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Economic indicator system for adaptive monitoring of compound climate change risks

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ABSTRACT

Climate change adaptation requires proactive development of adaptive planning strategies. To implement such strategies, it is crucial to identify indicators that can monitor and signal approaching adaptation thresholds. While existing research has focused on physical and hazard-based indicators, addressing social and economic indicators is essential for informed decision-making. This research aims to fill this gap by compiling 298 economic indicators across six categories: fiscal factors for central, regional, and local governments; financial system indicators; indicators for industries, businesses, and public organisations; and indicators for identifying socially vulnerable populations due to climate change. Derived from previous studies and the national climate change risk assessment framework, these indicators aim to provide policymakers at all levels and communities with a ready-to-use toolbox for monitoring climate change economic risks. Additionally, the research identifies measurable indicators as well as those that cannot currently be measured but could potentially be quantified. Future work involves further analysis and mapping of these indicators to form a cohesive set warning of the need for adaptation measures, aiming to equip decision-makers with tools to address the economic impacts of climate change.

SPECIFICATIONS TABLE

Subject area	1000
Category/categories of societal impact	Economic Environmental Political Societal
Sustainable Development Goals (SDGS) the research contributes to	*GOAL 11: Sustainable Cities and Communities GOAL 13: Climate Action*
Resource availability [optional]	*Data of the indicator system is attached as a supplementary document.*
Related research article OR Related supporting information **Please provide a link to the webpage if relevant**	*Project Description: the project is funded by the Ministry of Business, Innovation & Employment Strategic Science, New Zealand. It aims to advance understanding and prediction of current and future climate and associated hazards in New Zealand. Investment Fund project: Informing Climate Change Resilience Infrastructure Development. Grants - Program number CARH2407, 2023–2024. Conference name NZARES 2024; Conference dates, 30–31 August 2024; Name of paper "Economic indicators help monitor signals that trigger climate change adaptation to compound climate risks", Conference Programme available here: https://www.nzares.org.nz/ .*
Stage of research	***In Progress***

Societal impacts: economic indicators of climate change risks to the economy and society

Climate change is widely acknowledged as a global challenge affecting both the natural environment and human society. It poses various risks such as flooding, extreme weather events, droughts, and sea-level rise [1,19], potentially displacing millions of people globally [16]. Researchers have consistently warned about the consequences of climate change, including sea-level rise, agricultural droughts, reduced precipitation, and other physical hazards [8]. Additionally, studies have

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examined the social and economic impacts of climate change to highlight the vulnerability of society to these changes [3]. Climate-vulnerable communities must take proactive adaptation measures to deal with impending social and economic changes due to climate change. However, before making decisions on adaptation actions, it is crucial to know "what to monitor" and "when to act". Therefore, a clear gap arises in the current literature around the need for a framework/guidance to help detect the challenges that climate change may bring to socio-economic systems, whilst existing studies have mainly focused on indicators of physical- and hazard risks [17]. Thus, this research has developed an Economic Indicator System (EIS) to guide decision-makers on what to pay attention to, and what is crucial to observe to prevent early signals of economic changes from escalating into irreversible changes for society and the economy.

This multi-level, multi-subject, detailed EIS is the first step in leading towards a more comprehensive social and economic indicator system that underpins the socio-economic impact of climate change and establishes indicator systems for identifying earlier signals and triggers for society. This was developed as part of a research project, "Informing Climate Change Resilient Infrastructure Development",[2], which aims to advance understanding and prediction of current and future climate and associated hazards in New Zealand. The development of the EIS is crucial because climate change and associated consequences could systematically affect human society and economic systems by affecting assets, societal stability, public health, national, regional, and individual financial stability, and government fiscal stability [3]. The EIS developed in this article is a 'ready to use', practical indicator system that can help decision-makers to understand and estimate their tailored risk position and vulnerability to climate change to reduce uncertainties while helping them plan and make specific decisions. Applying the EIS could help address the unintended consequences of climate change policy interventions. For example, climate adaptation policies, such as infrastructure improvements to protect against sea level rise, can disproportionately burden low-income households through higher utility costs. The EIS can track income distribution and economic disparities, allowing for the design of compensatory measures to ensure equitable adaptation strategies.

