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Assessing 'Green Energy Economy' stimulus packages: Evidence from the U.S. programs targeting renewable energy

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*Published in:*  
Renewable & Sustainable Energy Reviews

*DOI:*  
[10.1016/j.rser.2014.10.060](https://doi.org/10.1016/j.rser.2014.10.060)

2015

[Link to publication](#)

*Citation for published version (APA):*  
Mundaca, L., & Richter, J. L. (2015). Assessing 'Green Energy Economy' stimulus packages: Evidence from the U.S. programs targeting renewable energy. *Renewable & Sustainable Energy Reviews*, 42, 1174-1186.  
<https://doi.org/10.1016/j.rser.2014.10.060>

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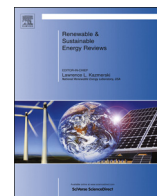
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## Renewable and Sustainable Energy Reviews

journal homepage: [www.elsevier.com/locate/rser](http://www.elsevier.com/locate/rser)

## Assessing ‘green energy economy’ stimulus packages: Evidence from the U.S. programs targeting renewable energy



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## ARTICLE INFO

## Article history:

Received 19 June 2014

Received in revised form

26 September 2014

Accepted 20 October 2014

## Keywords:

Renewable energy

Green energy economy

Policy evaluation

Indicators

Stimulus policy programs

The United States of America (USA)

## ABSTRACT

The paper provides a comprehensive empirical assessment of American stimulus policies aimed at renewable energy (RE) technologies. We use an indicator-based methodology to assess progress with respect to energy, environmental and socio-economic issues resulting from RE stimulus programs linked to the American Recovery and Reinvestment Act, and review and analyze the emerging but scattered literature. Overall, our results indicate that stimulus programs have had a positive effect on the RE sector. This is despite the fact that they were originally planned to work in combination with a greenhouse gas ‘cap-and-trade’ system, which has not been implemented. From the methodological perspective, our approach is resource-intensive and our analysis highlights numerous challenges, notably related to causality and additionality. Despite these limitations, this research improves our understanding of the broad effects and impacts of RE stimulus programs.

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## 1. Introduction

The 2008–2009 global financial crisis increased policy attention on the concepts of ‘Green Economic Growth’, the ‘Low-Carbon Economy’, and a ‘New Green Economy’. Together with the subsequent economic crisis – the worst in decades – the global financial crisis led to numerous economic pledges that aimed at reforming the economy towards a path much less damaging to the environment, society, and the economic system itself. Consequently, economic recovery packages were implemented in numerous countries to stimulate green growth, create jobs and support low-carbon economies. These stimulus packages were quickly portrayed as a golden opportunity to create a New Green Economy, in which the green energy sector would play a vital role [1]. Green (or low-carbon) energy was the target of recovery packages in many countries, and China and South Korea soon became the world leaders in green spending. In the United States (U.S.), direct financial support for clean energy technologies accounted for approximately US\$ 92 billion of the US\$ 840 billion included in the American Recovery and Reinvestment Act (ARRA) [2]. Of this, renewable energy (RE) accounted for approximately US \$ 21 billion. This direct ARRA spending was allocated to laying the foundation for a green (or clean) energy economy.

While the ‘clean energy’ stimulus was the subject of much attention, enthusiasm, and promise [3–7], there have been few holistic evaluations of the performance of the policies that were promoted or introduced as a result [8]. Our review of studies shows that there is an emerging but rather fragmented body of knowledge about the U.S. green energy stimulus programs. For instance, Barbier [9] examined various energy efficiency policies included in stimulus packages at national level (in general) and U. S. stimulus policies (in particular). Other U.S. renewable energy policies (mainly the Treasury 1603 program and Department of Energy loan programs) have been evaluated in terms of stimulus principles suggested by American economists, namely that they should be “timely, targeted, and temporary” [10]. However, it has been argued that the timely and temporary aspects have been overstated, and that stimulus packages should be considered in broader terms (see e.g. [11]). Similarly, other evaluations of U.S. stimulus policies have focused on a few criteria that address only one or two areas of a green economy (e.g. energy installations and/or employment effects) [2,12–20]. While informative, our review of this literature reveals that there has been no comprehensive ex-post analysis of the U.S. stimulus package, and several questions remain unanswered. For instance, how does the RE stimulus package perform in broad terms? What are the critical conditions or aspects that affect overall performance? What are the strengths and limitations of the methods used to assess the inclusive impacts of RE stimulus programs?

This paper provides answers to these questions and our analysis provides a better understanding of the broad effects of the RE stimulus program in practice. The objectives of this paper

are threefold. First, it provides an ex-post assessment of the American ‘Green Economy’ stimulus policies addressing RE technologies. To that end, we present a wide-ranging empirical analysis of their performance. Our approach encompasses key areas related to a Green Energy Economy (GEE), which is hereby defined as the study of how an economic system can pursue sustainable development through the expansion of green (or clean) energy systems and markets. Secondly, we review and bring together the growing but scattered literature related to U.S. stimulus programs that target RE. Where possible, we compare ex-ante research with ex-post findings. Thirdly, and taking into account the methodological challenges (details in the next section), we discuss our key findings and the compatibility, reliability, and measurability of the indicator-based method we applied. To the best of our knowledge, the analysis presented in this study is the first application of a wide-ranging evaluation framework for measuring progress towards a GEE at the national level. In turn, our paper contributes to the emerging field of ‘Energy-based Economic Development’ [8].

The paper is structured as follows. Section 2 outlines the methodology, including the background and key details of our case study. Section 3 presents the main findings. Results are grouped according to the following dimensions: (i) energy, (ii) environment, and (iii) economic and social aspects. In Section 4 we discuss some key findings and the appropriateness of the analytical framework in the light of our results and method. Finally we draw some conclusions in Section 5.

## 2. Methodology and materials

An important challenge when assessing progress towards a green economy has been the lack of consensus on an analytical framework and indicators. Reports from international organizations such as the United Nations Environment Programme (UNEP) [21], the Organization for Economic Co-operation and Development (OECD) [22,23], the World Bank [24], and the International Labor Organization (ILO) [25] that focus on green growth and the green economy acknowledge the ambiguities and differences between methods used to measure progress—in addition to conceptual issues.<sup>1</sup>

Approaches to the evaluation of green economy policies range from narrow considerations of job creation, patents [27], and expenditure on green initiatives as a proportion of gross domestic product (GDP) [28], to broader consideration of wider aspects of sustainable development [22]. Many international organizations have released reports on methodology [21,23–25], and many of these reports focus on the use and development of so-called

<sup>1</sup> For a comprehensive guide to publications by international organizations on green growth and the green economy see Allen and Clouth [26].

'Green Economy Indicators'. This approach seems to have its roots in the 2012 UN Conference on Sustainable Development (the Rio +20 Summit), in which Heads of State and their representatives recognized the importance of developing indicators to measure progress towards a green economy. This interest culminated in April 2013 in the development of a platform and scoping paper [29] for a standardized approach. The scoping paper outlines the challenges and limitations of developing a framework, and proposes a long list of multi-dimensional indicators that represent the three pillars (social, economic, and environmental) of sustainable development upon which the concept of the green economy seems to rest [29].

