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Green investment: Trends and determinants

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HIGHLIGHTS

- We offer a definition of green investment and review its trend since 2000.
- We analyze its determinants from both theoretical and empirical perspectives.
- Green investment is boosted by economic growth, interest rates, and fuel prices.
- Feed-in-tariffs and carbon pricing schemes impact positively green investment.

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ABSTRACT

This paper fills a gap in the macroeconomic literature on renewable sources of energy. It offers a definition of green investment and analyzes the trends and determinants of this investment over the last decade for 35 advanced and emerging countries. We use a new multi-country historical dataset and find that green investment has become a key driver of the energy sector and that its rapid growth is now mostly driven by China. Our econometric results suggest that green investment is boosted by economic growth, a sound financial system conducive to low interest rates, and high fuel prices. We also find that some policy interventions, such as the introduction of carbon pricing schemes or “feed-in-tariffs,” which require use of “green” energy, have a positive and significant impact on green investment. Other interventions, such as biofuel support, do not appear to be associated with higher green investment.

1. Introduction

There is now a wide consensus that climate change is occurring, caused by human-induced greenhouse gas emissions, mainly from fossil fuel combustion and changes in land use. Climate change could produce severe negative outcomes and has important macroeconomic consequences. Higher temperatures, rising sea levels, and extreme weather conditions may severely impair output and productivity (IMF, 2008a). Climate developments will also affect fiscal positions through their direct impact on tax bases and spending programs, and more importantly, through the policies needed to mitigate climate change and adapt behaviors and production to the new environment (IMF, 2008b; Jones and Keen, 2009; Parry, 2011). These costs and risks point to the unsustainability of current patterns of energy use. At the same time, the transition to a low-carbon emission model will require large investments in alternative energy sources, because green technologies, such as wind turbines or solar panels, are capital-intensive, especially in the early stages of development (Johnson and Lybecker, 2009).

Increasing the share of green investment (GI) is not only a medium-term climate target. Proponents of investment in low-carbon energy sources also cite the need to enhance energy security, reduce adverse health effects of air pollution, and find new sources of growth (Accenture, 2011; McKinsey, 2009; OECD, 2011; PriceWaterhouseCoopers, 2008). As of today, GI is already a significant contributor to electricity and energy generation. Renewable energies represent one-fifth of electricity generation worldwide (IEA WEO 2010). The pace of green capital accumulation has accelerated in recent years, led by technological progress, economies of scale, strong policy support, and favorable public opinion. Green programs had also proven to be important in national fiscal stimulus plans during the 2008/09 global financial crisis.

The purpose of this paper is to analyze and explain recent trends in GI based on a new multi-country dataset, with a view to better understanding what policies have been successful in promoting it. To our knowledge, no study has yet been conducted that defines the concept of GI in a macroeconomic sense, and relates it to macro determinants from a cross-country perspective.

The paper utilizes a broad definition of GI, which encompasses both traditional energy sources (e.g., hydropower) and new technologies. It shows that GI has become a key driver of the

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energy sector, as it now exists on a similar scale to investment in fossil-fuel capacity. GI is also a global phenomenon, with leadership shifting from Europe and the United States in the 1990s to China in more recent years.

Our econometric results have important implications for the design of policies to bolster GI. They suggest that macroeconomic policies that are generally effective for increasing private investment as a whole are also useful for GI, in particular, enhancing GDP growth and lowering the cost of capital. At the same time, not all public interventions are successful in boosting GI. Feed-in tariffs (a form of price support) and carbon pricing mechanisms are found to foster GI, while other policies, like biofuel support, do not appear to be associated with higher investment rates.

The paper is organized as follows: Section 2 discusses conceptual and methodological issues related to the definition and measurement of GI. Section 3 analyzes the relative importance of green and conventional energy sources. Section 4 reviews recent trends in GI, drawing from financial data and other relevant sources. Section 5 analyzes the determinants of GI from both theoretical and empirical perspectives. Finally, Section 6 concludes.

2. What is green investment and how can it be measured?

2.1. Definition and components of green investment

In this study, GI refers to the investment necessary to reduce greenhouse gas and air pollutant emissions, without significantly reducing the production and consumption of non-energy goods.[1] GI covers both public and private investment. Our approach to GI differs from that of the forward-looking economic literature on mitigation and abatement costs, which measures the *incremental* investment needed to meet a certain climate target relative to a business-as-usual scenario (Appendix A).

Core strategies for reducing emissions can be classified according to their intermediate objective. Most GI is intended either to reduce the pollution caused by energy generation, or to decrease energy consumption. In addition, GI also covers technologies that sequester carbon, as deforestation and agriculture are important sources of carbon emission. Accordingly, Table 1 identifies three main components of GI:

- *Low-emission energy supply*. GI involves shifting energy supply from fossil fuels to less polluting alternatives, either for electricity generation (wind, solar, hydropower, etc.), or as direct sources of energy (biofuel, for example). The GI concept thus extends not only to emerging environmental technologies such as wind and solar photovoltaic power, but also to more established technologies, like hydropower.[2]
- *Energy efficiency*. GI also includes technologies that reduce the amount of energy required to provide goods and services. In the electricity sector, there is scope for improving efficiency in power generation (moving from sub- to super-critical coal)[3] and transmission and distribution (by using more efficient grids and smart grid technologies).[4] There is also potential for efficiency gains in transport, including through the utilization of more fuel-efficient and hybrid cars, as well as greater use of mass transit. In industrial equipment, efficiency gains can be achieved through energy-saving appliances and improved waste management. In construction, efficiency could be enhanced through improved insulation and cooling systems.
- *Carbon sequestration*. After fossil fuel combustion, deforestation is the second-largest contributor to carbon emissions worldwide, accounting for 20% of total emissions (Report of the Intergovernmental Panel on Climate Change, 2007). Halting ongoing deforestation, reforesting, and sequestering more carbon in soils through new agricultural practices, are therefore crucial to reducing carbon emissions. Deforestation and agriculture may also offer some of the lowest-cost abatement opportunities. However, the main mitigation strategies in these areas rely on labor, rather than physical capital (for example, changes in crop and soil management practices), and available data on GI in this area is limited.

Although nuclear may also be considered as a low-emission energy supply, we do not include it in our definition of green investment for the following reasons. First, nuclear power produces radioactive waste. Second, the investment decisions in nuclear and renewable energy are likely to be very different. Renewable energy investments involve smaller-scale private investments, while nuclear spending is often larger and funded by the public sector. In addition, investment in renewable energy depends on geo-physical conditions (for instance the water supply), while the development of nuclear energy hinges more heavily on technological progress. Finally, the production costs of both types of energy might differ.

2.2. Measuring green investment

Our measure of GI covers: (i) financial investment in renewable technologies (including large hydroelectric projects), (ii) selected energy-efficient technologies,[5] and (iii) research and development (R&D) in green technologies. Investment in carbon sequestration, which is difficult to measure, is excluded from the analysis.

Excluding large hydro projects, data on renewable GI is provided by Bloomberg New Energy Finance (BNEF). BNEF has the most complete database on renewable energy projects and is widely used by public and private entities (Appendix B). BNEF records financial investment (acquisition of financial assets), which may differ from physical investment, although project financing is usually earmarked in the renewable sector. Investment covered by the database is mostly private, but BNEF separately reports the green component of fiscal stimulus programs and public R&D spending.

For large hydropower projects (not covered by the BNEF database), we use capacity data provided by the U.S. Energy Information Administration. Estimating investment flows from capacity data is particularly challenging.[6] This is because the capital costs of hydro projects are likely to be highly heterogeneous,

[1] The emission of greenhouse gases (in particular carbon dioxide) and pollutants (such as sulfur dioxide and nitrogen oxide) lead to global warming, smog, and acid rain, and have adverse effects on health. Our analysis focuses on emission reduction to restrict the scope of the GI concept in light of data availability. Other environmental objectives could have been considered, such as reducing the reliance on fossil fuels, avoiding resource depletion, preventing damages to water and soil, reducing waste, and preserving biodiversity. For instance, Eurostat (2009) adopts a broader approach by defining environmental spending as the acquisition of technologies, goods, and services whose main purpose is to limit the degradation and depletion of natural resources.

