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Analysis

The Emergy Perspective of Sustainable Trends in Puerto Rico From 1960 to 2013

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ABSTRACT

Emergy analysis quantifies the direct and indirect contributions of nature to human systems providing a sustainability assessment framework, which couples economic growth within biophysical constraints. In this study, Puerto Rico's sustainability was assessed with emergy flow dynamics from 1960 to 2013. During this period, the island shifted from an agriculture-based economy to an industrial base of manufacture and services (1960–1970). The emergy analysis indicated an exponential decline in sustainability during this period. From 1975 to 1992, the island became more industrialized and imported more goods and services. Since 1998, although more renewable production such as forest regeneration occurred, the rapid industrialization heavily relied on imported fossil fuels, goods, and services, resulting in a system that has not been self-sufficient, nor sustainable. The latest economic crisis and the most recently passed financial rescue bill represent an opportunity to redirect Puerto Rico towards a sustainable path with policies that decrease the ratio of imported y to exported emergy, and strategies that encourage efficient use of resources and local production based on the utilization of renewable sources within this U.S. territory.

1. Introduction

Sustainability and sustainable development concepts are a priority on the agendas of scientists, government, industry, and the public. Sustainable development implies a Triple Bottom Line for accounting growth in the social, environmental, and economic dimensions of a human system (Elkington, 1994). These are commonly called the "three pillars of sustainability" or 3Ps (people, planet, profits). The 3Ps captures the essence of sustainability acknowledging social, environmental, and economical capitals. When seeking strategies to move towards sustainable development for any system, these three pillars must be appraised altogether in order to identify critical factors that facilitate management and planning for human systems with a responsible long-term perspective. However, these three dimensions cannot be easily accounted for in a common unit of measure.

While integrated measures are needed to provide a holistic view of sustainability, they require a "common currency" to compare different units and scales (Hester and Little, 2013; Hopton et al., 2010). One such method is emergy synthesis, an energy system-based process applied to assess sustainability at multiple scales translating environmental, social, and economic capital into a common unit of nonmonetary measure (solar emjoules, sej). Emergy is defined as the available energy of one kind previously used up directly and indirectly to make a product or service (Odum, 1996). It is based on observation of the energy flow patterns in ecosystems and economic systems during self-organization. The theory states that the structure and functions of all systems (social, ecological, and economic) are derived from the transformations of available energy. Such transformations also define the relative energy quality in a hierarchical order. Emergy analysis has been applied broadly to evaluate the sustainability of nations (Ulgiati et al., 1994; Brown, 2002), states (Campbell, 1998, Campbell and Ohrt, 2009, Campbell et al., 2005), and regions (Campbell and Garmestani, 2012). This method is used in this paper to provide a better understanding of the nature of Puerto Rico's sustainability from 1960 to 2013. The understanding of past trends will set the stage for present policy and future decision making.

1.1. The Commonwealth of Puerto Rico, U.S.

Located between the Caribbean Sea and the Atlantic Ocean, Puerto Rico is an archipelago of the Greater Antilles (Fig. 1b) that occupies approximately 8900 km^2 (3435 mi^2) of land including the smaller islands of Culebra and Vieques to the east, Mona, Monito and Desecheo to the

