54] However, this can affect the risk of a country falling into the low carbon restructuring trap. In instances where economic diversification results in heightened exposure due to new asset creation and land use changes, coupled with a reduction of oil and gas revenues and increased investments in the economic diversification, there is a potential for (a temporary) reduction in welfare spending. This, in turn, could increase the social vulnerability of poorer households to the impacts of climate change.[55] Climate change adaptation can help reduce increases in

Technology 47/20 (2013), pp. 11739–46.

48 Gregor Semieniuk et al., 'Low-Carbon Transition Risks for Finance', *Wiley Interdisciplinary Reviews: Climate Change* 12/1 (2021).

49 Ilona M. Otto et al., 'Social Vulnerability to Climate Change: A Review of Concepts and Evidence', *Regional Environmental Change* 17/6 (2017), pp. 1651–62.

50 Christian Siderius et al., 'Multi-Scale Analysis of the Water-Energy-Food Nexus in the Gulf Region', *Environmental Research Letters* 15/9 (2020), p. 094024.

51 Hisham Tariq, Chaminda Pathirage and Terrence Fernando, 'Measuring Community Disaster Resilience at Local Levels: An Adaptable Resilience Framework', *International Journal of Disaster Risk Reduction* 62 (2021), p. 102358.

52 Thijs Van de Graaf and Aviel Verbruggen, 'The Oil Endgame: Strategies of Oil Exporters in a Carbon-Constrained World', *Environmental Science & Policy* 54 (2015), pp. 456–62.

53 Ibid.

54 Dawud Ansari and Franziska Holz, 'Between Stranded Assets and Green Transformation: Fossil-Fuel-Producing Developing Countries Towards 2055', *World Development* 130 (2020), p. 104947.

55 Charles Cohen and Eric D. Werker, 'The Political Economy of "Natural" Disasters', *Journal of Conflict*

disaster risk caused by both an increase in extreme weather and climate events as well increasing exposure and/or vulnerability. However, in many cases either physical limits will be reached, where the impacts of extreme weather and climate events will become too high to adapt to or, economic limits will be reached in which increases in exposure and vulnerability together with shrinking revenues will make it too costly to adapt.[56] In addition, the different scales between globally coordinated efforts to cut emissions and local action to adapt to the climate impacts already underway often leads to mitigation and adaptation being considered as separate policy areas and their integration often fails.[57] This disconnect can further increase the risk of falling in one of the two outlined traps. We empirically illustrate this challenge for the example of Kuwait in the following section.

An Empirical Illustration of the Climate Change Risk Reduction Trap: Flood Risk in Kuwait

Based on the conceptual framework of the climate change risk trap outlined in Figure 2 and described in the previous section, we use a combination of our own analysis and secondary source data to empirically illustrate the climate change risk reduction trap for the example of Kuwait, a wealthy petroleum economy in the Middle East. Figure 3 shows an illustration of the dynamics that can result in Kuwait's political economy fall into either the delayed decarbonisation trap or the low carbon restructuring trap. Details of our own analysis, including a description of the methods used to develop the first flash flood hazard map for Kuwait and a longitudinal census micro data set can be found in the Data and Methods section.

Kuwait is a high-income city-state in the north-east of the Arabian Peninsula with a total population of 4.2 million. With the discovery of oil and its international export from the 1950s, Kuwait underwent a large scale transformation from a small Arab maritime town with only 150,000 inhabitants to a modern day metropolis in just 70 years exceeding the growth rate of cities such as Shanghai or Mumbai.[58] The export of oil allowed Kuwait to transform and grow its economy with the desire to establish a welfare state to share its newly acquired wealth with its population as well as to create a modern urban hub in the region.[59]

Resolution 52/6 (2008).