[2] Biofuels are part of GI, despite their debated impact on carbon emissions (IMF, 2008d), so that all renewable energy sources are considered “green” in our study. For simplicity's sake, our measure excludes “fossil-fuel switching,” for example, the replacement of coal with natural gas, which also contributes to emission reduction.

[3] Supercritical coal-fired plants are highly efficient electricity plants that burn less coal per megawatt-hour produced.

[4] A smart grid is a form of electricity network using digital technology.

[5] The Bloomberg New Energy Finance database used in this study only covers selected energy efficient technologies, labeled under the category “Energy Smart Technologies” (for instance, smart grids or power storage).

[6] Capacity refers to the maximum output of electricity and is usually in the form of kilowatts (kW) and megawatts (MW).

Table 1
Structure of green investment by category.

Factors	Component	Item and sub-item
Supply factors	Low-emission energy supply	• Low-emission electricity supply – Renewable sources of electricity: Hydropower Wind Solar Biomass[a] – Other sources • Other low-emission/renewable energy supply – Biofuels – Biomass – Solar and geothermal for heating • R&D in clean energy
	Carbon sequestration	• Agriculture • Deforestation • Carbon capture and storage technologies
Demand factors	Energy efficiency in energy-consuming sectors	• Households • Services • Industry • Agriculture • Transport
Mixed factors[b]	Energy efficiency in the electricity sector (generation, transmission, distribution)	

[a] Biomass is carbon neutral in that plants absorb and store carbon while they are growing and return it when they burn or decay.
[b] The electricity sector both demands and produces energy, making it difficult to categorize efforts to improve energy efficiency in this area into those that affect energy demand or supply.

being affected not only by the type of technology and the efficiency of project implementation, but also, more fundamentally by essential physical and geological conditions. As such, no estimate of investment flows is attempted; only changes in capacity are reported in Section 4.2.

3. The growing importance of green energy sources

3.1. Green and brown energies

Although this paper will focus mainly on financial investment (in Section 4), this section briefly analyzes energy generation data in order to assess the scale of green energy sources (renewables) relative to conventional, or "brown," ones (coal, gas, oil, and nuclear). This section shows that renewables play an important role in electricity and more generally in energy generation, due to the traditional use of hydropower and biomass.[7]

3.1.1. Electricity generation

In 2008, about one-fifth of global electricity was generated from green sources (renewables, including hydro), and four-fifths from conventional sources (Fig. 1, left). These shares have been relatively stable over time. However, since the second half of the 1990s, green energy generation has slightly shifted from hydro to other renewables (Fig. 1, right).

Excluding hydroelectric power, renewable technologies account for a small share of the electricity mix compared to traditional resources like fossil fuels, nuclear, or hydropower. However, their contribution to new electricity capacity has been substantial in recent years (Fig. 2).

3.1.2. Energy consumption

Data on energy consumption is less reliable than that on electricity production because some fuels (like biomass and waste) are non-traded and their consumption is not well documented. It should also be noted that there are competing methods of measuring energy.[8]

Depending on the method, renewables supply about 15–20% of global energy consumption, owing to the traditional role of biomass for cooking and heating (Fig. 3, left).[9] Excluding non-traded fuels, the share of renewables falls to about 10% (Fig. 3, right).

3.2. Government support for renewables

Over the last decade, a wide range of public programs has been put in place, mostly in OECD countries, in order to encourage the production or consumption of renewable energy (Table 2). The number of countries with some type of policy target and/or support policy almost doubled during the last five years from 55 in early 2005 to more than 100 by early 2010 (Renewable Energy Policy Network, 2010).

Support schemes have three main goals: (i) reduce carbon emissions and avoid climate change,[10] (ii) improve energy security by diversifying the energy mix, and (iii) foster growth by promoting competitiveness, job creation, and innovation in new industries.[11]

The most common forms of policy support for renewable electricity generation are feed-in-tariffs (FITs, adopted by 50 countries and 25 states/provinces by early 2010), and renewable portfolio standards (RPS, found in 10 countries and 46 state/provinces). These terms are described in Table 2. In the case of biofuels, blending mandates are the most widespread instrument —24 countries, 41 states/provinces (Renewable Energy Policy Network, 2010).

[7] *Energy* is the capacity of a physical system to perform work. The standard unit of energy is the joule (J). But other units exist, such as, the Kilowatt hour (kWh). *Power* is the rate at which energy is generated. For instance, a hydroelectric plant converts water's potential energy into kinetic energy and, ultimately, into electric energy, whereas the amount of electric energy that is generated per unit of time is the electric power. Power has the unit "watt," which is equal to one joule per second. The economic literature uses the term electrical *capacity* to refer to the power of an electric plant (in watts), whereas electricity *generation* refers to the energy produced by the plant (in watt hour).

[8] Energy can be measured at the point of use (final demand) or at the input stage (primary demand). For instance, the energy produced by an electric plant can be measured by either the electricity generated by, or the fossil fuel needed to, operate the plant.

[9] In Fig. 3 left, the share of renewables (including biomass) is 13%. Measuring final energy consumption would result in a higher share.

[10] Achieving this objective faces several obstacles. First, if renewable policies reduce the use of nuclear energy or natural gas rather than coal or oil, the impact on emission is likely to be limited. Second, renewable subsidies are usually seen as less effective than emission pricing (like a carbon tax), because they do not curb energy use and do not deter the consumption of energy-intensive products. They also fail to penalize or reward fuels based on their carbon content, but instead create incentives to use a particular category of fuel (Krupnick et al., 2010). Third, the impact on emissions may also be constrained by the existence of cap-and-trade (such as the EU emission trading scheme); any gain in a particular country is likely to be offset by higher emissions in another country covered by the cap.

[11] The potential for green job creation should not be overestimated and has been subject to heated debate (see Morriss et al., 2009, Tuerck et al., 2009, and Pollin, 2009).

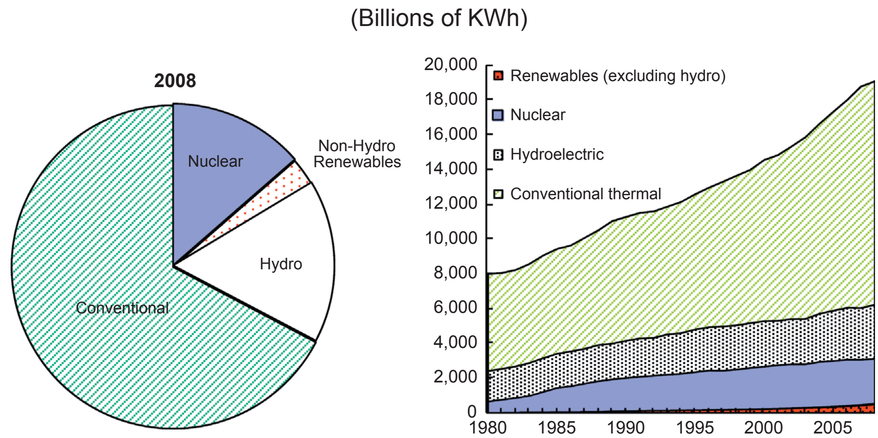

Fig. 1. World electricity generation (billions of KWh).
Source: U.S. Energy Information Administration.

Estimating the cost of public programs is tricky, as they not only include direct payments but also tax breaks, loan guarantees, or quotas. Published estimates provide a range of $40–60 billion per year worldwide (Table 3). Biofuel subsidies account for the lion's share of public program costs. Although total subsidies to renewables only amount to one-tenth of those to fossil fuels, renewables are, in fact, far more subsidized on an output basis (relative to the energy produced).[12]

Several of these programs have been scaled up in the context of the fiscal policy response to the 2008/09 global financial crisis. The Renewable Energy Policy Network (2010) and BNEF (2011a) estimate that support of renewables, pledged as part of fiscal stimulus plans, amounts to about $180–195 billion, of which the United States, China, and South Korea account for around $65, $46, and $32 billion, respectively. In the countries with the largest green packages (Fig. 4), green measures represent no more than 15% of the total fiscal stimulus,[13] except for South Korea, where 80% of the stimulus was earmarked for green investment.

