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# Global mapping and estimation of ecosystem services values and gross domestic product: A spatially explicit integration of national 'green GDP' accounting

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ABSTRACT

The economic value of ecosystem services (non-market) and the market value (represented by a proxy of gross domestic product (GDP)) represent the synthetic green GDP of the earth and of different nations. Mapping and estimating national green GDPs is a challenging task. In this study, we estimated the global market and non-market monetary values using two images, GlobCover 2009 and nighttime satellite imagery, as well as a comprehensive dataset. We also developed an integrated method supported by geographic information system (GIS) techniques, focused on spatial heterogeneity and real value, to create synthetic green GDP maps at global and national scales. Our results show that in 2009, for the entire biosphere, the ecosystem services value (ESV) could be estimated at US$ 149.61 trillion. Approximately 75.15% of the ESV is contributed by marine systems. The world GDP in 2009 was about US$ 71.75 trillion (for 225 countries or regions), resulting in a ratio of total ESV to GDP of approximately 2.09–1. Nighttime satellite imagery represents a more spatially explicit indicator of market value than does GDP. We also found that the distribution of the synthetic national green GDPs follows Zipf's Law, which holds that internal coherence exists among countries. A crude but simple indicator of the %ESV indicates that the relationship between the GDP and ESV is not always in a fixed pattern. The reliability of this result was demonstrated by comparing it with previous research and other relevant indices. We found a very high degree of confidence associated with this product. The method presented here is generally applicable at the global and continental scales and is applicable at the national scale for mapping the ESV and GDP. We hope that the results of this study will inform both policy-makers and the public about national green GDPs and encourage them to incorporate these values into policy decisions.



## 1. Introduction

### 1.1. Background

Since the introduction of "sustainable development" and "sustainability", these terms have become widely accepted in environmental and ecological discussions (Mäler et al., 2008). At the same time, sustainability science is motivated by fundamental questions about the interactions between nature and society and by compelling and urgent social needs (Carpenter et al., 2009; Clark, 2007). However, the implementation of sustainable development has remained opaque. Therefore, the pursuit of sustainable development impels scientific communities and international organizations to develop a set of indicators, measuring methods and accounting systems to understand socio-environmental interactions and the complex relationship between ecosystems and human well-being.

Over the last two decades, efforts to develop so-called "green" accounting have played a crucial role in exploring the links between human and natural systems (Mäler et al., 2008) and in understanding the interactions between the economy and the environment (United Nations et al., 2012). The term "Green GDP" is often used in green accounting; however, it has seldom been precisely defined. Two definitions are commonly cited: (1) the "corrected" GDP number, or the "corrected" GDP with the inclusion of depreciation or the depletion of natural resource stocks (Alfsen and Greaker, 2007); and (2) the inclusion of ecosystem services in current GDP accounting (Alexander et al., 1998). The first definition focuses on the 'negative' values caused by resource consumption and environmental pollution (Shi et al., 2012). In contrast, the second definition emphasizes

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the 'positive' accounting of economic values and ESVs. In this paper, we are more likely to endorse the latter view. The green GDP has been defined as a 'positive' accounting of internalized ESVs into current GDP accounting (Boyd and Banzhaf, 2007). It can provide an aggregate measure of values encompassing human and natural products (Boyd and Banzhaf, 2007). The original idea of green GDP accounting came from a study by Costanza in 1997 (Xu et al., 2010). A critical step of this green GDP accounting is the integration of ecosystem valuation with traditional economic accounting.

Although there are many different arguments for the green GDP concept and green GDP accounting, the literature does little to map and estimate the global spatial distribution and the spatial pattern of green GDP. A useable methodology for the spatial mapping of green GDP is therefore very important for policy decisions. This methodology undoubtedly provides the technical support needed for resource protection and ecosystem management. Accordingly, it may also help to identify the interactions between socioeconomic systems and ecosystems.

### 1.2. Analysis of existing studies

In 1993, with the aim of accounting for green GDP, the United Nations (UN) introduced an integrated system of ecosystem and economic accounting (SEEA) (United Nations et al., 1993). Holub et al. (1999: 329) maintained that "the publication of the 'System of Integrated Environmental and Economic Accounting' marked a decisive advance in the discussion of green accounting". Nevertheless, a host of theoretical and empirical studies conceded that methodological problems related to green GDP accounting remained unresolved (Bartelmus, 2007; Boyd, 2007; Dietz and Neumayer, 2007; United Nations et al., 2003). In terms of methodology, the SEEA is a 'negative' GDP correction because it includes the depreciation or depletion of natural resource stocks. In terms of the applied scale, instead of a green accounting system capable of connecting different spatial scales, the SEEA only considers whole economies and national level environmental accounting (Holub et al., 1999; Talberth and Bohara, 2006). Therefore, the SEEA has been criticized for ignoring the value of ecosystem services for human well-being (Alfsen and Greaker, 2007; Bartelmus, 2009; Boyd, 2007) and for lacking a spatial scale aggregation capacity.