### 2.1. Analytical framework

Like the scoping exercise conducted by representatives from the Global Green Growth Initiative, the OECD, UNEP, and the World Bank, our approach began with an in-depth examination of existing frameworks for evaluating a green (energy) economy, including sustainability aspects [30,31]. We also reviewed measuring frameworks, methodologies and indicators developed on a national level, with a particular focus on the U.S. [8,27,32–35], together with the few examples of OECD green growth indicators applied in other national contexts [21,23,36]. Overall, it appears that indicator-based methods are increasingly used (or commonly proposed) to measure progress towards a green economy, in particular in the energy sector.

Amongst these analytical approaches, the energy-based economic development (EBED) framework, proposed by Carley et al. [8] proved the most suitable for our research in terms of suggested dimensions, indicators and metrics. In this context, energy refers to advanced, efficient and/or clean energy, which leads to economic development through changes to the energy system that deliver economic, social and environmental benefits [8,37]. As the U.S. green stimulus programs were largely focused on energy, the explicit definition of the term together with appropriate indicators, were particularly relevant to our examination of a GEE.

Here, we build upon and modify the EBED framework; specifically, as our focus is on renewable energy, energy efficiency indicators are omitted. We also take into account other 'green economy' and 'clean energy' indicators and frameworks, and incorporate the following dimensions, indicators, and metrics:

#### Energy dimension:

- Renewable energy investments (government investments by amount, % of stimulus, and type);
- Installed capacity (GW or MW) and generation ();
- Share of renewable energy (% of renewable in total energy production/generation);
- Domestic manufacturing capacity (investment by amount; domestic content %); and,
- Renewable energy patents (number by year and technology type).

#### Environmental dimension:

- Reduction of CO<sub>2</sub> emissions (t).

#### Socio-economic dimension:

- Job creation (number/year; job years);
- Access to renewable energy jobs/ job training (number and demographics of trainees); and,
- Earnings, economic output (US\$ dollars), returns (% return on investments) and energy costs (levelized cost of renewable electricity).

We were also guided by the Green Growth Knowledge Platform (GGKP) scoping report [29] and OECD principles for the selection of green growth indicators [22]. We thus used three criteria to assess the degree of suitability and inclusivity of the proposed indicator-based method. *Policy compatibility* focuses on the coverage of the key features of a green economy and here looked at whether the evaluation method provides a balanced treatment of the subjects under enquiry. *Reliability* addresses the consistency and analytical soundness of the method, including its effectiveness in communicating critical outcomes to stakeholders. *Measurability* focuses on the complexity of input and output data, specifically the intensity of data requirements.

### 2.2. Data collection

Data was collected from a variety of sources in order to improve objectivity and reduce uncertainty. We reviewed the academic literature and reports from international and national organizations on green economy metrics. We then constructed the analytical framework, and reviewed primary and secondary data from governments, independent reports and peer-reviewed literature on ARRA programs and the RE sector.

We also conducted over 20 interviews with experts in the U.S. to gather more data and discuss the figures, indicators and performance of RE stimulus programs. In many cases we interviewed the people who carried out the work used in our research; for example, researchers at the Political Economy Research Institute (PERI), the World Resources Institute (WRI), the Climate Policy Initiative (CPI), the Rhodium Group, the Information Technology and Innovation Foundation (ITIF), and the BlueGreen Alliance. We also interviewed advocacy groups and representatives from industry, e.g. Green for All and the Solar Electric Power Association (SEPA). Interviews were also conducted with government officials and researchers involved in specific ARRA programs at the Department of Energy, Lawrence Berkeley Laboratory (LBL), and the National Renewable Energy Laboratory (NREL).

### 2.3. Case study: Renewable energy stimulus programs in the U.S.

The American Recovery and Reinvestment Act (ARRA) was passed in February 2009. The stimulus package included a 'clean energy' or 'green' component of between US\$ 67 and US\$ 112 billion [38,39] and represented approximately 0.7% of GDP [28]. Depending on the definition of 'green', lower estimates tend to focus solely on clean energy, while higher estimates include water, waste and conservation funding. Government departments and agencies generally estimate that US\$ 92 billion of the overall US\$ 840 billion budget was appropriated for direct ARRA spending on clean energy. Of this, RE accounted for approximately US\$ 21 billion [2]. Programs and funding specifically targeted at RE comprised 23% of ARRA clean energy spending and 2.5% of the entire U.S. stimulus package.<sup>2</sup>

Along with the stimulus package and the 2010 budget, President Obama announced clean energy goals for the U.S. One was to double the installed capacity of RE generation by 2012 [40] and create over 300,000 jobs [41]. Another goal was to increase domestic manufacturing capacity for renewable energy and provide jobs in renewable energy supply chains. However, it was acknowledged that "it will take considerable outreach to make the opportunity to work in a green job widely available" [42]. Consequently, the stimulus package included training programs as a

<sup>2</sup> In addition to the ARRA, the Emergency Economic Stabilization Act (EESA) of October 2008 and annual Federal budgets for 2010–2012 included clean energy-related spending.

pathway to RE and other green jobs. These Federal programs and investments in basic research, development, and the deployment of technology helped to bridge the so-called “valleys of death” in innovation [43,44].

Some of the key RE programs that were supported by the package and fall within the scope of our analysis are outlined below:

### 2.3.1. Basic research programs

The stimulus package included funding for early-stage clean energy innovation, research and development; the prime example was the Advanced Research Projects Agency-Energy (ARPA-E) program,<sup>3</sup> which aimed to accelerate the pace of innovation in advanced energy technologies. Both the stimulus package and the 2010 budget boosted basic research through institutions such as the National Science Foundation, which awarded research grants to numerous universities and laboratories. The Department of Energy's Office of Science also established 46 Energy Frontier Research Centers (EFRCs)<sup>4</sup> whose mission was to integrate talent and expertise and accelerate advanced research into a clean energy economy [45].

### 2.3.2. Extension of production/investment tax credits (PTC/ITC)

The vast majority of stimulus spending was allocated to the development of off-the-shelf technologies [46]. Historically, the main incentives for renewable energy manufacturing in the U.S. have been tax credits. Production tax credits (PTC) offer a 2.3-cent per kilowatt-hour (kWh) incentive for the first ten years of operation. Investment tax credits (ITC) provide a 30% credit on investments in solar energy, fuel cells and small wind, and a 10% credit for investments in geothermal, micro-turbines, and combined heat and power (CHP). These credits were initially part of the 1992 Energy Policy Act, and they have expired and been extended three times. The stimulus package extended these credits; although different technologies had different expiry dates, they were all extended for at least three years, which provided longer-term market certainty (unlike the last-minute one year extensions that had previously been put in place).