The largest share of the green stimulus financing (almost one-fourth) went to energy efficiency measures, in the form of grants for the improvement of public sector buildings and for weatherizing homes (BNEF, 2010b). Only half of the total allocated funds were disbursed in 2009 and 2010 ($20 and $74 billion, respectively). Implementation of green stimulus financing has been slowed down by the complex planning and processing required for releasing public financing. In addition, countries facing large public sector deficits have scaled down green spending when the economy started recovering. For instance, some projects appear to have been abandoned in Brazil, China, Spain, and the United Kingdom (BNEF, 2011a).

4. What are the recent trends in green investment?

4.1. Renewable energy[14]

4.1.1. Global trends

Renewable GI – as measured by BNEF in current dollars – has risen substantially during the past decade, with most of the increase occurring after 2004. Between 2000 and 2010, renewable GI increased more than 20-fold from $7 billion to $154 billion (Fig. 5). The main drivers include global economic growth, increasing prices of fossil fuels, technology advances, policy support, and increasing demand of populations for a cleaner environment. A reduction in the costs of green technologies has also been realized through economies of scale, technological progress (fostered by R&D), and lower interest rates. Today, green energy can already compete with fossil fuel sources on an unsubsidized basis in some specific markets (BNEF, 2011b), although total renewables remain highly subsidized (Section 3.2).

Renewable GI temporarily declined in 2009 during the global recession in the context of less favorable financial conditions, reduced liquidity, and uncertainty over the future demand for green energy as fossil fuel prices receded. This decline was nonetheless countered by the great amount of support received from the public sector: (i) Major development banks (EIB, KfW, EBRD, and WB) stepped in to take over from the private banks to finance large projects in offshore wind and solar thermal, (ii) monetary policy eased globally and interest rates reached historic lows, and (iii) above all, many green projects were supported by public measures in the context of fiscal stimulus programs (see above).

4.1.2. Regional trends

Renewable GI has become a global phenomenon since the beginning of the last decade (Fig. 6). It grew steadily in all major regions until the onset of the economic crisis. From 2004 to 2010,[15] Europe and North America quadrupled their renewable GIs, while Asia and Oceania increased renewable GIs 10-fold. At present, North America, Europe, and Asia are the largest markets for renewable GI, accounting for around $35 billion, $36 billion, and $64 billion in 2010, respectively. Within Europe, the main investors are Italy, Germany, and Spain, accounting for $8 billion, $7 billion, and $5 billion, respectively. In Asia, China is the leader with $54 billion. In North America, the United States invested $30 billion in 2010.

Over the period 2004–2010 the regional composition of GI changed dramatically. Leadership in spending shifted from Europe to Asia, reflecting, to a large extent, differences in economic performance. The share of Europe and North America in global GI fell to 46% in 2010, from 68% in 2004, while Asia and Oceania's share increased from 28% to 42%.

[12] Measuring subsidies per energy unit, Global Subsidies Initiative (2010a) finds that renewables receive about six times more subsidies than fossil fuels (respectively, $0.05 per kWh compared to $0.008).

[13] Fiscal stimulus estimates are provided by the IMF *Fiscal Monitor* (2010).

[14] Data used in this section comes from the BNEF database, and excludes large hydro projects (analyzed in Section 4.2). Data is not corrected for inflation, owing to the difficulty in finding a relevant deflator for financial investment. A detailed analysis of the GI components is provided in Appendix C.

[15] Investment data on GI components is less reliable (and insignificant) before 2004 in the BNEF database.

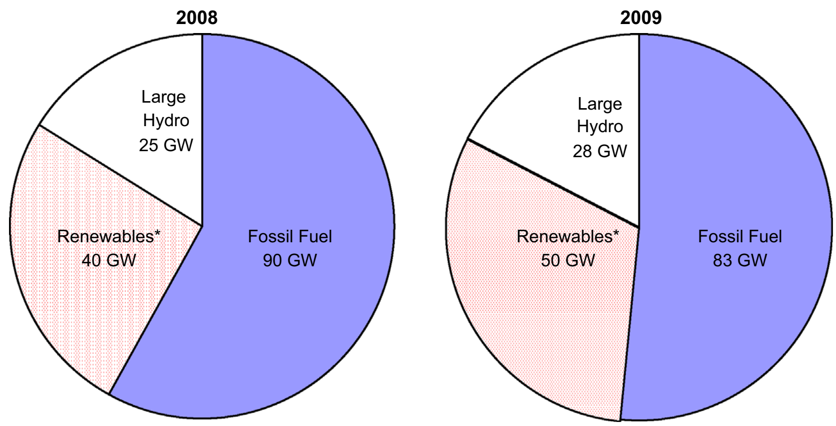

Fig. 2. New electricity capacity (World). Note: New Nuclear capacity is not reported, as nuclear capacity remained stable in 2008 and 2009. *Source*: Bloomberg New Energy Finance (BNEF).* Excluding large hydro.

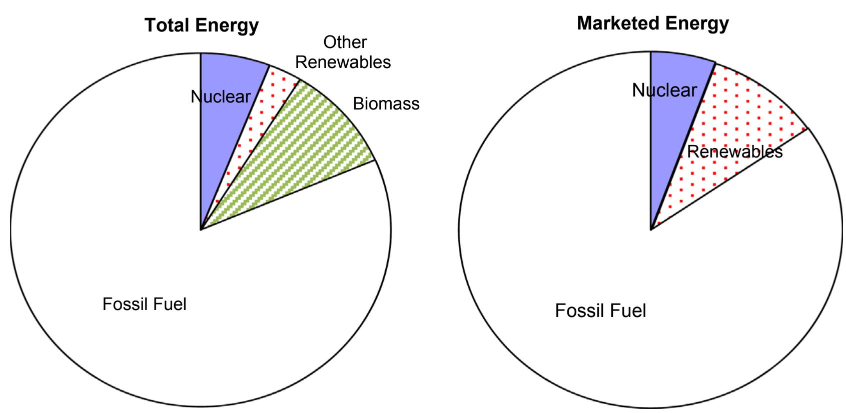

Fig. 3. World primary energy consumption, 2007.
Source: 2009 World Energy Outlook, 2010 International Energy Outlook.

Table 2
Main policy instruments.

Instrument		Description
Subsidies to producers and consumers	Direct payments	Cash transfers and "premia" for green energy production[a]
	Tax breaks	Reduction in tax liabilities
	Preferential financing	Either loan at lower interest rate or guarantees
Regulations	Blending mandates	Requires that fuels contain a given share of ethanol with gasoline, or biodiesel with diesel fuel
	Feed-in-tariffs[b]	Mandate making it compulsory for utilities to pay prices to green electricity producers that reflect the cost of the technology
	Cap and trade: renewable portfolio standards (RPS) and green certificates	RPS requires electricity companies to use a fraction of renewables for their energy sources. Companies can comply with RPS requirements by buying certificates from green producers
Indirect support	Support for energy efficiency	A variety of forms; for instance tax breaks to support efficient lighting and building technologies
	Fossil fuel taxation and cap-and-trade systems	Increase the cost of carbon emissions
	Upstream support	To intermediate consumption producers
	R&D	Development and deployment of new technologies

[a] Premia are a form of bonus paid to the producers on top of the electricity price (market-driven or regulated). These are a function of the renewable energy generated.
[b] FITs are not recorded under public subsidies, as the premia paid by utilities to renewable energy producers are not necessarily subsidized by the government.

In 2009, GI experienced a severe decline in the United States (by $14 billion), owing to less aggressive policy support and the effects of the global financial crisis.[16] This trend was less marked in

[16] In the United States, tax credits offered by the federal government are usually not used by renewable project developers, due to their relatively small size. Instead, they are sold to large institutions called "tax equity investors." These investors put money in green projects in exchange for tax credits, as long as they have taxable profits to shelter. This specific financing mode sustained the development of the renewable sector prior to the financial crisis. Conversely, green investment was badly hit in 2008 and 2009 due to the reduction in the number of tax equity investors (one of the leading providers of tax equity finance was Lehman Brothers), as well as the decline in profits in the wake of the global financial crisis.

Table 3
Estimates of public support for renewables (excluding hydro and nuclear power).

