How Stimulating Is a Green Stimulus? The Economic Attributes of Green Fiscal Spending

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Abstract

When deep recessions hit, some governments spend to rescue and recover their economies. Key economic objectives of such countercyclical spending include protecting and creating jobs while reinvigorating economic growth—but governments can also use this spending to achieve long-term social and environmental goals. During the COVID-19 (coronavirus disease 2019) pandemic, claims have been made that green recovery investments can meet both economic and environmental objectives. Here, we investigate the evidence behind these claims. We create a bespoke supervised machine learning algorithm to identify a comprehensive literature set. We analyze this literature using both structured qualitative assessment and machine learning models. We find evidence that green investments can indeed create more jobs and deliver higher fiscal multipliers than non-green investments. For policymakers, we suggest strong prioritization of green spending in recovery. For researchers, we highlight many research gaps and unalignment of research patterns with spending patterns.

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GLOSSARY

Biodiversity: the diversity in types of life forms and systems of life forms, including species, ecosystems, and liveable habitats

Green policy archetypes: the menu of options available to policymakers for green spending (see Table 1 for examples)

Green spending: public fiscal expenditures that are likely to reduce net greenhouse gas emissions, reduce air pollution, and/or strengthen natural capital, compared to a scenario in which the expenditure was not made

Keynesian: a macroeconomic theory that suggests, in the context of economic recovery, increased government spending in times of crisis to boost economic growth

Latent Dirichlet Allocation (LDA): a natural language processing method that uses statistical analysis to identify and categorize similarities in terms within a corpus t-Distributed

Machine learning algorithm: computer algorithms that automatically create models from data, iteratively improving themselves based on training data, sometimes with human supervision

Neural network models: machine learning algorithms that imitate human brains to recognize patterns and solve problems

Recession: a contraction in an economy's output or gross domestic product for two consecutive quarters

Recovery measures: policies used to reinvigorate economic activity following economic crisis

Rescue measures: policies used to protect lives and livelihoods in times of economic crisis

Reinforcement measures: policies used to embed new economic trajectories formed through recovery investment into long-term growth plans or development plans

Spillover effects: effects of an economic event on third parties, including benefits and harms

Stimulatory/ expansionary fiscal policy: policies that inject government funds into the economy, or reduce tax receipts, with the intent to restore or accelerate economic growth

Stochastic Neighbor Embedding (t-SNE): a statistical method used to visualize data through connecting similar objects and separating dissimilar objects

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1. INTRODUCTION

In 2020, two global crises converged. The coronavirus disease 2019 (COVID-19) pandemic crippled global health systems and economies, precipitating lockdowns and a global recession. The severity of the climate and nature crises became more obvious, with record-breaking floods and wildfires (e.g., 1). The co-occurrence of the two crises led to debates on the prospects of using green fiscal spending to simultaneously address both economic and environmental challenges. Proponents of a so-called green recovery claimed that public green investment could create jobs and grow national economies while reducing global net greenhouse gas (GHG) emissions and addressing other environmental and social priorities.

The intersecting themes of economy and environment were also present during the very different 2008–2009 Global Financial Crisis (GFC). These themes will likely be relevant in every economic crisis in the coming decades, irrespective of its cause and structure. This article reviews and synthesizes the current evidence on green spending, with a view to understanding the benefits and trade-offs associated with environmentally-focused fiscal stimulus for when the next crisis hits. By green spending, we mean public expenditure that is likely to reduce net GHG emissions, reduce air pollution, and/or strengthen natural capital, compared to a scenario in which the spending did not occur. This can include investment in established, emerging, or nascent green industries. The most common archetypes are set out in Table 1. Domestic fiscal incentives include direct investments, grants, loans, guarantees, and tax measures.

Table 1. Green recovery policy archetypes used in this article, adapted from the O'Callaghan *et al.* (30) fiscal archetype taxonomy. Abbreviations: CCS, carbon capture and storage; R&D, research and development; WWS, wind, water, and solar.