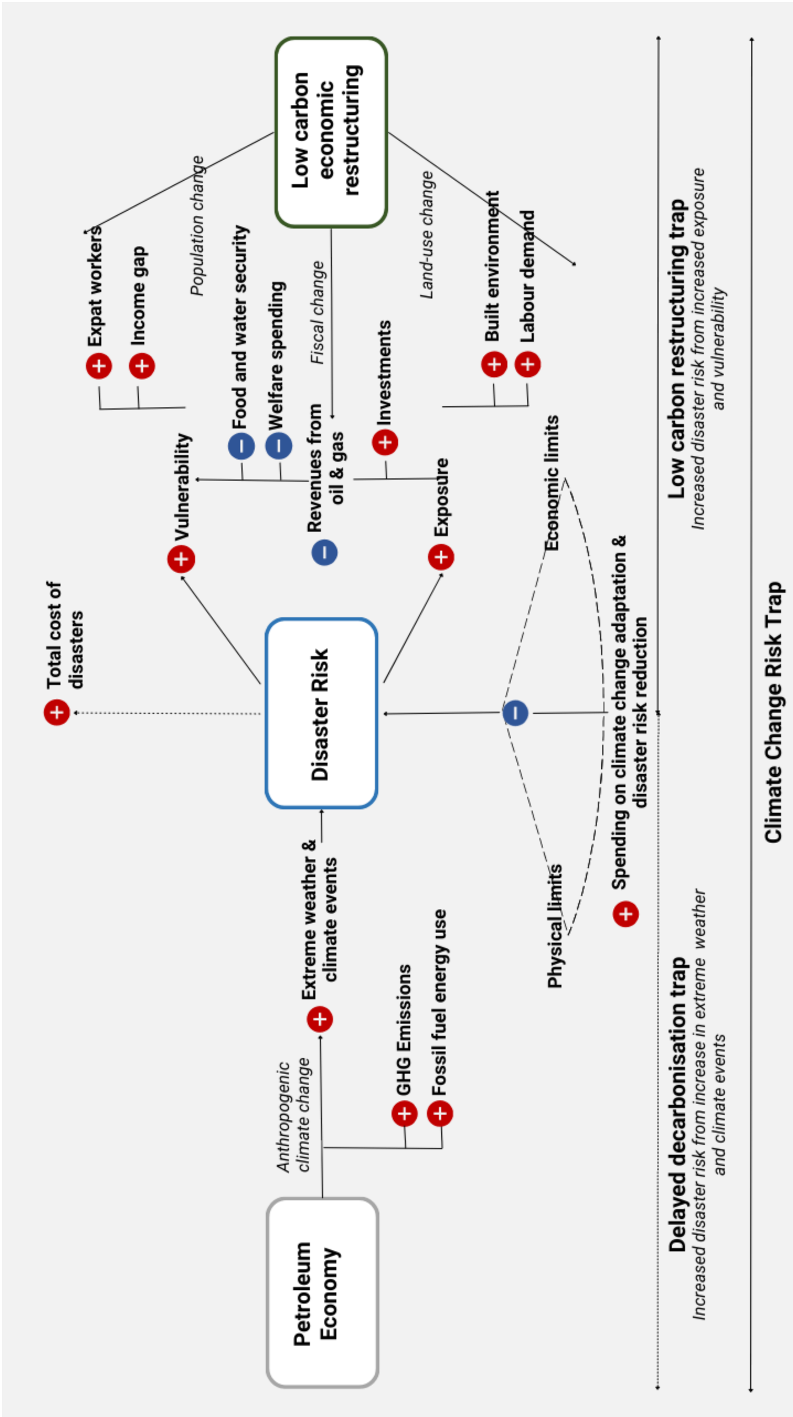
[56] Kirstin Dow et al., 'Limits to Adaptation', *Nature Climate Change* 3/4 (2013), pp. 305–7.

[57] Mia Landauer, Sirkku Juhola and Johannes Klein, 'The Role of Scale in Integrating Climate Change Adaptation and Mitigation in Cities', *Journal of Environmental Planning and Management* 62/5 (2019), pp. 741–65.

[58] Farah Al-Nakib, *Kuwait Transformed*.

[59] Farah Al-Nakib, 'Kuwait's Modern Spectacle: Oil Wealth And The Making Of A New Capital City', *Comparative Studies of South Asia, Africa and the Middle East* 33/1 (2013), pp. 7–25; Steffen Hertog, 'Reforming Wealth Distribution in Kuwait: Estimating Costs and Impacts', *LSE Middle East Centre Kuwait Programme Paper Series* 5 (2020), pp. 1-74.

Figure 2: The Climate Change Risk Trap Framework



The framework shows the interactions between low-carbon spatial economic restructuring on one side and unmitigated climate change on the other. It outlines the dynamic through which disaster risk in a region or country can still increase through an increase of exposure and vulnerability as the result of spatial low carbon restructuring ('low-carbon restructuring trap'). It also shows the more common dynamic through which disaster risk is increasing due to unmitigated climate change ('delayed decarbonisation trap'). Directed graphs show the direction of the dynamic while ('+': positive) and ('-': negative) indicates the direction of the trend.

One of the focus areas of the newly established welfare system was the provision of housing for citizens through a right to housing legislation.[60] Starting in 1951 overseas consultancies and urban planners were commissioned to develop an urban planning vision for Kuwait in the shape of a master plan.[61] The aim of the first master plan was to transform the small town into a state-of-the-art and socially progressive city.[62] The master plan largely followed Western urban planning principles and included the demolition of the historic old town of Kuwait to replace it with self-sufficient, low-density neighbourhoods separated by a radial road network with cars as the main mode of transportation.[63] This planning approach not only showed early signs of being inadequate for the climatic conditions of the region due to its lacking protection from sun, heat and sandstorms,[64] it has also put Kuwait on a trajectory of urban sprawl with a resource intensive and car-centric society.[65] The rapid population growth of Kuwait since the 1950s, mainly driven by immigration to meet the growing demand for labour, accelerated the urban sprawl, while at the same time leading to segregation between migrant workers, living in densely populated mixed-use areas and the Kuwaiti population, mostly living in single family units provided by the government.[66] Modern day Kuwait has reached a crossroads in its development. Its urban planning legacy is forcing Kuwait's residents into a carbon-intensive lifestyle through its car-centric transportation, high energy demand for cooling and drinking water production as well as an energy system solely relying on fossil fuels for energy generation.[67] With 21 tonnes of CO2 per year, Kuwait currently has one of the highest per capita emissions globally and its total emissions are still rising with its GHG emissions closely following its economic development,[68] resulting in CO2 emissions per GDP being almost twice above the OECD average.[69] Despite plans to diversify its economy around 90% of Kuwait's revenues and around half of its GDP are currently coming from oil rents, which is the highest share of all countries of the GCC.[70] While the GDP share of the oil sector fell from 53%

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[60] Sharifa Alshalfan, 'The Right to Housing in Kuwait: An Urban Injustice in a Socially Just System', *Kuwait Programme on Development, Governance and Globalisation in the Gulf States* 28 (2013), pp. 1–33.

