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## **Assessing the effectiveness of the ‘Green Economic Stimulus’ in South Korea: Evidence from the energy sector**

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### **Abstract**

The purpose of this paper is to provide an ex-post evaluation of the effectiveness of the South Korean Green New Deal (GND) as an instrument to deliver both an economic recovery and improved environmental performance. We use the energy sector as the main scope for our analysis when measured against climate-related indicators (e.g. CO<sub>2</sub> emissions, energy intensity, share of renewable energy in supply mix) adopted by the South Korean government as part of a broader commitment to green growth. The research involves complimentary methods to assess the economic and environmental effectiveness of the GND at the macro-level; including the so-called ‘Three T test’, a time series variability analysis and an econometric assessment. From a pure economic perspective, results suggest that the GND has been relatively successful as traditional fiscal stimulus. However, the GND seems ineffective as an instrument of environmental policy; at least in the short-term. In fact, and from an historical point of view, the econometric assessment confirms that the level of CO<sub>2</sub> emissions has been largely determined by (the rate of) economic growth. On the short-term, the level of environmental ineffectiveness of the GND can be explained by numerous factors; including the lack of complementary pricing reforms, insufficient renewable energy uptake, and improvements in energy intensity incapable of offsetting the negative effects of economic growth. The research findings need to be tempered by limitations associated with the analysis, notably related to causality. At all events, it is worth considering the role that the GND may have played in providing impetus for long-term action to enhance green growth policies in the energy sector, such as the implementation of the Renewable Energy Portfolio Standard in 2012 or the Emission Trading Scheme in 2015.

**Keywords:** Green economy, Stimulus packages, Economic growth, Energy sector, Low-carbon technologies, CO<sub>2</sub> emissions

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## 1. Introduction

In response to the 2008–09 global financial crisis, a number of national governments around the world adopted ‘green stimulus’<sup>1</sup> packages that aimed to revive economic activity in the short-term, and meet a range of environmental goals through the support and dissemination of low-carbon energy technologies. In fact, green stimulus packages were portrayed as a golden opportunity and entry point into a low-carbon economy, with the energy sector playing a critical role (IEA, 2009). Within this context, the Republic of Korea (South Korea) soon became the world leader and invested heavily in environmentally-driven initiatives. In response to the country’s second largest economic contraction on record in the final quarter of 2008, South Korea dedicated nearly 80% of its US\$ 38.1 billion stimulus package to green measures – a so called ‘Green New Deal’ (GND) (Barbier, 2010b). Of this amount (approximately US\$ 36.3 billion), around US\$ 16.5 billion targeted energy-efficiency projects, renewable energy technologies and low-carbon vehicles (UNEP, 2009). However, while a number of predictions and policy statements were made about the potential benefits of this green stimulus package (e.g. economic growth, reductions of CO<sub>2</sub> emissions), there is still limited knowledge about the actual outcomes and performance of policy measures.

Despite the significance of South Korea’s green stimulus package in terms of its relative size and anticipated impacts, there is little information available on either the economic or environmental outcomes of the GND, nor an ex-post evaluation of its performance. Given the volume of positive speculation about the potential benefits of green stimulus packages and the strong endorsement of the GND by institutions such as UNEP as an appropriate and environmentally responsible response to the global financial crisis (UNEP, 2009), this lack represents a growing research gap that needs to be addressed in order to improve the design and implementation of such stimulus packages in the context of sustainable economic development. In fact, and within the scope of our research, the emerging literature shows that there is substantial ambiguity and uncertainty about the effectiveness of fiscal spending programmes to drive a green energy economy (Barbier, 2011; Metcalf, 2015; Mundaca et al., 2013; Zenghelis, 2014).

To date, most evaluations of the green stimulus programs have been largely speculative in nature and based on the predictions of government agencies (Barbier, 2009, 2010a, 2010b; Jones & Yoo, 2011; Robins et al., 2009). Other evaluations are ex-ante in nature, but based on a qualitative assessment of green stimulus measures performance against selected criteria (A. Bowen & Stern, 2010; Bowen et al., 2009), comparative literature review (Strand & Toman, 2010) or a mix of criteria evaluation and forecasting techniques (Houser et al., 2009).<sup>2</sup> Some ex-post assessments of green stimulus measures have also been produced, but tend to focus strongly on economic performance and particularly during 2009 (OECD, 2011a; Robins et al., 2010). In the context of South Korea, Statistics Korea (2012) has produced an initial assessment of South Korea’s performance against the OECD green growth indicators at an aggregate level; including many of the climate-related indicators assessed in this paper. The assessment reveals that with regard to a number of indicators such as energy efficiency, greenhouse gas (GHG) intensity and share of renewable energy, South Korea has progressively improved its environmental performance over the period from 2000 to 2010 (Statistics Korea, 2012). However, while informative in its own right, this assessment fails to provide any accompanying analysis or consideration of internal or external drivers for any changes observed. As a result, the analysis provides little insight into how performance may have responded to external

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<sup>1</sup> Green Stimulus’ can be defined as “the application of policies and measures to stimulate short-run economic activity while at the same time preserving, protecting and enhancing environmental and natural resource quality both near-term and longer-term (Strand & Toman, 2010, pp.5).”

<sup>2</sup> Strand & Toman (2010) also employ a combination of short and long-term criteria to evaluate the potential effectiveness of different green stimulus measures. The authors use four criteria including potential to provide short-term stimulus; potential to deliver long-term growth; emissions reductions and the degree of potential environmental co-benefits (Strand & Toman, 2010).

shocks such as the global financial crisis or major policy changes such as the announcement of the GND.

To address this knowledge gap, the purpose of this paper was to conduct an ex-post evaluation of the effectiveness of the South Korean GND as an instrument to deliver both an economic recovery and improved environmental performance in the energy sector when measured against climate-related indicators adopted by the South Korean government as part of a broader commitment to green growth. We deployed a mix of methods to perform this assessment; including the so-called 'Three T test', a time series variability analysis, and an econometric assessment (details in the next section). Our choice to focus on the energy sector was influenced by two factors. Firstly, like many other countries, South Korea devoted a substantial amount of fiscal spending to clean energy-related initiatives, allocating approximately US\$16.8 billion or 45% of South Korea's US\$38.1 billion fiscal stimulus package for dealing with the crisis to renewable energy, energy efficiency and low-carbon vehicles (UNEP, 2009). Secondly, as energy is an important driver of economic growth and development, policy measures that influence the energy sector are critical to achieving green growth (OECD & IEA, 2011).

For the purpose of our analysis, it was proposed that to be effective as green stimulus the GND should meet two critical conditions. Firstly, the GND should meet the basic objectives of countercyclical economic stimulus by reviving economic activity in the short-term, but without creating a lasting fiscal liability for the government (economic effectiveness). Secondly, to be effective as an environmental policy instrument, the outcomes of the GND stimulus package, in this case the sub-programs related to the energy sector, should be consistent with national environmental objectives for the sector (environmental effectiveness). In the case of South Korea these objectives are represented by the National Strategy for Green Growth (NSGG) that was adopted just months before the announcement of the GND (details in Section 2). With due limitations, it is anticipated that the evaluation presented hereafter will improve our understanding of the merit of green stimulus packages, such as the GND.

The paper is structured in the following manner. In Section 2, and keeping in mind the scope of our research, further detail is provided on the financial crisis as it unfolded in South Korea and the GND as a response to it. In Section 3 the methodology and main data sources are presented. The main findings of the assessment are presented and discussed in Section 4. Conclusions are drawn in Section 5.

## **2. Financial crisis and the 'Green New Deal' in South Korea – An overview**

From an economic perspective, the historic development of the South Korean economic model can be best explained by rapid industrialization, which has been driven by a dynamic industrial policy and export market promotion (Lee et al., 2012). As a result, the South Korean economy was initially hit hard by the global financial crisis; particularly because of the accompanying drop in external demand for Korean exports (Cho, 2009; OECD, 2008b, 2009a). In the fourth quarter of 2008 South Korean exports declined by 31% at an annualized rate (OECD, 2009a). As a result, the IMF forecasted recession<sup>3</sup> for South Korea in 2009 (Cho, 2009). By January 2009, year-on-year growth in exports had already declined by 34.5 % (Pirie, 2012). This reverse of fortunes was accompanied by large outflows of foreign capital and tightening domestic and international credit markets (OECD, 2011a).

In its first economic outlook for South Korea in 2009, the OECD also predicted that the country would experience recession over the course of the year before rebounding through export growth in

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<sup>3</sup> While there is no official definition of recession, for the purpose of this paper a recession refers to a period of decline in economic activity equal to two consecutive quarters of decline in a country's real (inflation adjusted) GDP (Claessens & Kose, 2009).

response to relative depreciation of the Korean Won (KRW).<sup>4</sup> In the same outlook, it was predicted that unemployment, which was relatively low compared to the OECD average, would grow from 3.2 to 3.9% in 2009 (OECD, 2008b). The South Korean government's immediate response to the crisis was to progressively free up monetary policy by reducing interest rates from 5.25% to a record low of 2 % over the period from August 2008 to February 2009 (OECD, 2010c).