Policy archetype	**Description**
Electric vehicle incentives	Support for vehicle production and consumption, including vehicle scrappage schemes or "cash-for-clunkers" schemes, cash and tax rebate support for purchases of electric vehicles, and electric vehicle production tax incentives
Green worker retraining and job creation	Retraining members of current or soon-to-be displaced workforces with new skills suitable for future industries, including green ones
Clean transport infrastructure	Investment in low-carbon public transport solutions, such as buses, trams, and metro infrastructure, as well as electric vehicle charging networks and pedestrian/bike infrastructure
Clean energy infrastructure	Clean electricity and fuel generation, transport, and storage, including WWS, hydrogen, and transmission
Buildings upgrades and energy efficiency infrastructure	Increasing thermal efficiency through improved insulation, improved energy efficiency of appliances, clean heating (e.g., heat pumps, heat networks), and/or household energy generation
Natural infrastructure and green spaces	Environmental (re)building initiatives, including afforestation, reforestation, and environmental rehabilitation, and environmental protection initiatives, including conservation, natural infrastructure resilience, and improving green spaces
Clean R&D	Cash support for R&D in emerging green technologies, including hydrogen electrolysis, energy storage, alternative proteins, and greenhouse gas removal (such as CCS)

Harm minimization is the predominant objective of government in response to an economic crisis. This comes over three intervals: (*a*) short-term emergency rescue measures to counter the immediate direct and indirect impacts of the economic crisis and related crises, (*b*) medium-term recovery measures to spur economic reinvigoration once the root causes of the crises have been sufficiently countered, and (*c*) long-term reinforcement measures after the crisis to fortify and ensure permanent shifts of investments and behaviors (2, 3). The appropriate policy tools to employ depend on the nature of the crisis and the capacities of the nation. Policy tools include (*a*) monetary controls in the form of interest rates, reserve requirements, and quantitative easing; (*b*) regulatory interventions to change incentives; and (*c*) fiscal interventions in the form of changes to taxation and public expenditure. In the context of the COVID-19 pandemic, loose monetary positions entering the crisis meant that new stimulatory monetary interventions were unable to play a leading role. A need for expeditious protection of lives and livelihoods meant that only the fastest acting fiscal and regulatory interventions were relevant. Overwhelmingly, governments have focused on fiscal tools, and mostly public expenditure, to minimize harms over the COVID-19 crisis.

Countercyclical fiscal policy—where governments step in to compensate for the private sector stepping back in a crisis—has been well studied since Keynes (4) and popularized in multiple forms, even including by analogies about baby-sitting clubs (see 5, 6). But whether and when a public spending stimulus is appropriate depends on the circumstances. The recession induced by COVID-19 was not a conventional demand slump caused by a financial shock, or a collapse in private sector confidence, but rather the result of enforced shutdown of economic activity by governments to protect human life and to manage pressure on healthcare systems. During lockdowns, economic activity was muted by design. However, once government rescue packages, such as furlough schemes and other social safety nets, had played their role, further recovery measures were considered desirable to return economies to healthy levels of employment and growth.

What sort of stimulus should governments use? The options vary dramatically in economic, social, and environmental characteristics. This variation is driven by policy archetype (e.g., infrastructure spending versus healthcare spending), policy mechanism (e.g., tax incentive versus direct subsidy), the national context in which the policy is applied (e.g., demographic structures, geography, level of economic development, and industrial composition), and other external factors. Which policy investments best maximize future prosperity and minimize harms without introducing any new ones? For some, including Elmendorf & Furman (7), stimulus should be timely, targeted, and temporary—spending initiatives with the highest multipliers are technically strong, for instance, unemployment benefits where beneficiaries are likely to have higher marginal propensities to consume. However, others argue that recessionary investment is also a valuable way to shift national trajectories toward a more desirable form of economic growth. Investment that comes with long-term debt servicing costs should incorporate corresponding long-lived assets; on this view, infrastructure investments, research and development (R&D) spending, and industry building projects are attractive (8, 9). Approximately US$100 trillion of investment in assets like these will be required to deliver a net-zero emissions economy in the coming decades (10).