[61] Edward Nilsson, 'Urban Memory and Preservation in Kuwait: A Case Study of Souk Al Wataniya', *The Politics of Memory, Territory, and Heritage in Iraq and Syria – SAH Annual Conference* (Glasgow, 7-11 June 2017).

[62] Saba George Shiber, *Kuwait Urbanization: Documentation, Analysis, Critique* (Kuwait: Kuwait Government Printing Press, 1964).

[63] Alshalfan, 'The Right to Housing in Kuwait'.

[64] Ralph Hewins, *A Golden Dream: The Miracle of Kuwait* (London: WH Allen, 1963).

[65] Mohamed Alkhuzamy Aziz and Nayef Alghais, 'Cartographic Analysis of Urban Expansion in Kuwait', *Cartographica: The International Journal for Geographic Information and Geovisualization* 56/3 (2021), pp. 183–207.

[66] Alshalfan, 'The Right to Housing in Kuwait'.

[67] Osamah Alsayegh, Nathalie Saker and Ayman Alqattan, 'Integrating Sustainable Energy Strategy With The Second Development Plan Of Kuwait', *Renewable and Sustainable Energy Reviews* 82 (2018), pp. 3430–40.

[68] 'Historical GHG Emissions - Kuwait. 2023', *ClimateWatch*. Available at: https://www.climatewatchdata.org/embed/ countries/KWT/ghg-emissions?end_year=2019&start_year=1990#ghg-emissions (accessed 28 July 2023).

[69] Yousef Mohammad Al-Abdullah et al., *Kuwait Energy Outlook - Sustaining Prosperity Through Strategic Energy Management* (Kuwait City: Kuwait Institute for Scientific Research, 2019).

[70] Sharifa Alshalfan, Dhari S. Alrasheed and Barrak Albabtain, *Housing Kuwaitis* (Kuwait: Kuwait Foundation for the Advancement of Sciences, 2022).

in 2013 to a low point of 34% in 2018, this was mainly a result of declining oil prices on the world market and was accompanied by a contraction of the Kuwaiti economy by 5.6% underlining the continued high dependence on the oil sector.[71] High volatility of oil revenues, in combination with high government spending for Kuwait's welfare system, which includes publicly financed housing, subsidies for energy, water and food and provision of employment through public sector jobs, has pushed Kuwait into an unsustainable fiscal position with an increased risk of fiscal deficits in the future.[72] To address both the high dependency on oil rents and high government expenditures on the public sector, Kuwait's leaders have developed a plan for structural reforms to diversify its economy. Titled 'Kuwait 2035', the joint vision is to turn Kuwait into a regional and financial hub for the northern Gulf. Kuwait's economic diversification under this vision should mainly be achieved through the construction sector, with several infrastructure mega projects, including a new business hub, railway and metro systems, several new cities to house its growing population and additional basic infrastructure projects. To reduce the high government spending half of these investments are planned to come from the private sector.[73]

At the same time urban expansion and the construction of new housing have increased the exposure and vulnerability of its residents to climate-related extreme weather events as well as environmental hazards such as air pollution.[74] Over the last 5 years, Kuwait has suffered from two severe flash flood events with damages in range of several hundred million $US[75] and our analysis of flash flood exposure in the metro Kuwait area shows that between 1970 and 2020, the number of people living in areas with a flash flood risk (top 10% percentile) has quadrupled with currently around 140,000 people living in high risk areas. With a considerably higher increase in flash flood risk for non-Kuwaitis, whose income is significantly and consistently lower compared to Kuwaitis through all education and income levels, has led to environmental justice issues and concerns about a growing social vulnerability to flooding, heat and other climate related risks.[76] Climate change will further increase the risk of flooding due to projected increases in extreme rainfall in Kuwait,[77] leading to both higher costs from losses and damages and investments in adap-

[71] Ayele Gelan, Geoffrey JD Hewings and Ahmad Alawadhi, 'Diversifying a Resource-Dependent Economy: Private–Public Relationships in the Kuwaiti Economy', *Journal of Economic Structures* 10/1 (2021), pp. 1–22.

[72] Hertog, 'Reforming Wealth Distribution in Kuwait'; Gelan, Hewings and Alawadhi, 'Diversifying A Resource-Dependent Economy'.

[73] Anas Khaled Al-Saleh, *Diversification of the Kuwaiti Economy* (London: Tech. rep., 2016).

[74] Ali Al-Hemoud et al., 'Exposure Levels of Air Pollution (PM2. 5) and Associated Health Risk in Kuwait, *Environmental Research* 179 (2019), p. 108730.

[75] Hassan, Albanai and Goudie, 'Modeling and Managing Flash Flood Hazards in the State of Kuwait'; Hertog, 'Reforming Wealth Distribution in Kuwait'.

