Ecological Engineering 65 (2014) 33–48

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Sustainability and place: How emerging mega-trends of the 21st century will affect humans and nature at the landscape level

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ARTICLE INFO

Article history:
Received 11 December 2012
Received in revised form 29 July 2013
Accepted 19 August 2013
Available online 12 October 2013

Keywords:
Energy scarcity
Climate change
Population
Biophysical economics
Ecosystem services
Agriculture
Sustainability

ABSTRACT

We discuss the sustainability of natural and human systems in the United States in relation to 21st century threats associated with energy scarcity, climate change, the loss of ecosystem services, the limitations of neoclassical economics, and human settlement patterns. Increasing scarcity and the decreasing return on investment for existing conventional energy reserves are expected to significantly reduce the amount of affordable energy for societal needs and demands. This will also make dealing with the predicted impacts of climate change more difficult and expensive. Climate change will threaten the present sustainability of natural environments, agriculture, and urban areas but these impacts will manifest themselves differentially across the landscape. The impacts of projected climate change will make living in arid regions of the southern Great Plains, the Southwest, and the southern half of California increasingly difficult. Accelerated sea-level rise and increased frequency of strong hurricanes will increase the vulnerability of natural and human systems along the Gulf and Atlantic coasts while making them less sustainable. Ecosystem services provided by natural environments form the basis for the human economy everywhere and are also at risk from climate change impacts and overuse. Decreasing energy availability, climate change, and continued degradation of ecosystem services are likely to make continued economic growth difficult if not impossible. The capacity of neoclassical economics to effectively deal with these growing threats is limited. The areas of the country most compromised by these 21st century trends are likely to be the southern Great Plains, Southwest, southern California, the Atlantic and Gulf coasts, and densely populated areas everywhere, but especially in the northeast, Midwest, and southern California.

1. Introduction

Sustainability is the ability of a system to maintain functioning over an extended period of time. It depends upon the continuous availability of the materials and energy required to maintain system functioning and the ability of the surrounding environment to assimilate wastes from the system. The term has been adopted widely over the last 25 years as the ongoing debate about the earth's capacity to support the population and level of economic activity has developed (Gregory et al., 2009; Burger et al., 2012).

Trends relating to energy scarcity, climate change, economics, population, and ecosystem services will have to be factored into considerations of environmental and social sustainability (e.g. Day et al., 2009; Burger et al., 2012). These trends will combine to differentially affect sustainability across the landscape. Since the availability of resources (materials and energy) is limited and also not distributed homogenously over the landscape, the sustainability of cities and regions is dependent on both locally available and imported resources. Some regions have abundant natural resources (e.g. generally the eastern half of the U.S.), while others (the Southwest and northwestern Mexico) have fewer local resources, especially fertile soil and adequate water. Regions with high ecosystem services have a larger carrying capacity and natural advantage over those with low ecosystem services although these services would be compromised if more people live there.

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http://dx.doi.org/10.1016/j.ecoleng.2013.08.003

Most settlement in North America prior to the industrial revolution was in resource rich areas. This abundance of resources provided for growth of population and local economies and yielded a surplus that could be exported to outside markets in return for non-locally available goods and money. After the industrial revolution, fossil fuels were critical to the economy generally, but especially for development in resource poor areas. The growth of the fossil fuel industries, in combination with the development of transport and agriculture infrastructure and technology, allowed the widespread distribution of goods and services across the landscape and the development of the modern global economy. The maintenance of this system requires high material and energy throughput. Emerging energy scarcity, climate impacts, and degradation of natural systems threaten the sustainability of modern technological society, especially in areas with low natural resources.

The objective of this paper is to consider how these emerging megatrends of the 21st century will affect differentially the sustainability of cities and regions of the U.S. at the landscape level.

2. Regional impacts of climate change

Global climate change due to increased concentrations of greenhouse gases, primarily CO_2, is projected to have profound impacts over the middle section of North America in the 21st century. But these impacts will impact the landscape unevenly (U.S. Global Change Research Program, 2009). Impacts include increased temperature, changes in precipitation, accelerated sea-level rise, widespread melting of snow and ice, changes in strong storms, and more erratic weather patterns Intergovernmental Panel on Climate Change, (IPCC, 2007). In May 2013, the CO_2 concentration at the Mauna Loa observatory reached 400 ppm, a 40% increase over preindustrial levels of about 280 ppm (IPCC, 2007). Concentrations have not been this high for over 3 million years, before humans evolved.

There has been a global increase in temperature of about 1 °C over the past century and temperatures are predicted to rise from 1 °C to 5 °C during the 21st century (IPCC, 2007, Fig. 1a). Nine of the ten warmest years in the last century were in the last decade (NOAA/NASA, 2013). This warming has led to decreases in Arctic sea ice and the Greenland ice cap, worldwide retreat of glaciers, melting of permafrost, and sea-level rise.