From an energy policy perspective, at the time of the crisis South Korea was facing a number of challenges. While nuclear energy accounted for around 15% of primary energy supply and the share of natural gas had grown steadily during the 2000s, the country's energy supply in 2008 was still dominated by imported oil and coal (IEA, 2013). Cumulatively crude oil and coal accounted for over 80% of South Korea's primary energy supply in 2008 (IEA, 2014b). The share of renewable energy in energy supply at 1.5 % was one of the lowest among the OECD countries (IEA, 2012). Around the time that the impacts of the crisis were being felt in South Korea the government established the First National Basic Energy Plan, which was then followed by the Third Basic Plan for New and Renewable Energy in December 2008. These plans set a target for new and renewable energy in TPES of 11% by 2030 and included promotion strategies for investment in bioenergy, wind energy and solar PV (IEA, 2012). The targets were complemented by a government funded feed-in-tariff program to encourage the uptake of renewable energy sources. This scheme had been in place since 2002 (Duffield, 2014).

In the decade prior to the financial crisis the South Korean government was also facing problems associated with relatively high levels of energy and carbon dioxide intensity and poor energy efficiency. Over the period from 1990 to 2005 South Korea's per capita CO<sub>2</sub> emissions rose by 71.6%, primarily due to rising output as measured by per capita income (Jones & Yoo, 2011). However, while the energy intensity of the South Korean economy was still at a level well above the OECD average in 2008 (Jones & Yoo, 2011), it had been declining steadily over the 2000s (see Figure 2). At the time of the crisis the government had also implemented a range of policies to improve energy efficiency in buildings and industry including voluntary agreements with industry for energy saving and emissions reductions, compulsory energy audits for businesses that consume more than 2000 tonnes of oil equivalent (toe) per year and energy standards for buildings and appliances (IEA, 2012). The greater penetration of natural gas and nuclear energy during the 2000s was also facilitating a decline in the carbon intensity of energy (see Figure 2).

The measures adopted by the South Korean government as part of the GND were largely consistent with the broader consensus regarding economic and environmental objectives of green stimulus. Generally, green infrastructure measures containing spending on items such as rail networks, electricity grid expansion, and water and sewage projects were considered to be likely to meet the requirements of effective economic stimulus (Brahmbhatt, 2014) and, in some cases, effective green stimulus (A. Bowen & Stern, 2010; Strand & Toman, 2010). As part of the GND, around US\$1.8 billion was allocated for research into fuel efficient vehicles and US\$7 billion was to be invested to promote low-carbon railways and bicycle tracks (Robins et al., 2009) (see Table 1). Investments and incentives for renewable energy development and/or research and development were considered to have relatively weak short-term stimulus effect, but are likely to assist correct market failures and improve long-term environmental outcomes. Robins et al (2009) indicates that GND sub-programs to encourage low-carbon energy such as renewables were allocated US\$1.8 billion over the period until 2012. Energy efficiency was another major target for GND sub-programs with US\$6 billion being allocated to energy conservation in villages and schools, construction of green homes and installation of LED lighting in public facilities (Robins et al., 2009).

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<sup>4</sup> 1 KRW = 1.55 US\$ (as of March 8, 2014). <http://www.oanda.com/currency/historical-rates/>

**TABLE 1 BREAKDOWN OF TOTAL FUNDING FOR SOUTH KOREA'S 'GREEN NEW DEAL' STIMULUS PACKAGE**

Programs	Employment Created (Estimate)	US\$Million
Total South Korean Fiscal Stimulus Package		38,100
Total for the Green New Deal (GND)	960,000	36,280
Major GND programs on Energy Efficiency Measures and Low-Carbon Energy		
Energy conservation (villages and schools)	170,702	5,841
Fuel-efficient vehicles and clean energy	9,348	1,800
Environmentally friendly living space	10,789	351
Expanding mass transit and railroads	138,067	7,005
Low-carbon power (clean energy)	4,674	1,800
Sub-Total - Energy Efficiency & Low-Carbon Energy Programs	333,580	16,797

Sources: Barbier, 2010b; Robins et al., 2009

In addition, measures for environmental clean-up and natural resource maintenance were considered likely to have a stimulus effect and result in longer-term benefits for the environment (A. Bowen & Stern, 2010; Houser et al., 2009; Strand & Toman, 2010). However, both sets of measures were considered to have little impact on emissions. In the case of South Korea around US\$10 billion was allocated to the Four Major Rivers Restoration program (4R program), which was also the largest single program announced under the GND. The project called for amongst other things the construction of 16 dams and dredging of 570 million cubic metres of sand and gravel to deepen nearly 700 kilometres of riverbed (Normile, 2010). The program also integrated small-scale hydropower projects, measures to improve water quality and the provision of artificial wetlands as well as public green spaces (Cha et al., 2011).

The announcement of the GND as a response to the crisis was as an extension of a commitment by the South Korean government in August 2008 to a 'Green Growth'<sup>5</sup> Strategy that aimed to foster sustainable growth by reducing GHG emissions and environmental pollution (Mathews, 2012). The

<sup>5</sup> There is no agreed definition of the term 'Green Growth'. For example, the OECD (2011c) defines green growth as "fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies." It also recognises the role of innovation and technological development to support the "greening" of the economy, especially in the area of resource efficiency. According to European Environment Agency (EEA), NGE is an economy that "generates increasing prosperity while maintaining the natural systems that sustain us" (EEA, 2015). This definition does not explicitly refer to the social aspects, but instead includes only the economic and environmental ones. The Asian Development Bank (UNESCAP et al., 2012, 16) defines 'Green Growth' as the "economic progress that fosters, low carbon, and socially inclusive development". It stresses the importance of economic growth because of the fact that many countries in Asia are still developing or less developed countries. By emphasising the recent financial and economic crises, this organisation also highlights the issue of 'resilience' in green economics (i.e. able to withstand or recover quickly from difficult conditions). However, most definitions involve the combination of economic growth with improved environmental protection (Jacobs, 2012).

announcement of the GND in January 2009 represented a significant and logical step on the part of the South Korean Government toward advancing this commitment to green growth. At the time of its announcement the GND represented stimulus equal to approximately 3% of national GDP and was expected to create 960,000 new jobs (Table 1). Six months after announcing the GND, in July 2009 the South Korean government announced that the GND was to be rolled into the first five-year plan of the South Korean ‘National Strategy for Green Growth’ (NSGG), which covered the period from 2009 to 2013 (Jones & Yoo, 2011). This strategy further elaborated the South Korean government’s earlier commitments by specifying objectives, strategies and policy programs for green growth in the South Korean context (Jones & Yoo, 2011).

Of particular relevance to the energy sector and the assessment performed for this paper one of the three objectives of the NSGG focused on contributing to international efforts to fight climate change and other environmental threats (see Table 2). Generally, while a number of overviews of the GND have been published (Barbier, 2010a; Jones & Yoo, 2011; Robins et al., 2009), there is little detail available in English on the specific details of the GND sub-programs.

**TABLE 2 CLIMATE-RELATED OBJECTIVE, STRATEGY AND POLICY DIRECTIONS OF SOUTH KOREA’S GREEN GROWTH STRATEGY**

NGGS objective	Strategy	Policy Directions	Detail
Contribute to international efforts to fight climate change and other environmental threats	Mitigating climate change and promoting energy independence	Reduce carbon emissions	Effective mitigation of greenhouse gas emissions by pursuing mitigation strategies for buildings, transport and industry, require reporting on emissions and promote forestation
		Decrease energy dependence and enhance energy self-sufficiency	Reduce the use of fossil fuels and the enhancement of energy independence by reducing energy intensity to the OECD average, increasing the use of renewable energy and expand nuclear
		Support adaptation to climate change impacts	Strengthen capacity to adapt to climate change through Four Major Rivers Restoration Project and increasing the share of environment friendly agricultural products by 2020

Sources: IEA, 2012; UNEP, 2010

### 3. Methodology

The research methodology involved three complimentary qualitative and quantitative tools to assess the economic and environmental effectiveness of the GND at the macro-level. As a whole, the mix of methods included the so-called ‘Three T test’, a time series variability analysis, (including the development of baseline scenarios for comparison) and an econometric assessment (details below).

Note that before assessing the performance of specific green stimulus packages such as the GND, it was first necessary to establish that green stimulus constituted an appropriate response to the 2008-09 global financial crisis. Whether the crisis warranted a discretionary fiscal response such as the green stimulus, has been a subject of debate in the literature (Armington, 2012). While monetary stimulus<sup>6</sup> and automatic fiscal stabilizers<sup>7</sup> are generally preferred responses to economic downturns,

<sup>6</sup> Includes items such as the reduction of policy interest rates.