### 2.3.3. Cash grants (1603 program)

Many of the renewable energy businesses eligible for tax credits, like the ITC and PTC, were too small or not profitable enough to fully monetize the benefits, and third-party ‘tax equity providers’ had emerged to fill the gap. However, these providers disappeared during the recession, which spurred the introduction of the 1603 Program.<sup>5</sup> This program offered cash payments (30% of the cost) for RE properties in lieu of tax credits [47]; it was extended until 2011 and projects have until 2017 to become operational.

### 2.3.4. Tax credit for clean energy manufacturing (48C)

The stimulus package included a new tax credit program to incentivize clean energy manufacturing (battery, vehicle, smart grid, and RE). The Advanced Energy Manufacturing Tax Credit (Section 48C)<sup>6</sup> subsidized up to 30% of the cost of clean energy manufacturing projects. The program was over-subscribed; there were more than 500 applications for US\$ 8 billion of funding, but only US\$ 2.3 billion of credits were made available. Credits were allocated on the basis of factors including commercial viability, domestic job creation, technological innovation, speed to project

completion, and potential for reducing air pollution and greenhouse gas emissions [48].

### 2.3.5. Targeted loan guarantee (1705 program)

While the Department of Energy's Loan Guarantee Program existed before the stimulus package, ARRA added a new Section 1705 Loan Program<sup>7</sup> targeting renewable energy systems, power transmission systems, and biofuels that commenced construction before September 30, 2011. Unlike the earlier Section 1703 Program (which was only available for new or significantly improved technologies), Section 1705 loans were available to projects that utilized commercial technologies; they guaranteed not only the amount of the loan, but also credit subsidies<sup>8</sup> [49].

### 2.3.6. RE training grants

Stimulus funding was allocated to state agencies and non-profit organizations in order to support three programs that trained workers for jobs in clean energy: the State Energy Section Partnership (SESP), Pathways Out of Poverty (Pathways), and the Energy Training Partnership (ETP).

### 2.3.7. Faster green patent processing

Technically, this program was not part of the stimulus package, but it shared the goal of incentivizing RE. The U.S. Patent and Trademark Office's (USPTO) Green Technology Pilot Program was implemented in 2009 (and expired in 2012). The aim was to accelerate the processing of green patents and speed up the protection of clean energy technology [50].

## 3. Results

### 3.1. Energy dimension

#### 3.1.1. RE investments

The RE stimulus programs themselves are indicative of the major investment made by the U.S. government between 2009 and 2012 in the RE sector, in particular in solar and wind energy technologies (see Fig. 1). Government investments also leveraged private investment. The Department of Energy's (DOE) 1705 Loan Program guaranteed over US\$ 16 billion; it attracted another US\$ 9.3 billion in private equity (in some cases attracting new investors such as Google into renewable energy investment), and another US\$ 0.5 billion through co-lending with banks [51]. The DOE argued that its leading role in certain types of innovative projects increased private lending for similar projects [52]. By December 2013, the 1603 Program had awarded nearly US\$ 20 billion in Federal funding to 91,871 projects, rising to a total of nearly US\$ 69 billion including private and government investment [53]. The Section 48C clean energy manufacturing tax credit was awarded to 183 projects, leveraging private investment of up to US\$ 5.4 billion [48]. ARPA-E Deputy Director Cheryl Martin stated that the 17 companies which had received grants from ARPA-E had also attracted over US\$ 450 million in private investment [54].

#### 3.1.2. Installed capacity and generation

New energy generation (or conversion) was incentivized; the 1705 Program supported one of the largest wind farms in the world (Caithness Shepherds Flat in Oregon), the largest utility-scale photovoltaic (PV) generation facility (Agua Caliente in Arizona),

<sup>3</sup> For further details see (<http://www.arpa-e.energy.gov/>).

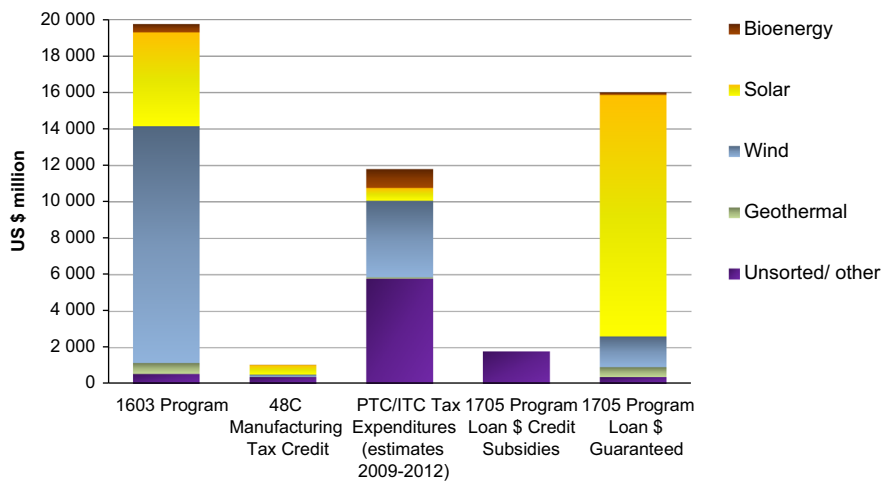
<sup>4</sup> For further details see (<http://science.energy.gov/bes/efrc/>).

<sup>5</sup> For further details see (<http://www.treasury.gov/initiatives/recovery/Pages/1603.aspx>).

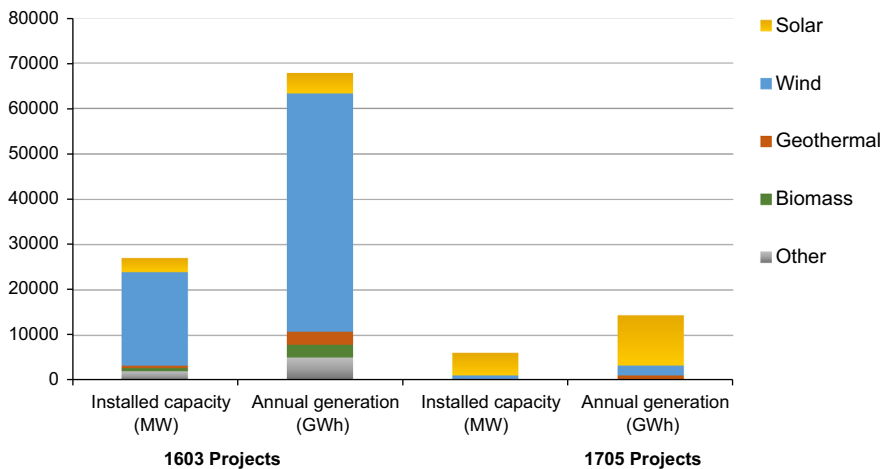
<sup>6</sup> For further details see [http://www.irs.gov/Businesses/Advanced-Energy-Credit-for-Manufacturers-\(IRC-48C\)](http://www.irs.gov/Businesses/Advanced-Energy-Credit-for-Manufacturers-(IRC-48C)).

