Date: Oct 17, 2020

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Subject: Green Growth Assignment

Word count: 2716 words

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Green growth and engineering economic analysis in city infrastructure

1. Introduction

Infrastructure projects contribute significantly to the economy as they connect the community, serve the basic needs of the population, and facilitate economic growth. However, city infrastructures are accountable for around 70% of global greenhouse gas emissions, which adversely impacts the environment [1]. As climate change and the degradation of the ecosystem have affected our quality of life, city infrastructure should be developed sustainably. To achieve sustainable development, economists have proposed a new economic concept - Green Growth (GG) - to account for the environmental impacts which the traditional market approach overlooks.

This report demonstrates that GG should be integrated into engineering economic analysis, specifically in infrastructure development, by attaching monetary values to the environmental and social impacts, which can minimize the negative externalities that our conventional market neglects. This report will first discuss (1) the detailed definition of GG, (2) the GG indicators, (3) the implementations of GG at the national level, (4) how engineers can contribute to GG, and (5) the feasibility of placing monetary values on natural capital.

1.1. Detailed Definition of Green Growth

According to the Organisation for Economic Co-operation and Development (OECD), GG is an economic concept that strives to develop the economy, while ensuring that resources are used sustainably, and resources and environmental services will be available for future needs [2]. One significant distinction between GG and conventional economic growth is how the two concepts consider and value natural resources. In China's five year plan for 1986 to 1990, one of the goals was to extract more raw resources to achieve the targeted GDP growth [3]. In contrast, South Korea's Five years plan for 2009 to 2013, which emphasized GG, has listed the reduction of the use of fossil fuels as one of their ten policy directions [4].

Adopting GG can provide directions for the government to make policies and decisions that can lead to sustainable development. Yet, GG is not equivalent to sustainable development. Sustainable development covers a broad range of objectives, primarily ending poverty, creating social inclusion and protecting the environment. However, sustainable development lacks the effort in combining economic growth and environmental protection. GG resolves the conflict and focuses on fostering economic growth by making use of the resources and services the environment provides [5]. One of South Korea's GG Strategy is to develop green technologies. This strategy can balance the economic and environmental benefits by expanding the market of green technology and generates more job opportunities [4].

2. Green Growth Indicators

To measure the impact of GG, measurable and quantitative indicators are essential in engineering economic analysis because engineers can compare and evaluate the overall benefits and costs of a decision objectively. Green Growth Knowledge Platform (GGKP) and The Organisation for Economic Co-operation and Development (OECD) have organized and suggested a set of indicators to measure GG. These two sets of indicators share four categories in common [2][6]:

1. Natural Asset Base
2. Environmental and resource productivity/Intensity
3. Environmental Quality of Life
4. Policies and Economic Opportunities

These four categories of indicators measure the conventional economic and environmental conditions, with emphasis on natural capital depletion, resource production efficiency, and the environmental impacts on the quality of life. GGKP includes one additional category - Socio-Economic Context [2]. This category considers the social dimension such as the ability of the population to adapt to the transition to GG.

The limitations of each indicator need to be considered since an individual indicator is not sufficient to reflect the actual performance of a country in GG. For instance, OECD provides two indicators to describe the state of forestry conservation in a country: land cover percentage and forest resource stocks. In China, only 30% of the land is covered with forests, which is significantly less than the adjacent developed countries like Japan with over 60% [6]. If we consider the forest resources stock in China, however, the stock has increased from 10 to 15 billion m^2 since 1990 [6]. Other countries such as Korea have less than 1 billion m^2 and have shown virtually no increase in forest resource stocks. By intuition, more forest resource stocks should lead to a higher percentage of forest land coverage. This implication may not be accurate as the total land area of the countries was not considered - China's total area is 25 times greater than Japan's [7]. Therefore, the complete picture of the environment should be depicted based on multiple indicators from different perspectives.

3. Green Growth Performance

Several countries have attempted to implement GG to build a sustainable economy, and they have achieved different levels of success. The following two case studies discuss the performance of South Korea and China in measuring and achieving GG, respectively.

3.1. Case study: South Korea in measuring Green Growth

South Korea is one of the most ambitious countries in GG. In 2009, South Korea devised a short-term five years plan, "Road to Our Future: GG" which outlines ten policy directions to achieve GG. The OECD GG indicators are adopted and used for measuring success. In terms of natural asset base and resource productivity, the indicators capture greenhouse gas (GHG) emissions reduction, reduction of energy intensity, resource recycling etc. Some indicators also measure the economic growth of the country, such as South Korea's market shares in global green technology and the number of enterprises in green partnerships. However, the emphasis on the environment has led to a lack of measurement in the socio-economic context, especially in education. As Korea's energy production heavily relies on fossil fuels [2], the rapid transition to renewable energy could lead to job losses if the majority of the population does not have the relevant skills. Therefore, a variety of indicators should be included to measure the adaptability of the population as the economy shifts towards GG.

