

Informing adaptation strategy through mapping the dynamics linking climate change, health, and other human systems

Case studies from Georgia, Lebanon, Mozambique and Costa Rica



Giulia Loffreda, Liz Grant and Alastair Ager

with Idvity Chikovani, Ana Olga Mocumbi, Michele Asmar and Laura Cristina Blanco

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Queen Margaret University
INSTITUTE FOR GLOBAL HEALTH
AND DEVELOPMENT



THE UNIVERSITY of EDINBURGH
Global Health Academy



Introduction

Of all nations, low- and middle-income countries (LMIC) face the severest consequences of the climate crisis, despite having contributed the least to its occurrence. Climate change significantly threatens the major health gains witnessed across these settings over recent decades. Established direct and indirect pathways of influence¹ include: floods, increasing risk of water-borne disease; diminishing freshwater availability, eroding food security and sanitation; changes in temperature and rainfall impacting habitats and thus the spread of zoonotic and vector-borne disease; air pollution impacting pulmonary health and lung functions; land degradation and deforestation driving food insecurity and undernutrition; and environmental change compromising mental health.

Critically, highly inequitable, inefficient, and unsustainable patterns of resource consumption and technological development, together with population growth, exacerbate these risks. Addressing these pathways therefore requires an understanding of their interaction and linkage.

Adaptation and resilience measures are actions to accommodate environmental changes anticipated as a result of projected increases in global temperature, complementing mitigation actions seeking to reduce drivers of further temperature increase (centrally through reduction of carbon emissions).

Resilience, a crucial theme within environmental research, has also emerged as a central concept in the health systems literature². Research has come to increasingly focus on identifying system capacities for absorption, adaptation, and transformation developed from system dynamic analyses^{3,4}. In a similar fashion, the planetary health education framework highlights the importance of using system dynamics to understand how different factors interact as part of a complex system⁵.

This study addressed the linkages between climate change and health, by adopting a case study approach drawing on system science. The aim was to map the complex dynamics between climate change and population health across four settings linked to the Research Unit on Health in Situations of Fragility (RUHF)^{6,7} network. By making more explicit the interrelationships between the factors shaping climate and health in each context the aim was to identify key entry-points and pathways for targeted adaptation and resilience measures.

¹ Whitmee, S et al., Safeguarding human health in the anthropocene epoch: report of The Rockefeller Foundation–*Lancet* Commission on Planetary Health, *The Lancet*

² European Observatory on Health Systems and Policies, (2020). Strengthening health systems resilience: key concepts and strategies. World Health Organization

³ Zeina Jamal, et al, Health system resilience in the face of crisis: analysing the challenges, strategies, and capacities for UNRWA in Syria, *Health Policy and Planning*, 2020, <https://doi.org/10.1093/heapol/czz129>

⁴ Blanchet K, et al, Governance and capacity to manage resilience of health systems: towards a new conceptual framework, *International Journal of Health Policy and Management*, 2017

⁵ Guzmán, Carlos A Faerron et al., A framework to guide planetary health education, *The Lancet Planetary Health*

⁶ [Research Unit on Health in Situations of Fragility \(RUHF\). QMU webpage](#)

⁷ Ager A, et al, Health systems research in fragile settings, *WHO Bulletin*, 2020, doi: <http://dx.doi.org/10.2471/BLT.19.233965>

Methods

We conducted case studies with partners in four low- and middle- income countries representing different geographical, social, political characteristics, and climate vulnerability: Mozambique, Lebanon, Georgia, and Costa Rica.

We adopted a mixed method approach incorporating a literature review and system dynamic modelling. The search strategy for the literature review included key terms such as climate change, country name, and adaptation or resilience. We intentionally kept our search approach broad to have a comprehensive focus and retrieve papers from different disciplines. No timeframe restrictions were applied. We searched peer-reviewed articles and grey literature both in English and Spanish (for Costa Rica) in the following databases: PubMed/Medline, Google Scholar, WHO IRIS, World Bank. Based on our pre-defined inclusion criteria, we screened the retrieved papers identifying 36 papers for review. Additionally, 5 papers were shared by country partners. The country specific literature was complemented and triangulated with global literature to assess accuracy of information on the more general issues. We piloted, revised, and finalised an extraction matrix covering the following information: bibliographic information; socio-ecological factors (such as climate, political, social stressors, human health, animal health)⁸; adaptation and resilience measures proposed; political

ecology factors⁹; and other themes such as gender¹⁰.

We collated country-specific data using a causal loop seed model suggested by the work of Proust and colleagues.¹¹ This spatially located variables identified in the reviewed literature with respect to three core domains: the state of the earth system; human made influence/activities, and human health/wellbeing. A preliminary causal loop diagram (CLD) was then elaborated for each country linking variables on the basis of the evidence presented by the reviewed literature.

These CLDs were then refined during online consultations with collaborators in each setting. The consultations involved participatory workshops with health, climate and environment specialists convened in each setting (see Annex). Workshops involved confirmation of the key variables of relevance and negotiation – on the basis of the local multidisciplinary expertise and evidence available – of the core dynamics linking them. The consultations concluded with a review of implications for national and local adaptation strategies.

⁸ De Garine-Wichatitsky Michel et al., “Health in” and “Health of” Social-Ecological Systems: A Practical Framework for the Management of Healthy and Resilient Agricultural and Natural Ecosystems, *Frontiers in Public Health*, 2021, 10.3389/fpubh.2020.616328

⁹ Tor A. Benjaminsen, Hanne Svarstad, *Political Ecology*, Encyclopedia of Ecology, Elsevier, 2019

¹⁰ Gender & Climate Change: an important connection, UNFCCC, 2020

¹¹ Proust K, et al, Human health and climate change: leverage points for adaptation in urban environments. *Int J Environ Res Public Health*. 2012, doi: 10.3390/ijerph9062134

Georgia Case Study

a. Country profile

Georgia is located in the South Caucasus, a region characterised by instability and economic challenges¹². Georgia is a post-Soviet upper-middle-income country with a population of 3.7 million.¹³ It is rated as moderately fragile on the Fragile State Index (FSI)¹⁴, with progressive erosion of state legitimacy and aspects of community cohesion. The country borders Armenia and Azerbaijan (now in conflict over the disputed region of Nagorno-Karabakh), Turkey and Russia. Armed conflict in 1990 in Tskhinvali region and Abkhazia, a history of civil war, rapid marketisation and hyperinflation following independence from the Soviet Union in 1991, have left Georgia in a state of economic collapse¹⁵. Since 1994, policy reforms and economic growth have improved the economic situation in the country¹⁶; however, signs of economic stress were again observed in 2008 due to the conflict between Georgia and Russia over Tskhinvali region⁹. While recent decades have witnessed rapid economic development, socio-economic inequalities continue to pose a challenge, with one-fifth of the population living in relative poverty⁹.