<sup>7</sup> For further details see (<https://lpo.energy.gov/programs/1705-2/>).

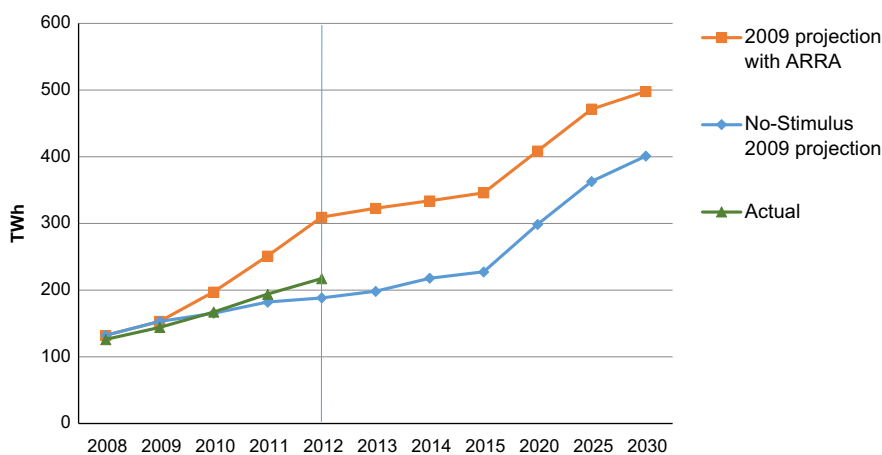
<sup>8</sup> A credit subsidy is the estimated amount that a loan guarantee will cost the Federal Government and it is intended to protect the government against the risk of estimated defaults or shortfalls in loan repayments.



**Fig. 1.** RE spending and incentives by program and technology. Credit subsidy amounts are the amounts appropriated to guarantee the loan amounts but neither these nor the loan amounts guaranteed represent actual government spending (unless recipients default). The DOE has acknowledged the bankruptcies of Solyndra and Abound Solar, representing US\$ 596 million in drawn-down loans, but it may be possible to recover some of this money). The Joint Committee on Taxation (JCT) estimates refer to loss of Federal revenue associated with a specific tax credit provision. While only ARRA related RE expenditures are noted here; there were some other RE and advance fuel expenditures 2009–2012, for example tax expenditures for biodiesel, alcohol and alternative fuel tax credits. Sources: [46,49,53,55–59].



**Fig. 2.** New RE installations supported by ARRA programs. Note that some 1705 projects are based on predicted installed capacity. Sources: [49,53].



**Fig. 3.** EIA projections of non-hydro RE generation in 2009 with and without the ARRA program, and actual RE generation. Sources: [63,64].

and the largest solar power plant in the world (BrightSource in California) [49]. The 1603 Program incentivized small-scale and distributed generation, particularly in solar energy, where nearly

76,000 projects received grants. The fact that these were cash grants (rather than tax credits) made the program more accessible to small-scale project managers who were less likely to take advantage of ITC

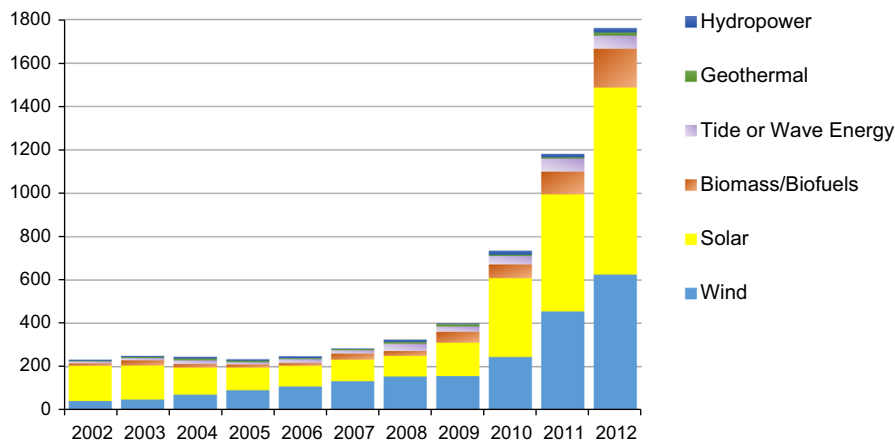


Fig. 4. Number of RE patents.  
Source: [69].

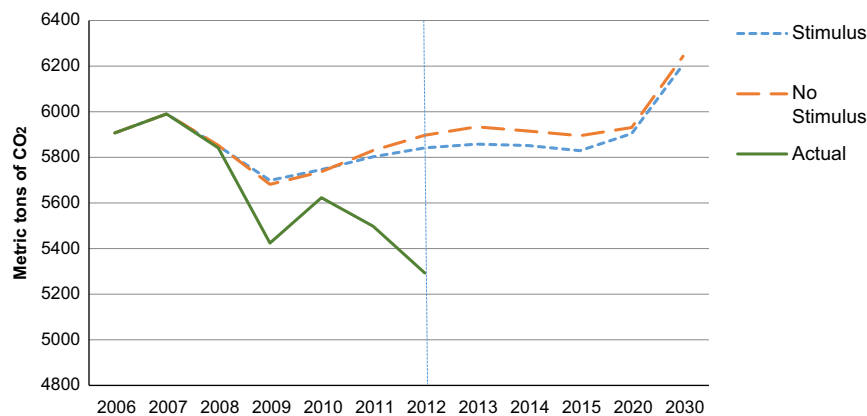


Fig. 5. Projected and actual energy-related CO<sub>2</sub> emissions.  
Sources: [63,71].

or PTC incentives [47]. As of March 2013, the 1603 Program had supported an installed capacity of 27.1 GW (estimated to generate 67.7 TWh annually). The 21 renewable generation projects that the 1705 Program supported have an installed capacity of 6.1 GW and it is estimated that they will generate 14.5 TWh annually when completed (although all projects were required to begin construction by 30 September 2011, not all of them have become operational). Total capacity and generation resulting from the 1603 and 1707 programs are summarized in Fig. 2.<sup>9</sup>

Another impact of the stimulus to increase capacity and generation is technological innovation. One example is the rapid growth in hub height and rotor scaling, and increased efficiency in wind industry technology since 2009, which has resulted in less energetic regions becoming more viable for wind energy development [61]. Actual wind generation grew from 55.4 TWh in 2008 to 138.7 by 2012.

By the end of 2012, the Obama administration's goal of doubling non-hydro renewable generation capacity had nearly been met. Overall, non-hydro renewable generation capacity stood at 43.5 GW in 2008; this had risen to 85.7 GW in 2012 [62]. In 2012, RE represented the single largest source of new capacity growth, adding an extra 17 GW (13.2 GW from wind alone).