The objective of an economic stimulus in a crisis may seem obvious enough: gross domestic product (GDP) growth needs to be restored and the economy returned to healthy full employment. But growth within our current model of economic production and consumption has devastating and terrifying consequences for natural ecosystems, nonhuman life, and indeed human life. The economy and the environment are inexorably intertwined: all economic production requires natural resources, and economic prosperity requires ecosystem services, including climate stability. More broadly, human wellbeing is not only driven by innovation, good jobs, and growth but also by our relationship with nature itself, its ecosystems, landscapes, and nonhuman species.

As such, a stimulus that targets short-term GDP growth but simultaneously undermines the very basis for human existence (hence also undermining medium-term growth) is counterproductive. Even if decoupling environmental damage from GDP is theoretically possible (11), it is clearly not occurring fast enough in reality (12, 13). Given these trends, GDP is even less suitable as a proxy for wellbeing (14–16), especially in developed economies. The deeper objective of economic policy is societal wellbeing, of which material prosperity is merely one (important) component. Environmental considerations take a more central position within ecological and steady-state economics (see 17, 18), the degrowth movement (19), the economics of wellbeing, and so-called doughnut economics (20). Although the environment has become a more mainstream political and economic issue in recent decades, most economic policy decisions, especially in a crisis, remain focused on jobs and GDP, which are admittedly more closely correlated with economic wellbeing in a recession than in normal times. Here, we focus instrumentally on the relationship between green stimulus and GDP. We stress that in most cases, factoring in the nongrowth benefits of green investments would significantly improve their policy appeal compared to other investments—examining only the impacts on GDP understates benefits of green investment spanning health (21–23), the environment (24,25), economic stability (26–28), among others (see 29).

Even with a narrow, orthodox lens, the response to the COVID-19 pandemic arguably represented the single biggest opportunity to date to decouple fossil emissions from economic growth and keep within Paris climate targets (2). Table 1 outlines key investment archetypes used in analyzing COVID-19 spending.

Just how stimulating is a green stimulus? In this article, we review the economic characteristics of stimulatory green fiscal spending, identify misalignments between research and public spending in the first 18 months of the COVID-19 pandemic, and synthesize recommendations for policymakers. In Section 2, we narrate an abridged history of green stimulus spending, beginning in ancient Egypt and exploring modern patterns. In Section 3, we create a bespoke machine learning algorithm to systematically identify and understand green investment literature. In Section 4, we build on the quantitative analysis to provide a comparative account of the literature on the speed of implementation, job creation, and national income multiplier characteristics of green fiscal spending. We identify the most pressing gaps in the literature. In Section 5, we provide recommendations to policymakers and priority areas for future research.

2. HISTORY OF GREEN RECOVERY SPENDING

2.1. Green Fiscal Spending Before 2008

Human civilizations have long used public interventions to mitigate and adapt to localized climatic change. Archaeological evidence suggests that local governors in the ancient Egyptian imperial economy used dry farming to stabilize areas of the Levant in response to localized drought (31). Although the source of finance is unknown, there is evidence that communities in ancient Arabia responded to changes in climate through water resource management and by diversifying construction practices, using economic intensification (32).

In the 1930s, John Maynard Keynes (4) challenged the prevailing classical aggregate supply-focused thinking that suggested stimulatory/expansionary fiscal policy would only lead to higher inflation, without net-positive growth or employment impact. Keynes provided a new hypothesis to the following question: How should the government act to get an economy out of a recession, restore consumer confidence, and enable full employment? His answer: Spend.