<sup>7</sup> Includes items such as changes in rates of taxation and distributive payments such unemployment benefits.

discretionary stimulus may be desirable in instances such as those during the 2008-09 crisis where nominal interest rates were close to zero in a number of countries including South Korea (A. Bowen & Stern, 2010; Freedman et al., 2010; Taylor, 2000). Further, Bowen & Stern (2010) argue that situations of demand deficiency and under-utilization of resources such as that which characterized the impact of the global financial crisis in South Korea (OECD, 2008a, 2011a), are opportune times to bring forward public spending including the provision of long-lived environmental public goods that would benefit from temporarily lower opportunity costs. The authors go on to argue that the stock of suitable environmentally oriented projects would be larger where new environmental problems were recently identified or if there had been a recent shift in a country's environmental goals (A. Bowen & Stern, 2010). This would seem to be particularly relevant to the case of South Korea, which had adopted the NGGS only four months before the crisis reached the Korean peninsula.

### **3.1. Economic assessment**

The economic assessment of the GND employed in this paper consisted of a qualitative assessment of the extent to which the GND could: 1) be considered to have improved key economic indicators such as GDP growth and employment; and 2) be considered to meet the 'Three T' test of effective countercyclical, economic stimulus. The Three T test refers to whether the GND was timely, targeted and temporary. Timely refers to measures that are designed to provide stimulus when an economy needs it most (Brahmbhatt, 2014). Targeted refers to measures that will have a large impact on spending and jobs per dollar of outlay (Brahmbhatt, 2014). Finally, Temporary refers to the concept that measures should not become a source of permanent budget deficits or crowd out private sector investment (Brahmbhatt, 2014; Zenghelis, 2014). In our case, the information used to conduct the economic assessment was sourced from peer-reviewed journals, OECD country reviews and grey literature including interim evaluations of GND programs.

There is agreement in the literature that to qualify as effective green stimulus, measures adopted should meet basic economic requirements including the Three T test and score well against selected environmentally-focused criteria (A. Bowen & Stern, 2010; Bowen et al., 2009; Brahmbhatt, 2014; Houser et al., 2009; Robins et al., 2009; Strand & Toman, 2010; Zenghelis, 2014). Bowen & Stern (2010) note that targeting is a particular challenge for the design of green stimulus measures and propose four sub-criteria to evaluate whether green stimulus measures in particular are appropriately targeted. These criteria include the size of the fiscal multiplier and anticipated employment impacts; whether measures make use of underutilized resources; the potential for measures to 'lock-in' investment for long-lived low-carbon capital stock; and the potential for measures to result in long-term social returns (A. Bowen & Stern, 2010).<sup>8</sup>

### **3.2. Environmental Assessment**

The environmental assessment of the GND measures the performance of the GND against South Korea's climate-related green growth objectives. Given the focus of this paper on the energy sector, for the purpose of the analysis the environmental objectives of the South Korean government were considered solely in terms of the climate-related objective of the NSGG (as shown in Table 2). As our research was limited to the energy sector the third policy direction of the NGGS climate-related objective on adaptation was not considered as part of the assessment.

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<sup>8</sup> The authors go on to advocate a 'bottom-up' approach to evaluating the effectiveness of green stimulus programs noting that not all green measures will score well as countercyclical tools. Brahmbhatt (2014) in a more recent analysis also emphasizes the importance of the Three T test, but is more sceptical regarding the possibility that green stimulus can adequately address both economic and environmental objectives. Houser et al (2009) in their ex-ante assessment of selected programs under the US Government's green stimulus package draw upon elements of the Three T test while also integrating forecasts of selected indicators such as change in CO<sub>2</sub> emissions to measure environmental performance; particularly in terms of climate and energy benefits. Acknowledging that the energy import and CO<sub>2</sub> emissions reductions that could be achieved by green stimulus programs alone would be modest, the authors also evaluated the programs in terms of their potential to address market failures, overcome hurdles for low-carbon technologies and reduce infrastructure bottlenecks (Houser et al., 2009).



A variability analysis was performed to identify how the GND may have affected selected climate-related green growth indicators compared to a baseline scenario. We estimate the percentage change in CO<sub>2</sub> emissions from energy use and analyse annual changes in: (1) Gross Domestic Product (GDP) (adjusted by purchasing power parities [ppp]), (2) energy use, (3) the ratio of energy use to GDP (energy intensity), and (4) the ratio of CO<sub>2</sub> to energy use (carbon dioxide intensity of energy) (for definitions see Table 3). Variability analysis is a way of framing time series data to observe year-on-year changes and gain insight into how measures implemented at a specific point in time such as the GND may have influenced indicators of economic and environmental performance. Time series data (1971-2012) used for this analysis comes from the IEA CO<sub>2</sub> Emissions from Fuel Combustion report and the OECD environmental statistics database (IEA, 2014a). The formula used to estimate the year-on-year change in selected indicators is based on that used by Jotzo et al. (2012) and Mundaca et al. (2013) in their (regional) decomposition analyses of CO<sub>2</sub> emissions from fuel combustion:

$$\text{Annual change (in \%)} \text{ of } X_{\text{end year}} = \left( \frac{X_{\text{end year value}} - X_{\text{previous year value}}}{X_{\text{previous year value}}} \right) * 100$$

Organizations such as OECD, World Bank, UNEP and the Global Green Growth Institute have been developing indicators to measure and quantify green growth that will be of relevance to an assessment of the effectiveness stimulus packages such as the GND (GGKP, 2013). Particularly relevant to this paper are indicators being developed to measure and monitor CO<sub>2</sub> emissions and their macro-economic drivers such as energy use and GDP. The economic and green growth indicators utilized for the research presented in this paper are presented in Table 3.

**TABLE 3 ECONOMIC AND GREEN GROWTH INDICATORS UTILIZED FOR THE RESEARCH**

Variable	Definition	Data sources
CO <sub>2</sub> emissions	Emissions from fuel combustion (in million tonnes of CO <sub>2</sub> [MtCO <sub>2</sub> ]), excluding emissions from marine and aviation bunkers, and following the IPCC Sectoral Approach	IEA(2014a)
Population	All residents regardless of legal status or citizenship (in millions)	
Total Primary Energy Supply (TPES)	Production + imports – exports – international marine bunkers – international aviation bunkers ± stock changes (in million tonnes of oil equivalent [Mtoe])	
GDP <sub>ppp</sub> and GDP <sub>ppp</sub> per capita	Total annual output valued in billion 2005 US\$ dollars, adjusted by purchasing power parities (ppp) (in 2005 US\$) and divided by midyear population	
Energy intensity	TPES per GDP <sub>ppp</sub>	
Carbon dioxide intensity	CO <sub>2</sub> emissions per TPES (in tonnes of CO <sub>2</sub> per Terajoule [tCO <sub>2</sub> /Tj])	
Share of renewable energy	Share of renewable energy as a % of TPES	

### 3.3. Baseline scenarios

For the purpose of comparison an economic and environmental baseline scenarios were developed based on the hypothetical scenario that the South Korean government opted not to adopt the GND in January 2009. From an economic perspective, the baseline scenario for the economic assessment was that the South Korean economy would experience recession in 2009 and higher unemployment before moving into an export-led recovery in 2010. Based on the information above, the baseline scenario for the economic assessment was that the South Korean economy would experience recession in 2009 and higher unemployment before moving into an export-led recovery in 2010. Based on the information above, the baseline environmental scenario as it relates to climate-related indicators assumes that carbon emissions would decline reflecting reduced industrial and economic output and historical trends of declining energy intensity and carbon dioxide intensity of energy used. It is also assumed that the share of renewable energy would grow in keeping with the 2008 Basic Energy Plan.

**TABLE 4 BASELINE SCENARIO SUMMARIES FOR ECONOMIC AND ENVIRONMENTAL ASSESSMENTS**

Assessment	Baseline Summary
Economic	<ul style="list-style-type: none"> <li>• Economic recession in 2009 followed by export led recovery in 2010</li> </ul>
Environmental	<ul style="list-style-type: none"> <li>• Carbon emissions decline during the recession reflecting reduced industrial and economic output</li> <li>• Reduced energy intensity and carbon dioxide intensity of energy used consistent with historical trends</li> <li>• TPES dominated by fossil energy sources such as coal and crude oil</li> <li>• Marginal but growing supply of renewable energy</li> </ul>

### 3.4. Econometric assessment

To support the methods and evaluation criteria presented above, and thus provide more detail from an historical perspective about the reconciliation of economic growth and environmental protection that GND aims to drive, we specified an econometric model based on the I=PAT' equation<sup>9</sup> (Holdren & Ehrlich, 1974) and the 'Kaya Identity' (Yamaji et al., 1991) to analyse the statistical relationship between key aggregate green growth determinants (or indicators) for South Korea. We use the same time series data from the IEA (2014) to perform the analysis. The I=PAT equation assesses the contribution of population (P), affluence (A), understood as GDP per capita or level of consumption per person, and technology level (T), understood as environmental impact per unit of GDP to the whole environmental impact (I). In this study, and consistent with previous work (Mundaca T., 2013; Raupach et al., 2007), the following original model was applied to the case of South Korea:

$$CO_2 = Pop \left( \frac{GDP_{ppp}}{Pop} \right) \left( \frac{TPES}{GDP_{ppp}} \right) \left( \frac{CO_2}{TPES} \right) = Pop g e_{int} c_{int} \quad (1)$$

where CO<sub>2</sub> represents South Korea's CO<sub>2</sub> emissions from fuel combustion and industrial processes. In turn, CO<sub>2</sub> emissions are the product of four driving factors for South Korea: *Pop* is the population,  $\frac{GDP_{ppp}}{Pop} = g$  is the per-capita GDPppp (or 'affluence'),  $\frac{TPES}{GDP_{ppp}} = e_{int}$  is the energy supply intensity of GDPppp, and  $\frac{CO_2}{TPES} = c_{int}$  is the CO<sub>2</sub> intensity of the total primary energy supply (TPES) in the country.