The country's disease profile is dominated by non-communicable diseases (NCD) which account for over 97% of all deaths and comprise 9 out of 10 conditions

presenting for care, with prevalence of hypertensive heart disease and diabetes⁷. Financing and delivery of NCD services is a priority for the country's Ministry of Health. Effective and affordable access to specialist care in these regions remains low, and health worker capacity to manage comorbidities is an additional challenge.

Since 2013 the government increased public spending on health to reduce financial barriers to access and use of services. As a result, the share of out-of-pocket payment in current spending on health reduced to 48% in 2018. However public spending on health remains low (2.8% of GDP) and degree of financial hardship (impoverishing and catastrophic health spending) is among the highest in the European region¹⁷.

Topographically, Georgia is characterized by the Great Caucasus mountains in the north and the Lesser Caucasus in the south. Georgia has many natural resources and is highly dependent upon tourism, both of which are highly vulnerable to climate variability and change¹⁸. Almost half of the population lives in rural areas. In 2015, Georgia submitted its Nationally Determined Contribution (NDC) and has pledged to reduce its Green House Gas (GHG) emissions by 15% by 2030. Georgia's National Adaptation Plan¹⁹ includes the healthcare sector, although a lack of data is viewed as constraining progress in implementation.

¹² Markedonov SM, Suchkov MA. Russia and the United States in the Caucasus: cooperation and competition. *Caucasus Surv.* 2020

¹³ Rukhadze T. An overview of the health care system in Georgia: expert recommendations in the context of predictive, preventive and personalised medicine. *EPMA J.* 2013

¹⁴ The Fund for Peace. *Fragile States Index Report.* 2020.

¹⁵ World Health Organization. Regional Office for Europe, European Observatory on Health Systems and Policies, (2017). *Georgia: health system review.* World Health Organization. Regional Office for Europe.

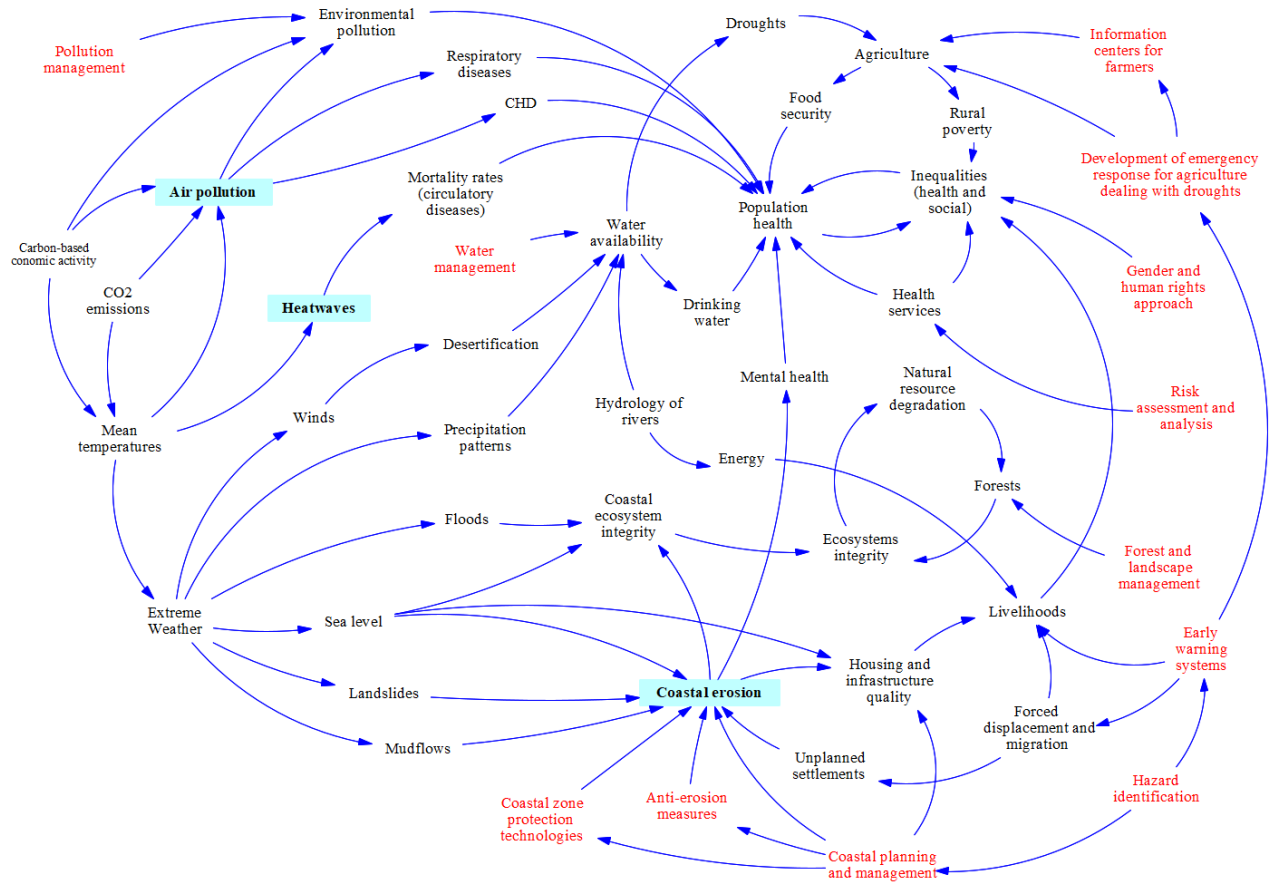
¹⁶ World Health Organization. Regional Office for Europe, European Observatory on Health Systems and Policies, Gamkrelidze, Amiran, Atun, Rifat, Gotsadze, George. et al. (2002). *Health care systems in transition: Georgia.* WHO, Regional Office for Europe.

¹⁷ Goginashvili K, Nadareishvili M, Habicht T. Can people afford to pay for health care? New evidence on financial protection in Georgia. Copenhagen: WHO Regional Office for Europe; 2021.