3.2. Case study: China in achieving Green Growth

As one of the major GHG emitters, China has implemented various strategies to meet the carbon emission reduction target in the Paris agreement by 2030. In terms of regulation, according to China's Fourth National Report, the law system was improved by integrating different environmental protection laws related to Forest and Water conservation [8]. China has also led the world in the percentage of Gross Domestic Product (GDP) spent on energy research at 0.07% from 2014 to 2018. Compared to the developed countries in North America, only half of that was spent in the same period [9].

As a result, the overall progress in environmental protection in China is accelerating. Natural asset base and environmental productivity indicators such as the number of nature reserves, water quality in ecosystems, and discharge of major pollutants have shown a positive trend from 1998 to 2007 [8]. This result reflects a progressive improvement of environmental quality in China. Furthermore, China reduced its 2005 carbon intensity level by 46 percent in 2017, which was three years earlier than the target stated in the Paris Agreement [10]. Nevertheless, China has not yet decoupled the economic growth and the depletion of natural capital as a positive correlation between GDP growth and CO_2 emissions still exists [11].

4. Roles of Engineers in Green Growth

At the national level, any government is responsible for implementing regulations, policies and market interventions, which provides a framework to guide the national economy towards GG. For Green Infrastructure projects, the engineers can participate from both the public and the private sectors. The roles of the engineers entail using their technical knowledge and experiences to empower the projects to achieve GG. (See Table 1)

Table 1. Roles of engineers in GG

Category	Roles
Preliminary phase	- Identify the issues and constraints in the environment and community
Design and Planning Phase	- Design solution which satisfies the need of the local community and the ecosystem through green technology - Assess the cost and benefits in terms of economic and environmental impacts of proposed solutions

An example for the preliminary phase is the mapping and visualization of the land surface temperature in Greater London, which Arup developed based on the data from the UK Space Agency and University College London. The research analyzes how heat risk can affect urban areas and helps the authorities to better understand the urban heat island effects on the population. This could inspire better plans and policies to combat climate change and improve the quality of life of the citizens living in Greater London [12].

Beam Parklands in East London developed a successful example of what a good design and planning phase should look like. This project was a subset of the All London Green Grid project, which aims to create links between the urban areas and the natural environment, and improves the economic growth and the living quality of the population [12]. The design of Beam Parklands incorporates different types of natural capital, including wetland habitats, green space, and bike lanes which link the isolated communities. Regarding the environment, the wetland acts as a flood defence as it is more permeable than the impervious materials like concrete. The wetland habitats also help to support biodiversity in an urban system. For social impact, this green space provides a common recreation area for the people in the communities to interact with each other and embrace the beauty of nature [12].

5. Capital investment in Green Engineering

To facilitate GG, three main types of capital need to be invested in engineering projects to meet the triple bottom line: economy, society, and environment (See Table 2).

Table 2. Types of Capital Investment in Engineering Projects

Type	**Definition and Examples**
Traditional capital (i.e. real capital)	- Equipments and machineries used to produce goods - e.g. Construction equipments, manufacturing machineries
Natural capital	- Natural resources which can provide good and services - e.g. Soil, ecosystem, atmosphere
Intellectual capital	- Intangible assets which can generate values - e.g. Skills, knowledges, technology, data

GG emphasizes and values more on natural capital relative to real capital since it recognizes the monetary value of natural resources and its extensive impact on the economy. Intellectual capital investment is also important in GG since more intensive research is required to evaluate the overall effectiveness of an engineering decision in multiple aspects.

5.1. Case Study: Green Infrastructure in Chicago, Illinois

A Green City Infrastructure project in Chicago, Illinois, demonstrates how investing in natural capital can translate to economic benefits. The system of water and wastewater infrastructure in Chicago was mostly composed of grey infrastructure, including the use of impervious concrete cover and single pipe system. The grey infrastructures had adverse impacts on the environment and the economy. For instance, concrete covers absorb a substantial amount of heat which intensifies the urban heat island effect. Moreover, the single pipe system approach is not capable to handle more frequent extreme weather events. This can degrade the water quality at the source (e.g. lake) as the pipe overflows.

To solve the above issues, the City of Chicago implemented two main green infrastructure initiatives: (1) Green Streets Program and (2) Green Alley Program [13]. For the Green Streets Program, the objective is to increase the urban canopy in the city by planting more trees. A higher fraction of the city area shaded by trees can reduce the urban temperature since leaves have a higher albedo compared to concrete surfaces, which lowers the absorption of solar radiation energy. Furthermore, leaf canopy can lower runoff volume as it can intercept the precipitation and enables a higher degree of evapotranspiration. The Green Alley Program aims to reduce the flooding and increase infiltration in the alley by replacing the impervious covers with permeable materials. In 2006, the Chicago Department of Transportation researched and tested different paving materials to meet their needs. To share their successful experience, the government published the Green Alley Handbook in 2017 for future reference [13].