<sup>9</sup> The I=PAT equation evaluates the contribution of population *P*, affluence *A* (GDP per capita or level of consumption per person), and technology level *T* (environmental impact per unit of GDP) on the overall environmental impact *I*.

Based on the above, a multiple regression model for South Korea was formulated as follows. Data from the IEA (2014) (as presented in Table 3) was used to populate the model.

$$Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} + \beta_3 X_{3t} + \beta_4 X_{4t} + \mu_t \quad (2)$$

where  $Y_t$  = CO<sub>2</sub> emissions (in million tonnes) from fuel combustion (dependent variable),  $t = 1 \dots T$  years (=42);  $\beta_0$  is a constant intercept;  $\beta_1$ ,  $\beta_2$ ,  $\beta_3$  and  $\beta_4$  are the regression coefficients to be estimated for  $X_1$  (*Pop*),  $X_2$  (*g*),  $X_3$  (*e\_int*) and  $X_4$  (*c\_int*) respectively; and  $\mu_t$  is an unobserved error in the model.

Using the multiple regression model defined in (2), a stepwise regression analysis quantified the specific contribution of the various drivers of CO<sub>2</sub> emissions. The analysis sequentially assessed the unique impact of each independent variable on CO<sub>2</sub> emissions. If a variable partially explained the behaviour of  $Y$  (CO<sub>2</sub>) it was retained, while all other variables were re-tested to identify whether they were still significant contributors. When a variable no longer contributed significantly to the model, it was removed. This iterative process ran in parallel with multicollinearity tests. The aim was to identify the regression model that explained the greatest part of the variance of CO<sub>2</sub> emissions (i.e. highest adjusted R<sup>2</sup>), with p-values below 0.10 (for independent variables), lowest variation coefficients, and no indication of multicollinearity. A variation coefficient

$Coef\ Var_j = \left( \frac{Std\ error\ estimate_j}{Mean\ value\ CO_{2j}} \right)$  of the estimated regression model  $j$  was calculated in order to

evaluate the variability of the dataset and thus the predictive capability (CO<sub>2</sub> variability). A 10% maximum threshold was set (i.e.  $Coef\ Var_j < 10\%$ ). To investigate multicollinearity, Variance Inflation Factors (VIF) were computed to quantify how much the variance of estimated regression coefficients were inflated as compared to when the predictor variables are not linearly associated. A VIF greater than five (i.e., tolerance level below 0.20) was defined a maximum threshold value. That is, any VIF value above five was taken as a strong indication of multicollinearity.

Following on from the findings of the variability analysis and environmental assessment of the GND presented above, the initial hypothesis was that GDP<sub>ppp</sub> per capita (*g*) was most closely correlated with CO<sub>2</sub> emissions, and thus it is an important determinant for explaining the emission levels in South Korea over the period observed. Unless otherwise stated, all tests and parameters were estimated using a 90% confidence level (i.e.  $\alpha=0.10$ ).

## 4. Results and Discussion

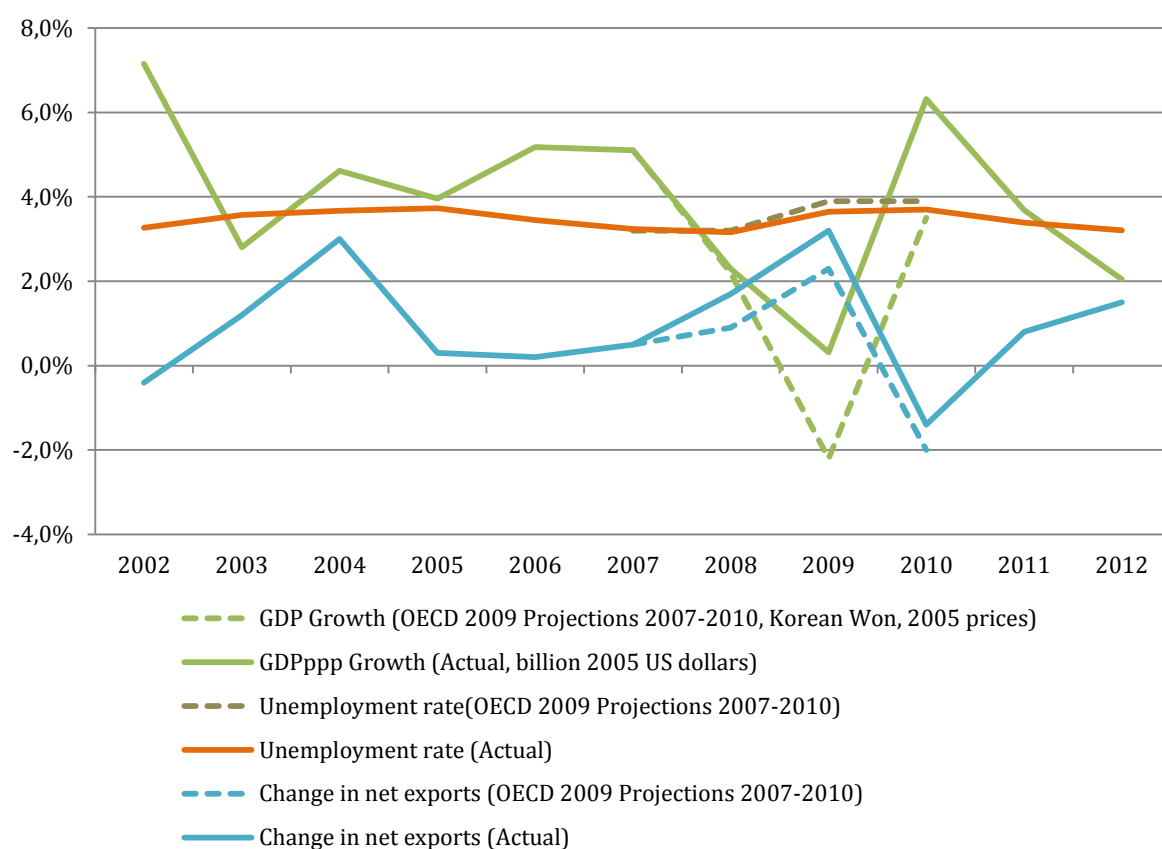
### 4.1. Economic aspects of the GND

Results suggest that the GND was relatively successful as traditional fiscal stimulus. Compared to the baseline scenario of economic recession in 2009, the South Korean recorded strong and consistent economic growth following the announcement of the GND in January 2009, which continued over the remainder of the year and into subsequent years. The actual performance of the South Korean economy in the immediate aftermath of the crisis was much stronger than anticipated. Figure 1 presents the actual performance of the South Korean economy when measured against three key indicators (GDP growth, unemployment rate and change in net exports). The figure also includes projections for these three indicators that were published in the OECD's first economic outlook for South Korean in 2009 (see OECD, 2009a).

Figure 1 shows that the actual performance of the South Korean economy when measured against these economic indicators was markedly better than the OECD projections from early 2009. In particular, the recession that the OECD predicted for South Korea in 2009, which was the basis of the economic baseline scenario for our research, did not materialize. The exact extent to which the GND contributed to this result is unclear, and available (rather aggregated) data did not allow us to

identify impacts on the energy sector. However, there is general agreement in the literature that the GND played a positive role. In evaluating South Korea’s economic performance following the crisis, the OECD judged that the GND programs were a key factor in restricting a rise in unemployment and boosting private consumption (OECD, 2010a). This view was supported by subsequent assessments that credited the GND with helping South Korea avoid the worst effects of the crisis (OECD, 2010a, 2011a; Pirie, 2012; Ryan, 2013).

We found that the GND also displayed a number of the characteristics consistent with the ‘Three T’ test for countercyclical, economic stimulus. First, the GND appears to be *timely* having been announced in January 2009 immediately after South Korea’s economic performance in the final quarter of 2008 indicated that the country was on the verge of a potentially significant downturn. To improve the timeliness of the delivery of stimulus, the South Korean government loosened public procurement procedures and established an “Emergency Desk for Speedy Budget Execution” to track and facilitate spending by local government agencies (OECD, 2011a).