It has to be acknowledged that the U.S. Energy Information Administration (EIA) generation capacity models had predicted in 2009 a "significant expansion in the use of renewable fuels for

electricity generation, particularly in the near-term" as a result of the ARRA [63]. EIA predictions, and actual generation of non-hydro resources, are shown in Fig. 3. Data revealed that EIA projections overestimated RE growth; this was not only because they underestimated macroeconomic factors (such as the extent and depth of the recession), but also because programs were originally intended to work in combination with a greenhouse gas 'Cap-and-Trade' program.

### 3.1.3. Domestic manufacturing capacity

The Section 48C Program directly incentivized RE manufacturing by awarding tax credits to over 150 applicants. Over US\$ 1.1 billion was awarded to 58 solar equipment manufacturing facilities, accounting for nearly a third of selected projects (of the total 183 successful applicants for the credits) [65]. Four loan guarantees were awarded under the 1705 Program to solar manufacturers, although two (Abound and Solyndra) subsequently declared bankruptcy in response to the global crash in PV prices.<sup>10</sup> By the end of 2011, 470 wind turbine manufacturing facilities were located in the U.S., more than 10 times the number of such factories in 2004 [67]. In particular, the domestic production of wind turbine components rose from 2008 to 2012, while estimated imports, which had been increasing rapidly prior to 2008, dramatically decreased. The percentage of wind turbine equipment manufactured domestically was estimated to have increased

<sup>9</sup> Beyond the U.S., other studies have highlighted increased capacity and generation resulting from stimulus programs that address RE see e.g. [60]

<sup>10</sup> Domestic manufacturing of solar technologies in the U.S. has been the subject of protective tariffs and trade disputes with China see e.g. [66].

**Table 1**  
RE jobs related to the ARRA program.  
Source: [2].

	Direct and indirect jobs created by clean energy spending	Jobs supported by clean energy programs (includes induced jobs)	Total job years through 2012
Renewable energy generation	26,600	33,800	192,900
Clean energy manufacturing	800	900	9,500
Green innovation and job training	5,100	5,700	32,200

significantly: from 25% in 2006–2007 to 72% in 2012 [61,68]. Finally, two bioenergy projects received manufacturing tax credits; one of which was focused on producing the biocatalysts (enzymes) used in manufacturing cellulosic ethanol from corn stover.

### 3.1.4. Renewable energy patents

We found that stimulus programs incentivizing research and development in the RE sector correlated with growth in the number of RE technology patents issued by the USPTO from 2009 to 2012. Solar and wind technology patents rose the most dramatically, by a factor of 9 and 4, respectively (see Fig. 4). This growth has been partially attributed to Federal RE stimulus programs [69].

Another reason for the increase in clean energy patents between 2009 and 2012 is the USPTO's Green Technology Pilot Program that was implemented in 2009. The program accelerated the processing of 'green patents' in order to protect clean energy technologies more quickly. In turn, this led to increased private investment and technological progress [70]. By the time the program ended in March 2012, it had granted 3,533 green patents [50].

## 3.2. Environmental dimension

### 3.2.1. CO<sub>2</sub> emission reductions

Official documents estimated an annual reduction in CO<sub>2</sub> emissions of approximately 8.6 Mt due to the 1705 Program [49]. The EIA modelled the impact of RE tax incentives and 1603 Programs on energy-related CO<sub>2</sub> emissions in the updated reference case (with ARRA). Emissions were projected to be lower than in the no-stimulus case due to ARRA's impacts on renewable electricity generation and overall energy consumption. In fact, actual emission reductions were far more dramatic than predicted (Fig. 5). While RE played a role, other short-term factors were highly influential. These included the economic crisis, fuel switching from coal to natural gas, decreased demand for transportation fuels, and a mild winter in 2012 [71].

Aggregate figures from the Breakthrough Institute estimated that in 2012, 34–102 Mt CO<sub>2</sub> were displaced by a combination of wind, solar, biomass, and geothermal energy. These figures were in comparison to a business-as-usual counterfactual that only looked at the power sector and used a range of 0.3–0.9 tCO<sub>2</sub>/MWh. However, an analysis by the Rhodium Group found that RE played an even greater role in the overall energy sector. They estimated emission reductions from RE to be in the range of 270 Mt. Of this, 124 Mt CO<sub>2</sub> were due to wind, 110 Mt CO<sub>2</sub>, to biomass and biofuels and 18 Mt CO<sub>2</sub> due to solar energy [72].

## 3.3. Socio-economic dimension

### 3.3.1. Job creation

In 2010, the U.S. Council of Economic Advisers estimated that 26,600 jobs were created by the ARRA RE and clean energy programs (see Table 1). Official documents estimate that the 1705 Loan Program supported 1,518 permanent and 13,733 construction jobs

**Table 2**  
Average jobs/year for large wind and solar PV projects under the 1603 program.  
Source: [74].

	Construction (2009–2011)	Operation (annually for lifetime of system)
Large wind	44,000–66,000	4,500–4,900
Solar PV	8,300–9,700	610–630
Total	52,000–75,000	5,100–5,500

[49].<sup>11</sup> A more detailed preliminary analysis of jobs created by the 1603 Program for large wind and PV projects examined data up to November 2011 (see Table 2). However, it must be stressed that such jobs may not have been created solely as a result of grant funding, nor do the figures consider the net effect of employment (i.e. if jobs were lost elsewhere as a result) cf. [74].

The Brookings Institution and Battelle Technology Partnership Program developed a clean energy database for tracking job growth in the clean energy economy, which showed growth in both RE jobs and in the clean economy as a whole [35]. They found that while overall, clean energy sectors grew more slowly than the U.S. economy from 2003 to 2010, young segments such as wind, solar PV, and smart grid grew very quickly, albeit from a low baseline. During the 2009 recession, renewable and clean energy-related jobs grew much faster than the rest of the economy. This growth was attributed in large part to the stimulus investments in clean energy in 2009 [35].<sup>12</sup> Notwithstanding causality or additionality effects between the stimulus program and job creation, estimated figures are in line with related RE employment studies in the U.S. [75–77].<sup>13</sup>

### 3.3.2. Access to RE jobs and job training

Although green job training programs were already in place prior to the stimulus package, ARRA provided further funding. These programs aimed to prepare individuals for jobs in green industry sectors, including RE [80], which accounted for 37% of the training provided (primarily in energy efficiency) [81]. US\$ 500 million was allocated to programs that targeted populations that were suffering most from the recession. The U.S. Office of Inspector General (OIG) reviewed the program; it assessed 97 grant-

<sup>11</sup> The Obama administration set up a system to report jobs generated by recipients of stimulus packages, including RE programs, with the objective of measuring direct job creation and jobs saved, and making this information transparent. However, the officials we interviewed noted that recipients were initially confused by the methodology used to measure saved/ created jobs. Furthermore, they highlighted that reports are of limited use in calculating the full employment impacts of ARRA investments as they only report jobs on a quarterly basis (i.e. they are not cumulative) and they omit certain incentives (e.g. tax incentives) and supply chain and other related jobs [73].

