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Editorial

Introduction: The Metabolism of Islands

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Abstract: This editorial introduces the Special Issue "Metabolism of Islands". It makes a case why we should care about islands and their sustainability. Islands are hotspots of biocultural diversity, and home to 600 million people that depend on one-sixth of the earth's total area, including the surrounding oceans, for their subsistence. Today, they are on the frontlines of climate change and face an existential crisis. Islands are, however, potential "hubs of innovation" and are uniquely positioned to be leaders in sustainability and climate action. We argue that a full-fledged program on "island industrial ecology" is urgently needed with the aim to offer policy-relevant insights and strategies to sustain small islands in an era of global environmental change. We introduce key industrial ecology concepts, and the state-of-the-art in applying them to islands. Nine contributions in this Special Issue are briefly reviewed to highlight the *metabolic risks* inherent in the island cases. The contributors explore how reconfiguring patterns of resource use will allow island governments to build resilience and adapt to the challenges of climate change.

Keywords: island metabolism; island sustainability; island industrial ecology; socio-metabolic research; metabolic risk; socio-metabolic collapse

1. Why Care about Islands?

On 23 September 2017, five days after Hurricane Maria ravaged the small island nation of Dominica, Prime Minister Roosevelt Skerrit boldly announced to the 72nd UN General Assembly his goal of rebuilding the country as the world's first climate resilient nation. Only six months later, with financial support from Canada and the U.K., the *Climate Resilience Execution Agency for Dominica* (CREAD) was launched. By the end of 2018, Dominica had passed its *Climate Resilience Act* [1]. Dominica's urgency for a sustainability transformation and to build resilience to the impacts of climate change is a concern increasingly shared by most small island states and island communities around the world.

According to *Island Conservation*, there are ~465,000 islands in the world [2], of which some 80,000 are inhabited by approximately 600 million people, or 8.5% of the global population [3]. Islands comprise 5.3% of the earth's terrestrial area, and if we include the surrounding oceans, this amounts to one-sixth of the earth's total area on which island communities depend [4]. Thus, islands are home to rich and rare biodiverse systems. Harboring 20% of all plant, bird and reptile species found globally, islands are biodiversity hotspots; 7 out of 10 coral reef concentrations, and 12 of 18 centers of marine endemism surround islands. Islands are, therefore, conservation frontiers, with a third of the world's conservation areas being on islands [5,6].

In addition to a thriving biodiversity, islands have for millennia been at the crossroads of human culture–nature interactions, that have forged new forms of social expression. As a result, diverse island cultures have evolved [7,8]. They have developed from the days of the wind-propelled long and arduous journeys where ships anchored at islands to replenish supplies or to enter into trade, to the times of colonial and slave trade, to more recent times where a significant portion of island populations are living and working abroad. Given such dynamic histories, regions such as the Caribbean, Oceania, and the Pacific, are referred to as the microcosms of the Earth, with multiple ethnicities, languages, and ideologies [9].

Today, islands are severely threatened, and are on the frontlines of climate change. With less than 1% of greenhouse emission, island communities contribute the least to climate change; yet they remain the most impacted [10–12]. They have become sites of compound events and multiple risks. With fragile economies and ecosystems, the ability for small island economies to withstand the shocks caused by climate-induced extreme weather events are limited, and losses tend to be disproportionate, relative to the size of the island economy. The 2017 hurricane season, for example, resulted in severe losses relative to GDP in Sint Maarten (797%), the British Virgin Islands (309%), and Dominica (259%) [13], with the economic costs of recurring disasters only increasing over time [14–17]. Even in the much less exposed Mediterranean Sea, an extreme weather event of so far unknown intensity in 2017 washed away part of the central medieval town on the small island of Samothraki [18].

Besides their exposure to the increasing frequency and intensity of extreme weather events, most islands suffer from resource shortages, are import dependent, have undiversified exports, and some degree of brain drain [19]. The Caribbean region, for example, is the most tourism-reliant region in the world, with its countries importing up to 90% or more of its food and energy needs and construction materials. Caribbean nations are among the top 20 countries in the world with the highest migration rates of those having a post-secondary education with severe impacts on the local labor market [5,20–24]. Practices such as concentrated infrastructure development along the coast (coastal squeeze), population growth and drift to main centers, poor waste management, land-and-ocean degradation, and centralized energy systems are additional stressors on small islands [25].