The EIS includes four types of indicators: 1. Fiscal indicators for central, regional, and local governments; 2. Indicators for the financial system associated with climate change financial risks; and 3. Indicators for industries, businesses, and public organisations associated with climate change risks and opportunities; and 4. Indicators for identifying socially vulnerable populations due to climate change for governments to estimate potential fiscal costs/budgets for government compensation. The EIS provides clear guidance of indicators for different hierarchical levels of governments, businesses, and organisations to apply and implement in their risk assessment frameworks to prepare for climate change. The EIS is particularly useful because associated decisions have to be made in advance and under deep uncertainty for climate change adaptation [7]. Specifically, climate change-related hazards or consequences result from various factors, necessitating multiple responses. Their uncertainty stems from the complex decision-making processes involved, and the outcomes hinge on present decisions, manifesting either gradually over decades or in the long term [18]. This makes merging the concept of adaptation pathways with adaptive policy-making challenging [17]. This research provides socio-economic indicators to be integrated with physical climate change information to identify narratives to "fit for purpose" for climate change adaptation, which is crucial to narrowing future uncertainties to a manageable level [6].

The EIS provides clear guidance of indicators for different hierarchical levels of governments, businesses, and organisations to apply and implement in their risk assessment frameworks to prepare for climate change. This research contributes to emerging physical climate change research using socio-economic indicators to identify narratives for climate change adaptation strategies. The EIS can help multiple subjects understand and estimate their tailored risk position and vulnerability to climate change to reduce uncertainties. This multi-level, multi-subject EIS is the first step in leading towards a more comprehensive social and economic indicator system that underpins the socio-economic impact of climate change for identifying earlier signals to narrow future uncertainties for society.

Methodology

The EIS was developed in the framework of the Dynamic Adaptive Pathways Planning (DAPP) process. DAPP enables a series of interlinked pathways (including exploratory modelling, scenario development, multiple plausible futures, stress testing, robustness metrics, and vulnerability analysis), where 'signals' of change are needed to alert the decision maker of a pending 'trigger': the time at which a decision should be made to switch pathway [10] (Fig. 1). In the DAPP process, information is particularly valuable for the delegation of uncertainty. Therefore, the EIS developed in this research is essential to inform the further four steps of DAPP: robustness metrics, vulnerability analysis, value of information, and delegation of uncertainty. Based on DAPP, the EIS is developed to provide support for adaptive, resilient, and robust planning strategies to deal with deep uncertainties of climate change risks – making it different from the other indicator systems/methods. The indicators can be used in exploratory models of human-environment systems to demonstrate under what conditions triggers may be reached, when they may be reached, and what adaptation pathways are robust across a range of plausible future scenarios (Fig. 1).

The EIS is informed by previous work on a set of physical, hazard-based, social, and economic signals [11]. The development of this EIS is built based on the New Zealand National Climate Change Risk Assessment guidance and wider literature [14,15]. The full EIS is provided in the supplementary Excel document. A more comprehensive socio-economic indicator system is currently being developed, and detailed social indicators will be included in the current EIS system later.

Results and implications

The main result of this research is the development of a multi-level, multi-subject, systematic economic indicator framework to guide economic risk assessment associated with climate change (Fig. 2). This framework maintains: 1. The multi-level indicators for different levels of government agencies; 2. The financial system indicators; and 3. The industry, business, and organizations indicators. We identified a full range of indicators to help the policy makers or communities to understand the potential impacts of climate change on government, financial system, and business and organizations' capability and stability.

The multi-level indicators for different levels of government agencies

We developed 84 indicators to observe the central/regional/local government's fiscal position, fiscal spending and planning, and potential costs and impacts associated with climate change. Our government indicator system is based on a democratic government system. The assumption is that regional and local government's revenue mainly comes from land rates, property rates, and regional and local taxes. We then identified the potential impact of climate change on local/regional/central governments in terms of their capability and stability in generating revenue. We also highlighted the additional costs incurred due to climate change, which exceed normal situations. If a regional or local government's budget is currently tight, the risks are higher because the costs due to climate change are almost guaranteed to increase, especially

[2] Strategic Science Investment Fund Project CARH2407, funded by the Ministry of Business, Innovation & Employment.