A Keynesian approach to demand management came into vogue for economies including the United States and Sweden following the Great Depression, aiding their economic recovery (33). Some early recessionary spending programs included elements with positive climate outcomes. For instance, introduced in Roosevelt's New Deal, the Civilian Conservation Corps planted more than 2 billion trees, slowed soil erosion on 40 million acres of farmland, and in total altered more than 118 million acres of land, overall providing employment for up to three million young men at a time when unemployment was at 25% (34, 35). Keynesian approaches to fiscal spending were adopted by other nations including the United Kingdom, France, and Japan following the Second World War (36) but soon fell out of favor to neoliberal and monetarist ideas (37, 38) that reduced the role of government and emphasized the risks of inflation.

2.2. The 2008–2009 Global Financial Crisis and Great Recession

Stimulatory/expansionary fiscal policy saw somewhat of a resurgence following the GFC (39). As governments attempted to restore their economies to growth, some adopted stimulatory economic policy, with a subset using fiscal investments to simultaneously address environmental harms. Leaders included the United States with the American Recovery and Reinvestment Act (ARRA), South Korea with its Green New Deal (GND), and China with a scattering of investments across several green sectors including green energy and sustainable transport. Various additional green policies were introduced by European Union (EU) member states, Canada, and Australia, among others (40). By cataloging G20 fiscal stimulus policies following the GFC, Hepburn *et al.* (2) find that, by number, 32% of announced policies were green and Robins *et al.* (40) determine that, by value, 15.6% of spending was green. Studies of GFC green investment mainly adopt a focus on the United States (41–47), South Korea (48–50), or China (40, 51, 52), or investigate across mixed/global economies (see 52 on Europe; see also 53–55), with findings explored below.

For the United States, it appears that the ARRA's clean energy package successfully stimulated the economy, creating jobs and catalyzing additional long-term green investment (41–44). US$21 billion in spending on renewable energy included production/investment tax credits, cash grants, tax credits for manufacturing, targeted loan guarantees, and training grants. Together, these likely increased renewable electricity capacity, lowered US emissions, and increased renewable energy patents in the medium term (42). The spending supported a significant immediate employment boost across the green energy supply chain, while also supporting long-term industry growth and associated opportunities for green labor (43). Grants proved more cost-efficient than tax credits due to effective transaction costs, and grants and tax credits proved "significantly more effective than loan guarantees" in that they were more likely to be used by corporate actors (41). Although the process of distributing funds was slowed by identifying suitable projects, new public investments paired with private capital sustained aggregate demand as the economy moved out of the rescue phase (41). Outside of renewable energy programs, the next largest green contributions were to energy efficiency, transit, grid modernization, and advanced vehicles, with lower support for green job training and early-stage carbon capture and storage (CCS) R&D (55). Compared to non-green alternatives, ex post evaluations find high job and GHG impacts for spending on energy efficiency (see 45, 55) and restoration of coastal habitats (46). As they grew, green industries tended to increase their demand for medium-educated workers and lower their demand for lower-skilled workers (47), suggesting that it is important to pair green investments with the current or planned future skill base of the local economy (56). Across the board, evaluations of US GFC stimulus policies predominantly address one or two aspects of the green economy and focus on one or two policies, rather than the entire package.

The South Korean GND appropriated US$36.3 billion over four years, intending to create almost one million jobs in mass transit systems, fuel-efficient vehicles, energy conservation, and more (53). The package comprised ~69% of total South Korean crisis spending, reflecting a significantly higher ratio of green investment than other nations (40). However, although the economic returns of the package were high in terms of both jobs and economic growth (48, 52), the net environmental impact of the spending remains unclear and might have been negative (48, 50). Complications included insufficient renewable energy uptake, broad continued support of coal-powered electricity generation, increased energy intensity from new investments, exportled growth in energy-intensive sectors, and environmentally-destructive waterway investments (40, 48–50, 54).

In China, approximately US$586 billion was appropriated for economic recovery, including US$221 billion for green purposes. However, of this, US$99 billion was for rail with unknown environmental consequences and unknown impacts on the displacement of automobile transport (40). In totality, although the literature is sparse, the stimulus might have supported a return of Chinese growth to precrisis levels (51, 52).