<sup>12</sup> It is important to note that these are estimates of direct jobs in clean and renewable industries. Estimates from the industry itself are considerably higher as they also take into account indirect employment. For example, in 2008, the wind and solar industries estimated 75,000 and 100,000 jobs, respectively, which had risen to 85,000 and 119,000 by 2013.

<sup>13</sup> For studies outside the U.S. see e.g. Sastresa et al. [78] and More and López [79].



awarding bodies and conducted on-site audits at eight locations in order to characterize participants and training, and measure progress towards the program's intended outcomes. Table 3 outlines the groups that took part in green job training programs up to mid-2012. Most programs targeted both incumbent and unemployed workers with the aim of up-skilling them in order to retain their jobs during the recession [82]. The low numbers of women participating in the program should be noted, despite the fact that this group was a particular target. The challenge of recruiting women to non-traditional industries was highlighted by grant-awarding bodies, and both government and NGO programs devoted extra resources to incentivize this group (e.g. WOW's Pink to Green Guide [83]). One potential barrier may have been the nature of training programs themselves, which emphasized on-the-job training that required cooperation with male co-workers and supervisors, unlike the standards-based approach of college degree programs [84]

### 3.3.3. Earnings, economic output, returns and energy costs

NREL's in-depth analysis of the 1603 Program provides the most detailed insight into earnings and total economic output (Table 4) from RE projects such as PV and large wind projects. An examination of the construction phase alone indicates that RE stimulus programs resulted in an economic output for 2009–2011 equivalent to 1.2 to 2.1 the value of the US\$ 21 billion allocated in the ARRA stimulus package (Fig. 6).

Revenue from PV technology increased from nearly US\$ 2.1 billion in 2010, up from US\$ 941 million in 2009 [65]. The 1603 Program played a role in the growth of sales in the small wind turbine sector (Table 5), although the Department of Agriculture and state-level incentives also helped. PTC and ITC policies, 1603 grants, and the decline in turbine prices also improved the economic attractiveness of wind energy, even in low wind speed sites [85]. Federal incentives also influenced returns. For example, the Shepherds Flat wind generation project (a recipient of a DOE

**Table 3**

Targeted and recipient groups.

Sources: [80,81].

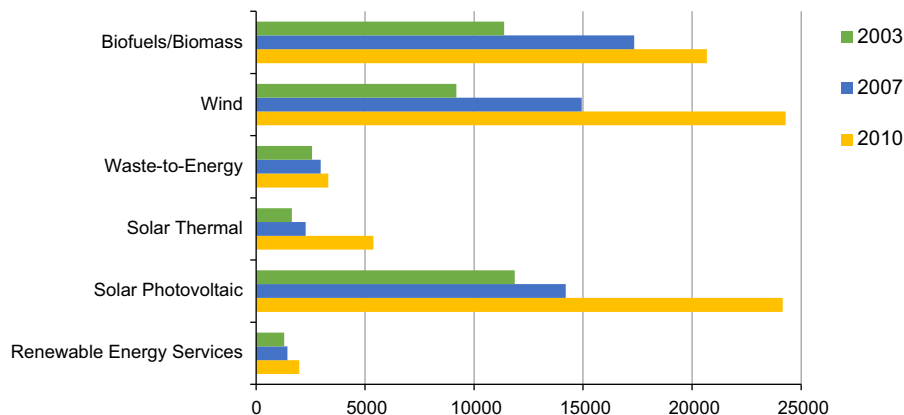
Targeted groups	Number of grantees targeting this specific group (%)	Actual participation of this group out of total participants served (%)
Unemployed	93	42
Incumbent workers	81	47
High school drop outs	69	6
Ex-offenders	41	9
Persons with disabilities	64	1
Auto workers	40	4
Low-income individuals	36	16
Women	60	16
Racial minorities	28	42

**Table 4**

Estimated earnings and economic output under the 1603 program.

Source: [74].

	Earnings (US\$ billions)	Economic output (US\$ billions)
<b>Construction (2009–2011)</b>		
Large wind	\$7.70–12.00	\$23.00–39.00
Solar PV	\$1.50–1.80	\$3.50–\$4.70
Total direct and indirect	\$9.20–\$14.00	\$26.00–\$44.00
<b>Operation (annual for lifetime of system)</b>		
Large wind	\$0.26–0.29	\$1.60–1.70
Solar PV	\$0.04	\$0.09
Total direct and indirect	\$0.30	\$1.70–1.80



**Fig. 6.** Estimated direct jobs in RE industries and the clean economy overall.

Source: [35].

**Table 5**  
Sales of small wind turbines.  
Sources: [61,68].

Year	Number of turbines	Capacity additions (MW)	Sales revenue (US\$ Million)
2005	4,324	3.3	11
2006	8,330	8.6	36
2007	9,102	9.7	43
2008	10,386	17.4	74
2009	9,820	20.4	91
2010	7,811	25.6	139
2011	7,303	19.0	115
2012	3,700	18.4	N/A

loan and other Federal and state incentives) provided investors with a 30% return on equity [52].<sup>14</sup> On the other hand, a decline in U.S. sales in 2011 was partially attributed to inconsistent state incentives and a weak economy [61].

Federal incentives influenced the leveled costs of electricity (LCOE) for utility generation plants, thereby impacting the cost to consumers. According to NREL's analysis of various financing scenarios, the low-cost debt available under the loan guarantee program had the potential to reduce LCOE by approximately 20%, and possibly more, depending on the amount of debt allowed. The authors examined some typical (rather than actual) cases and found that DOE loans had the potential to reduce the leveled cost of solar-generated electricity by about \$0.025/kW h–\$0.03/kW h (17%) for concentrated solar power technologies, while PV projects could realize savings of \$0.02/kW h (15%) [88]. Federal incentives were important in enabling renewable energy technologies to compete with conventional fuel sources on a cost basis, particularly given low natural gas prices (although it should be noted that in many regions wind, geothermal, and biomass generation were already competitive with coal and nuclear power) [89].

## 4. Discussion

### 4.1. Perceived benefits

The perceived benefits<sup>15</sup> of RE investments triggered by the stimulus package were an important aspect of whether they were considered successful, regardless of any demonstrated progress towards stated objectives (see e.g. [52,90,91]). For example, the 1705 Loan Program had multiple (and arguably, conflicting) goals that left it vulnerable to criticism [13], both for putting public money at risk and being too discretionary [10], and for being overly conservative and risk-averse [35,43]. While most independent reviews did not find any examples of unacceptable risk in the loan program's investment portfolio, bankruptcies were widely publicized by the media. In reality, bankruptcies (such as Solyndra) represented a pool of failing companies that was smaller than originally anticipated when the program was designed [12,13,92–94]. However, the negative publicity tarnished similar, ongoing loan programs, and the U.S. Government Accountability Office (GAO) noted that “the negative publicity makes DOE more risk-averse or makes companies wary of being associated with government support” [94]. Consequently, negative public perceptions have tended to impede policy development, although objectives have been met.