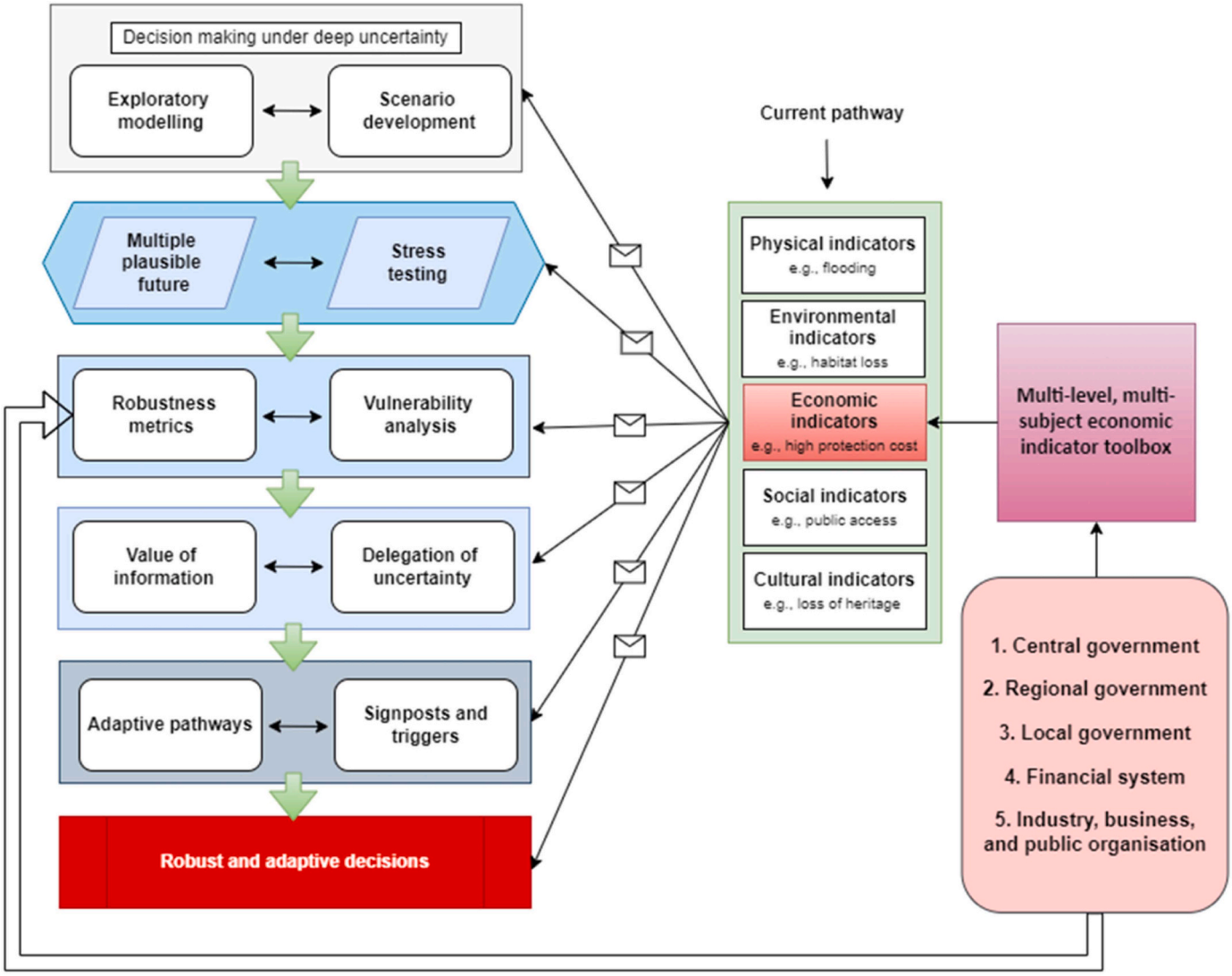

Fig. 1. Framework of decision-making under deep uncertainty in the face of multiple plausible futures of climate change.

for health needs and infrastructure adaptation (e.g., repairing water purification infrastructure damaged by extreme weather events) (based on the literature review, expert opinion, and interpretation, haven't been tested quantitively). We also included indirect costs of climate change that regional and local governments should be aware of, such as trauma among residents due to climate change and extreme weather events, compensation due to insurance retreat on residential and commercial properties, and the impact on non-market ecosystem services. Governments' situations differ depending on the level of wealth of a country/region/local area, which then could impact a country's efficiency of governance in dealing with climate change challenges and affect their capability of providing necessary services to their people.

We also highlight the government's prerogative to identify potentially vulnerable populations in society (at-risk population (46 indicators), partly adapted from the Social Vulnerability Index (SVI) framework [4,12]). Managing at-risk populations is important, as otherwise, it could add instability to the country due to the ongoing and rapid impact of climate change on society. Detailed, SVI includes important indicators to identify "at risk" populations in society due to climate change, such as aging population, gender, income, employment, health facilities, population density, household composition, micro and macro socioeconomic status, population health statistics, healthcare infrastructure, transportation, infrastructure (e.g., roads, airports, water infrastructure), social connections and social capital, land use, and disaster preparedness.