Within the EU, up to US$54 billion worth of green stimulatory fiscal packages were introduced in total, at the supranational level and in member states (40). Focal green industries included energy efficiency, public transport, renewable energy, vehicle scrappage schemes, and green R&D (52). Green investments are likely to have delivered short-term multipliers similar to non-green investments (52) and employment opportunities to stressed sectors at low public cost (40, 52). For instance, for the German Building Rehabilitation Program, when projects did not crowd out other investments, the net impact of spending was to reduce the public deficit due to increased income taxes and social security contributions (57). Environmentally, the long-term net effects of spending were generally favorable and are thought to have supported the long-term development of nascent green industries, particularly for energy efficiency and renewable energy investments (52).

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2.3. The COVID-19 Recession

The overall fiscal response to the COVID-19 crisis has set new records for countercyclical spending. This time, the economic contraction came more severely and with greater geographic coverage, precipitated by synchronized demand- and supply-side shocks (2). Over the first year of the pandemic, governments with the capacity to spend on rescue measures often did so to protect lives and livelihoods. In many nations, trillions in recovery-type investment quickly followed rescue measures. Compared to the GFC period, debate on the role of stimulus spending has been muted in most countries, with discourse instead focusing on the volume of spending and its recipients. For instance, analysis in France finds that public discourse has shifted against austerity narratives (58). With already loose monetary policy moving into the crisis, and negative effective monetary interest rates in several advanced economies, governments have felt it necessary to spend and had the public license to do so.

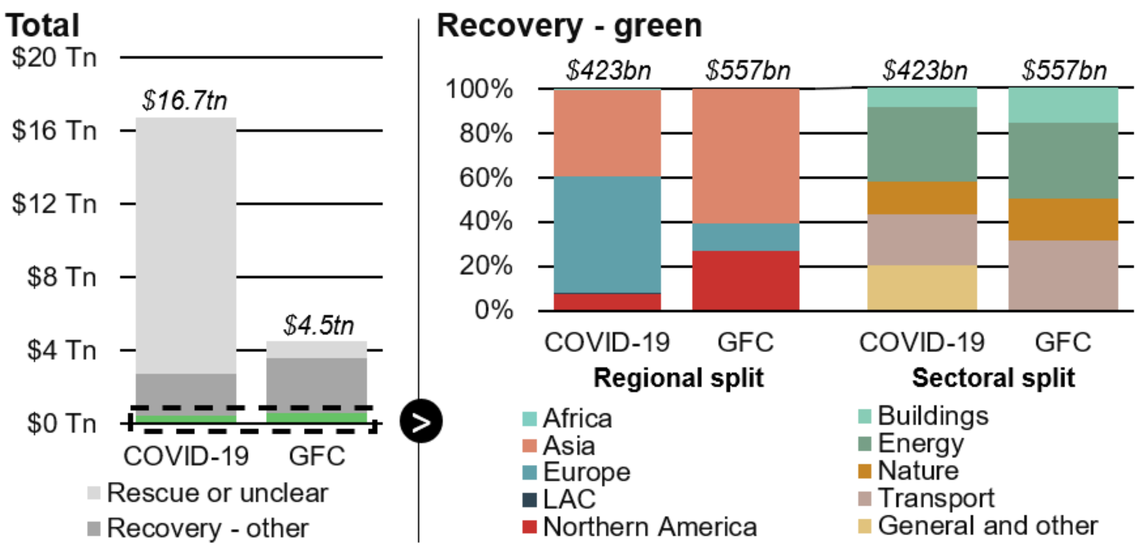

Figure 1. LHS: Green characteristics of total COVID-19 and GFC investment (US$, real values). RHS: Regional and sectoral/archetype characteristics of total green COVID-19 and green GFC investment (US$, real values). Nature includes water and waste. Energy includes CCS. Sources: COVID-19 data to October 2021 from the Global Recovery Observatory (59); GFC data adapted from Robins *et al.* (40), supplemented with missed policies and adjusted for real values. Abbreviations: CCS, carbon capture and storage; COVID-19, coronavirus disease 2019; GFC, 2008–2009 Global Financial Crisis; LAC, Latin America and the Caribbean.