Green GDP calculations have been developed for countries, such as Australia, Canada, China, Costa Rica, Indonesia, Mexico, Papua New Guinea, and the US (Costanza et al., 2009). In a typical example, China's State Environmental Protection Agency (SEPA) recently conducted a nation-wide pilot green GDP accounting between 2004 and 2006. China's practice, however, also concluded that it is best to avoid public environmental accounting for lacking any reliable measures (Li and Lang, 2010).

A variety of corrective green GDP accounting methodologies and corresponding accounting indicators have been suggested by different academics and institutions, such as the Index of Sustainable Economic Welfare (ISEW) (Daly and Cobb, 1989), the Genuine Progress Indicator (GPI) (Redefining Progress, 1999), Genuine Savings (GS, also known as Adjusted Net Savings) (World Bank, 1997), and Wealth Estimates (World Bank, 2006). However, because these accounting systems or indicators are based on the same economic GDP data, these measures still have limitations (Costanza et al., 2009). As Herman Daly once commented, "the current national accounting system treats the earth as a business in liquidation" (Daly and Cobb, 1989: 191). Conventional calculation of green GDP misses the sustainability concept because it ignores the usefulness of ecosystem services benefit valuations. In most countries, national green GDP accounts have been used only for particular sectors of the economy (Li and Lang, 2010). However, global biophysical and socioeconomic drivers, processes, patterns and value flows affect the entire biosphere and communities, as well as human welfare (Robards et al., 2011). From the perspective of sustainable development and system theory, we should treat human systems and natural systems as one complex synthesis system.

In accordance with the idea of green GDP accounting, a handful of studies have attempted to plug ESV into green GDP accounting (Gren, 2003; Matero and Saastamoinen, 2007). To the best of our knowledge, Sutton and Costanza (2002) was the first attempt to map the national ESVs and GDPs. Sutton and Costanza used the Defense Meteorological Satellite Program's Operational Linescan System (DMSP/OLS) imagery and the International Geosphere-Biosphere Program (IGBP) land cover data to estimate the GDP and ESV (Sutton et al., 2012). Furthermore, Sutton and Costanza (2002) developed and presented an integrated indicator called the "Subtotal Ecological-economic Product (SEP)". It can be described as SEP = GDP + ESP (ESP is the ecosystem services product) (Sutton and Costanza, 2002: 509). The SEP is a measure of the subtotal of the ecological and economic product (Sutton and Costanza, 2002).

Beyond that, Boyd and Banzhaf (2007) proposed an ecosystem services index (ESI). The ESI is a measure of quantity that relates to, but does not measure directly, the total value of nature (Banzhaf and Boyd, 2012). An ESI is also a practical indicator for measuring the value of "final" ecosystem services ("Final ecosystem services are components of nature, directly enjoyed, consumed, or used to yield human well-being" (Boyd and Banzhaf, 2007: 619)). By limiting an ESI to only the final non-market services, it could be combined with the GDP to form a measure of green GDP. Boyd and Banzhaf (2007) argue that green GDP accounting should measure a combination of the traditional GDP and the ESI.

In fact, most of the green GDP accounting efforts are ad-hoc because official statistics focus on less controversial accounts that do not affect the main economic aggregates (Bartelmus, 2009). The interdependencies between socioeconomic systems and ecological systems and the integration of human-dominated market values with nature-dominated non-market values remain among the most important unresolved questions in contemporary science (Grêt-Regamey and Kytzia, 2007). In particular, most studies have indicated that, so far, there is a lack of any reliable measures that can be used to integrate the ESV into the green GDP. Separately, the methods for mapping, estimating and accounting for the ESV and GDP have advanced much faster than the integrated methods. The following sections focus on the related development of these two fields.

Market values are mostly "captured" in commercial markets (Costanza et al., 1997). Gross Domestic Product is the most common measure of the value of an economy (Boyd and Banzhaf, 2007). However, the GDP only represents a portion of economic activity or gross income; it does not measure economic welfare itself (Boyd and Banzhaf, 2007). In this paper, we define the GDP as a proxy for economic activity and market values. Statistical GDP data are usually provided on a national or regional basis (Doll et al., 2006). Administrative boundaries are commonly used as a basic statistical unit for the collecting and counting of GDP data. However, it may be an inappropriate spatial unit on which to base a specific spatial analysis (Doll et al., 2006). Numerous studies have documented that nighttime satellite imagery is applicable to mapping and estimating global and national level GDP maps (Doll et al., 2006; Elvidge et al., 1997b; Sutton et al., 2007). The spatial uniqueness, objectivity, and potential availability of nighttime satellite imagery are crucial advantages (Doll et al., 2000). More specifically, nighttime imagery data contain large amounts of spatial information that can be aggregated to the national, sub-national, and regional scales (Sutton et al., 2012). In terms of accuracy and availability, nighttime imagery is more spatially explicit than entire national and regional GDP estimates, may be a more accurate indicator of economic activity than GDP itself, and can be easily updated on an annual basis (Sutton and Costanza, 2002).