**FIGURE 1 KEY OECD PROJECTIONS AND ACTUAL ECONOMIC INDICATORS IN SOUTH KOREA, 2002-2012**

Data sources: OECD, 2008b, 2009b, 2010b, 2011b, 2013, 2014

Judging whether the GND programs were effectively *targeted* is more difficult to determine. We found some evidence to suggest that the composition of GND programs could have produced strong multiplier effects. For instance, HSBC estimated that actual GND disbursements by the South Korean government was US\$2.3 billion in 2009 and could have been as high as US\$25 billion in 2010 (Robins et al., 2010). However, based on the information assessed for our research it is unclear how much of these disbursements were directed toward the energy efficiency and low carbon energy measures incorporated into the GND.

The injection of government spending represented by the GND resulted in positive gains for employment and investment. It was estimated that in 2009 spending on the green stimulus boosted short-term public employment by 276,000 jobs (OECD, 2010a). Encouraging private investment was also a feature of some of the GND programs with the South Korean government introducing a number of incentives for private sector partners to support GND programs and other stimulus measures through public private partnerships. However, the OECD found that the majority of these PPPs were related to infrastructure investment such as road and railway construction and river restoration (OECD, 2011a). Strong public investment in infrastructure immediately after the onset of the crisis was later followed by similar levels of investment by private sector firms (OECD, 2011a). However, the proportion of this additional investment that was applicable to the GND's energy efficiency or low-carbon energy measures was likely to be relatively low.

Finally, judging whether the GND measures could be considered *temporary* is complicated by the fact that the GND was eventually rolled into the first five-year plan of the NSGG in July 2009. The GND, at least when first announced, was clearly time-bound with implementation of all programs expected by the close of 2012 (Jones & Yoo, 2011b). This time limit implied that the GND was not intended to result in long-term fiscal obligations for the South Korean government, which would have satisfied the temporary criteria of the Three T test. While some sub-programs such as the four rivers restoration project may have resulted in unforeseen, long-term fiscal commitment for the South Korean government (Jin-hwan & Young-rule, 2011), there is no evidence to suggest that this was true of the GND's energy efficiency or low-carbon energy measures. As noted above, some programs were modified with the announcement of the NSGG. But by 2010, the improved economic situation allowed the government to scale back some of its stimulus measures that appeared to be less effective including spending originally intended under the GND including measures intended for the energy sector (OECD, 2010a, 2011a). Some of this reduction in spending was offset by increased government expenditure on research and development for green technologies under the first five year plan of the NSGG including technologies for renewable energy generation and energy efficiency such as solar cells, green buildings and green cars (Jones & Yoo, 2011).

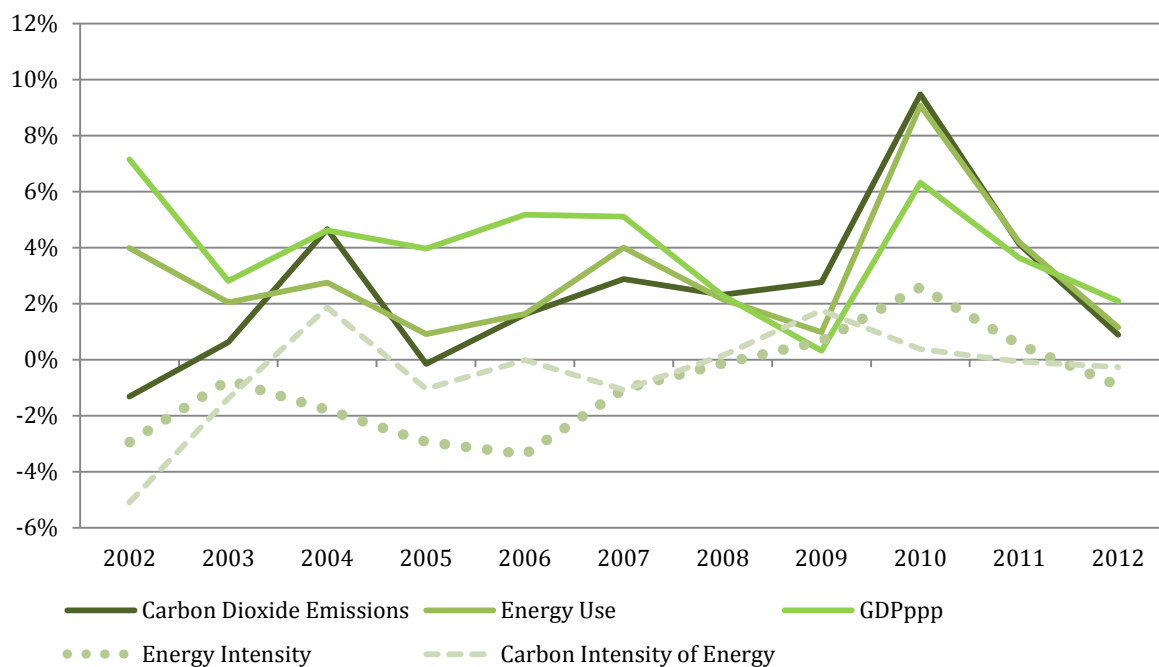
Based on the above, it is considered likely that the GND was effective as traditional fiscal stimulus when assessed against the observed improvement in key economic indicators from the baseline and overall consistency with the requirements of the Three T test. However, the GND was not the sole factor responsible for the observed turn around in the South Korean economy. In reality a number of factors contributed to the rebound of which the GND, while important, was not the primary factor (OECD, 2010a). As anticipated at the time of the crisis, the sharp depreciation of the Korean Won quickly increased the competitiveness of Korean exports and restored the country's most important driver of economic growth. Complimentary stimulus policies such as monetary easing and tax reductions for industry, business and households also played an important role in South Korea's quick recovery (OECD, 2010a). On balance it is considered that without the GND, the recovery would not have been as strong as was observed. However, it is difficult to determine to what extent this favourable result could be attributed to the GND's measures for energy efficiency and low-carbon energy. The information available suggests that the contribution of these stimulus measures to the economic recovery was relatively low compared to the GND's significant portfolio of shovel-ready, infrastructure projects (OECD, 2011a).

#### **4.2. Findings for Environmental Assessment of the GND**

To be considered effective in contributing to South Korea's climate-related green growth objectives the GND should have been able to demonstrate improvement against the baseline scenario outlined in Table 4. Figure 2 presents the variability analysis for CO<sub>2</sub> emissions from fuel combustion and their drivers in the lead up to the crisis and the period immediately following its onset. While the baseline scenario anticipated that overall emissions in South Korea would decline reflecting reduced industrial and economic output, it can be observed that during 2009 CO<sub>2</sub> emissions and energy use

actually increased dramatically. It appears that this large spike of additional annual emissions corresponded with the increased economic activity and recovery following the announcement of the GND. While these increases cannot be fully attributed to the GND itself, they suggest that the GND was ultimately ineffective at influencing the nature of the recovery, which resulted in worse short-term environmental outcomes when compared to the baseline scenario.

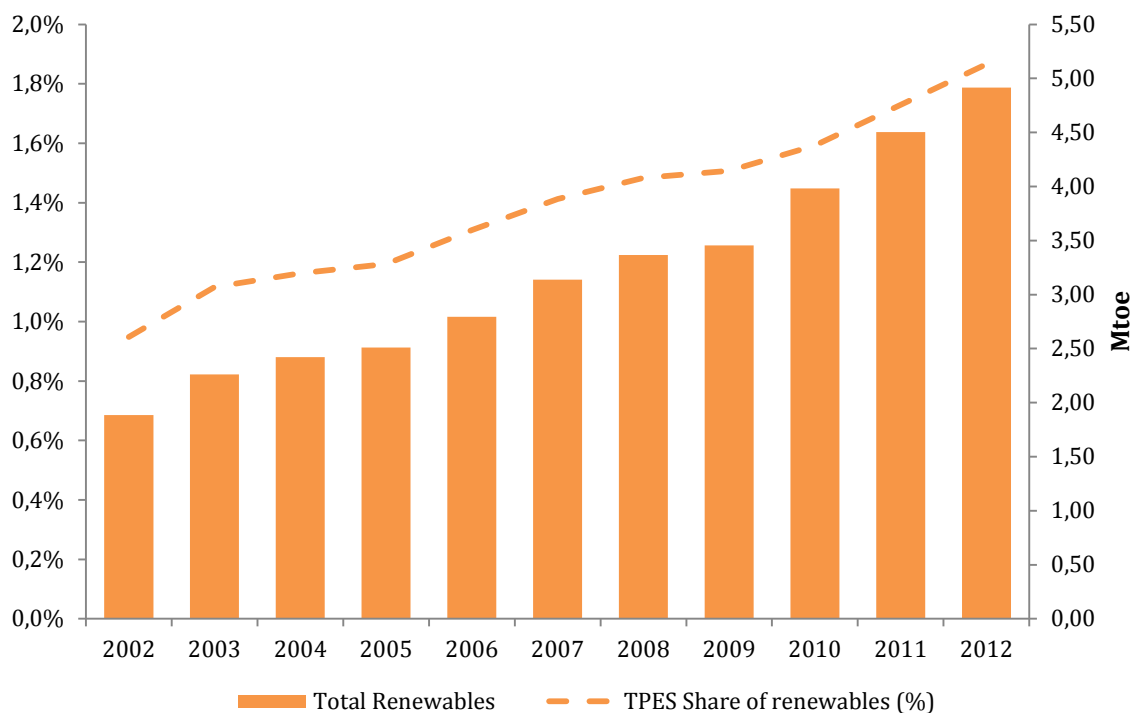
In contrast to what was expected under the baseline scenario, the energy intensity of GDPppp also increased during 2009 and 2010 before declining in 2011 and 2012 (see Figure 2). This growth in energy intensity may have been linked to the nature of South Korea's economic recovery, which was in-turn linked to improved international competitiveness and export growth, particularly in industries such as semiconductor and electric appliance manufacture, and infrastructure spending including spending on GND programs such as railway construction and the building of dams and other water control measures (OECD, 2010c).