[76] Mohammad M. Alsahli and Meshari Al-Harbi, 'Environmental Justice in Kuwait Metropolitan Area: A Spatial Analysis of Land-Use Impact on Environmental Quality Variability', *Local Environment* (2022), pp. 1–19; Alahmad et al., 'Climate Change and Health in Kuwait: Temperature and Mortality Projections Under Different Climatic Scenarios'.

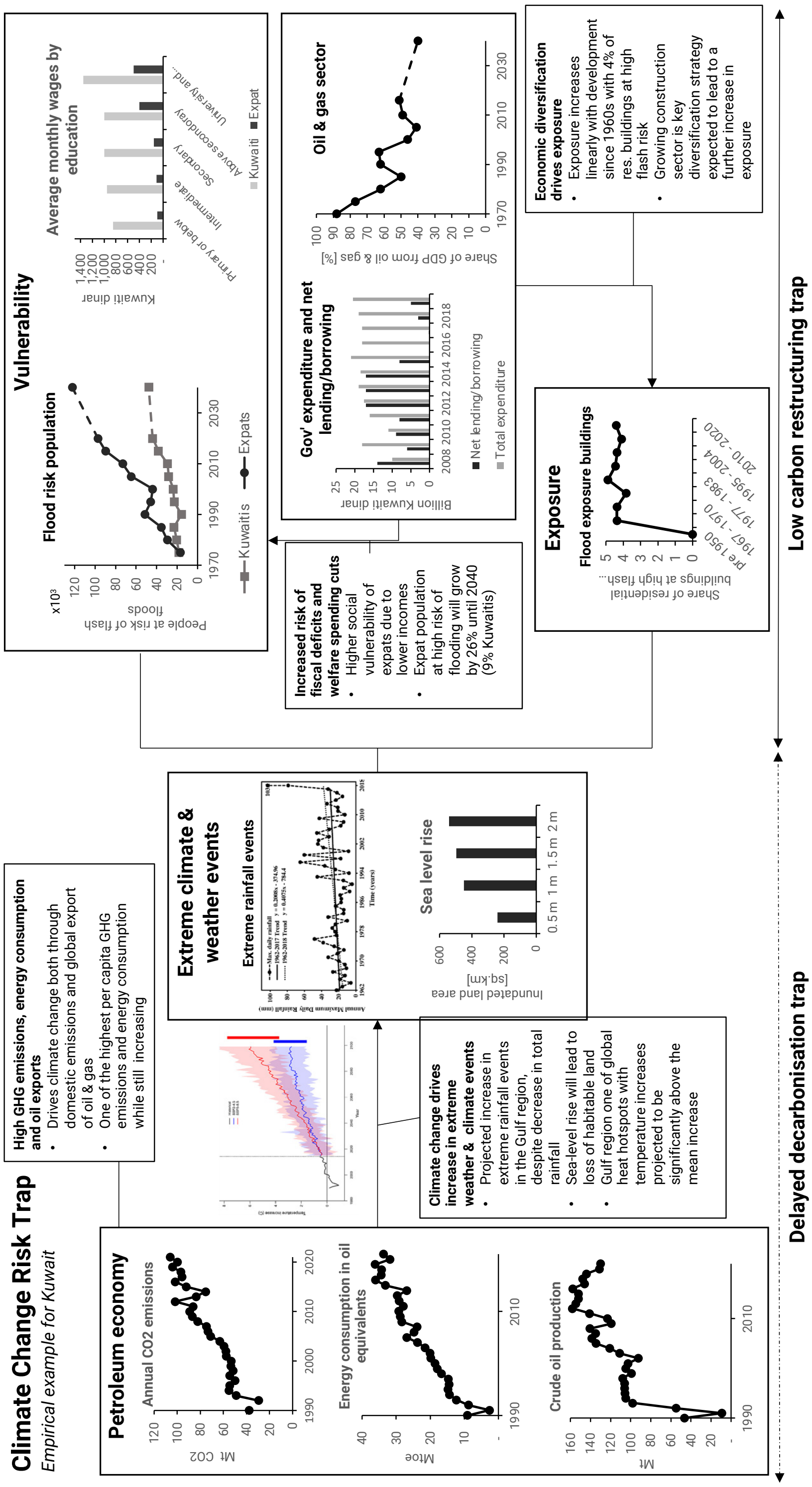
[77] Habib Al-Qallaf, Amjad Aliewi and Ahmed Abdulhadi, 'Assessment of the Effect of Extreme Rainfall Events on Temporal Rainfall Variability in Kuwait', *Arabian Journal of Geosciences* 13/21 (2020), pp. 1–11.

tation. Without significant global emission reductions including Kuwait's own emissions,[78] it is estimated that sea level rise will lead to Kuwait losing land by 2100 currently worth USD $193.8 billion. Heat-related mortality in Kuwait is projected to increase by 3.4% under a moderate (SSP2-4.5) and by 5% under an extreme (SSP5-8.5) climate scenario by the 2050s.[79] Especially in the case of an extreme climate scenario (RCP 8.5), the risk of reaching wet-bulb temperatures in Kuwait that are above the threshold for survivability of a fit human (35°C) is increasing considerably.[80] This increase in extreme weather and climate events as a result of failed climate change mitigation poses a real risk of Kuwait falling into a delayed decarbonisation trap with a continued increase in costs for adaptation and losses and damages from extreme weather and climate events as well as permanent loss of habitable land due to extreme heat, drought and sea level rise.