<sup>14</sup> Such high returns are unusual in the renewable energy industry [86]; 10–15% is more normal [87].

<sup>15</sup> Note that ‘perceived benefits’ is one of the indicators suggested in the literature (see [8]).

Other programs found it difficult to meet their objectives, but were nevertheless perceived as beneficial. In particular, the Green Jobs Program was contentious and subject to criticism from the House of Representatives Committee of Oversight and Government Reform [82,95]. The OIG was highly critical of the program's low reported success rate (38% of the stated goal) in placing trainees in new employment [80]. However, it was argued that access to training and preferential policies could not lead to jobs if the sector did not grow as anticipated [14]. Instability in emerging green industries and government incentives, together with unsuitable strategies for the development of the workforce were proposed as factors underlying the lack of success [16]. Evaluations of training programs also noted the slow deployment of funds. The time required for grants to be awarded, programs designed, and participants recruited resulted in training taking place towards the end, rather than the beginning of the stimulus. This meant that many trainees were ready to join the workforce only after many of the stimulus incentives had expired. Grant-awarding bodies found that the “weak economy and changes in plans for Federal, state, or local industry incentives or programs reduced the number of jobs available in the target industries and made it difficult for employer partners to honor their commitments to hire program graduates” [81]. This criticism of the program underscores themes found in academic, government and industry literature concerning the challenges of aligning supply and demand in emerging green industry markets [16,33,80,81,84,96,97].

The Department of Labor's Assistant Secretary responded to this criticism, noting that many programs performed well in upskilling incumbent workers. She pointed out that over 90% of workers retained their existing job rather than seeking new employment [82]. Furthermore, Department of Labor representatives noted that many training programs did not conclude until the end of 2013, which was not reflected in employment figures reported at the end of 2012. They also emphasized broader issues such as qualitative data that highlighted the role of the training in raising awareness and green thinking. On-the-job training in energy audits had raised public awareness of this service and increased demand from business. Even when trainees did not pursue green jobs, their employers reported that they tended to offer suggestions about how to ‘green’ the business, based on their training. Similarly, the wider benefits of training programs for both individuals and communities were noted at a local level [73,97,98].

### 4.2. Social aspects revisited

There are at least three key aspects of social issues that merit discussion: demographics, job quality and job distribution. Regarding demographics, although the ARRA included a commitment to transparent reporting (e.g. the recovery.gov website reports jobs generated by Federal spending organized by department, program, and congressional district), critics have pointed out a lack of accountability in data related to the distribution of funding to low-income and minority groups [99]. At the program level there is no data that can be used to determine which demographic groups gained most as a result of the RE stimulus. A study modelling the jobs created following the first two years of operation (including energy efficiency programs) estimated that about 20% of positions had been filled by Hispanics, 9% by African Americans, and 24% by women [73]. Although specific demographic data is lacking for the RE sector, industry experts and a forthcoming NREL study estimate that women make up 20–25% of the workforce in the wind industry [100] and nearly 20% in the solar industry [101].

An overall evaluation of the stimulus package found an emphasis on the construction sector, where minorities and women are under-represented [73,99]. However, there are indications that

the stimulus, combined with the Department of Labor's policies to strengthen and enforce Federal affirmative action did result in gains for some minority groups in sectors where historically they have been under-represented. For example, ex-post analyses showed an improvement in the number of women and Hispanics employed in the construction industry, which was linked with stimulus spending (the number of African-Americans also increased, although the increase could not be attributed solely to the stimulus) [18]. More detailed data at the program level may show whether the stimulus had similar effects for under-represented groups in the RE sector.

With respect to job quality, while there is some data related to wages for the 1603 Program, there were few other indications of the quality of jobs created or saved by the RE stimulus. Aggregated data (for example from the Brookings Institution) indicated that average salaries in the clean economy were higher than in the economy as a whole (around US\$ 44,000 compared to US\$ 38,600) [35]. More generally, we found that green and RE jobs were linked to better career opportunities [16,102], but again no disaggregated data was available in relation to RE stimulus programs. Although green economy frameworks suggest the inclusion of indicators pertaining to the level of education of jobs created or saved, we only found macro-level data (e.g. 24% of RE workers have a bachelor's degree). Other job quality indicators found in frameworks such as labor rights (union participation) were not found at the program level, or for RE jobs in general.

In terms of job distribution, ex-post research [19] claimed that the stimulus was poorly targeted to those in economic need, despite the fact that one of the stated goals of the ARRA legislation was "to assist those most impacted by the recession" [103]. This research found the geographic distribution of stimulus funding was more aligned with policy goals of advancing clean energy,<sup>16</sup> medical and scientific research, repairing existing infrastructure, and subsidizing state and local government services than with helping those in economic hardship (i.e. areas with the highest unemployment). While the authors acknowledged that spending had stimulated employment and the economy at a macro level, they argued that multiple policy goals resulted in trade-offs [19]. Here again, more detailed data at the program level would give a better picture of whether RE spending did reach those areas experiencing the greatest hardship.

#### 4.3. Policy learning

While the stimulus was designed to have temporary and short-term effects, there were longer-term impacts. One such impact that was not captured by the framework, but was found in our interviews, was policy learning. The ARRA represented a new approach to RE incentives, particularly in offering cash grants through the Treasury and the expansion of the role of the Department of Energy. This led to the innovative use of limited resources, effective processes for controlling fraud [104] and public-private partnerships [105]. The DOE hired Wall Street veterans, and its loan office developed a project finance team that invested more in green energy than the next ten largest American funds combined [52]. While the role proved controversial, we would argue that the increased experience and knowledge of clean energy financing expanded the department's capacity.

Similarly, the experience gained by the Treasury in assessing 1603 tax credits is now used by the Internal Revenue Service in its administration of tax credit programs. The approach taken by the

1603 Program also initiated discussions about alternatives to the PTC and ITC that could provide the same incentives for less cost see e.g. [106]. Innovation in clean energy financing continues to be of keen interest to policymakers [62].

Moreover, the Department of Labor used the ARRA program to fund Labor Market Information (LMI) grants for research into the labor market for green jobs, and identify the skills needed for these jobs, in the hope this would lead to a better match between supply and demand (as discussed earlier [107]).

#### 4.4. Assessing the undertaken method

##### 4.4.1. Policy compatibility

One can safely argue that the method has the potential to cover a very wide range of green economy issues. The indicator-based method conveys, simply and clearly, a wide range of complex issues that were affected by the RE components of the ARRA package. Although it was relatively easy to capture the energy and economic dimensions of the RE stimulus, establishing causation and additionality remain significant challenges (details below). The chosen indicators help to measure and illustrate (relative) progress. Where data is available, historical trends and changes associated with RE stimulus programs support a better understanding of the aggregated determinants of clean energy efforts. If 'intensity' indicators are used (e.g. the ratio of energy use or CO<sub>2</sub> emissions to economic output), careful policy consideration is required. This is because intensity indicators are often linked to the issue of 'decoupling', which refers to a situation in which resource or environmental impacts decline relative to economic growth (e.g. greenhouse gas emissions may rise, but more slowly than GDP). One can argue that if the RE stimulus aimed to prevent dangerous impacts on the climate, CO<sub>2</sub> emissions must be reduced in absolute terms; in other words, they must not be allowed to continue to rise, even at a slower rate than GDP. In addition, as the Green Growth Knowledge Platform (GGKP) acknowledges, "more detailed information may be needed when indicators are meant to support sub-national or sectoral decision making" [29]. Indeed, many of the aggregated indicators at the international level (e.g. as a ratio or percentage of GDP) may be unhelpful in assessing country, sector or issue-specific policies (and the relationship between them) in more depth.