In an era of climate urgency, islands will need to undergo a transformation to sustainability, where all citizens can enjoy a high quality of life at the lowest environmental cost. This will require a fundamental shift in the way small islands respond to problems and the way they conceive island development. Policy responses to challenges such as extreme weather events, resource insufficiency, international debt, brain drain, and waste are inevitably tackled independently, and on a narrow time-frame [26]. Links amongst these problems are often poorly understood, and the solution to one is frequently at the expense of another. To monitor progress towards sustainability and guide the development of innovative solutions, systemic approaches need to be adopted [27,28].

That said, few systemic studies exist for small islands that study the linkages between societal resource use, derived benefits, and environmental impact. This represents a significant knowledge gap with respect to understanding island sustainability which, in turn, inhibits effective policy. This volume is a step in addressing this critical gap. Through the nine contributions in this book, we not only highlight some of the pressing sustainability challenges on islands from a systems perspective, but also aim to provoke further research on the "metabolism of islands" and pave the way for a full-fledged research program on "island industrial ecology"—a program with the aim to offer policy-relevant insights and strategies to sustain small islands in an era of global environmental change.

2. Towards a Metabolism of Islands: Clarifying Core Concepts

"Metabolism" is a biological concept that refers to the chemical conversion and breakdown of organic matter to sustain reproduction. Analogous to biological metabolism, any given society organizes material and energy flows through their natural environment (or through imports with other societies) for their sustenance and reproduction. Some materials and energy become waste (outflows), while the rest of the flows are net additions to "material stocks" (or built environment). This process of organizing and reproducing material stocks and flows by society is referred to as *social metabolism* [29] (Figure 1).

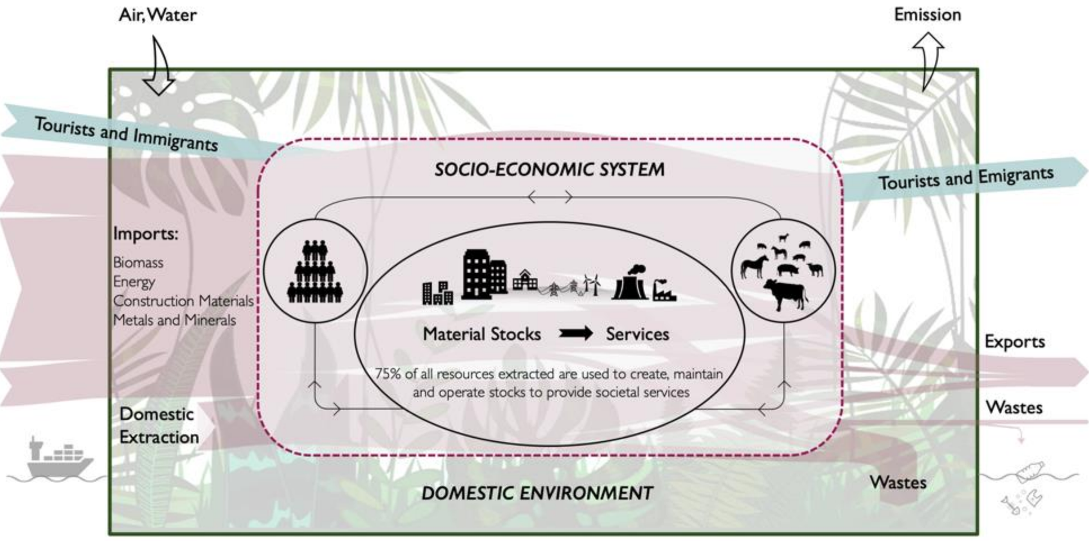

Figure 1. Specific combinations of material stocks and flows contribute to the system's exposure to risk (metabolic risk) and its ability to provide essential services.

Material stocks (or simply "stocks") provide critical societal services such as housing, food, energy, transport, health, and education. As economies develop, they stimulate the demand for *essential services* that are provided by the stocks and hence, they are viewed as the material basis of societal well-being. The larger the stocks, the greater the flows required to maintain and reproduce these stocks, creating a feedback loop, referred to as the *material stock–flow–service* (SFS) nexus [30]. The quantity and composition of resource throughput in a socioeconomic system characterizes its *metabolic profile* and is indicative of the pressure an economy exerts on the environment.

Just as metabolism influences a person's body, the process of *social metabolism* influences the natural environment by altering land-and-sea-use (by mining, urbanization, fishing, and agriculture) and, over time, causes pressure on ecosystems, the atmosphere and bio-geo-chemical cycles [31]. Climate disruptions, sea-level rise, hurricanes, and possibly even pandemics are examples of ecosystem *dis*-services, against which society needs to adapt and protect itself by altering existing patterns of *social metabolism*.