**FIGURE 2 ESTIMATED ANNUAL CHANGE (2002-2012) IN CO<sub>2</sub> EMISSIONS ENERGY USE, GDP, CARBON DIOXIDE INTENSITY AND ENERGY INTENSITY IN SOUTH KOREA**

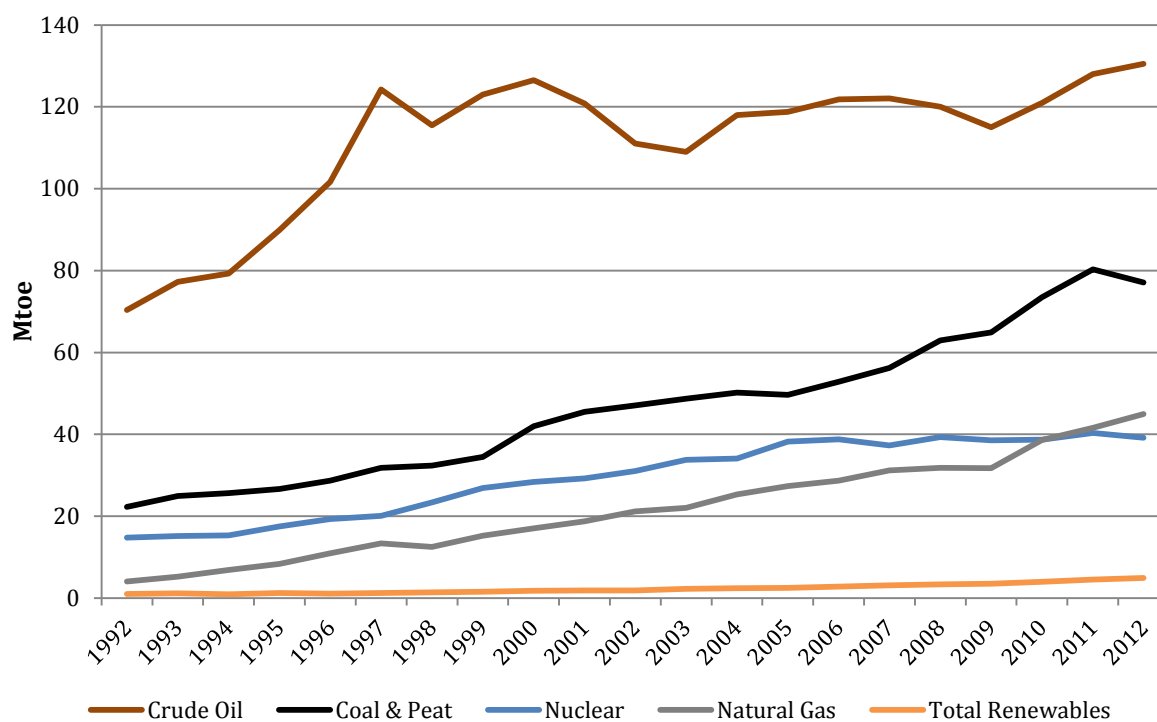
Data source: IEA, 2014a

Similarly, while the baseline scenario anticipated that the carbon dioxide intensity of energy used would decline as a result of the projected economic recession and historical trends towards less carbon intensive energy sources, Figure 2 shows that it actually increased in 2009. However, it then went on to quickly decrease in 2010 and again in 2011 (see Figure 2) suggesting that less carbon intensive energy sources may have been employed as the recovery gained momentum. To investigate this possibility further, we analysed renewable energy supply before and after the crisis. From Figure 3 it can be seen that the share of renewable energy did grow strongly in 2010 and 2011, although from a low base (see Figure 4). This was an improvement on the baseline scenario, which anticipated a slower rate of growth in the use of renewable energy consistent with recent historical trends.



**FIGURE 3 TOTAL RENEWABLE ENERGY SUPPLY (MTOE) AND SHARE OF RENEWABLES IN SOUTH KOREA, 2002-2012**

Data sources: IEA, 2014a, 2014b

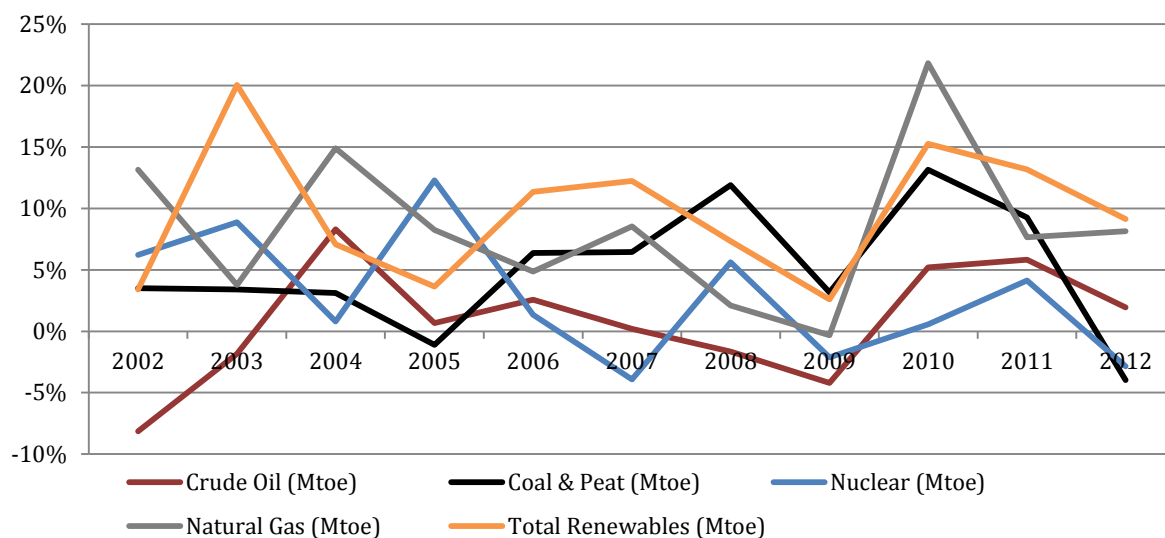


**FIGURE 4 TOTAL PRIMARY ENERGY SUPPLY BY FUEL TYPE IN SOUTH KOREA (MTOE), 1992-2012**

Data source: IEA, 2014b

However, as aggregate energy use increased dramatically during 2009 (see Figure 2), it is also necessary to understand the growth in the use of renewable energy at this time relative to other energy sources. Again applying variability analysis, Figure 5 illustrates that while renewable energy supply did grow at a stronger rate during the recovery, this growth was accompanied by strong growth in the use of fossil energy sources; particularly natural gas and coal in 2009 and then crude oil in 2010. Thus, while the strong growth in the use of renewable energy during the crisis could be considered a slight improvement against the baseline scenario, overall the energy mix shifted towards more carbon intensive fuels.

As a result, the boarder uptake of fossil fuels during the recovery led to increased emissions, so that any reduced carbon dioxide intensity effect associated with improved energy efficiency or the uptake of renewable energy following the crisis did not appear to have a significant influence on South Korea’s CO<sub>2</sub> emissions from fuel combustion during the recovery. In fact the positive move towards less carbon intensive energy sources following the recovery was most likely attributable, not to the GND or other policies to promote renewable energy such as the 2008 Basic Energy Plan, but rather to the increased use of natural gas; a trend that was already underway before the onset of the crisis (IEA, 2012). In other words, in spite of the positive trends seen for renewable energy, the scale in Korea was too low to have a substantive effect on the CO<sub>2</sub> intensity of the energy mix. Our findings are consistent with discussion in the literature on green stimulus and green growth regarding the difficulty of reconciling economic growth with improved environmental protection (Brahmbhatt, 2014; Huberty et al., 2011). Traditionally, macroeconomic stimulus aims to foster a fast, broad increase in economy-wide levels of aggregate demand, output and employment back to levels consistent with potential output (Brahmbhatt, 2014).