¹⁸ USAIDS, Climate risk profile Georgia, Factsheet, 2017 ([link](#))

¹⁹ Fourth National Communication of Georgia under the UNFCCC, 2021 ([link](#))

b. Georgia causal loop analysis



The causal loop diagram above represents a ‘mental map’ of interactions developed by participants on the basis of the initial variables and pathways identified by the literature review. Key pathways exacerbating threat considered in the workshop are flagged in light blue; potential foci of adaptation and resilience are shown in red.

c. Emerging themes and strategies

Workshop participants highlighted several dynamics characterising climate impact in the country. One related to **air pollution** and climate change and how they influence each other through complex interactions in the atmosphere and their consequences on health. Air pollution has been directly associated with **cardiovascular and pulmonary related health issues**. This has received political attention and is being recognised as a research priority with health impact assessments now underway.

Heatwaves are becoming more common in the country and are associated with **increased mortality due to cerebrovascular events, dehydration, and other health problems.** Heatwaves additionally **burden health services** through increased strain on water, energy, and transportation resources. High temperatures also raise the **levels of ozone and other pollutants in the air** that exacerbate cardiovascular and respiratory disease. **Food and livelihood security** is also be impacted when people lose their crops or livestock due to extreme heat.

Extreme weather events (such as floods) are causing **coastal erosion**, which impacts the

livelihoods and mental health of people living in coastal areas; coastal erosion has also led to the **displacement of communities**. Despite most of the Georgian population having access to improved water supplies, participants noted that availability of **water resources and sanitation** was potentially at risk with **projected increases in extreme weather events**. For many of these pathways of impact it was observed that risks fell disproportionately on lower-income households, and act to increase socio-economic and health inequalities in the country.

In terms of **adaptation, capacity building** was considered to be a key requirement. In the health sector, one participant highlighted the importance of **planetary health advocacy** targeted to medical students and health professionals. Setting up **multi-sectoral collaborations and a 'whole-of-society-approach'** was viewed as essential for political progress on, and effective implementation of, adaptation strategies. To achieve this necessary coordination across actors and stakeholders in tackling climate change **networks or institutions** needed to be established connecting civil society, non-governmental organisations and academics. In terms of practical measures to strengthen resilience, discussion focused on the establishment of **alerts and early warning systems** to protect populations from the risks of floods and poor air quality.

Mozambique Case Study

a. Country profile

Mozambique is located in sub-Saharan Africa, a region exposed to generally high levels of economic and environmental risk. The OECD formally classifies Mozambique as fragile, with several dimensions of fragility flagging concern, including environmental risk²⁰. Following independence from Portugal in 1975, Mozambique experienced a long-lasting civil war which damaged the country's infrastructure and institutions, severely limiting the state's capacity to provide essential services²¹. The country faces many development challenges, including widespread poverty, low life expectancy, and wide gaps in educational achievement. Provision of social sector services is heavily dependent upon donor contributions, which have prevented greater deterioration of wellbeing of vulnerable groups²².

Despite sustained economic growth and improvements in socio-economic indicators in recent years, Mozambique is still one of the poorest countries in the world²³. Tropical cyclones Idai and Kenneth, which hit the country in 2019, massively damaged infrastructure and left 2.2 million people in need urgent assistance¹⁴. Environmental, security and economic risks shape both resource availability for the health system and the burden of NCD²⁴ in the country.

While communicable diseases (including HIV/AIDS) and maternal and neonatal

conditions remain the greatest contributors to disease burden, 15 of the top 22 causes of loss of disability-adjusted life-years (DALYs) relate to NCD, notably cardiovascular disease, neoplasms, unintentional injuries and mental health disorders²⁵.

Over two-thirds of the population live and work in rural areas. The country is endowed with ample arable land, water, energy, as well as newly discovered natural gas and mineral resources offshore; three, deep seaports; and a relatively large potential pool of labour. Agriculture remains the pillar of Mozambique's economy, contributing 28% of GDP and employing over 81% of the workforce. The majority of the country's agricultural production is through small-scale subsistence farming, with 95% of food production is rain-fed.

Through the Ministry for Coordination of Environmental Affairs (MICOA), the Government of Mozambique developed a national climate change strategy in 2011. This targeted increased resilience in communities and the national economy and the promotion of low carbon development and the green economy through integration of adaptation and mitigation strategies across multiple sectors. It signed the Paris Agreement in 2016 and defined its climate mitigation and adaptation commitments and priorities through its Intended Nationally Determined Contribution (INDC)²⁶.

²⁰ OECD. States of Fragility 2020 ([webpage](#)), 2020.

²¹ Batley R, Bjørnstad L, Cumbi A, Mozambique Country Report. OECD ([webpage](#)), 2006.

²² Anselmi L, Lagarde M, Hanson K. Health service availability and health seeking behaviour in resource poor settings: evidence from Mozambique. *Health Econ Rev*. 2015.