Source	Coverage	Country	Year	Amount
ELI (2009)	Tax expenditures and direct payments	United States	2002–2008	$29 billion over the period
GSI (2010a)	N/A	World	2007	$47 billion, of which $27 billion for renewable sources of electricity; and $20 billion were for biofuels.
IEA WEO (2010)	FIT, PTC, ITC, GC, Premiums, mandates	World	2009	$57 billion, of which $37 billion for renewable electricity source; and $20 billion were for biofuels.
BNEF (2010a)	FITs, RECs, tax credits, cash grants	World	2009	$43–$46 billion

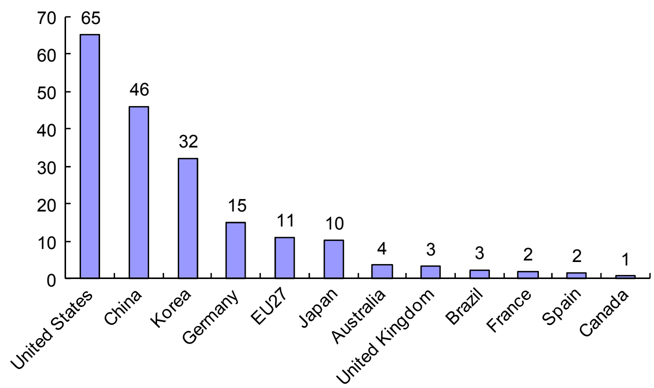

Fig. 4. Green component of economic stimulus programs as of February 2011, (pledged, not necessarily disbursed; billions of dollars).
Source: BNEF.

Europe, where government interventions remained stronger, in particular through feed-in-tariffs (FIT). However, European investment continued to decline in 2010, affected by the lingering credit crunch, whereas investment in the United States picked up.

In contrast, GI in Asia continued to soar during the financial crisis, increasing by about $30 billion in 2009 and 2010, with China accounting for the bulk of the growth. This increase was supported by benign macroeconomic conditions, a resilient banking sector, and high saving rates. Through a series of new laws and financial support measures (including loans from state-owned banks), the Chinese government has encouraged large renewable energy projects, with a view to promoting domestic manufacturing industry and improving energy security (U.S.-China Economic and Security Review Commission, 2010). In 2009, China moved ahead of the United States as the country with the highest financial investment in renewables, and added 37 GW (gigawatts) of renewable electricity capacity, particularly in wind power, which is more than any other country in the world (Renewable Energy Policy Network, 2010). In 2010, China was responsible for more GI than the entire European region alone. It is now the world leader in the production of photovoltaic modules and wind power equipment. China has also stepped up its research and development efforts and has the lead in clean technology patents and Initial Public Offerings (IPOs) in the renewable sector.

4.2. Hydropower capacity

Hydropower is the second-largest renewable energy source (after biomass) and the largest source of renewable-based electricity. Global hydro capacity has grown steadily from 480 GW in the 1980s to 920 GW in 2007, aided by the relatively inexpensive construction costs of this energy source vis-à-vis its alternatives. As a share of total electrical capacity, hydropower has, nonetheless, declined from 23% in the early 1980s to 19% in 2008 (Fig. 7). Environmental regulations, and stagnation in technological advances in this area, have slowed down expansion in industrialized countries, and many of the best sites for hydropower have already been exploited. Compared to other renewables and nuclear power, hydro projects do not benefit from significant public support, owing to better cost competitiveness.

Respectively, Asia, Europe, and North America currently account for 32%, 30%, and 20% of total capacity. Over the last decade, capacity growth has been the strongest in Asia, with an average annual growth of 12%; compared to about 1.5% in Europe or North America. China has been the most dynamic market, nearly doubling its hydropower capacity over 2004–2009.

5. What drives green investment?

The economic literature on climate change has largely overlooked the macroeconomic determinants of GI. Most studies have focused on the design of policies to curb greenhouse gas emissions, emphasizing the costs and benefits of limiting environmental damage (Stiglitz, 1998; Stokey, 1998). Some studies have looked at the determinants of energy-saving innovations at the firm level (Ambec and Lanoine, 2007) or at the sector level (Brunnermeier and Cohen, 2003). Others have examined the determinants of low-carbon investment at the manufacturing firm level (Martin et al., 2011). As far as we know, however, no study has attempted an empirical investigation of the macroeconomic drivers of GI. This section aims at bridging this gap, using data on renewable investment from BNEF on 35 advanced and emerging countries over 2004–2010.

5.1. Theoretical determinants of green investment

The economic literature suggests two broad categories of drivers of GI. The first category includes traditional determinants of investment as a whole, for instance, interest rates, income level and growth, and production costs. The second category covers determinants specific to green capital accumulation.

5.1.1. Economic growth and income level

Economic activity is expected to boost demand for energy and investment in the energy sector ("accelerator effect"). In addition, the "environmental Kuznets curve" (EKC) hypotheses that at higher levels of development, structural change toward information-intensive industries and services, international relocation of manufacturing industries, increased environmental awareness, and better enforcement of environmental regulations should result in larger environmental expenditures and a gradual decline of environmental degradation. The theoretical underpinnings of this EKC have been intensively debated (Stern, 2004). Nevertheless, several authors have found that while increases in GDP may be associated with worsening environmental conditions in poor countries, economic growth tends to be associated with lower pollution once a critical level of income is reached (Cropper and Griffiths, 1994; Grossman and Krueger, 1994; Selden and Song, 1994, and Stern et al., 1996). To capture these relationships, the

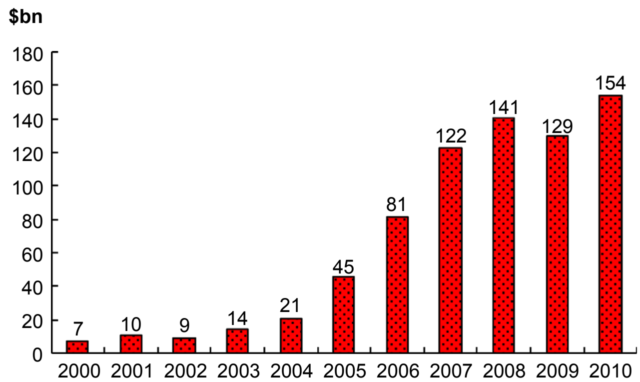

Fig. 5. Renewable green investment, 2000–2010.
Source: BNEF.

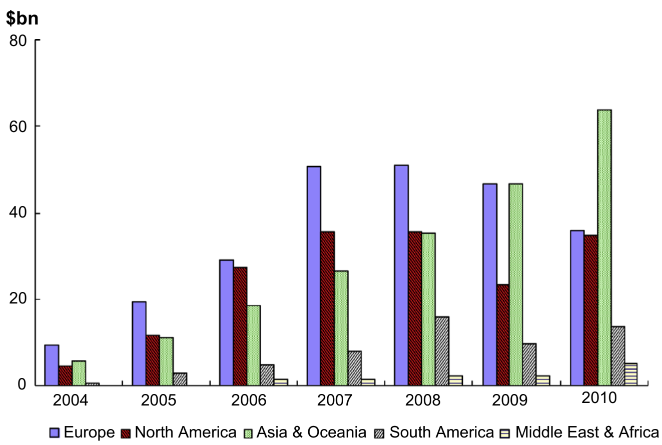

Fig. 6. Renewable green investment by region, 2004–2010.
Source: BNEF.

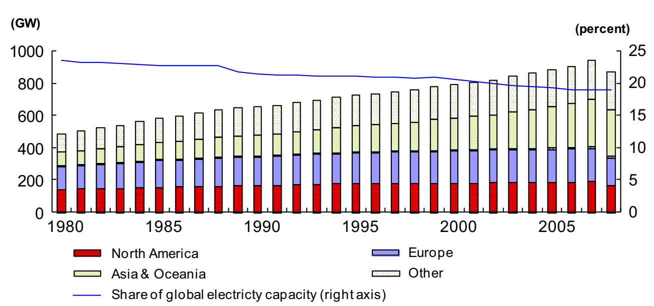

Fig. 7. Installed hydroelectric capacity, 1980–2008, (In GW and as a share of global electricity capacity).
Source: U.S. Energy Information Administration. Note: "Other" comprises Africa, Eurasia, Middle East, and South America.

econometric analysis uses GDP and GDP per capita (both in level and growth rate).