**FIGURE 5 BREAKDOWNS OF ENERGY SUPPLY BY FUEL TYPE IN SOUTH KOREA, 2002-2012**

Data sources: IEA, 2013a, 2013b

The GND may also have been relatively ineffective from an energy security perspective. According to the baseline scenario it was expected that South Korea’s TPES would continue to be dominated by fossil energy sources such as coal and crude oil during the period following the crisis. Immediately following the crisis this dependency intensified dramatically (see Figure 5). While strong growth in domestically produced renewable energy was a positive feature of the recovery, this was more than offset by the strong growth in imported fossil energy sources, particularly crude oil (see Figure 5).



An important challenge associated with this assessment is that it is difficult to determine to what extent observed trends in the variability analysis can be attributed to the GND or other complimentary policies. For example, in 2011 the South Korean government introduced legislation to establish an cap-and-trade emissions trading system (ETS) covering six types of greenhouse gases (OECD, 2012). The scheme, in operation since 2015, required firms emitting more than 15 thousand tonnes of CO<sub>2</sub> per year to participate in a ‘Target Management System’ starting in 2012. Whether the announcement of the scheme contributed to the observed improvement in key green growth indicators in 2012 is difficult to determine.

### 4.3. Econometric assessment

The model findings suggest that over the period observed the level of emissions is largely determined by (the rate of) economic growth. This implies that any action designed to stimulate economic growth such as the GND adopted by the South Korean government would have been incapable of simultaneously delivering a ‘green’ low-emissions recovery – at least in the short-term. This is unsurprising as recalibrating the country’s energy networks to accommodate more renewable energy will take considerable time, as will restructuring the South Korean economy to be less carbon intensive.<sup>10</sup>

Results from the stepwise multiple regression can be summarised as follows (see Table 5). First, all the variables were introduced in our original model, called ‘Model A’, but the sequential statistical tests and related simulations only allowed us to momentarily retain  $g$ ,  $e\_int$  and  $c\_int$  as the main dependent variables. As a result of this, Model A was significant ( $F_{3, 38} = 4710.29$ ;  $p$ -value = 0.000). The estimated adjusted R<sup>2</sup> was 0.997, indicating that 99.7% of the variability of CO<sub>2</sub> emissions could be explained collectively by  $g$ ,  $e\_int$  and  $c\_int$ . The coefficient of variation for Model A ( $Coef\_Var_{Model-A} = Std. error estimate (+/-9.29) / mean value of CO_2 emissions (285.74 MtCO_2)$ ) yielded a value of 3.25%, which suggested that large fluctuations of CO<sub>2</sub> emissions could be explained by the estimated model. However, estimated VIF values for Model A revealed strong signs of multicollinearity, with estimated indexes for  $g$  and  $c\_int$  in particular, much higher than the defined maximum threshold value.

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<sup>10</sup> For example, the renewable energy targets announced just prior to the GND and Korea’s voluntary commitments for emissions reductions have long-term milestones out to 2030 and 2020 respectively (IEA, 2012).

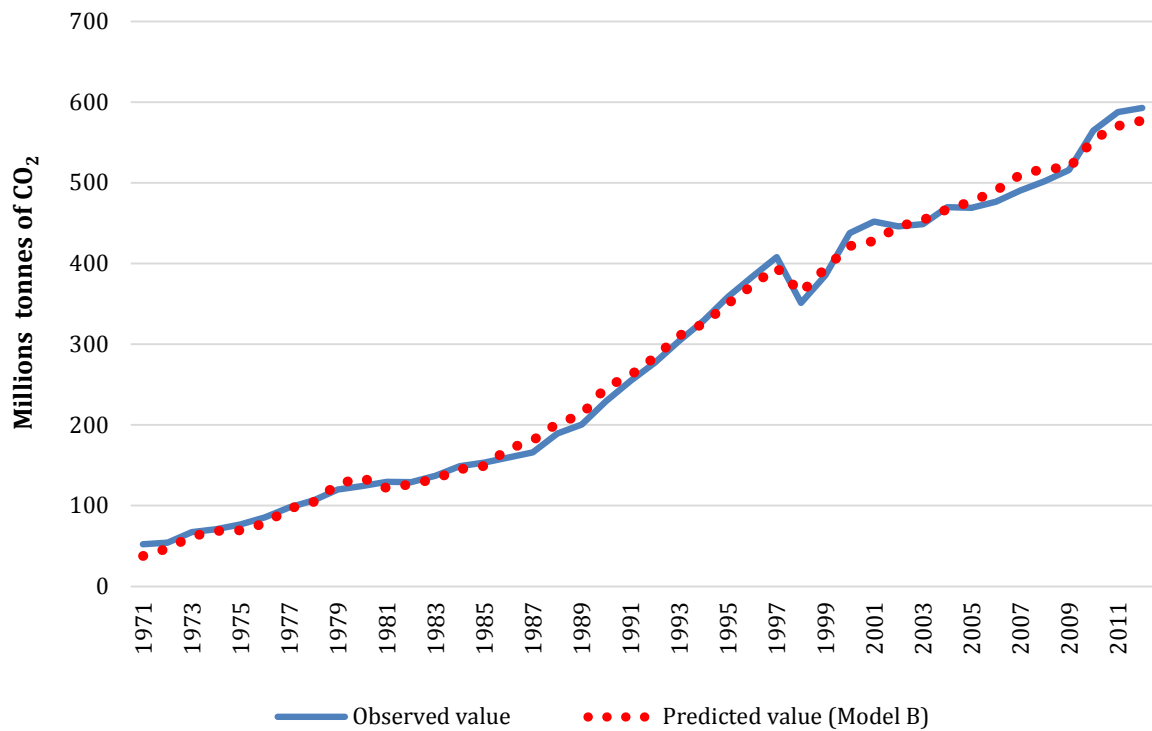
**TABLE 5 SUMMARY OUTPUT FROM STEPWISE REGRESSION ANALYSIS**

Regression summary		R	R2	Adjusted R2	Std. Error	
Model A*		0.999	0.997	0.997	9.29	
Model B**		0.998	0.996	0.996	11.08	
ANOVA		Sum of Squares	df	Mean Square	F	p-value
Model A*	Regression	1220304.51	3	406768.17	4710.29	0.000
	Residual	3281.57	38	86.35		
Model B**	Regression	1218797.91	2	609398.96	4963.60	0.000
	Residual	4788.16	39	122.77		
Coefficients		$\beta$ (Unstandardised)	Std. Error	t	p-value	VIF
Model A*	$\beta_0$	-403.27	49.63	-8.12	0.000	-
	$\beta_2$ ( <i>g</i> )	0,028	0.00	48.35	0.000	6.05
	$\beta_3$ ( <i>e_int</i> )	1110,00	93.80	11.83	0.000	1.98
	$\beta_4$ ( <i>c_int</i> )	48184,09	11536.00	4.17	0.000	7.66
Model B**	$\beta_0$	-210.65	21.88	-9.62	0.000	-
	$\beta_2$ ( <i>g</i> )	0.026	0.00	74.69	0.000	1.52
	$\beta_3$ ( <i>e_int</i> )	922.98	98.27	9.39	0.000	1.52

\* Predictors: (Constant), *g*, *e\_int*, *c\_int*

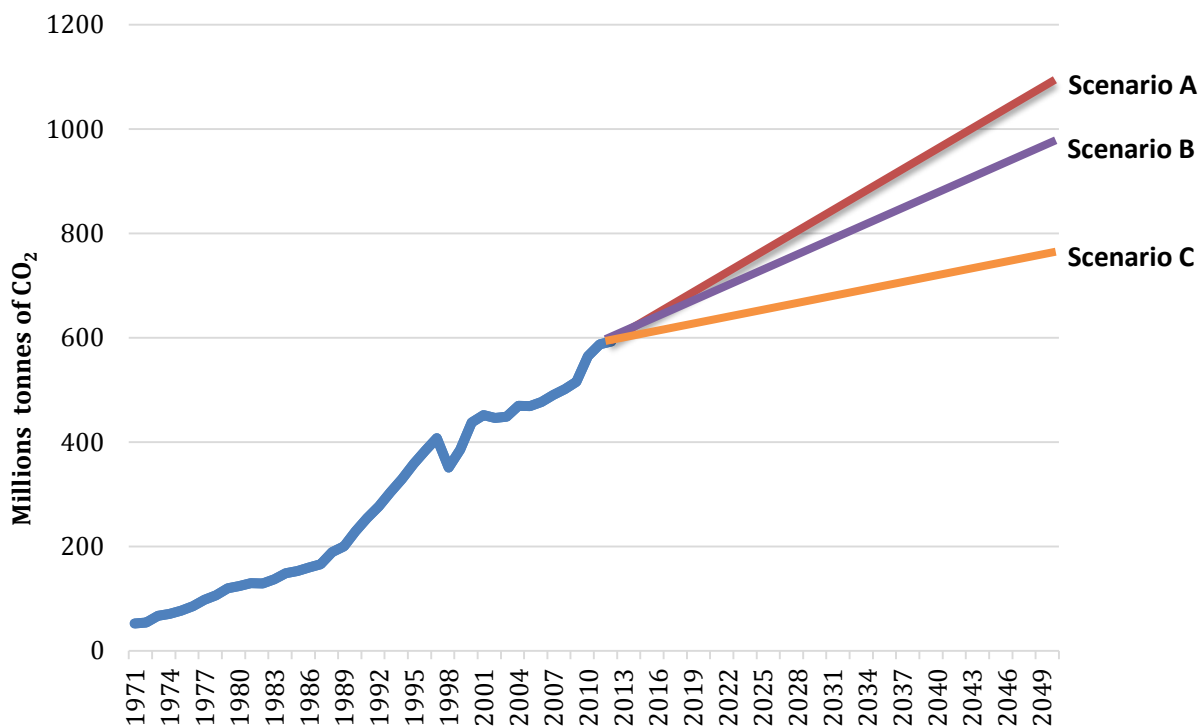
\*\*Predictors: (Constant), *g*, *e\_int*,