While the threat of escalating climate related hazards on one side and concerns about fiscal stability due to a high dependency to volatile oil revenues on the other underscores the need for economic diversification in Kuwait, our analysis indicates a potential risk of falling into a low-carbon economic restructuring trap. Based on analysis of Kuwait's flash flood risk and population projections outlined in the fourth Kuwait master plan, we find that even without the projected increase in extreme rainfall events an additional 30,000 people will be exposed to a high risk of flash flooding by 2040, with 89% being non-Kuwaitis on low wages and no access to the state welfare system. Analysing historic urban expansion patterns and its influence of flood risk, we find that Kuwait has so far failed to decouple its urban growth from increasing its exposure to extreme weather events such as floods, which has led to a continued increase in flash risk since the 1950s. We find a similar trend for Kuwait's road infrastructure, which has been severely affected during the past two flash flood events (see Data and Methods). The expansion of the road network in recent years has led to considerable increase in the lengths of roads in high flash flood risk areas. Roads particularly affect supply chains and can cause high indirect losses and damages when goods cannot be transported as usual. These metrics indicate the risk of a potential trap in which Kuwait's decarbonisation efforts increase the exposure and vulnerability to extreme weather and climate events. This could result in elevated risk of climate-related disaster, even in scenarios where concerted local and global efforts effectively mitigate the increase in global mean temperature.

[78] Subramaniam Neelamani et al., 'Assessment of Coastal Inundation Cost Due to Future Sea Level Rise: A Case Study for Kuwait', *Marine Georesources $ Geotechnology* 40/5 (2022), pp. 523–37.
[79] Barrak Alahmad et al., 'Climate Change and Health in Kuwait: Temperature and Mortality Projections Under Different Climatic Scenarios', *Environmental Research Letters* 17/7 (2022), pp. 1–8.
[80] Jeremy Pal and Elfatih Eltahir, 'Future Temperature in Southwest Asia Projected to Exceed a Threshold for Human Adaptability', *Narure Climate Change* 6/2 (2016), pp. 197–200.

Figure 3: Empirical Example of the Climate Change Risk Trap for Kuwait Using a Combination of Secondary Source Data and our Own Analysis



Conclusions and Future Research

The paper illustrates, using the example of Kuwait, the dual challenge many petroleum economies face in the context of climate change. With their current and past economic development almost entirely based on the export of oil and gas, countries of the Gulf region are starting to prepare for a global decline in the demand for fossil fuels.[81] While the proposed plans for diversifying petroleum economies are as diverse as the individual challenges each country is facing,[82] there is a common pattern that includes spatial economic restructuring.[83] We argue that the resulting demographic, fiscal and land use changes can increase the climate change disaster risk of a country through an increase in exposure and vulnerability, despite successfully averting the most extreme climate and weather events through ambitious reduction of global GHG emissions over the coming decades. Using the first flash flood hazard map produced for Kuwait, we empirically show that the countries' urban expansion over the past 70 years with new residential homes built in areas at risk of flooding has significantly contributed to the increase in flash flood risk in Kuwait and that current plans for spatial economic restructuring over the next two decades is expected to lead to a further increase in the flash flood risk in Kuwait. While the increase in disaster risk driven by increases in exposure and vulnerability is a global phenomenon,[84] and sector-specific or individual conflicts between climate change mitigation and adaption have previously been analysed,[85] our framework describes the systemic dilemma petroleum economies face due to the need to entirely restructure their economies compared to individual sectors in most countries. To avoid falling in either the delayed decarbonisation or the low-carbon restructuring trap, petroleum economies will have to carefully manage their low carbon economic restructuring to effectively reduce local and global GHG emissions without creating new risks by exposing vulnerable green assets and populations to climate related hazards. The integration of environmental impact assessments as part of the planning process for the economic transition has been put forward by researchers to better understand the risks of new low-carbon spatial economic restructuring projects but has so far stayed behind its ambition.[86] Given the projected demand for additional infrastructure and labour as part of the envisioned economic diversification as well as the long lifetime of many built assets, rapid action is required to avoid high additional investments

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[81] 'Economic Diversification in the GCC: Past, Present, and Future', *International Monetary Fund* (2014). Available at: https://www.imf.org/external/pubs/ft/sdn/2014/sdn1412.pdf (accessed 30 April 2024).

[82] Ashraf Mishrif and Yousuf Hamad Al Balushi, 'Challenges of Economic Diversification in the GCC', *Gulf Research Centre Cambridge* (2018), pp. 1–19; Ansari and Holz, 'Between Stranded Assets and Green Transformation'.

[83] Aidan While and Will Eadson, 'Zero Carbon as Economic Restructuring: A Spatial Divisions of Labour and Just Transition', *New Political Economy* 27/3 (2022), pp. 385–402.

[84] Hessel C. Winsemius et al., 'Global Drivers of Future River Flood Risk', *Nature Climate Change* 6/4 (2016), pp. 381–5; Simpson et al., 'A Framework for Complex Climate Change Risk Assessment'.