In these two programs, the City of Chicago developed these infrastructures relying mainly on natural capital and intellectual capital. These capital investments have led to a reduction in energy use as the demand for heating decreases due to the temperature drop. Moreover, the infiltration helps to improve the water quality and reduce the load on the sewage system, which can implicitly lower the tax burden on the citizens.

6. Natural Capital and Decision-making in Engineering

Engineering decision-making process requires different economic analyses such as cost-benefit analysis, to objectively evaluate the design alternatives and identify the optimal design solution. To achieve GG, engineers should account for the values of the natural capital involved with the design decision. This approach ensures the value of the services and goods natural resources provide are considered.

A natural capital accounting project led by Shep Buchanan - consulting environmental economist - demonstrates clearly how values can be assigned [14]. In

Shep's approach, the value of a type of natural capital is determined by the "society's collective willingness to pay (WTP)" to avoid the environmental impacts or risks caused by the loss of that type of natural capital [15]. The most practical measure of WTF is the expected damage which the loss of the natural capital has on the economy. To obtain the precise values of the damages, it requires an extensive and complex Life Cycle Assessment (LCA) on the entire ecosystem and economy.

An example of this measure is carbon storage. As carbon emission intensifies global warming, it leads to higher global temperature and increases the energy demand for cooling. The additional cost spent on cooling then contributes partially to the value of the carbon storage.

6.1. Case Study: Chicago's Urban Forest Values

The City of Chicago calculated and analyzed the monetary values of their Green Infrastructure project - Urban Forest - to evaluate its effectiveness in adapting and mitigating climate change. The values were determined based on the functions or services which the forest provides to the economy and society. This includes air pollution removal, air temperature cooling, reduction in building energy, carbon storage and sequestration. The following table summarizes the values of natural capital in the forest (See Table 3).

Table 3. Summary of the Urban Forest Values [15]

Category	**Value**
Pollution removal	888 tons/year ($6.4 million/year)
Carbon storage	716,000 tons ($14.8 million)
Carbon sequestration	25,200 tons/year ($521,000/year)
Building energy reduction	$360,000/year
Increased carbon emissions	-$25,000/year
Structural value	$2.3 billion

To calculate the values of the services, measurable attributes need to be identified and be associated with the economic value. For instance, carbon storage and sequestration can be measured by the biomass and the diameter growth of the trees [15]. The parameters are then converted to monetary values using the national median externality costs developed by the energy sector in the State of New York [15].

6.2. Challenges to quantify natural capital

Although placing monetary values on natural capital can internalize the environmental cost and eventually lead to GG, it is extremely challenging to (1) account and quantify all the environmental and social damages and (2) evaluate them with reasonable precisionness.

Many environmental and social impacts cannot be associated with market values. Categories of impacts such culture, religion and spiritual practice have no direct or very little value in our existing market. For instance, the religious or cultural significance of a piece of sacred land for Native Americans is difficult to quantify. Since Native Americans are considered as a minority in our society, their culture and religion has limited influence on the economy [14].

Another problem when quantifying natural capital is the preciseness of the values assigned. The significance of environmental impacts on the society and the economy is uncertain and constantly changing as it depends on the technology level, population density, politics and other factors. Therefore, it is virtually impossible for the economists to obtain the exact value of natural capital and incorporate it precisely in the economic analysis, which can lead to a false representation of the effectiveness of an engineering decision.

6.3. Appropriateness of assigning monetary values on natural capital

In theory, assigning monetary values on natural capital is appropriate and useful if we perform the analysis by assessing the majority of factors involved with reasonable precision. However, the current methodology in practice lacks comprehensiveness and precision which requires immediate adjustment to adequately assess natural capital.

iTree system is a software developed by the United States Department of Agriculture (USDA) that provides benefits assessment for urban forest. The original data of the estimated cost and benefits of the environmental impacts were extracted from the New York State energy plan which was published in 1994 [16]. To account for the time value of money, USDA decided to adjust the numbers based on the producer price index from the United States Department of Labour [16]. This simple adjustment to the outdated numbers neglects the changes in the society (e.g. advancement in technology, education level, social awareness) that affect the values of the natural capital. Thus, it loses credibility the economic analysis if these values were incorporated.

7. Conclusion

GG is an excellent economic concept that can lead to sustainable development. Multiple countries have demonstrated success in measuring and achieving GG based on the indicators from GGKP and OECD. Engineers are responsible to account for the environmental externalities in the economic analysis and quantitatively assess the overall cost and benefit of their decision. However, incorporating the actual value of natural capital is challenging and requires tremendous effort in research. For that reason, more frequent and higher quality research in the value of natural capital, such as LCA, is crucial to shift our economy towards GG more efficiently.

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