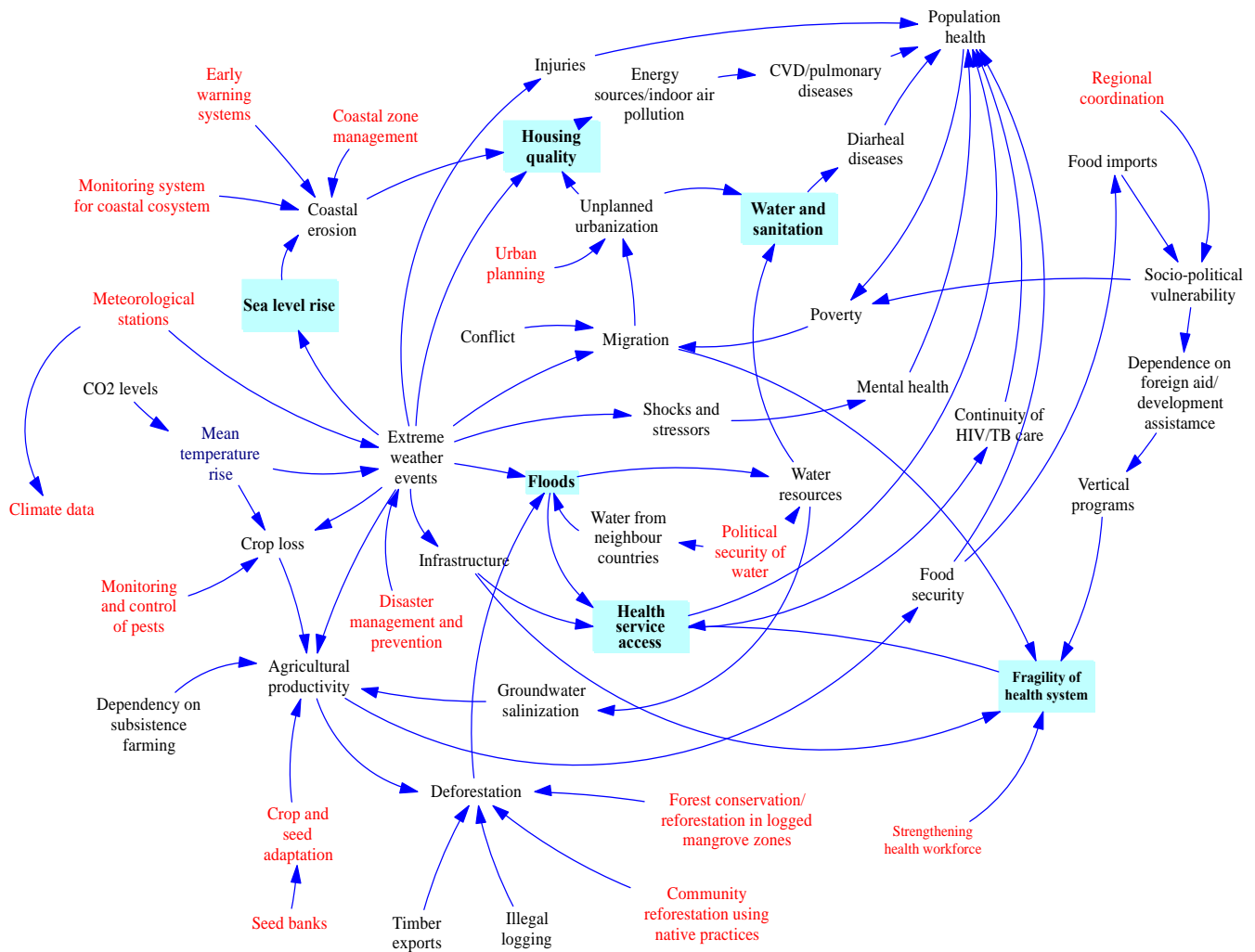
²³ World Bank. The World Bank in Mozambique ([webpage](#)), 2018.

²⁴ Bukhman G, Mocumbi AO, et al; Lancet NCDI Poverty Commission Study Group. The Lancet NCDI Poverty Commission: bridging a gap in universal health coverage for the poorest billion. *Lancet*. 2020 doi: 10.1016/S0140-6736(20)31907-3

²⁵ Institute for Health Metrics and Evaluation, Global Burden of Disease: Mozambique. ([webpage](#)) 2020.

²⁶ Mozambique INDC, UNFCCC ([link](#))

b. Mozambique causal loop analysis



The causal loop diagram above represents a 'mental map' of interactions developed by participants on the basis of the initial variables and pathways identified by the literature review. Key pathways exacerbating threat considered in the workshop are flagged in light blue; potential foci of adaptation and resilience are shown in red.

c. Emerging themes and strategies

Workshop participants addressed several dynamics linking climate change and health. Key threats were identified in relation to the increased intensity and frequency of extreme weather events. Participants highlighted that water resources were a particular focus of concern with regard to both floods (influenced by La Niña, in the north) and droughts (by El Niño, in the south). During **floods**, large amounts of water (including from neighbour countries) strained the ability of the country to effectively manage water resources, impacting **water**

quality and sanitation and thus population health risk from water-borne disease. Population health was also impacted by the influence of restricted **access to health services** due to flooding.

Due to its low-lying topography, **rising sea level** is a cause of coastal erosion, impacting both biodiversity and the livelihoods of the poor populations living in coastal zones depending on fishing and agriculture. With respect to such populations, the **quality of housing** was

considered an important factor in mediating the impacts of climate change. Poor housing exposed households to much greater risks regarding health and livelihoods, and was linked to a range of factors including migration, unplanned urbanisation and dependence on biomass fuels.

Current governance of the health system, constraints on the health workforce due to migration and damage to infrastructure due to extreme events were all contributing to greater **fragility of the health system**, with implications for addressing the increasing burden of both non-communicable (including mental health) and communicable disease (including emerging infections and chronic infectious disease such as HIV and TB).

Discussion on **adaptation strategies** focused particularly on issues of water management. **Monitoring and surveillance systems** needed to be strengthened, particularly in the coastal areas and to anticipate flooding. Given hydrological linkages with neighbouring countries, the **political security of water** needed be addressed when designing water management strategies. In this regard, stronger **data collection and information systems** would enable and support political decision-making as well as inform locally driven strategies. Strengthening the health system – in terms of **preparedness, capacity and resilience of infrastructure** – was also identified as a key focus for action if the impacts of climate change were to be moderated.

Lebanon Case Study

a. Country profile

Lebanon is located on the eastern basin of the Mediterranean Sea. It is a low-middle-income country with a population of approximately 6 million people²⁷. In recent years, Lebanon has witnessed political instability, sectarian division, economic crises and recurring civil unrest²⁸ which has affected its ability to build consensus on political issues and develop equitable and effective policies²⁹. The World Bank characterises Lebanon as exhibiting high institutional and social fragility¹¹. Even before considering the significant impacts of climate change, the stressors experienced by the country are substantive, including the need to accommodate the highest number of Syrian refugees per capita post 2011^{30,31,32}, progressive economic collapse precipitated by high levels of unrest and limited economic growth, and the devastating impacts of the August 4th 2020 explosion³³.

Lebanon struggles with an increased burden of NCD (including mental health) needs, precipitated by the fragility-related risks it has navigated over time and which have limited the country's capacity to deliver primary care and related NCD services^{34,35,36}. Current circumstances underscore the need to identify effective and affordable primary care-based services which can be sustainably financed by the diverse stakeholders active in Lebanon (e.g., Ministry of Health, World Bank, UNHCR).

Dominated by mountains, 67% of the country's total land is arable and 24% is forest and other wooded lands. The economy is dominated by the service sector, which contributes 45% of the country's GDP. Degraded sandy soils contribute to dust and sandstorms, which are hazardous to both humans and livestock. Signs of water shortages are evident due to increased demand from agriculture and industry. Weak institutional structures, policies and legislations, limited access to new technologies, skills and technical resources all hamper Lebanon's ability to address the current challenges, especially in relation to water, agriculture, forests, and management of coastal areas.