[85] Ayoob Sharifi, 'Trade-Offs and Conflicts Between Urban Climate Change Mitigation and Adaptation Measures: A Literature Review', *Journal of Clearer Production* 276 (2020), pp. 1–14.

[86] Ali Mohamed Al-Damkhi et al., 'Integrating Environmental Impact Assessment Within Kuwait Master Plans as a Tool for Human and Ecological Risk Control', *Human and Ecological Risk Assessment* 14/5 (2008), pp. 1070–85.

in climate change adaptation measures over the coming decades as a result of increasing exposure and vulnerability to climate-related hazards. In addition, it is crucial for Kuwait's national plans, such as the National Adaptation Plan (NAP), National Communications (NCs), Nationally Determined Contribution (NDC), and National Development Plan (NDP), to acknowledge and address the socio-environmental impacts of development projects in Kuwait, specifically regarding the escalating flood risks. While Kuwait's NAP and NCs have acknowledged certain climate hazards like heatwaves and sea level rise, they currently fail to acknowledge flooding as a significant climate hazard in the country. Likewise, the NDP and NDC do not acknowledge the interconnectedness between development projects and socio-physical risks stemming from climate change. While our study provides the conceptual basis to understand the challenges and opportunities of spatial-low carbon economic spatial restructuring of petroleum economies, future studies should focus on a full implementation of the framework, including the interaction between projected restructuring projects in combination with expected changes in extreme weather and climate events as a result of climate change. Using the Gulf region as one of the world's largest producers of oil and gas as a case study, the results might not be transferable to petroleum economies where political instability, corruption and/or poverty is preventing any ambitious economic restructuring.[87]

Data and Methods

Flash Flood Risk Maps

We integrated various geospatial data to map the flash flood risks on Kuwait's lands. These geospatial data were Ground Control Points (GCPs), Advanced Land Observing Satellite-1 (ALOS), Sentinel-2A multispectral imagery and Geographic Information System (GIS) vector layers of Kuwait. The GCPs of the Global navigation satellite system (GNSS) were recorded using a Catalyst Tremble unit. The GCPs had an average vertical accuracy of ± 11 cm (median = 55 cm) and were fairly distributed over Kuwait's lands. The ALOS has s Synthetic Aperture Radar (SAR) sensor, recording L-band (1.27 GHz) with various polarizations and spatial resolutions. The ALOS data stored as GeoTIFF images, containing Digital Elevation model (DEM) data with a spatial resolution of 10 m and vertical accuracy of ± 15 m; the data have already been radiometrically and geometrically corrected. The ALOS data were downloaded from the Alaska Satellite Facility (ASF) website.[88]

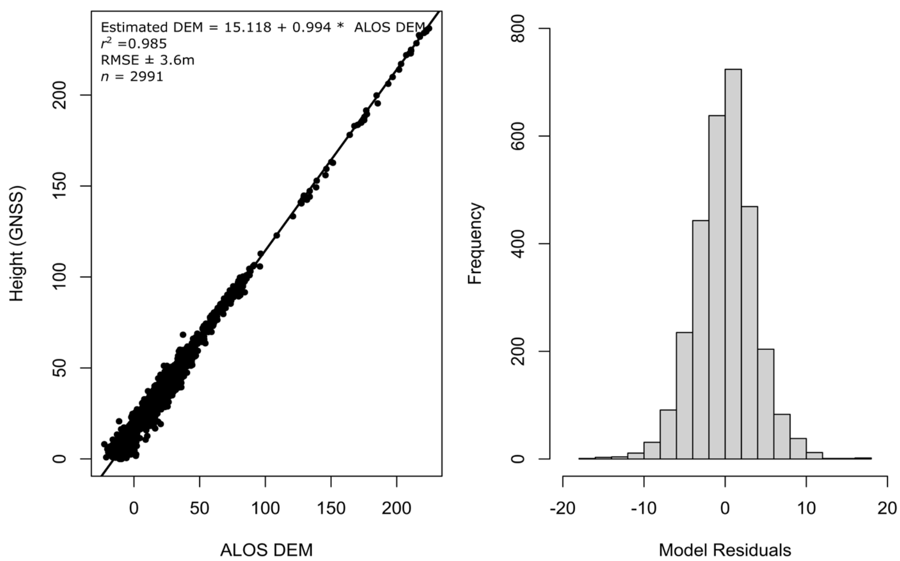
The Sentinel-2A level-1C images were downloaded from the Copernicus website; the level-1C products are radiometric and geometrically corrected by the European Space Agency (ESA). Sentinel-2A images over Kuwait were obtained on 28 October 2018 and 27 November 2018, before and after a massive flash flood event. The images were used to classify land-cover features and determine flooded areas. Moreover, GIS vector layers illustrating the country boundary and districts' boundary were obtained from Kuwait Environmental Public Authority (KEPA).[89]

[87] Dan Calverley and Kevin Anderson, 'Phaseout Pathways for Fossil Fuel Production within Paris-Compliant Carbon Budgets', *International Institution for Sustainable Development* (2022).
[88] 'Copernicus Open Access Hub', *Copernicus*. Available at: https://scihub.copernicus.eu (accessed 30 April 2024).
[89] 'Kuwait Environmental Public Authority, KEPA. Available at: https://epa.gov.kw (accessed 30 April 2024).