As such, specific combinations of material stocks and flows can become a *metabolic trap* and contribute to the system's exposure to risk, which we refer to as the *(socio-)metabolic risk* [32]. The IPCC [33] defines risk as "the potential for adverse consequence", that results from the "interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence" (p. 557). Maladaptive practices such as reliance on imports for basic needs, centralized energy systems, coastal squeeze, or population drift can increase metabolic risks on islands. Systems that exhibit high metabolic risks are inherently vulnerable to shocks and disruptions, and to impacts of climate change.

A *(socio-)metabolic collapse* is an adverse outcome for systems that embody high metabolic risk, where the system's ability to organize its *social metabolism* is severely compromised. It signals the crossing of a threshold or *tipping point* that is often irreversible. Reaching a tipping point can be due to a biophysical (e.g., overuse of natural resources causing an ecological disaster), or social phenomenon (out-migration due to lack of services or jobs on an island causing a demographic shift), or a combination of both [34]. In the case of small islands, a metabolic collapse can be rapid, such as disruptions from hurricanes, or slow from gradual depletion of resources, or sea-level rise. Reconstruction following an adverse event, such as a hurricane, comes with large fiscal and environmental costs and can increase the metabolic risk if rebuilding actions are maladaptive.

Research presented in this volume illustrates the complex interactions in the stock–flow–service nexus. In analyzing the metabolism of islands, the 35 authors conducted *socio-metabolic research* (SMR), a research tradition within *industrial ecology* (IE) for systematically studying the biophysical stocks and flows of material and energy associated with societal production and consumption. SMR offers crucial insights to develop strategies to reconfigure and reduce societies' use of natural resources that are compatible with ecological boundaries, while also providing essential services to reach social thresholds [28].

3. Brief Overview of Socio-Metabolic Research (SMR) on Islands

The first known socio-metabolic research (SMR) on an island was for Nämdö in the Stockholm archipelago, Sweden, that analyzed energy and food flows [35]. Subsequently, Singh et al. [36] conducted a full material and energy stock and flow account for Trinket Island (India) that portrayed the changing metabolic profile of an indigenous society affected by development programs from the Indian state. The same case was later compared to the rise in material and energy consumption caused by excessive aid following the 2004 Asian tsunami [37,38]. Most SMR on islands have focused on "flows". Some have considered all material and energy throughput, while others have emphasized specific (problematic) materials or sectors of interest. Prominent examples of "flow" studies are Iceland and Trinidad and Tobago [39], Malta [40], the Philippines [41], Cuba [42], and Hawaii [43]. Flow studies with a focus on specific materials or sectors are: biomass flows for Jamaica 1961–2015 [44], e-waste for five Caribbean countries [45], plastics and packaging material on Trinidad [46], disaster waste on St. Martin [47], material and energy use in the tourism sector on Grenada [48] and on Menorca, Spain [49], solid waste on Grenada [50], and the metal–energy–construction materials nexus in New Caledonia [51].

Interest in material stock research is relatively recent, hence, stock accounts for islands are still very rare. Tanikawa et al. [52] estimated the loss in material stocks following the earthquake and tsunami in Japan, and conducted a stock account for construction materials for Japan for the period 1945 and 2010 [53]. Symmes et al. [54] conducted the first spatially explicit material *stock–flow* analysis in the Caribbean, focusing on Grenada's metabolism of construction materials, their distribution across the different sectors of the economy, and the potential impacts from sea-level rise. Noll et al. [55] analyzed the stock–flow relationship for the Greek island of Samothraki between 1971 to 2016, with a focus on construction materials, including inflows, as well as the construction and demolition waste generated. Merschroth et al. [56] estimated the loss in stocks in Fiji due to sea-level rise and global warming. Bradshaw et al. [57] explores the first material *stock–service* relationship for any island (Antigua and Barbuda) with consequences for island tourism under sea-level rise scenarios. Stock analysis on islands is extremely important, both from a perspective of total resource requirements over time, but also to identify infrastructure vulnerability (or *metabolic risks*) and resulting loss of societal services during and after a crisis.

4. Contributions in This Volume

The nine contributions in this volume cover a wide range of application of socio-metabolic research, from flow accounts, to stock analysis, and their relationship to services in space and time. Marian Chertow and colleagues (Chapter 1) analyze material flows for the archipelago of Hawaii and their scale interactions for five nested layers (or *holons*). They argue for a multi-level material flow analysis or a "holarchic" approach to island metabolism to better identify drivers of resource use at multiple scales and associated sustainability challenges.