In 2013 Lebanon identified Nationally Appropriate Mitigation Actions (NAMAs)³⁷ articulating voluntary emission reduction proposals, and established working groups on the transport, energy, waste, forestry, and industry sectors. Lebanon signed the Paris Agreement in 2016 and submitted an update to its 2015 NDC in 2020³⁸.

²⁷ United Nations. Government of Lebanon and United Nations, Lebanon Crisis Response Plan 2017– 2020. 2019.

²⁸ United Nation Refugee Agency (UNHCR). UNHCR Global Appeal, 2015.

²⁹ European Union. Action Document for the EU Regional Trust Fund in Response to the Syrian crisis to be used for the decisions of the Operational Board. 2018.

³⁰ Masri, S., Srour I. Assessment of the impact of Syrian refugees in Lebanon and their employment profile. International Labour Organization. 2014.

³¹ CARE. Care International report: Syrian Refugees in Lebanon - Eight years on: What works and why that matters for the future. 2018.

³² United Nation Refugee Agency (UNHCR). Situation Syria Regional Refugee Response. 2018.

³³ Devi S. Lebanon faces humanitarian emergency after blast. Lancet (London, England). 2020

³⁴ Noubani A, Diaconu K, Loffreda G, et al. Readiness to deliver person-focused Care in a fragile situation: The Case of Mental Health Services in Lebanon. BMC Int J Ment Heal Syst (Under Review 2020).

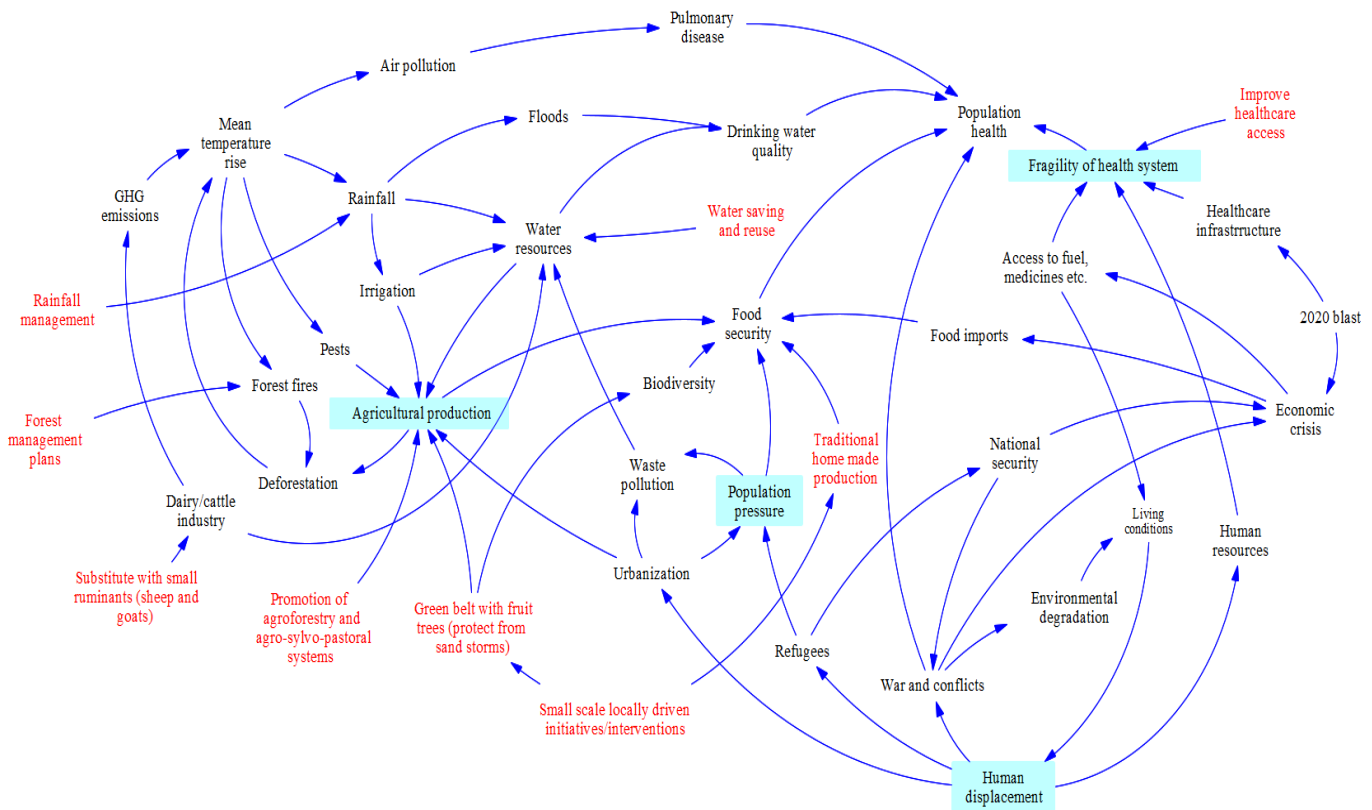
³⁵ Bou Orm I. Determinants of Non-communicable Diseases Prevention and Control in Lebanon. PhD thesis; Queen Margaret University; 2021.

³⁶ Naja F, et al, Burden of non-communicable diseases among Syrian refugees: a scoping review. BMC Public Health. 2019

³⁷ Nationally Appropriate Mitigation Strategies (NAMA) in Lebanon ([link](#))

³⁸ Ministry of Environment, Lebanon's Nationally Determined Contribution, 2020 ([link](#))

b. Lebanon causal loop analysis



The causal loop diagram above represents a 'mental map' of interactions developed by participants on the basis of the initial variables and pathways identified by the literature review. Key pathways exacerbating threat considered in the workshop are flagged in light blue; potential foci of adaptation and resilience are shown in red.

c. Emerging themes and strategies

A core focus of workshop discussion were the complex dynamics related to the environment and **agricultural production** which mediated between climate and health. Harvesting of pine nuts, for example, is one of a number of important sources of livelihood threatened by changing climatic conditions. Irrigation to sustain horticulture through changing seasonal conditions is placing a strain on insecure water sources. Extension of dairy and cattle farming to meet local demand for food supply is further taxing water resources, as well as contributing to greenhouse gas emissions. All these dynamics impact population health (e.g. through food security or availability of water) as well as upon household livelihoods and environmental conditions.