By October 2021, total COVID-19 spending was already 3.7 times GFC spending in real terms (59) (Figure 1), with more to come. Yet, despite this, on green investment, compared to the GFC, COVID-19 initiatives are lower in value and as a proportion of total spending (53,59).The biggest green spending nations so far are Spain (US$63.5 billion), Japan (US$61.8 billion), and France (US$53.9 billion), with the highest proportionate green spending coming from Denmark (62.6% of recovery spend), Finland (58.3%), and Belgium (58.3%) (59).[1] Green investment allocations have been made in every region and for almost every emerging mainstream green industry (8, 59–61); however, the scale of spending is much lower than the need. The International

[1] Only nations that have spent >1% of GDP on recovery initiatives are considered in leadership rankings. Other nations, including Turkey, Mauritius, Bangladesh, and Burkina Faso, might have high levels of green spending as a proportion of total spending but low levels of overall recovery spending.

Panel on Climate Change (62) found that to meet a 1.5-degree Celsius trajectory, it would take total investment of US$1.6–3.8 trillion per (in 2010 dollars) year to 2050 from public and private sources to transition just the world's supply-side energy system, let alone the various transitions required in industry and agriculture. Extrapolating funding requirements submitted to the UNFCCC (63), non-Annex 1 nations might require US$11 trillion just to meet their Nationally Determined Contributions, most of which are not aligned with a safe climate trajectory. By every measure, the scale of green public and private investment will need to increase many times over to meet the needs of a sustainable climate.

Our understanding so far of the impacts of the green stimulus in response to COVID-19 is necessarily limited, as the crisis is still in motion at the time of writing and most funds are yet to be disbursed. However, ex ante studies suggest high potential positive economic impacts of green stimulus across regions and sectors, using macroeconomic and general-equilibrium modeling (64–67), employment multiplier modeling (68), input-output modeling (66, 69, 70), and surveys or other approaches (2, 66). This is also supported by Batini *et al.* (71), who use multi-decadal data to ascertain directional green multipliers and support ex ante statements on the strength of a green COVID-19 response. Studies currently continue to commentate on these impacts through a variety of analytical approaches (72–74), but the full impacts of green COVID19 spending will remain unclear until ex post studies can be completed, with the validity of studies governed in large part by data collection and strengthened by government commitments to policy experimentation (61, 75). Fortunately, much can be learned from non-stimulatory or so-called peace time literature and applied with caveats to periods of economic contraction. These might also be relevant to "reinforcement measures" in years to come. The next section reports on a comprehensive review of the literature using a novel approach.

3. QUANTITATIVE LITERATURE ANALYSIS WITH MACHINELEARNING

We present a bespoke supervised machine learning algorithm based on the word2vec neural network model (76) to identify the academic literature on green public expenditure and all English language gray literature in the Web of Science collection (Table 2). This provided a corpus of 908 texts for quantitative analysis, across three categories: premier journals (190 texts), secondary journals (514 texts), and Web of Science gray literature (204 texts) (see definitions in the Supplemental Appendixes). For the cumulative corpus, we analyzed collocation of economic and environmental terms, applied unsupervised topic modeling with Latent Dirichlet Allocation (LDA), and visualized word relationships using t-Distributed Stochastic Neighbor Embedding (t-SNE) (77, 78; also see the Supplemental Appendixes).