Secondly, and based on the results obtained when computing Model A, another simulation round took place and 'Model B' was estimated. In this case, each of the highly-correlated variables were removed iteratively and the regression equation that was significant, explained the most variance of CO<sub>2</sub> (i.e. highest adjusted R2) and showed no sign of multicollinearity was finally kept. This resulted in 'Model B' containing only *g* and *e\_int* as significant drivers for South Korea's CO<sub>2</sub> emissions. Model B was significant ( $F_{2, 39} = 4963.6$ ;  $p\text{-value} = 0.000$ ) and the estimated adjusted R2 was still very high: 99.6% of the variability of CO<sub>2</sub> emissions is explained collectively by *g* and *e\_int*. This level of determination was only marginally reduced compared to Model A. Although the standard error was slightly higher (+/- 11.08 MtCO<sub>2</sub>) compared to Model A, the estimated  $\text{Coef\_Var}_{\text{Model-B}}$  was equal to 3.87%, which also suggested that Model B would also be useful in predicting CO<sub>2</sub> emission interval values (i.e. ratio is lower than 10% threshold). VIF measures revealed no signs of multicollinearity, with estimated values for the independent variables equal to 1.52, a value lower than the defined 5 maximum threshold value. Finally, estimated coefficients (standardised) confirmed that *g* had the strongest impact on CO<sub>2</sub> emission levels.



**FIGURE 6 OBSERVED AND PREDICTED CO<sub>2</sub> EMISSIONS VALUES FROM FUEL COMBUSTION FOR SOUTH KOREA (1971-2011)**

Using model 'Model B' (with  $g$  and  $e_{int}$  as predictors), three scenarios (until 2050) were developed for comparison to explore this potential (Figure 7). Scenario A is equivalent to business-as-usual assuming no further policy interventions. Scenario B considers continuous  $g$  growth but a 15% reduction in  $e_{int}$  by 2050 (compared to 2012 levels) due to policy efforts. Scenario C assumes a moderate  $g$  growth and a 25% reduction in  $e_{int}$  by 2050 (compared to 2012 levels) due to stronger energy efficiency policy efforts. The scenarios imply that action taken to enhance energy efficiency such as the measures adopted in the GND and the impact of other more targeted climate and energy policies (e.g. energy saving obligations, ambitious minimum energy performance standards, cap and trade schemes) may result in measurable emissions reductions and environmental benefits over time. It is important to note that policy measures such as the Renewable Energy Portfolio standard (which replaced the feed-in-tariff system in 2012) and the national ETS that were all announced after the GND are not captured in Model B, as  $c_{int}$  was dropped due to the stepwise modelling approach. However, these policy measures can certainly affect and reduce the carbon and energy intensities.



**FIGURE 7 ALTERNATIVE SCENARIOS FOR FUTURE CO<sub>2</sub> EMISSIONS FROM FUEL COMBUSTION IN SOUTH KOREA (1971-2050)**

## 5. Conclusions

This paper presented an ex-post evaluation of the effectiveness of South Korea’s GND as an instrument to deliver both an economic recovery and improved environmental outcomes in the energy sector; particularly when measured against climate-related indicators. Our findings would appear to confirm that, at least in the short-term, it is difficult to design economic stimulus that does not lead to increased levels of energy use and carbon emissions.

Results clearly suggest that there was a strong economic recovery in South Korea immediately following the global financial crisis of 2008-09. However, results also indicate that the recovery did not meet the climate-related objectives of green growth as defined in South Korea’s green growth strategy. As a result, to the extent that any of the economic recovery or environmental outcomes observed in South Korea since the crisis can be attributed to the GND, the GND was relatively effective as an economic policy instrument but ineffective as an instrument of environmental policy; at least in the short-term. In fact, econometric results show that GDP per capita in particular; including energy intensity, are statistically significant drivers of South Korea’s CO<sub>2</sub> emissions.

On the short term, this outcome may have been the result of a number of factors. When the stimulus package was announced it was not supported by complementary pricing reforms such as an ETS or carbon tax that are needed to drive industrial restructuring and would have provided uniform incentives for producers to adopt low carbon energy sources during the recovery (OECD, 2012). In addition, despite the growth in the use of renewable energy observed in the period after the GND was announced, it appears that the scale of renewable energy uptake was too low to affect the CO<sub>2</sub> intensity of the energy mix. Similarly, CO<sub>2</sub> emissions resulting from increased economic activity were not offset by improvements in the energy intensity of GDP or decarbonization of South Korea’s energy mix. As a result, it was unlikely that the energy efficiency measures adopted under the GND

delivered as expected. However, even if they did perform as expected (i.e. fully effective), our results indicate that they were incapable of counteracting the negative effects of economic growth on emissions. As a result, any reduced carbon dioxide intensity effect associated with improved energy efficiency or the uptake of renewable energy following the crisis did not appear to have a significant influence on South Korea's CO<sub>2</sub> emissions from fuel combustion during the recovery. It has to be acknowledged; however, that due to the empirical nature of our study our findings are unable to properly capture future long-term effects and subsequent monitoring and research to better understand the impact of the GND is required.

While our analysis would appear to indicate that the GND was relatively effective as economic stimulus but less so as green stimulus, there is reason to believe the performance of the green elements of the GND may strengthen or improved with time. The Renewable Energy Portfolio (RPS) standard, which replaced the feed-in-tariff system, was introduced in 2011 and the national ETS started its operation 2012. In fact, our variability analysis suggests that key climate-related indicators had started to improve by the original intended close of the GND package in 2012. By then, CO<sub>2</sub> emissions and energy use had slowed to rates lower than GDP growth. Similarly, by 2012 the annualized rate of growth of energy intensity and the carbon dioxide intensity of energy used had dropped below zero. After the spike in utilization of fossil fuels in 2009 and 2010 the rates of growth in utilization of these fuels started to decline. Our econometric assessment also finds that action taken to enhance energy efficiency such as the measures adopted in the GND and the impact of other more targeted climate and energy policies have the potential to result in measurable emissions reductions over time. When evaluated against the categories of long-term benefit defined by Houser et al (2009) programs for funding research into renewable energy and energy efficiency measures will likely help address hurdles for low carbon investment. Therefore it is worth considering the role that the perceived success of the GND may have played (or be playing) in facilitating the adoption of these additional green growth policies, like the RPS and ETS. This capacity of green stimulus packages to demonstrate commitment to longer-term environmental outcomes and provide impetus for further action on environmental matters has been identified as a potential co-benefit of such packages (Bowen et al., 2009).

Our findings need to be tempered with the acknowledgement of a number of limitations associated with the evaluation. A key issue was associated with causality: whether and to what extent any changes that have been observed could be attributed to the GND and not to other government policies or complimentary economic or environmental phenomena. In turn, this challenge relates to disentangling the effects of policy instruments that target low-carbon technologies from the specific effects of the GND—the so-called 'impact problem' in policy evaluation (Scriven, 1991). As a whole, causality and attribution were further exacerbated by the fact that there is little detailed information available on the GND programs in English and that the GND was later merged into the first five year plan of the NSGG. Also note that we focused only on the energy sector and low-carbon development aspects of the NGGS climate-related objectives. As a result, the third policy direction of the NGGS climate-related objective on adaptation was not considered.

Regarding the implications of this evaluation for policy makers, despite the limitations identified, the method employed presents a novel way to conduct an ex-post evaluation of stimulus measures and other similar policies using green growth indicators and supplementary peer-reviewed and grey literature. Similar research in other country contexts may help shed further light on the general effectiveness of green stimulus as a response to future economic crises. In the context of South Korea, additional research based on the specific outcomes of the various GND programs would be useful to address the limitations associated with this evaluation and better attribute the observed changes in key indicators to the measures incorporated under this particular green stimulus package.

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