Human displacement and population pressure were other factors considered to be shaping the dynamics of climate and health. War and conflict in the region has driven a cycle of environmental degradation and population movement. The influx of refugees has exacerbated pressure on land, urban settlements, food and water, adding to the direct impacts of climate change.

The political and economic crisis facing the country drives further dynamics eroding population health and the capacity to moderate climate impacts. There are implications for food security and the sustainability of agricultural production. Economic conditions are also restricting access to vital commodities to support the operation of the health system. Together with

population displacement involving outward migration of health workers, these trends are contributing to greater **fragility of the health system**, with major implications for population health.

Potential **adaptation strategies** addressed include strengthening sustainable agricultural solutions (such as climate smart agriculture, **agroforestry** and **greater use of small ruminants** such as local goats and sheep) and developing **sustainable water services**. Although government policy can facilitate development, given the economic and governance challenges in the country, **local community-based initiatives** were considered crucial. Conflict- and climate- sensitive approaches were viewed as vital to **sustain access to health services** enabling universal health coverage (UHC). Greater cross-sectoral collaboration is required to ensure public health safety and disaster risk reduction are integrated into national health plans.

Costa Rica Case Study

a. Country profile

Costa Rica, situated between Nicaragua and Panama in Central America, has the lowest poverty rates in Latin America and the Caribbean. However, fiscal challenges and increasing income inequality are persistent pressing issues,³⁹ with the Fragile State Index (FSI)⁴⁰ noting escalating concerns on issues of security and resource distribution⁴¹.

The country is characterised by high rates of migration from across Central America, being one of the top ten countries in the world to receive asylum requests⁴². Evidence from 2015 suggests that the average disposable income of the 10% richest households was 32 times higher than that of the poorest 10% (c.f. OECD average of 9.6)⁴³.

The threat of economic recession leaves the Costa Rican population open to health-related risk. While UHC is formally guaranteed, more than one-third of the assets of the *Caja Costarricense de Seguro Social* (social security and health insurance agency) are owed to it by the State⁴⁴, itself struggling to raise revenues given rapid increases in unemployment, informal employment⁴⁵ and effects of COVID-19.

The country's disease profile is dominated by a high NCD burden, typically addressed by high-cost treatments at the level of secondary care.

The country has a varied topography that includes coastal plains separated by rugged mountains, including over 100 volcanic cones. Even though Costa Rica constitutes less than 0.05 percent of the total Earth surface, its habitats represent around 5 percent of the planet's biodiversity. Costa Rica is known worldwide for its conservation efforts and is a 'hot spot' for eco-tourism, with more than 26 percent of its land under protection.

However, due to a combination of geographic and economic factors, Costa Rica is highly vulnerable to extreme climate events and natural hazards. Part of this vulnerability is a result of the presence of populations in areas prone to volcanic eruptions and in unstable lands, degraded by widespread cattle ranching, or in poorly planned settlements prone to landslides and flooding. Costa Rica's National Climate Change Strategy (ENCC) and its Plan of Action, as well as advances in the Framework Law on Climate Change, frame policy objectives in this area. The ENCC prioritizes action on mitigation, adaptation, technology, education and finance with the goal to integrate climate change policy with the long-term competitiveness of the country and a strategy of sustainable development. The National Adaptation Policy (2018-2030)⁴⁶, the National Decarbonization Plan (2018-2050)⁴⁷, NDC⁴⁸, and NAMA all affirm the country priorities and commitment to tackle climate change.

³⁹ World Bank. Costa Rica Data ([webpage](#)), 2020.

⁴⁰ Fragile State Index Annual Report 2021 ([link](#))

⁴¹ The Fund for Peace. Fragile States Index Report. 2020.

⁴² United Nation Refugee Agency (UNHCR). Costa Rica country statistics ([webpage](#)), 2020.

⁴³ OECD, Costa Rica Policy Brief ([link](#)), 2016.

⁴⁴ Caja Costarricense de Seguro Social. Estados financieros: Seguro de salud, San José: CCSS. Gerencia Financiera. 2020.

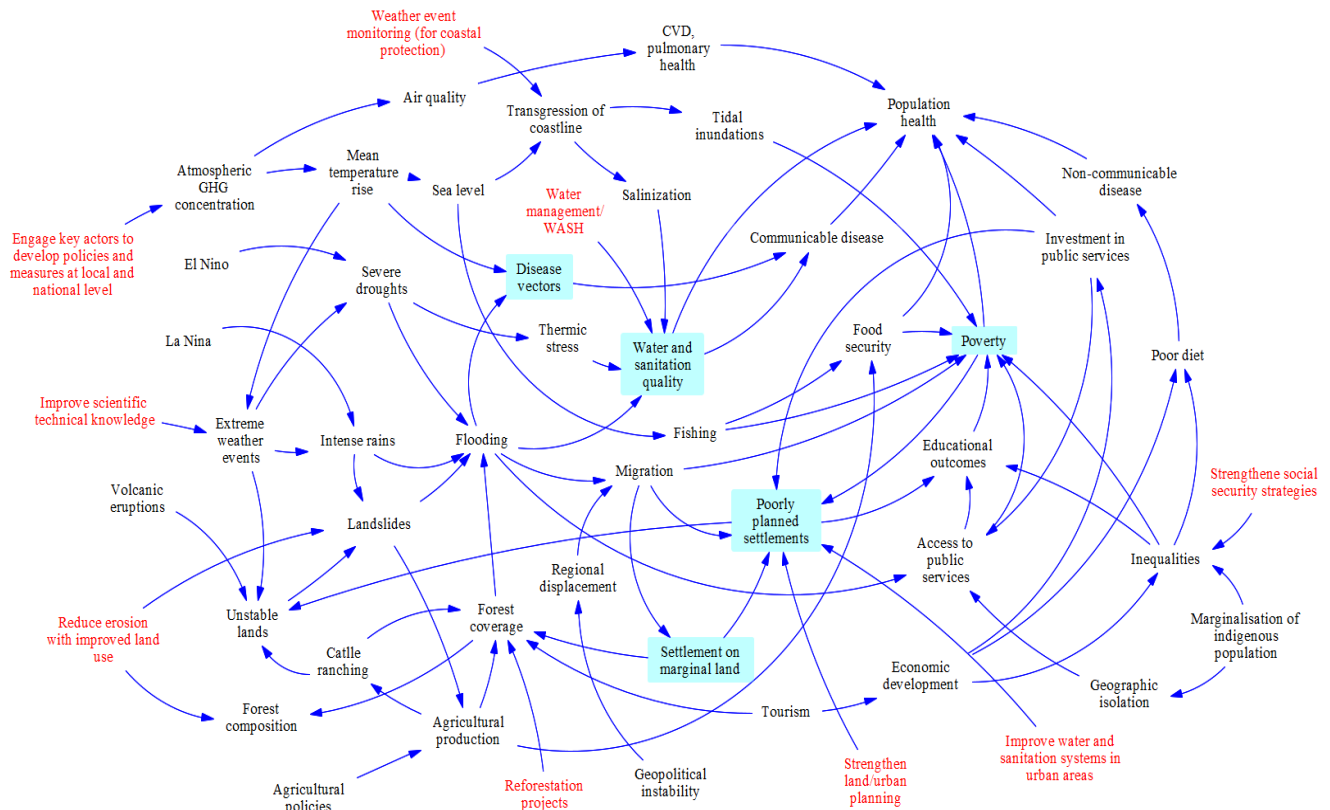
⁴⁵ National Institute of Statistics and Census. Continuous Survey on Employment for the first quarter of 2020. General results. San José: INEC. 2020.