3.1. Literature Identification

For traditional systematic review processes, scholars face a trade-off between precision and breadth; the manual review of all facets of a topic of literature is too labor intensive to be feasible (79,80). Traditional reviews either risk errors, omissions, and bias (81) or are excessively time- and cost-intensive (82, 83). Automated text analysis can help to address these issues (79, 81, 83, 84); however, such analyses also face several practical and technical constraints (84).Automated models for literature identification often rely on domain-specific dictionaries, and subject matter experts can fail to provide adequate dictionaries for complete reviews (85). Emerging active unsupervised learning methodologies, which use iterative user guidance to sort relevant literature and identify the pieces of highest relevance for manual review (79), also rely on input dictionaries defined by the user. Recent supervised machine learning approaches in reviews on climate policy represent an important advance in the field but also rely on relatively small dictionaries, potentially resulting in missed works (86).

In contrast, here we employ embedding models to expand an initial user-defined dictionary to include all related domain-specific terms, whereby the domain is defined by the literature itself (see the Supplemental Appendixes). Such embedding models operate by identifying how terms in a corpus relate to each other and vectorizing the terms into a *n*-dimensional space (alternative tools are discussed in the Supplemental Appendixes). Here, we use the word2vec embedding model (76) of dimension 100 with a minimum count of three in order to expand our user-defined dictionary to capture groups of related terms (rather than synonyms) that convey similar concepts.[2] Figure 2 describes the methodology for literature identification: The algorithm finds related words to an input dictionary set, uses these new words to identify additional literature, updates the corpus with this new literature, and repeats until no new words or papers are identified. Related words are identified by cycling through each potential term pairing in every dictionary category, taking the average of the term vectors, and finding the closest term to this vectorized location. The cycle repeats by pairing the new term vector with every existing term vector in the dictionary category until the closest term vectors to the average of the pair vectorization are the input word pair. Papers are identified based on dictionary search terms used with the Web of Science Topic Search function, which considers titles, abstracts, keyword fields, and KeyWords Plus fields. Manual postprocessing is applied on every iteration of the cycle to filter out unrelated papers.

Table 2 Descriptive characteristics of the literature identified by application of a bespoke algorithm based on the word2vec neural network model. Rows might not sum to total due to rounding.

Iteration number	**Terms added to dictionary set (*words*, *bigrams*)**	**Papers added to review set**				**New unique words in review set, postprocessing (*lemmatized*)**	**Total words in review set [preprocessed millions (M)]**	**Total words in review set [postprocessed millions (M)]**
		Premier journals	**Secondary journals**	**Gray literature**	**Total**			
Initial	154 (*13*, *141*)	158	434	174	766	20,898 (*16,950*)	6.42 M	3.48 M
First review	70 (*4*, *66*)	29	75	28	132	3,584 (*2,981*)	1.85 M	1.03 M
Second review	9 (*1*, *8*)	3	5	2	10	157 (*137*)	0.09 M	0.05 M
Third review	1 (*0*, *1*)	0	0	0	0	0 (*0*)	0	0
Total	**234**	**190**	**514**	**204**	**908**	**24,639 (*20,068*)**	**8.36 M**	**4.55 M**

Our initial term set was significantly larger than that used by others (86), and even still, the algorithm was able to identify 18.5% additional highly relevant papers that would have been missed without the embedding model. Descriptive dictionary and literature statistics are included in Table 2.

[2] For instance, in our specific literature domain, the algorithm found “emissions” to be related to “clean,” but these are clearly not synonyms. Beyond related words, the approach also identified related N-grams; for instance, “spending policy” was considered related to “fiscal recovery” and “economic stimulus.” Importantly, acronyms are included in the word vectorization; for instance, “ghg” was identified as a key missing term by the algorithm.

3.2. Thematic and Quantitative Analysis

For a preliminary understanding of literature coverage, themes, and gaps, we first applied established LDA and t-SNE methods (see the Supplemental Appendixes) before analyzing cooccurrence of environmental and economic terms across predefined categories. To distinguish between literature types, the analysis was repeated for groups 1, 2, and Web of Science gray literature, with results included in the Supplemental Appendixes.