5.1.2. Population

Population variables could have an impact on GI beyond that of economic growth, as parts of fuel consumption and land use do not pass through formal markets, especially in developing countries (for instance, consumption of fuel woods). Countries with rapidly increasing populations face important energy needs, which are not always well reflected by GDP growth. These needs require investment in alternative energy sources, especially when fossil fuels are scarce or relatively expensive, and/or when renewable resources are abundant (like water in China). In addition, countries may encourage investment in green technologies to offset increases in gas emissions unrelated to production. We expect a positive relationship between population and GI, as is found in other, more general, equations for investment (e.g., Baldacci et al., 2008).

5.1.3. Technological progress and innovation

The expansion of GI has also been made possible by innovation. For instance, new techniques to store energy have fostered the use of intermittent energy sources, like solar or wind power. More generally, the "digital divide" literature shows that investment in new technologies is highly dependent on technical advances and the level of human capital (Guerrieri et al., 2010). Skilled workers are more capable of learning how to use new technologies and are more flexible with respect to their job assignments. We expect GI to be positively related to R&D spending and human capital variables (proxied by the spending on and enrollment in tertiary education in the econometric analysis).

5.1.4. Interest rates

High interest rates reflect the relative scarcity of financing and tend to reduce investment. Renewables should be particularly sensitive to interest rates because the bulk of the cost of producing renewable energy is upfront, and because their capital intensity is generally high compared to traditional technologies. We expect a negative relationship between interest rates and GI. In the empirical analysis, we test the significance of variables measuring the availability and cost of financing, including: nominal, real, short- and long-term interest rates, domestic credit provided by banks, and bank capital ratios.

5.1.5. The cost of fossil energy sources

High fossil energy prices are expected to foster GI, not only because our GI indicator encompasses investment in the biofuel industry, but also because higher fuel prices lower the cost of the electricity produced from renewables and nuclear power relative to that generated through fossil fuel combustion. This effect is reinforced when carbon emissions are taxed. Newell et al. (1999) show that oil price hikes boosted innovations in green technologies that made air conditioners more energy efficient. Popp (2002) provides evidence of the impact of energy prices on patents for energy-saving innovations. In the econometric estimation, we use the international prices of crude oil and coal, and the domestic price of gasoline, to measure the cost of brown capital. In addition, we test the effect of energy dependence (share of imported energy), and of carbon emissions. More polluted or energy-dependent countries may face stronger incentives to invest in green technologies.

5.1.6. The production cost of green capital goods

The demand for investment should be inversely related to its cost. We include several cost variables in the equation, such as unit labor costs, wages, cost of starting a business, and corporate income tax.

5.1.7. Profit

If agents have static expectations, the current profit ("cash flow") will be the best predictor of future profits ("profitability"), and as such, will become a determinant of investment. In addition, both variables are related when firms are credit-constrained and have to retain cash flows for investing, or if the access to credit is conditioned by the firm's financial situation (Blanchard, 2008; Lamont, 1997).

5.1.8. Public policies to support green investment

Public interventions are necessary to correct market failures stemming from carbon emission externalities. We construct four (time-varying) dummy variables, measuring whether country i in year t implements one of the four main policy instruments: feed-in-tariffs, renewable portfolio standards, biofuel mandates,[17] and carbon pricing schemes[18] (described in Section 3.2). As these policies are more likely to be conducted by governments that are sensitive to environmental issues, we also search for a potential relationship between GI and green parties.

5.1.9. Geophysical conditions

GI should also depend on the availability of natural resources, such as the number of hours of sunshine in a year, or the water and wind supply available. The impact of these variables cannot be assessed in the next section owing to data and econometric constraints (most of these variables, being time invariant, are absorbed in the fixed-effect term, and their specific effect cannot be estimated by the least square dummy variable estimator).

5.2. Empirical model and econometric results

A panel approach is used to identify the determinants of GI and estimate their effect. In this section, GI is measured as financial investment in renewables (using the BNEF database). The panel includes 35 countries over 2000–2010. Although the sample is driven by data availability, the BNEF database is comprehensive, and covers all countries with significant investment in renewable energy.

The following model is estimated in real terms,[19] using the fixed-effect methodology,[20]

$$y_{it} = a_i + \sum_{k=1}^{K} \beta^k * X_{it}^k + \varepsilon_{it}$$

where y_{it} denotes GI (in log), X_{it}^k signifies the covariates described in the previous section, and a_i represents country-specific fixed effects.

We tested the significance of a large set of covariates (described in Table 4). Our preferred specification is reported in the first column of Table 5. It is both robust and parsimonious – a necessity given the small sample size –, and explains a higher share of the sample variance (as measured by the within-country R2) than alternative specifications. The regression includes six statistically significant explanatory variables which are: (i) GDP per capita in constant dollars, (ii) the long-term nominal interest rate, (iii) the relative price of international crude oil,[21] (iv) the FIT dummy, (v) the carbon pricing mechanism variable, and (vi) the population. Variables are in logarithm form (except the dummies and the population variable). Some enter the equation with a lag to allow sufficient time for GI to respond to its determinants.

We estimate our preferred model using robust standard errors (column 1), as the Wald test for groupwise heteroskedasticity rejects the hypothesis that error variances are identical across countries. Using robust standard errors, however, does not affect significantly the results: column 1 shows the regression with robust errors (clustered at the country level); column 2 shows the same regression without correction. All other columns are estimated with cluster-robust standard errors. In addition, there is no evidence of multi-collinearity in the preferred model, according to variance inflation factors (all below 3) and tolerance values (all above 0.5).

Table 6 provides descriptive statistics on the variables used in the econometric analysis. The regressions use about two-thirds of the available observations. In particular, the preferred specification drops about 145 data points for three main reasons. First, using lagged variables (in particular the second lag of FIT) removes 70 observations. As the main objective of the paper is to test the effect of public policies, it is important to keep the FIT variable despite the loss of degrees of freedom. As a robustness check, we estimate the equation of column (1) without FIT, and the coefficients of the other variables remain broadly unchanged and are all significant (results not reported). Second, some data are missing for the long-term nominal interest rate, removing about 45 observations; in particular, the IFS and WEO databases do not have data for China, Chile, and India. As the long-term interest rate is one of the key drivers of investment in theoretical models, our preferred specification still includes it. In an alternative specification, we use instead the short-term interest rate, which is less relevant economically, but is available for China; the results, reported in Table 5 (column 7), are not fundamentally affected. We also run the regression without the interest rate variable and the main results remain unchanged (not reported). Finally, using the logarithm of green investment removes about 60 observations, as some countries did not invest in green technologies at the beginning of the sample period (for instance, the Slovak Republic). Despite the loss of observations, we consider that the relationship should still be estimated in logarithm form. Indeed, theoretical models of investment are non-linear and investment equations are generally estimated in log form to capture this non-linearity. In addition, the use of logarithms allows interpreting estimated coefficients as elasticities. Most important, logarithms exclude observations with zero GI, thereby correcting for a potential specification bias. The decision to start investing in green technologies is fundamentally different from that of increasing/decreasing an existing stock of green capital. If the model was not in logarithm, a single equation would be used to estimate two separate structural relations. The downside is that using logarithms restricts the interpretation of the results: our model is not informative about the drivers of the initial investment in green technologies; it identifies the determinants of green investment for the subsample of observations with positive GI.[22]

In Table 5, the signs of the estimated coefficients are consistent with priors, as analyzed in detail in the following sections.

5.2.1. Income

Our results support the hypothesis that higher levels of income tend to boost investment in green technologies (column 1). Based on the estimated elasticity, an additional 1 percentage point of real GDP per capita growth raises real GI growth by about 4 percentage points in the long run, other factors being equal. To test the sensitivity of the result to the choice of the output variable, we re-estimate the model with GDP or the PPP GDP per capita. The

[17] Although the share of biofuels in GI has considerably decreased in recent years, it was a major component of GI during the last decade (Appendix C). In addition, biofuel mandates constitute a very widespread policy (REN21 2010).

[18] The carbon pricing proxy is a time-varying categorical variable taking the value 0 if the country has neither a carbon tax nor a cap-and-trade system in year t, 1 if the country has one of the two schemes, and 2 if the country has both.

[19] Series in current dollars are converted into constant 2000 dollars to correct for domestic inflation and exchange rate movements.

[20] We use a fixed-effects estimator, although some of our variables are non-stationary. Kao (1999) and Phillips and Moon (2000) show that this estimator is consistent in non-stationary panels, even in the absence of co-integration. In support of this prediction, we find that the estimated coefficients of the covariates do not change significantly when the equation is estimated in levels or in ratios (see text).