⁴⁶ National Adaptation Policy ([link](#))

⁴⁷ Plan Nacional de Descarbonization 2018-2050, Gobierno de Costa Rica ([link](#))

⁴⁸ Contribution Nacionalmente Determinada 2020 ([link](#))

b. Costa Rica causal loop analysis



The causal loop diagram above represents a 'mental map' of interactions developed by participants on the basis of the initial variables and pathways identified by the literature review. Key pathways exacerbating threat considered in the workshop are flagged in light blue; potential foci of adaptation and resilience are shown in red.

c. Emerging themes and strategies

With important changes in patterns of rainfall, a major focus of discussion amongst participants were the dynamics influencing **water resources**, whether directly through droughts, floods and salinization of aquifers or indirectly through the impact of forestry and agricultural practices. A lack of safe water was seen as impacting economic growth (due to water cuts and rationing) and as a major contribution to compromised hygiene and increased risk of diarrhoeal disease. Floods contaminate freshwater supplies, heighten the risk of water-borne diseases, and create breeding grounds for **disease vectors**, for many of which climate change was lengthening the transmission season and geographic range.

Another major focus of discussion was the role of **settlement on marginal land, poorly planned settlements** and, more broadly, **poverty** on mediating the influences of climate change. Areas where there was significant population pressure on land and public infrastructure had poorer access to public services, which data confirmed affected both health and educational outcomes. Economic development which addressed deep inequalities was viewed as important to confront these sources of vulnerability.

Potential **adaptation strategies** discussed included the need to tackle the direct impacts of climate change via **surveillance, monitoring and early warning systems**. **Strengthened**

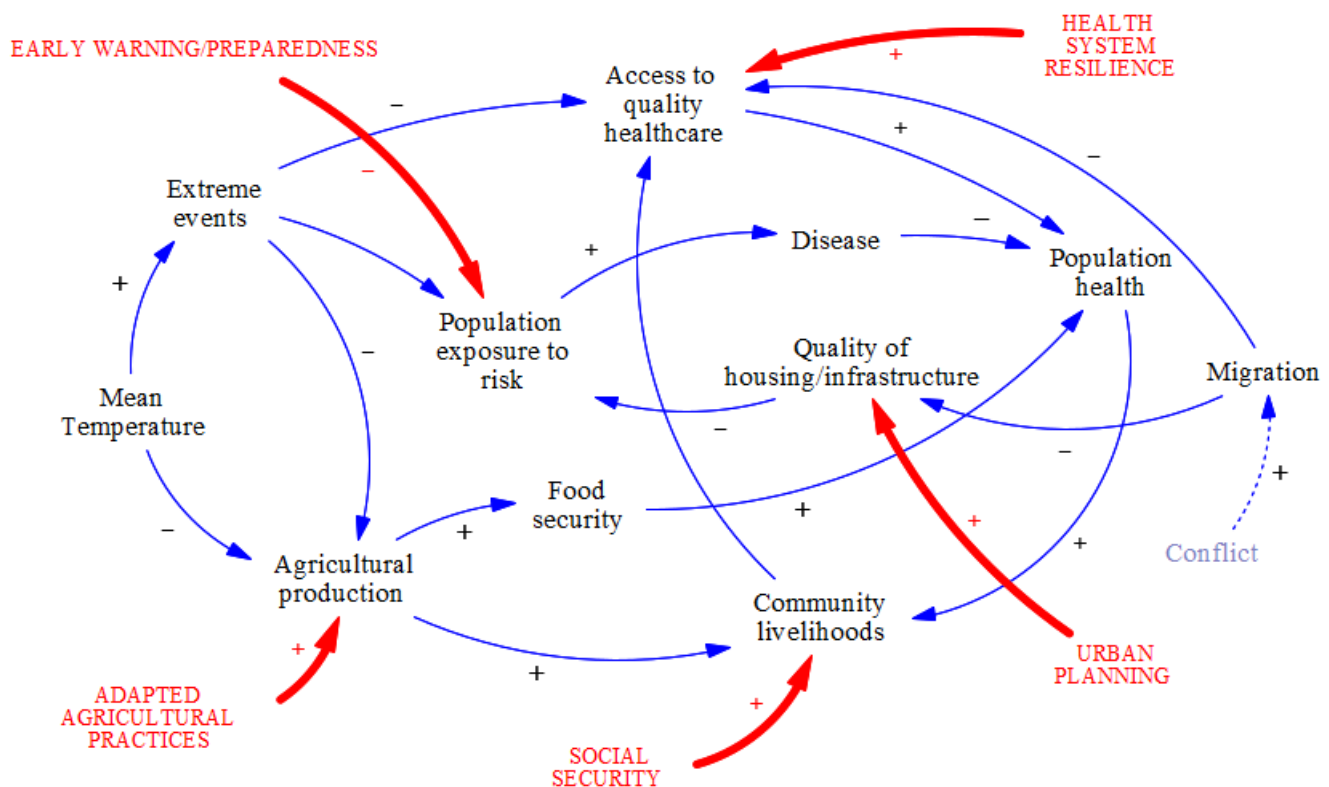
social security strategies were considered of significance in reducing the multiple risks linked to poverty. Health systems need to expand traditional systems of healthcare delivery by integrating **climate change considerations** (e.g. control of climate-sensitive diseases), improving **management of environmental determinants of health** (such as water and sanitation, nutrition, and air quality), and establish **emergency preparedness** plans for extreme events. **Urban and housing planning** in marginal lands, coastal or flood-risk areas was also considered a key area of intervention.