Digital Elevation Model Calibration

The DEM layer is an essential layer of mapping flood model risk as it is used to derive terrain-based analysis layers, such as slope, aspect and drainage network layers. Thus, the DEM accuracy significantly influences the flood risk map reliability. To improve the accuracy of the DEM layer used to map the flash flood risks, we modelled the relationship between 2991 GCPs and the ALOS DEM layer using regression analysis (Figure 4a). The DEM model accuracy was assessed using a 5-fold cross-validation analysis (CVA). The model significantly estimated the elevation values (r2 = 0.985, RMSE ± 3.6 m, and P-value << 00.1) (Figure 4b); the CVA result revealed that the model was very robust and consistent (r2 = 0.984, RMSE ± 3.6 m). The statistical analysis was conducted using the R programming language.

Figure 4: The Relationship between Gcps (Height [Gnss]) and ALOS DEM was Statistically Significant (A) and the Model Residuals were Normally Distributed (B)



Flash Flood Risk Mapping

The flood risk mapping went through five main steps:

1. creating an accurate digital elevation model (DEM) layer,
2. modelling the stream network over Kuwait land,
3. analysing 13 conditioning factors of flood risks to find the most significant ones,
4. building a spatial model using the most significant factors to map flood risks in Kuwait, and
5. assessing the spatial model accuracy.

The flood risk spatial model was built based on ten factors derived from surface analyses and remotely sensed data (Figure 5). The model accuracy was evaluated using Area Under Curve (AUC) method and the overall accuracy percentage; the AUC and the overall accuracy were 81 and 80%, respectively. The most significant factor was flood accumulation, whereas the slope was the least (Figure 6).

Figure 5: Illustration of the Overall Method

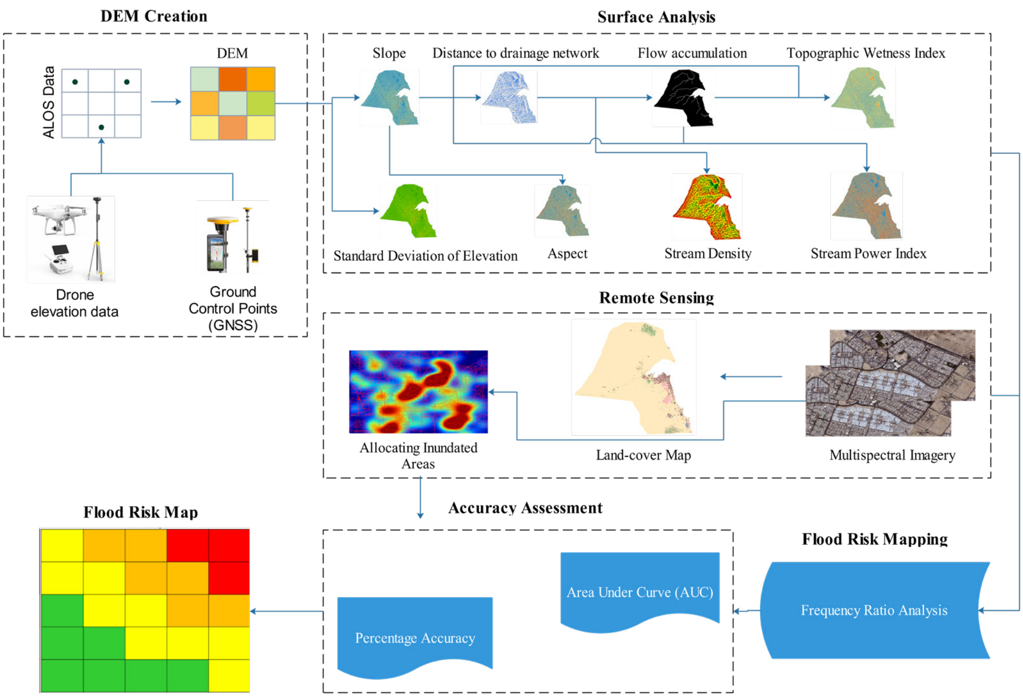
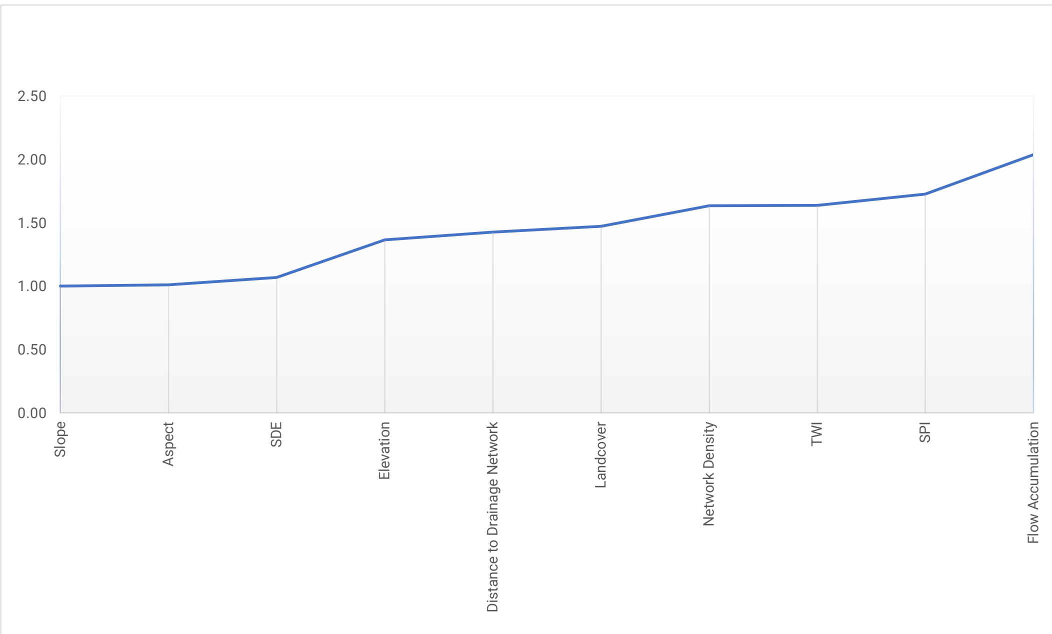