##### 4.4.2. Reliability

The approach has proved useful in estimating the scale of the deployment and environmental benefits (e.g. decreased greenhouse gas emissions) that can be associated (if not directly attributed) to the RE stimulus program. Although both our sources and methodology are transparent, they still require careful consideration in the interpretation and communication of the findings. For example, the reliability of economic and employment data varied. Challenges were compounded in the socio-economic and social dimensions by a lack of data at the sector and program level (e.g. economic output) and different approaches to estimating employment. Comparing results from different studies presented even greater challenges in the economic and social dimensions due to the multiple methods and interpretations of indicators. As the GGKP report highlights, the choice of indicators, the level of aggregation, organization within dimensions, and their explanatory power differ according to the context they are applied in; it also acknowledges that indicators often "tend to simplify the underlying reality" [29]. It is important to note that many of the indicators we present are influenced by the local context, state-level policies (e.g. renewable portfolio standard quotas), and global trends (e.g. the dramatic fall in the price of PV technology globally), that are beyond the scope of national policies.

<sup>16</sup> It should be noted that the authors use 'Centers of Science and Technology', i.e. universities and research institutions, as a proxy for the distribution of clean energy funds. However, our research suggests that most RE funding was allocated to deployment rather than research, and this aspect is not examined in detail.

Furthermore, the lack of data and a straightforward counterfactual (s) makes it more difficult to establish causality and additionality of particular policies with particular outcomes. While here we present the most up-to-date data for the U.S., we acknowledge that there are difficulties at the national level for some indicators. Further improvements in the design of policies for monitoring and collecting this data would improve their evaluation.

#### 4.4.3. Measurability

The approach is very data-intensive and related uncertainties are unavoidable. There is a great need for disaggregated data and counterfactual(s) (e.g. what would have happened in the RE sector in the absence of stimulus programs?) to better understand causation between individual programs and their performance via indicators. We found that the development of counterfactuals – the so-called ‘evaluation problem’ [108] – is critical in ascertaining the ‘additional’ component of the stimulus programs and the robustness and sensitivity of their impacts. Another key challenge relates to disentangling the effects of policy instruments that target RE from the specific effects of RE stimulus programs—the so-called ‘impact problem’ in policy evaluation [109]. The challenge of de-linking the effects of different policy instruments depends heavily on data disaggregation. We also found that data from individual programs overlapped. Furthermore, the method requires that policies set specific targets in order to ascertain effectiveness, but these targets not always defined in such a way that makes them measurable. The RE stimulus was comprised of several programs, each with a different goal (and sometimes more than one) and spending attempted to address both the transition to a green economy and the recession. However, there was a lack of clearly defined ways to measure effectiveness. Some data was collected, beyond energy installation and general job estimates, which made the ex-post application of a green economy framework a difficult task. Finally, some indicators, particularly in the social dimension, were both vague and difficult to measure and remain a challenge in assessing progress towards a GEE.

## 5. Conclusions

This paper provides a comprehensive ex-post assessment of stimulus policies addressing RE technologies in the U.S. Our analysis brought together the emerging, but fragmented literature concerning the performance of RE stimulus programs linked to the American Recovery and Reinvestment Act (ARRA). The approach attempted to capture the full range of Green Energy Economy (GEE) areas that stimulus programs focused on (e.g. technology development, innovation, CO<sub>2</sub> emission reductions, job creation). We used a range of indicators in our evaluative framework in order to capture these aspects.

Overall, and from a holistic perspective, our findings suggest that the stimulus programs had a positive effect on the RE sector. With due uncertainties the findings revealed significant (or immediate) growth in investments, installations, and contribution to the energy supply from RE sources. ARRA-specific projects played a significant role in new RE installations. The stimulus programs helped to boost manufacturing capacity and the RE supply chain, particularly for large wind (where domestic manufacturing supports stable deployment through logistical savings [110]). While RE played a role in CO<sub>2</sub> reductions, other short term factors, notably the economic crisis, were also highly influential in decreasing emissions from energy [71]. This in turn contributed to a decline in CO<sub>2</sub> emissions and carbon intensity. Estimates indicated positive employment effects and increased revenue in the RE sector. However, with so many different programs, each with a different focus there was also evidence of misalignment and

missed opportunities for them to work together. For example, the development of RE technology was incentivized early in the stimulus, while more time was needed to train employees for the new jobs associated with its deployment.

It is also important to highlight that the stimulus programs we examined were originally intended to be combined with a greenhouse gas ‘Cap-and-Trade’ program, which may have increased RE investment, even after short-term incentives had expired. Although this short-term spending will no doubt have long-term impacts, and has set the stage for a green energy transition, the impacts of the RE stimulus are not in and of themselves enough for the large-scale transformation needed. We found numerous studies that stressed the need for a sustained RE policy [37, 111, 112]. The long-term effects across the energy system remain to be seen and examined, which emphasizes the need for policy evaluation.

From the methodological perspective, our research highlighted numerous challenges (e.g. ‘impact’ and ‘evaluation’ problems) in evaluating and assembling indicators at the same level of analysis, together with areas for data development. Our experience of this indicator-based approach showed that it is both time- and information-intensive. To address additionality, the approach requires counterfactual(s) and disaggregated data to cover all aspects of the GEE. Our results indicate a need for numerous indicators that can capture and characterize the multiple attributes of the GEE and the context in which related policy instruments work. The measurement of social indicators can become a crucial challenge when programs do not adequately address or support their assessment (e.g. when there is no program-level data or when aggregate or macro-level data cannot be correlated with programs). However, these issues are part of the challenge of the evaluation and not a deficiency of the approach as such. Asymmetric information made the evaluation complex, but possible. As more countries implement policies that promote a GEE, it is necessary to be able to adapt indicators for different purposes, priorities, and scales. The approach adopted by international organizations provides guidance concerning the various dimensions that should be included in order to form a comprehensive and accountable picture. Although (comprehensive) GEE policy evaluation is likely to be a complex, challenging and resource-intensive process, it is a valuable exercise that offers ongoing policy learning and opportunities for policy improvements.

## Acknowledgements

The authors are very grateful to the AES Research Program of the Swedish Energy Agency for financial support through Grant no. 33684-1. We would also like to thank the stakeholders who made themselves available to participate in our research and provided various resources.

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