Integrative Analysis

Causal loop analysis identified complex dynamics reflecting the unique characteristics of each setting. Modelling served a valuable function in collating evidence from multiple sources, convening consultations from researchers of varied disciplines, and identifying actions - and interactions - of relevance across multiple sectors.

This approach to mapping the linkage of climate change, health, and other human systems such as agriculture, settlement, and livelihoods is thus perhaps best suited to local, contextual engagement of actors in identifying key leverage points for adaption strategy. However, while the causal loop analyses across these four settings reflect the unique characteristics of each setting, they also suggest some dynamics that are shared across these contexts.

The causal loop diagram below seeks to represent some of these recurrent features. In all settings, mean temperature rise is leading to an increased frequent and intensity of extreme weather events that – whether through the means of floods, droughts, heatwaves etc. – expose populations to health risks. These risks exacerbate disease burden and undermine population health. This pathway of climate impact on population health is complemented by a pathway mediated by loss of agricultural production and reduced food security. Additional dynamics influencing the degree of impact of climate change are commonly mediated by the economic livelihoods of communities; migration (often related to conflict) and the resulting pressures on housing and infrastructure; and access to quality healthcare.



Causal loop diagram showing common dynamics across the four settings.

There may – as illustrated in the country case studies - be multiple factors linking these pathways. This interlinkage may be crucial in determining appropriate foci for local adaptation policy and practice. However, these pathways serve to highlight broad classes of adaptation strategy operating with respect to different factors highlighted in this integrative analysis.

The five strategies are focused on **early warning/preparedness regarding extreme events** (thus mitigating exposure to risk); **adapted agricultural practices** (to sustain food security and community livelihoods in changing environmental conditions); **urban planning** (to strengthen the quality of housing and infrastructure and thus reduce population exposure to risks); **health systems resilience** (to maintain access to quality healthcare both for the treatment of disease associated with increased risk exposure and for other conditions for which access may be disrupted by extreme events); and **social security** (supporting the livelihoods of communities vulnerable through the impact of climate change or otherwise) enabling their access to public services, including healthcare.

Identification of key leverage points for intervention within a complex system of interactions is a valuable outcome of system dynamics analyses and an increasingly important focus of inter-disciplinary research focus.^{49,50}

⁴⁹ Proust K, et al, Human health and climate change: leverage points for adaptation in urban environments. *Int J Environ Res Public Health*. 2012, doi: 10.3390/ijerph9062134

⁵⁰ Schnitter, R. and Berry, P. The Climate Change, Food Security and Human Health Nexus in Canada: A Framework to Protect Population

Recommendations

a. System dynamics modelling methods, such as participatory group model building, provide a useful mechanism for convening actors across multiple sectors to consider the development of adaptation strategies. **Consultations at national and local levels using approaches informed by systems dynamics should be used to identify linkages that can promote – or, unattended, would undermine – coherent, cross-sectoral action in support of adaptation.**

b. In line with the OECD multi-dimensional analysis of fragility⁵¹, **climate-related environmental risks need to be increasingly factored into appraisal of state and regional fragility**, alongside issues of security and social, economic and political risks.

c. Our modelling has highlighted how pathways of impact of climate change can disproportionately affect those with lower household incomes, exacerbating inequalities. **Adaptation strategies need to consider *a priori* investments which prioritise social security of vulnerable communities and populations.**

d. **Strategies focused on strengthening health systems resilience need to consider the relevant influences** not only of national preparedness and early warning systems, but also **of the impacts of evolving agricultural (and wider livelihood) practices and patterns of settlement.**

e. **Effective data monitoring systems needs to be prioritised at national level to integrate information from all relevant sectors**, with datasets and analyses shared across all ministries.

⁵¹ Diaconu et al. Understanding fragility: implications for global health research and practice Health Policy and Planning, Volume 35, Issue 2, March 2020, Pages 235–243, <https://doi.org/10.1093/heapol/czz142>

Annex

Workshops participants

Georgia

Dr Ivdity Chikovani, Senior Researcher, Curatio International Foundation
Dr Maia Uchaneishvili, Research Unit Director, Curatio International Foundation
Dr Nia Giuashvili, Environmental Health Expert, Advisor of the National Center for Disease Control and Public Health General Director on Environmental Health
Dr Mariam Maglakelidze, Head, Department of Institutional Culture Development, Petre Shotadze Tbilisi Medical Academy; Affiliate Scholar, Institute for Advanced Sustainability Studies, Potsdam, Germany
Ina Girard, Climate Change and Human Health Expert, WHO Focal Point on the Environmental Health Issues at the National Environmental Agency
Dr Tamar Kashibadze, Public Health Specialist, NCD Department, National Center for Disease Control and Public Health

Mozambique

Dr Ana Olga Mocumbi, Program Lead, Non-Communicable Diseases, Instituto Nacional de Saúde, Mozambique and Associate Professor, Faculty of Medicine, Universidade Eduardo Mondlane, Mozambique
Dr Tatiana Marrufo, Instituto Nacional de Saúde (INS), National Health Observatory Technical Secretariat, Program Lead of Environmental Health

Lebanon

Dr Michèle Kosremelli Asmar, Directrice, Professeur Associé, Institut Supérieur de Santé Publique, Université St Joseph, Beirut
Dr Fady Asmar, Forestry Expert, Lebanon

Costa Rica

Dr Laura C. Blanco, Associate Professor, School of Economics, Universidad de Costa Rica
D.E.A. Pascal Giro, Head of the School of Geography, Universidad de Costa Rica
Dr Valeria Lentini, Lecturer, School of Economics, Universidad de Costa Rica
Dr Juan Robalino, Head of the Economics Research Institute, Universidad de Costa Rica
Dr Yanira Xirinachs-Salazar, Associate Professor, School of Economics, Universidad de Costa Rica
Dr Paola Zúñiga-Brenes, Associate Professor, School of Economics, Universidad de Costa Rica

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