Bahers and colleagues (Chapter 2) utilize a nexus approach, analyzing the nodes of interdependence for metal, energy, and construction mineral flows on the island of New Caledonia. The authors examine how extractive activities impact resilience and metabolic sustainability on a small remote island. To understand scale interactions and power relations, they apply the idea of "territorial metabolism" to conduct a material flow analysis of New Caledonia, combining biophysical analysis with the political decision-making that impacts resource flows.

Fischer-Kowalski et al. (Chapter 3) illustrate how islands can serve as real-world laboratories to promote sustainability. The authors conduct socio-metabolic research in a transdisciplinary setting on the Greek island of Samothraki to pave the way for the island to become a member of UNESCO's World Network of Biosphere Reserves. They argue that the transformation of local agriculture, as well as infrastructure, is critical for the island's sustainability. However, a collaborative process with stakeholders is essential to maximize social, economic, and environmental outcomes.

In Chapter 4, Dominik Noll and colleagues focus on biomass flows in the context of livestock overgrazing on Samothraki (as in Chapter 3). They show the degradation of the local ecology through focusing on ever-increasing livestock numbers incentivized by the European Union's Common Agriculture Policy (CAP). The case of Samothraki presented here reveals the complex interaction between environmental, economic, and social factors at an island level.

Chapters 5 and 6 focus on island waste. Shah et al. (Chapter 5) highlight the limitations of islands to absorb large volumes of waste produced because of high imports and associated packaging materials. Using the case of Trinidad and Tobago in the Caribbean, the authors identify three temporal phases and describe the efforts, reactions, drivers, and circumstances to deal with plastics and packaging materials. This work contributes to our understanding of the institutional factors that shape the search for solutions to the wicked problem of island waste metabolism.

Popescu and colleagues (Chapter 6) analyze stocks and disaster waste flows after hurricane Irma devastated the Caribbean French municipality of Saint Martin in 2017. They ask whether shocks such as this helped sustainably transform the island's waste management system. In answering this question, the authors focused on the intensity of waste flows, the spatial structure of metabolism and the actors and techniques that determine metabolic dynamics. They argue that islands urgently need to develop strategies for recovering, recycling, and reusing disaster waste as part of resilience building efforts.

Chapters 7 and 8 analyze material stocks in Antigua and Barbuda and in Fiji, respectively. Bradshaw and colleagues (Chapter 7) use Geographic Information System (GIS) techniques to quantify and locate the material stocks for Antigua and Barbuda in the Caribbean. The authors show how tourism would be most impacted under a 1- and 2-m sea-level rise scenario, given that most of the infrastructure is along the coast. By linking stocks with services, this research uncovers the complexities that connect environmental and economic vulnerabilities on an island, and the need for better infrastructure and spatial planning to enhance system resilience.

Similarly, Merschroth et al. (Chapter 8) adopt IPCC sea-level rise scenarios for the years 2050 and 2100 to estimate the amount of material stocks that will be inundated with sea-level rise in Fiji. The authors combine GIS-based digital inundation analysis with material stock analysis to reveal the hidden vulnerabilities with respect to spatial and infrastructure planning in Fiji. They show that by 2050 and 2100, some 4.5% and 6.2% of all existing buildings in Fiji will be inundated, which is equal to 40% of new construction each year.

In Chapter 9, Bogadóttir takes a long view to investigate the interrelations between social metabolism and socio-ecological sustainability in the Faroe Islands. She shows the importance of localizing food production that will foster food security, food sovereignty and biocultural diversity. Drawing from the Faroese experience, she describes their traditional food practices as "quiet sustainability" that contributes to local food security. She argues that such local practices should be considered real alternatives to import-based consumption, and so deserve a place in sustainability discourses.

The collection of articles in this volume suggest that islands have "methodological utility" [43]. They have the potential to pave the way for sustainability education, research, and practice. Islands are systems with clearly delineated boundaries and are, therefore, excellent geographies for socio-metabolic research. They offer numerous educational stories and lessons. Islands experience feedback rapidly (whether positive or negative), and consequences are more pronounced on small islands than on a mainland, prompting learning and immediate corrective action. There is also the aspect of urgency, especially since the impact of global environmental change on small islands is disproportionate and grips them in a spiral of increasing metabolic risk. Restructuring patterns of resource use, both for stocks and flows, will allow island governments to build resilience and adapt to the challenges of climate change. Small islands, therefore, urgently need to overcome systemic impasses to achieve their full competitive and equitable human development potential. Islands as potential "hubs of innovation" are uniquely positioned to be leaders in sustainability and climate action, therefore, in this journey, "island industrial ecology" and socio-metabolic research can certainly play an important role in helping islands achieve that status.

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