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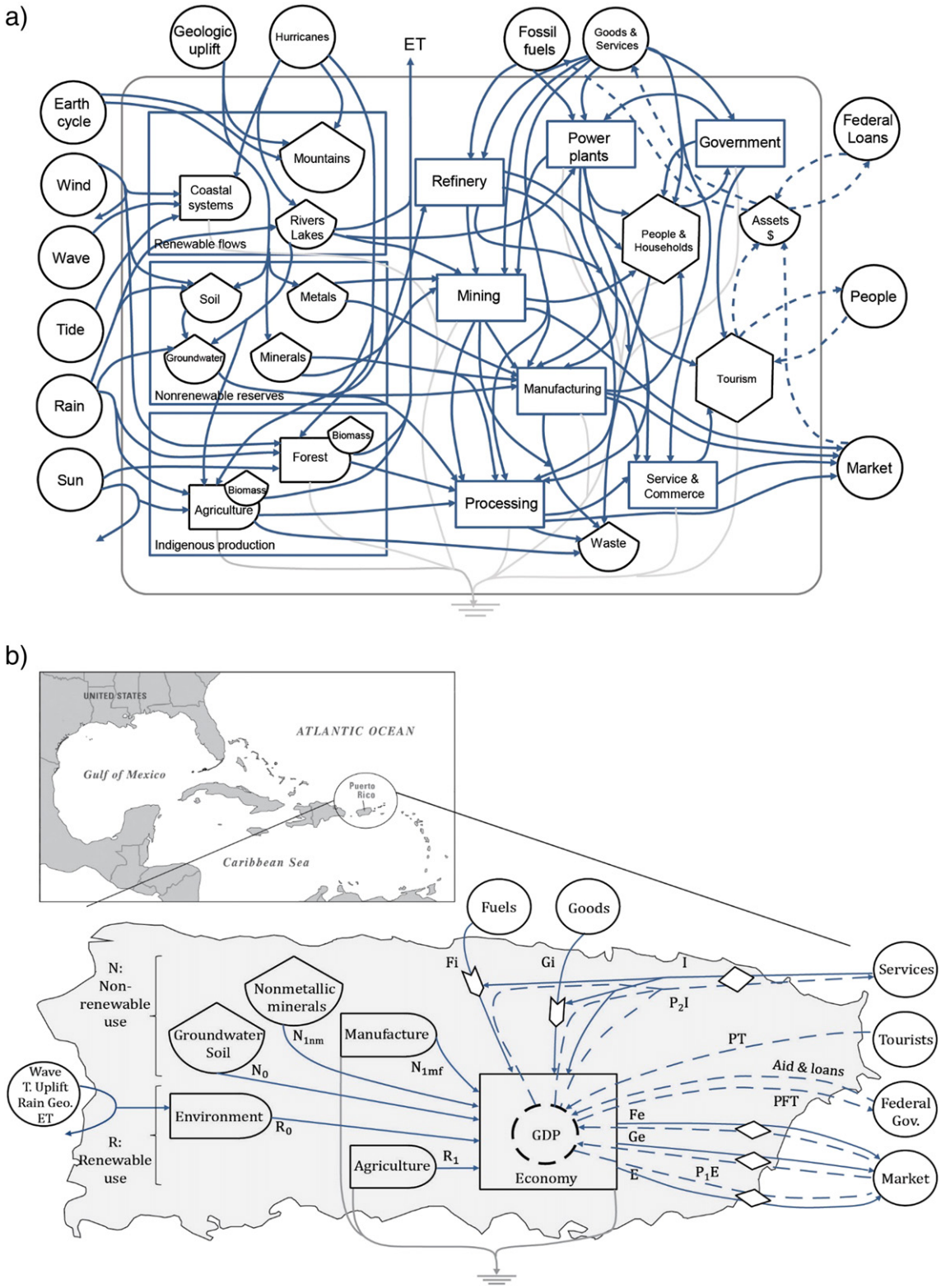

Fig. 1. Puerto Rico system. a) System diagram of Puerto Rico showing the major features of the island. External forcing functions (circles) provide inflow energy, materials and information to the producers (bullet-shape symbols) and consumers (hexagons). Internal storages (tank symbols) and economic and social subsystems (boxes) are shown. The money flows are shown as dashed lines. Energy, materials, and information flows are solid lines. Used energy flows (gray lines) that no longer has the potential to do useful work disperse and exit the system through heat sink at the bottom of the boundary. b) An aggregated model used to calculate summary variables and indices for the system. Local renewable resources (R) and nonrenewable resources (N) interact with fuels (F) and goods (G) and services (P_2I) to support regional economic activity (GDP). Letter "i" denotes imports and letter "e" exports.

west (Department of Natural and Environmental Resources, 2010). The main island is mostly mountainous (only 25% of the area can be considered plains) with a main range named Cordillera Central that stretches east west and two smaller ranges in the eastern part of the island, the Luquillo and Cayey Mountains (Pico, 1974). Although the highest elevation is 1339 m (4390 ft), Puerto Rico's approximate mean altitude is 549 m (1800 ft) (U.S. Census Bureau, 2012). Located in the tropics, mean daily temperatures normally oscillate between 23.4 °C (71.1 °F)