It is important to notice that some of the indicators in the EIS can be measured or estimated, while some indicators are important but currently cannot be measured due to data availability or uncertainty (color-coded green) (Fig. 2). These indicators are particularly important for the government to pay attention to because non-measurable indicators tend to be overlooked [11]. Such overlook, due to the difficulty of estimating non-measurable indicators, can lead to increasing uncertainties in the whole system and may lead to radical uncertainty[3] [9].

The EIS can be used to investigate the government's climate-related governance risks and responsibilities and to identify potential indicators for the government's short or medium to longer-term fiscal plans (e.g., 5–10 years' plan) for preparing for climate change risks and uncertainties. The climate change thresholds can be approached more rapidly than expected because climate change can be systematic rather than linear [2]. Therefore, the key to applying adaptive planning

[3] Radical uncertainty describes a situation in which it is not possible to enumerate a list of all possible future outcomes, making it impossible to attach probabilities based on mathematical calculations. If all possible outcomes can be described in advance, and the probabilities of each outcome can be calculated using well-established statistical techniques, these uncertainties are named resolvable uncertainties.

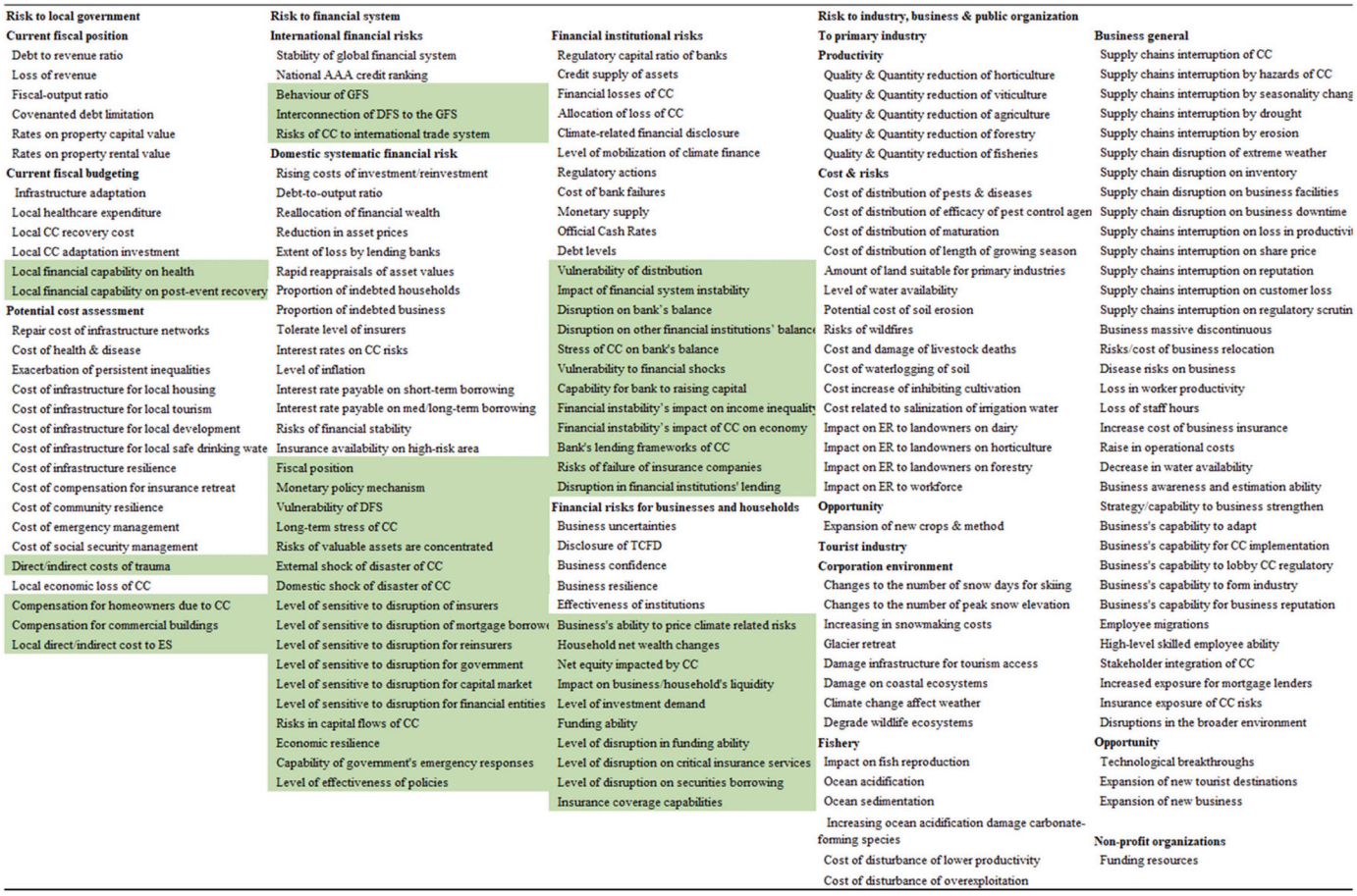

Fig. 2. Economic indicator domains and items of climate change. GDP = Gross Domestic Product; SVP = Social Vulnerable Population; CC = Climate Change; ES = Ecosystem Services; GFS = Global Financial System; DFS = Domestic Financial System; TCFD = Task Force on Climate-related Financial Disclosure; ER = Economic Return.

approaches is knowing what to monitor to know that a trigger or adaptation threshold is likely approaching. The indicators developed in this study highlight the crucial role of monitoring and reviewing adaptation thresholds and triggers, which is key to implementing adaptive plans.

The financial system indicators

The climate change-related risks in the financial sector are crucial, complicated, dynamic, and highly dependent on the international financial system (e.g., the behaviour of the Federal Reserve Bank in the USA and the Institute of Global Finance). A country's cost of borrowing depends on the central bank's official cash rates, which directly influence interest rates, thereby affecting liquidity and the capital capability of lending and borrowing, subsequently influencing the stability of financial institutions, banks, businesses, households, and individuals. A clear indicator system (76 indicators) is essential to closely monitor climate change risks to the financial systems and maintain risks at a manageable level. The dynamic nature of financial systems makes the climate change-linked risks compound and may make the current financial systems more vulnerable than currently estimated.

The industry, business, and organizations indicators