Figure 6: Weights of Each Factor Used in the Flood Risk Model



Exposure and Vulnerability

In addition to secondary source data on the dynamics that drive disaster risk, we conduct our own analysis on flash flood risk in Kuwait. For the exposure to flash floods combine the flash flood hazard maps described in the previous section with all 165,000 building polygons of residential buildings in the Kuwait metro area from.[90] We classify the building polygons into eight urban expansion periods since the 1950s (1950–67, 1967–70, 1970–7, 1977–83, 1983–95, 1995–2004, 2004–10, 2010–20) as identified by[91] to reconstruct the temporal development of the exposure of residential buildings to flash flood hazards. Given that the spatial resolution of the flash flood hazard map is higher than the size of most building footprints we extract the minimum, maximum and mean values for flash flood susceptibility for each building polygon. We calculate the share of residential buildings with a high exposure to flash floods for each of the eight urban expansion periods by dividing the total number of buildings built during each urban expansion period by the number of buildings that are in the 10th percentile of flash flood susceptibility (i.e. flash flood susceptibility index >= 90).

For the vulnerability analysis we construct a longitudinal micro data set of the population on the neighbourhood block level (median population per neighbourhood block 4267) in five years increments from 1975 to 2020 including projection data for 2040. For that we use dasymetric mapping to match the population data from the Global Human Settlement Layers (GHSL) from 1975 to 2020 with a 100 m spatial resolution to the neighbourhood block level.[92] The resulting population for each neighbourhood block is than proportionally adjusted to match the total population number of Kuwait based on census data for the respective year. Given the large and growing proportion of non-Kuwaiti citizens (or expats) and their higher social vulnerability to flooding as a result of their significantly worse economic and housing conditions, we focus our vulnerability analysis on the different flash flood susceptabilities between the Kuwaiti and non-Kuwaiti population. In order to downscale the national level numbers on the Kuwaiti and non-Kuwaiti population we use iterative proportional fitting, a spatial micro simulation method described in 'Spatial Microsimulation With R'.[93] Using the mipfp package in R,[94] we take the neighbourhood block level information on the Kuwaiti and non-Kuwaiti population from the 2011 official Kuwait census as the target marginal distribution to determine the Kuwaiti and non-Kuwaiti population for each year of analysis (1975 to 2020). The resulting dataset containing the number of Kuwaitis and non-Kuwaitis living in each neighbourhood block for the five year increments from 1975 and 2020 is then combined with the flash flood susceptibility map. The population in each neighbourhood block is randomly distributed and point values of the flash flood susceptibility are extracted. The process is repeated in an ensemble of 1000 runs to quantify the uncertainty of the flash flood susceptibility. For the vulnerability analysis we count the number of Kuwaitis and non-Kuwaitis in each neighbourhood block for each analysis year from 1975 to 2020 which are in the 10th percentile of flash flood susceptibility (i.e. flash flood susceptibility index >= 90). We use the same procedure for the population projections for the Kuwaiti and non-Kuwaiti population by 2040, which is provided on the neighbourhood block level as part of the fourth Kuwait master plan.[95]

[90] '4th Kuwait Masterplan 2040', *Dar Al-Handasah*. Available at: https://www.dar.com/work/project/kuwait-master-plan-2040 (accessed 30 April 2024).

[91] Mohamed Alkhuzamy Aziz and Nayef Alghais, 'Cartographic Analysis of Urban Expansion in Kuwait', *Cartographica* 56/3 (2021), pp. 183–207.

[92] Marcello Schiavina et al., *GHSL Data Package 2022* (Luxembourg: Publications Office of the European Union, 2022).

[93] Robin Lovelace and Morgane Dumont, *Spatial Microsimulation With R* (Boca Raton: CRC Press, 2017).

[94] Johan Barthelemy and Thomas Suesse, 'mipfp: An R Package for Multidimensional Array Fitting and Simulating Multivariate Bernoulli distributions', *Journal of Statistical Software* 86 (2018), pp. 1–20.

[95] '4th Kuwait Masterplan 2040', *Dar Al-Handasah*.

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