[21] The relative price is computed as the ratio of the international crude oil expressed in domestic currency to the domestic GDP deflator.

[22] The three effects partially overlap. That is why the total loss of observations (145) is lower than the sum of the effects of each factor (70 + 45 + 60).

Table 4
List of variables, definitions, and sources.

Variable	Definition	Source
Renewable investment	Financial investment in renewables, excluding large hydro projects, in billions of dollars	BNEF
GDP	Nominal and real GDP in dollars and domestic currency, in billions	WEO
GDP per capita PPP, constant	In billions of dollars	OECD
Population	In millions	WEO
Inflation	GDP deflator	WEO
Internal gasoline price	In dollars per liter	Reuters
Crude oil price	Simple average of three spot prices: Dated Brent, West Texas Intermediate, and the Dubai Fateh, US$ per barrel	WEO
Domestic gasoline price	In dollars per liter	IMF FAD
Wage	Compensation of employees, in billions of dollars (National Accounts)	OECD, Economic Outlook
Unit labor cost	Total economy, 2005 base	OECD, Economic Outlook
Profit	Gross operating surplus and mixed income, in millions of dollars (National Accounts)	OECD, Economic Outlook
Cost of starting a business	Percent of per capita income	Doing Business indicators, WDI
Interest rates	Nominal and real, short-term and long-term	WEO, IFS
Tax on business	Tax paid by businesses in percent of profit	Doing Business indicators, WDI
Fossil fuel use	Fossil energy use, percent total energy use	WDI
Green parties	Share of votes and share of seats	Comparative political dataset
Domestic credit	Domestic credit to the private sector (percent of GDP)	IMF IFS
Bank capital	Bank capital-to-asset ration	IMF GFS report
Energy dependency	Net energy imports, percent of energy use	WDI
Carbon emissions	Per capita metric tons	WDI
R&D	Expenditure for R&D, percent of GDP	WDI
FIT	Dummy (0=no FIT)	IMF staff
RPS	Dummy (0=no RPS)	IMF staff
Biofuel mandates	Dummy (0=no mandate)	IMF staff
Carbon pricing schemes	Categorical viable (0=neither carbon tax nor cap-and-trade; 1=neither; 2=both)	IMF staff
Spending on tertiary education	Public expenditure per student, percent of GDP per capita	UNESCO, WDI
Enrollment in tertiary education	Gross enrollment, in percent of relevant age group	UNESCO, WDI
Coal price	Australian coal; 2005-based index (US$ per Mt)	WEO

income elasticity remains broadly unchanged (columns 3 and 4). Population is also found significant in almost all specifications, suggesting that the GDP variable does not fully captures energy needs, and non-market energy consumption exists in our sample of advanced and emerging economies. In contrast, GDP growth and technological progress variables (R&D and tertiary education) are not found to be significant.

5.2.2. Interest rate

The cost of capital has a significant and negative impact on GI. Consistent with theory, our preferred specification includes the long-term interest rate, as investment and saving decisions are generally based on medium- to long-term plans. In the regression with the highest R2 (column 1), the interest rate enters in logarithmic form which complicates the interpretation of the results. Based on an alternative regression where we measure this variable in levels (that is not in logarithmic form) (column 5), the estimated semi-elasticity of the interest rate appears to be quite large: GI declines by about 15% when the nominal interest rate increases by 1 percentage point. In contrast to the empirical literature on business investment, which finds that investment is relatively insensitive to real interest rates (Taylor, 1999), GI seems to be very responsive to interest rate movements. This result, which is well documented in descriptive studies (BNEF, 2011b), is not surprising given that renewable projects are capital intensive and rely mostly on external financing. In theory, investment decisions should depend on the real interest rate (rather than the nominal rate), as the relevant cost of capital should incorporate inflation expectations. The long-term real interest rate is found significant with a lag, and the elasticity has the same order of magnitude, but the R2 is smaller than in the preferred specification (column 6). In contrast, short-term real interest rates are less significant and stable, consistent with the notion that investment decisions in this area usually rely on multi-year financing plans (column 7). Apart from the interest rate, other cost variables (wages, taxes, cost of starting a business) were found to be insignificant.

5.2.3. Fuel prices

Our preferred specification includes the relative price of crude oil rather than coal, as the former price better reflects the cost of fossil fuel energy.[23] Crude oil prices have a positive and large impact on GI with a lag (column 1): higher relative fuel prices increase the return to GI by raising the relative cost of electricity production based on fossil fuel combustion. Based on the coefficient estimate, GI grows about by an additional percentage point when there is a 1 percentage point differential between increases in crude oil prices and economy-wide inflation (as proxied by the GDP deflator). In an alternative specification, coal (instead of crude oil) is also significant, but with a weaker and less robust impact on GI (column 8). In order to take into account country-specific energy pricing policies, we also run a model with domestic gasoline prices, which are significant, but also sensitive to specification changes (results not reported). However, we do not find evidence that energy dependence encourages countries to invest in green technologies. We could also not find any direct impact of

[23] Despite the predominant use of coal in electricity generation, our preferred specification includes crude oil, to better capture the substitution effect between gasoline and biofuels, and also because crude oil is a reference price in fossil fuel markets (for example, natural gas prices are often indexed to oil prices). In addition, international trade is less important for coal than crude oil, so that our coal reference price—the Australian thermal coal price—is an imperfect proxy for domestic coal prices in some countries (for instance in the United States).

Table 5
Green investment determinants.

Variables	Preferred specification	Alternative specifications and robustness checks								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable: Log(GI)[a]	Level	Level	Ratio	Level	Level	Level	Level	Level	Ratio	Level
Log(GDP per capita)	4.14**	4.14**			3.34	3.66*	4.71**	3.63*	3.14*	4.00**
	(2.28)	(2.27)			(1.65)	(1.82)	(2.30)	(1.72)	(1.72)	(2.13)
Log(LT nominal interest rate)	−1.45***	−1.45***	−1.64***	−1.61***					−1.44***	−1.49***
	(−2.89)	(−3.04)	(−3.28)	(−3.25)					(−2.86)	(−3.04)
Log(relative crude oil price){1}	0.89**	0.89***	0.91**	1.12***	0.97**	0.85**	1.17***		0.86**	0.85**
	(2.46)	(2.71)	(2.56)	(3.42)	(2.52)	(2.57)	(3.12)		(2.39)	(2.31)
FIT{2}	0.98***	0.98***	0.89**	0.97**	0.98***	1.12***	0.91**	0.94**	0.96***	1.10***
	(2.95)	(3.48)	(2.57)	(2.70)	(2.85)	(3.18)	(2.23)	(2.64)	(2.87)	(3.21)
Carbon pricing schemes[b]	1.26***	1.26***	1.20***	1.15**	1.33***	1.17**	0.92*	1.03**	1.26***	
	(2.84)	(3.80)	(2.76)	(2.67)	(2.80)	(2.44)	(1.84)	(2.42)	(2.84)	
Population	0.09**	0.09*			0.08*	0.09***	0.08**	0.07**	0.08**	0.09**
	(2.11)	(1.81)			(1.90)	(2.75)	(2.17)	(2.62)	(2.04)	(2.19)
Log(GDP)			4.36***							
			(2.74)							
Log(GDP per capita PPP)				4.42***						
				(3.00)						
LT nominal interest rate					−0.14**					
					(−2.08)					
LT real interest rate{1}						−0.12***				
						(−3.35)				
Log(ST nominal interest rate){1}							−0.16*			
							(−1.77)			
Log(LT nominal interest rate){1}								−2.37***		
								(−4.53)		
Log(relative coal price){1}								0.58**		
								(2.14)		
Carbon pricing schemes{1}[b]										1.06***
										(3.02)
R2	0.44	0.44	0.43	0.44	0.43	0.42	0.39	0.44	0.41	0.43
OBS	241	241	241	232	241	250	249	250	241	241

Note: Annual data over 2000–2010; fixed-effects estimation; robust t-statistics in parentheses; ***(**, *)=significant at the 1 (5, 10) percent level. X{1} refers to first lag of the variable, X{2} to the second lag.

[a] Level: Log (GI); ratio: Log (GI/GDP).