The EIS comprehensively includes multiple indicators (92 indicators) to observe climate change-related risks in industries, businesses, and organizations. The EIS includes indicators of climate change impacts on primary industries such as rainfall levels, sea level rise affecting groundwater levels of farmland, and the conversion of coastal farmland to saline conditions [5,13]. The EIS also includes indicators of a warmer climate that disrupts pollination, increases pests and diseases, and affects the efficacy of pest control agents (including maturation and growing periods of crops), and indicators of the impact on the quality and quantity of output in horticulture, viticulture, agriculture, forestry, and fisheries (National Climate Change Risk Assessment, 2020).

The EIS also includes indicators for climate change impacts on businesses on soil erosion, increases the possibility of wildfires, impacts on livestock, leads to salinization of irrigation water, and increases business costs while affecting business returns (National Climate Change Risk Assessment, 2020). The EIS on the tourism industry includes indicators of snow seasons for tourists and impacts on infrastructure that provide access to tourist destinations and tourism resources. In particular, the EIS highlights climate change impact indicators on indigenous peoples who might be more vulnerable to climate change. Mātauranga Māori[4](Māori indigenous knowledge) plays an important role in climate risk assessments and adaptation planning. Many Māori/iwi (tribes)/hapū (sub-tribes) emphasize that climate change represents a significant challenge for New Zealand (National Climate Change Risk Assessment, 2020).

The EIS for businesses and organizations includes indicators of climate change that influence supply chains, value chains, cooperation capabilities, ability to obtain resources, and business profitability, maintenance, and increased insurance risks. Also, the EIS includes

[4] Māori are the indigenous peoples of New Zealand.

indicators that climate change might bring opportunities to businesses, such as new tourism destinations or new business opportunities. Measuring these indicators is important for businesses to identify a clear picture of their business future so they can plan their business strategies.

Ethics statements

The Authors have read and followed the ethical requirements for publication in Societal Impacts and confirm that the current work does not involve human subjects, animal experiments, or any data collected from social media platforms.

CRediT authorship contribution statement

Zoe Qu: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Visualization. **WEI YANG:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization, Visualization. **Andrew Allison:** Writing – review & editing, Project administration, Investigation, Funding acquisition, Conceptualization. **Paula Blackett:** Writing – review & editing, Funding acquisition, Conceptualization.

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.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.socimp.2024.100073.

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