Climate change is projected to have impacts on precipitation patterns and freshwater availability. Average annual precipitation varies greatly in the United States. In general, the 100th meridian divides the U.S. into a moist eastern half and a dry western half (Fig. 1b). Exceptions to dryness in the west are in higher elevation areas and the northwest. Most of the western U.S. has precipitation less than 50 cm/yr while the highest precipitation in the country occurs in the northwest and along the north central Gulf coast. Climate projections predict both increases and decreases in precipitation (IPCC, 2007; U.S. Global Change Research Program, 2009). The southern Great Plains and the southwest are projected to have decreased freshwater availability from 10% to 50%. The upper Mississippi and Ohio valleys and the northeast are projected to have 5% to 20% increases in precipitation leading to increased Mississippi River discharge.

2.1. Drying and the southwest

The region that is projected to experience the severest climate change impacts is the Southwest. This, the driest and hottest region of the country, is projected to become drier and hotter with greater evaporation and more extremes of both rainfall and droughts (DeBuys, 2011). These conditions are leading to more tree death, super forest fires, loss of species, and more dust in the atmosphere (Williams et al., 2012). Increasing temperatures are leading to more winter precipitation falling as rain rather than snow leading to higher stream flow in the winter and spring and less in summer months. This affects both natural ecosystems and human uses of water. Along the west coast of the U.S., summer water use is strongly dependent on snow melt as reservoirs are sized for slowly melting snow pack. This problem becomes increasingly more acute to the south because of increasing aridity and higher water demand.

The most important river for human use in the Southwest is the Colorado with a watershed covering almost 650,000 km^2 or about 8% of the lower 48 states. Discharge of the Colorado is projected to decrease by 5% to 20% by 2050 or more by 2100 (DeBuys, 2011). Lake Meade is at less than 50% capacity, and recent studies predict it has a 50% chance of drying up within two decades or less as a result of reduced river discharge and increasing evaporation and consumption (Barnett and Pierce, 2008). It is likely that Lake Mead will rarely if ever refill to capacity again.

2.2. More water and the Mississippi basin

In general, the Mississippi basin is wet and discharge averages about 18,000 m^3/s (the 8th largest discharge in the world) compared to 550 m^3/s for the Colorado. The Mississippi drains an area of 3.2 million km^2, the world's fifth-largest drainage basin. The basin is about five times larger than the Colorado basin, but discharges 32 times as much water, a reflection of the higher precipitation over the Mississippi drainage.

In 2011, there was record flooding on the Mississippi. The factors that led to the flood are all consistent with climate change projections. The intense storms that delivered so much precipitation are largely due to the interaction of warm Gulf air masses and colder continental air masses (Min et al., 2011; Pall et al., 2011). And given the trajectory of rainfall intensity in the upper basin, floods like those in 2011 are likely to become more common.

2.3. Rising sea level and stronger hurricanes in coastal zones

One of the most important climate impacts is accelerating sea-level rise. Sea level rose 15–20 cm during the 20th century (Gornitz et al., 1982; Meehl et al., 2007; FitzGerald et al., 2008) and is likely to rise a meter or more by 2100 (Pfeffer et al., 2008; Vermeer and Rahmstorf, 2009; Moser et al., 2012, Fig. 1c). Sea-level rise on the east coast is accelerating at 3–4 times the global rate (Sallenger et al., 2012).

Recent reports have indicated that hurricane intensity is related to warming of the surface waters of the ocean (Emanuel, 2005; Webster et al., 2005; Hoyos et al., 2006; Elsner et al., 2008) and that stronger storms will increase in frequency (Bender et al., 2010). Knutson et al. (2010) concluded that warming will cause the globally averaged intensity of tropical cyclones to increase. Eight of the nine costliest Atlantic hurricanes in the U.S. have occurred since 2000 (NOAA, 2011; Blake et al., 2013). Hurricanes Katrina in 2005, Irene in 2011, and Sandy in 2012 perhaps exemplify the future of the Gulf and Atlantic coasts with respect to hurricanes. Katrina made landfall in late August 2005 as a Category 3 storm (it had reached Category 5 in the open Gulf) with 194 km/h winds and a nearly 10 m surge near the Louisiana–Mississippi border (Day et al., 2007). Sandy made landfall as a post tropical cyclone. Water levels reached nearly 5 m at Battery Park in Manhattan. Storm surge during Sandy was 3.86 m at Kings Point on the North Shore of Long Island, and storm tides (storm surge + astronomical tide) reached record levels throughout the New York City area (Blake et al., 2013).