[b] Dummy taking the value 1 if a country has both a cap-and-trade and a carbon tax; 0 otherwise.

Table 6
Descriptive statistics of the variables used in the regressions.

Variable		Obs	Mean	Std. Dev.	Min	Max
Original variables	Green investment[a]	385	1.2	3.6	0.0	29.5
	GDP per capita	385	19985.3	12834.0	460.3	56577.7
	GDP	385	918.7	1964.1	8.7	11741.8
	GDP per capita PPP	369	23944.1	11048.6	1517.7	65140.2
	LT nominal interest rate	339	6.1	6.8	1.0	93.2
	ST nominal interest rate	351	4.6	5.8	0.0	70.0
	LT real interest rate	308	2.6	3.5	−5.5	40.2
	Relative crude oil price	385	2633.0	9398.4	15.8	88377.8
	Relative coal price	385	6016.5	22486.3	31.9	242184.6
	FIT	385	0.5	0.5	0.0	1.0
	Carbon pricing scheme V1[b]	385	0.6	0.8	0.0	2.0
	Carbon pricing scheme V2[c]	385	0.2	0.4	0.0	1.0
	Population	385	108.6	280.8	0.3	1341.4
Variables in preferred specification	Log(green investment)	327	−1.4	2.1	−8.3	3.4
	Log(GDP per capita)	385	9.6	1.0	6.1	10.9
	Log(LT nominal interest rate)	339	1.6	0.5	0.0	4.5
	Log(relative crude oil price){1}	350	4.9	2.1	2.8	11.4
	FIT{2}	315	0.4	0.5	0.0	1.0
Variables in alternative specifications	Log(GDP)	385	5.7	1.5	2.2	9.4
	Log(GDP per capita PPP)	369	9.9	0.7	7.3	11.1
	LT real interest rate{1}	286	2.6	3.5	−5.5	40.2
	Log(ST nominal interest rate){1}	318	1.1	1.2	−6.9	4.2
	Log(LT nominal interest rate){1}	317	1.6	0.5	0.0	4.5
	Log(relative coal price){1}	350	5.7	2.1	3.5	12.4

[a] Green investment is in billions of dollars.

[b] Categorical variable for countries having either a carbon tax or a cap-and-trade or both.

[c] Dummy variable for countries having both a carbon tax and a cap-and-trade.

carbon emissions on GI, probably because this effect is already captured by the carbon pricing variable.

5.2.4. FIT and carbon pricing schemes

Finally, we tested the impact of the four policy support variables. Renewable portfolio standards and biofuel mandates do not seem to affect GI in our sample. In contrast, the FIT variable has a statistically significant effect with a lag (column 1). This result supports the view that FITs are one of the most important instruments supporting the expansion of renewables. Given that the FIT variable is a dummy, the estimate means that GI (in log and in real terms) is higher by about 1 point in countries with FITs. GI should therefore be two to three times larger in countries adopting FITs, other factors being equal. The carbon pricing scheme variable is not significant in the regression with robust errors. But if this variable is split into two dummies (one identifying countries with either a carbon tax or a cap-and-trade, the other one identifying countries with both schemes), the second dummy is highly significant in all specifications. The results of Table 5 show that GI is higher by about 1.25 point in countries with both a carbon tax and cap-and-trade, indicating that GI should be about three times larger in these countries. The effect of green parties is insignificant in most specifications.

As indicated above, our results are robust to several alternative specifications. The sign, magnitude, and significance level of the aforementioned variables remain broadly unchanged when the model includes additional variables. Results are also robust if (i) we change the start and end dates of the sample, (ii) emerging countries are excluded from the sample, (iii) the model is estimated in nominal terms, or (iv) the explained variable is the GI-to-GDP ratio, rather than GI (column 9). We also re-estimated the model with de-trended variables to ensure that previous results are not distorted by the omission of a deterministic trend; the estimated coefficients are not fundamentally affected, although the R2 is smaller. The fall in GI during the financial crisis seems to be consistent with fundamentals, as the 2009 time dummy is not significant. The Hausman test of random versus fixed effects also suggests that the fixed effect model is the preferred specification (Table 7 reports the results of all specification tests). Finally, we do not correct for a possible endogeneity of GDP, as the reverse causality from investment to GDP is expected to be weak, given the relatively small size of the renewable sector. The two policy variables may also create an endogeneity bias, as policy decisions are partly motivated by the evolution of green investment. However, the fact that FIT enters the equation with two lags mitigates this risk. Regarding the carbon pricing scheme variable, we run an alternative regression with its lagged value, and the results are only slightly affected, with the R2 being slightly smaller than in the preferred regression (column 10).

Table 7
Specification tests.

Collinearity diagnostics			
Variable	VIF	SQRT VIF	Tolerance
Log(green investment)	1.6	1.3	0.6
Log(GDP per capita)	1.9	1.4	0.5
Log(LT nominal interest rate)	2.1	1.4	0.5
Log(relative crude oil price){1}	1.1	1.0	0.9
FIT	1.2	1.1	0.8
Population	1.7	1.3	0.6
Carbon pricing schemes[a]	1.1	1.1	0.9
Modified Wald test for groupwise heteroskedasticity			
chi2 (32)=8239.59			
Prob > chi2=0.0000			
Breusch and Pagan Lagrangian multiplier test for random effects			
chi2(1)=96.96			
Prob > chi2=0.0000			
Hausman test			
chi2(5)=147.24			
Prob > chi2=0.0000			

[a] Dummy taking the value 1 if a country has both a cap-and-trade and a carbon tax; 0 otherwise.

6. Conclusion and policy implications

Our study contributes to the economic literature on GI in three main ways. First, we propose a measurable definition of GI. Second, we analyze the trends in GI and underline important changes in country leadership in the GI sector. Third, we conduct the first econometric assessment of the macroeconomic drivers of GI, which yields important insights for policy design.

Our results suggest that renewable GI has become a global phenomenon. At the same time, the regional composition of GI has changed dramatically in recent years. Asia, led by China, is increasingly important. China became the country with the highest investment in renewables in 2009, and has invested more in renewable energy than Europe as a whole in 2010. This shift in leadership reflected, to a large extent, differences in macroeconomic performance.

Our results imply that GI can be powerfully influenced by public policies. While macroeconomic factors such as economic growth and interest rates matter so too do energy policies. GI increases when its cost, relative to traditional fossil fuel technologies, is reduced by higher oil prices. This implies that higher taxation of fossil fuels to address negative externalities associated with their use, or a reduction in subsidies, would help foster green investment.[24] The boost to GI from higher energy prices could be quite large: a 10% increase in fuel prices – assuming other prices in the economy were to remain constant – could lead to a 10% increase in GI.

Specific public interventions to support GI can also be useful. The econometric results suggest that feed-in-tariffs and carbon pricing mechanisms tend to support GI. FIT stands out as one of the most important instruments for supporting the expansion of renewable energy, with GI being two to three times larger when countries adopt such a scheme (other factors being equal). Many policies, however, do not seem to be effective, including support for biofuels. This adds further to concerns regarding the effectiveness of biofuel subsidies and their adverse effects on food supply (IMF, 2008c, 2008d; Jones and Keen, 2009).

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Appendix A. Green Investment in Economic and Business Publications

GI in this study differs from other concepts used in the climate change and environmental literature:

[24] See Coady et al. (2010) for an overview of developments in fuel subsidies.

- Few insights into GI can be gained from macroeconomic studies. The macroeconomic approach to climate change has focused on the output or consumption costs of reducing GHG emissions. These studies are intended to inform the setting of objectives and the choice and design of delivery mechanisms, such as carbon taxes, or permit trading schemes. IMF (2008a), for example, explicitly models the impact of a carbon tax on total investment, but capital is not differentiated by type (e.g., "green" or "brown").
- A vast forward-looking literature estimates mitigation and adaptation costs to climate change and needed investments. Most studies compare two scenarios by 2030: a business-as-usual (or reference) scenario, in which emissions and temperature increase sharply, and a normative scenario designed to meet a certain climate target (IEA, 2010). Reports measure incremental investment needs compared to the business-as-usual scenario.[25] Generally, the needed investment is computed using climate models (see World Bank 2009 for a model review).
- The term GI is also commonly used by development banks, but this is not directly relevant to our study. Countries with commitments under the Kyoto Protocol face several options to reduce greenhouse gas emissions. One is to acquire emission reduction credits from other countries through a procedure called "emission trading." A Green Investment Scheme (GIS) is one type of contract within the framework of the international emission trade market. Most economies in transition do not exhaust their Kyoto quotas and have carbon emission credits to sell to countries that exceed their quotas. Under the GIS, the proceeds from the sale of surplus assigned emission amounts by transition economies are "greened," which means they are reinvested locally in mitigation projects. GIS are not yet precisely defined or requested by the Kyoto Protocol, but countries can sign such agreements on a voluntary basis. Some development banks are actively involved in the development of GIS (see Tuerk et al., 2010).

Appendix B. The New Energy and Finance Database

The BNEF database is the most comprehensive source of information on finance in the renewable energy sector available. It covers 32,500 organizations, 21,500 projects, and 17,000 transactions. The database also records information on the type, location, and timing of investments in green technologies such as biomass, geothermal, wind (more than 1 MW), solar (more than 0.3 MW), biofuel, marine, and small scale hydro (between 0.5 and 50 MW). BNEF only includes the investment figure when a project/business is completed or becomes operational. BNEF does not report investment on large hydro and nuclear projects. Public investment is also largely not recorded.

BNEF provides limited data on energy efficiency investments (for instance, investment in energy smart technologies). However, these are highly incomplete and exclude some mainstream investments (for example, energy efficiency technologies in buildings and industrial equipment are not included).

BNEF has separate investment data on corporate and government R&D and small projects (such as micro wind turbine, solar rooftop and solar water heaters). This data is not included in the general trend discussion in Section 4.1, and is addressed separately in Appendix D.

Appendix C. Trends in Key Renewable Technologies[26]

Renewable GI (excluding large hydro projects) is dominated by wind power. However, solar, biomass, and biofuels are also fast-growing technologies (Appendix Fig. C1). Together, these four technologies accounted for over 90% of total renewable GI in 2010.

Wind power is the most commercially viable renewable technology. It represented on average about half of total renewable GI over 2004–2010. Compared to other renewable technologies, wind investment has experienced steadier growth due to technology maturity, lower risk, policy support (especially under the form of FITs), and cheaper capital costs. Wind also proved more robust in the face of the economic slowdown, sustaining growth rates of 22% and 14% in 2008 and 2009, respectively. Most investment in renewable energy now goes into wind power. Recent increases are almost exclusively due to a boom in wind projects in China, which toppled the United States and became the largest investor in this technology in 2009 (although installed capacity is still larger in the United States).

To date, solar is the second-most invested technology after wind. Investment in solar power increased 11-fold between 2005 and 2008, but suffered a significant correction in 2009 (by 24%) and stagnated in 2010. The decline was due to several factors. These included a shortage of financing, with solar being perceived as a less mature and higher-risk technology; a sharp drop in solar equipment prices as the whole industry shifted suddenly from excess demand to excess supply; and less favorable public support in Spain, one of the most important markets.

Biomass, the second-largest technology in the early 2000s, lost its leading role owing to less supportive public policies and feedstock-related bottlenecks (long-term availability and price security cannot be guaranteed by suppliers, and prices lack transparency, as biomass is mostly bilaterally traded). Nonetheless, it showed some resilience in 2009, which could reflect the perception by investors that this is a more mature technology (BNEF, 2010c). Investment in biofuels boomed in 2005 and 2006, having been supported by aggressive policies,[27] but has since stalled due to high feedstock prices and over-capacity, particularly in the United States. In 2009, the biofuel industry was severely affected by the fall in oil prices and lower overall demand for oil that limited the amount of biofuels that could be absorbed by gasoline and diesel blending pools. Investment was also deterred by higher crop and output prices, concerns about the environmental sustainability of production, as well as the impact on overall greenhouse gas emissions and food prices (IEA, 2009).[28]

Appendix D. Research and Development in Green Technologies

R&D in green technologies is an important component of GI. R&D can also be measured using the BNEF database, although it does not cover R&D in large hydro power

[25] This investment need is not a measure of GI: First, the reference scenario also incorporates mitigation measures. Second, incremental investment results from the combination of higher green investment and lower "dirty" investment (for instance, investment in fossil fuel supply is significantly scaled down in the IEA 450 scenario).

[26] This appendix is based on data from the BNEF database. Investment data on GI components is less reliable (and insignificant) before 2004 in this database.

[27] According to Global Subsidies Initiative (2010b), EU governments provided around $5 billion in public support in 2006, principally in the form of excise tax credits, while direct support to the industry in the United States amounted to $8–$10 billion.

[28] Large increases in biofuel production in the United States and Europe could be a driving factor behind the steep rise in global food prices, as corn is a food as well as a fuel (on the food vs. fuel controversy, see Mitchell, 2008; IEA, 2008, and IMF, 2008a).

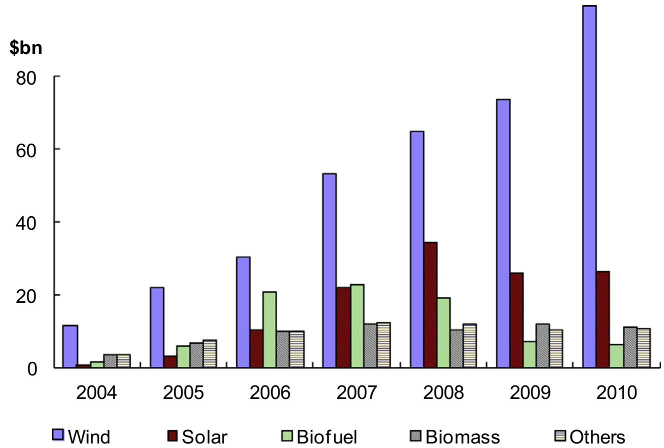

Fig. C1. Renewable green investment by technology, 2004–2010.
Source: BNEF

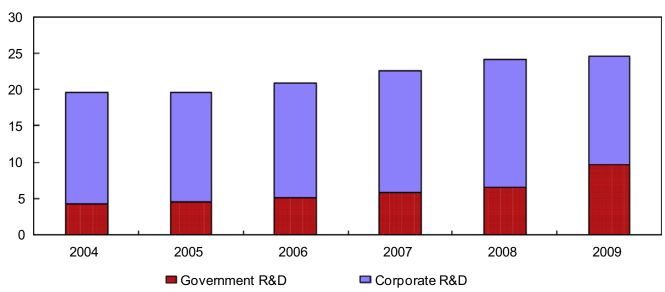

Fig. D1. Public and private R&D in the world (billions of dollars).
Source: BNEF

R&D in renewable energies has steadily increased since 2004[29] and was broadly constant in nominal terms in 2009 despite the crisis (Appendix Fig. D1). That year, the increase in public R&D, as supported by stimulus plans, more than offset lower private spending. BNEF (2010c) estimates that, on average, 14% of the green stimulus was allocated R&D.

Europe and the United States are the largest investors in renewable R&D, respectively, with $12 billion and $7 billion in 2009. Private sector R&D accounted for the majority of European spending ($8 billion out of $12 billion), whereas R&D was more equally distributed in the United States ($4 billion for public R&D out of $7 billion).

In terms of technology, R&D mainly focuses on improving the energy efficiency of existing processes rather than bringing new technologies into the market. In 2008, 70% of total R&D was allocated to energy-smart technologies.[30]

Amounts allocated to R&D on renewables remain small compared to nuclear power. In the sample of IEA countries, public R&D on renewable energy – although comparable in size with fossil fuel R&D – accounted for only one-third of the financing given to nuclear power in recent years (IEA, OPEC, OECD, and WB joint report 2010). This seems surprising, given that many renewable technologies are still in early stages of development and need significant research funding. The fact that R&D spending is relatively small and concentrated on energy efficiency may be a source of concern for the further deployment of new technologies (IEA, 2008).

[29] BNEF provides data on R&D starting in 2004.

[30] These technologies include, for instance, efficient lighting and insulation, smart grids, new batteries, and hybrid or electric vehicles.

Appendix E. Country List

The 35 countries covered in the econometric analysis are Australia, Austria, Belgium, Brazil, Canada, Chile, China, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, India, Ireland, Italy, Japan, Korea (Republic), Luxemburg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

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