As a form of topic modeling, LDA is highly suited to drawing unknown themes from well-constructed texts like journal articles (87). In our study, optimizing for low perplexity with a 90% train, 10% test model suggested a 15-theme analysis to balance theme quality and theme redundancy. Analyzing the full 908 paper corpus reveals prominent environmental themes including clean energy, green jobs, and forest services, as well as economic themes, including economic growth impact, productive labor, and development outcomes (Figure 3). t-SNE dimensionality reduction (88) of the final corpus word2vec word embedding model was used as an alternative visualization to observe relationships between terms within the corpus. The *k*-means algorithm (89) with the squared Euclidean distance metric proved the most informative for visual comparisons.

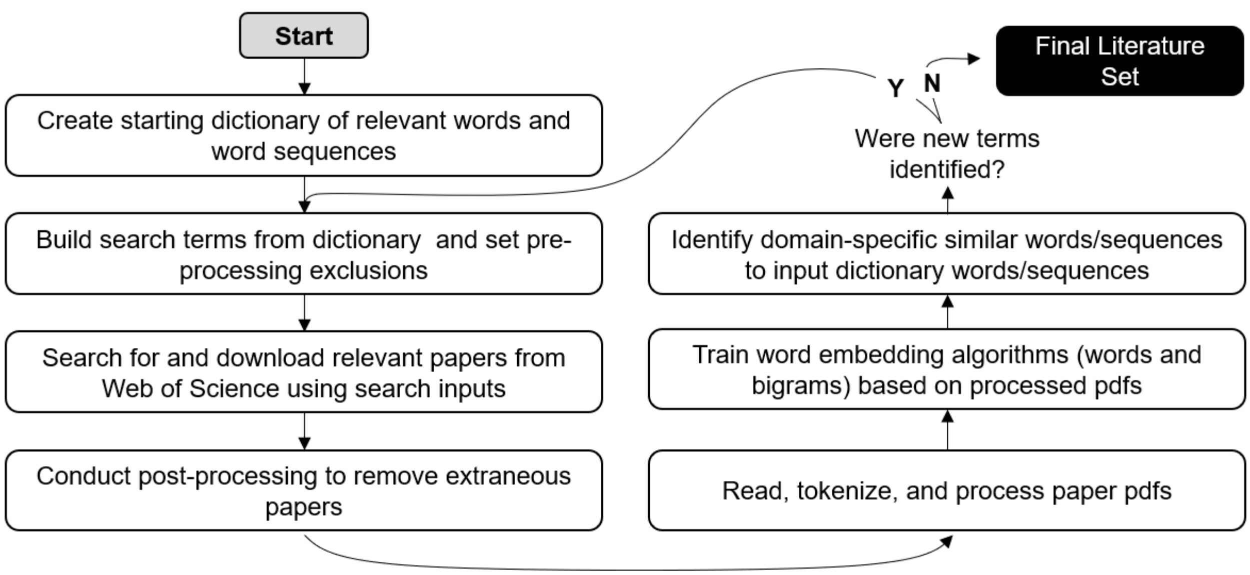

Figure 2. Process of literature identification using iterative machine learning model. Dictionary for identification defined internally with word embedding. Method malleable to any corpus across disciplines.

To understand coverage of the economic characteristics of environmental topics, we developed a collocation frequency analysis with four economic categories and eight environmental categories, defined by a total of 614 terms. This term list is an expansion from the dictionary outputs found through the learning process described in Section 3.2. The economic categories are employment, economic growth, investment as stimulus, policy implementation speed, and economic impact assessment. The environmental categories align with the previously discussed set of green recovery archetypes (30): clean energy, natural infrastructure and green spaces, green transport infrastructure, buildings upgrades and energy efficiency, clean R&D, CCS (as a subset of clean R&D), electric vehicles, green worker retraining, electronic appliances, and other environmental, which incorporates green market creation and general environmental commentary.

Green rescue type terms were excluded. The collocation process considers the occasions that an economic term and an environmental term (or their derivatives) occur close to each other, for instance, "job creation" and "solar energy." Observed trends were persistent across all "close proximity" scenarios, where context varied from 100 to 500 characters in either direction.

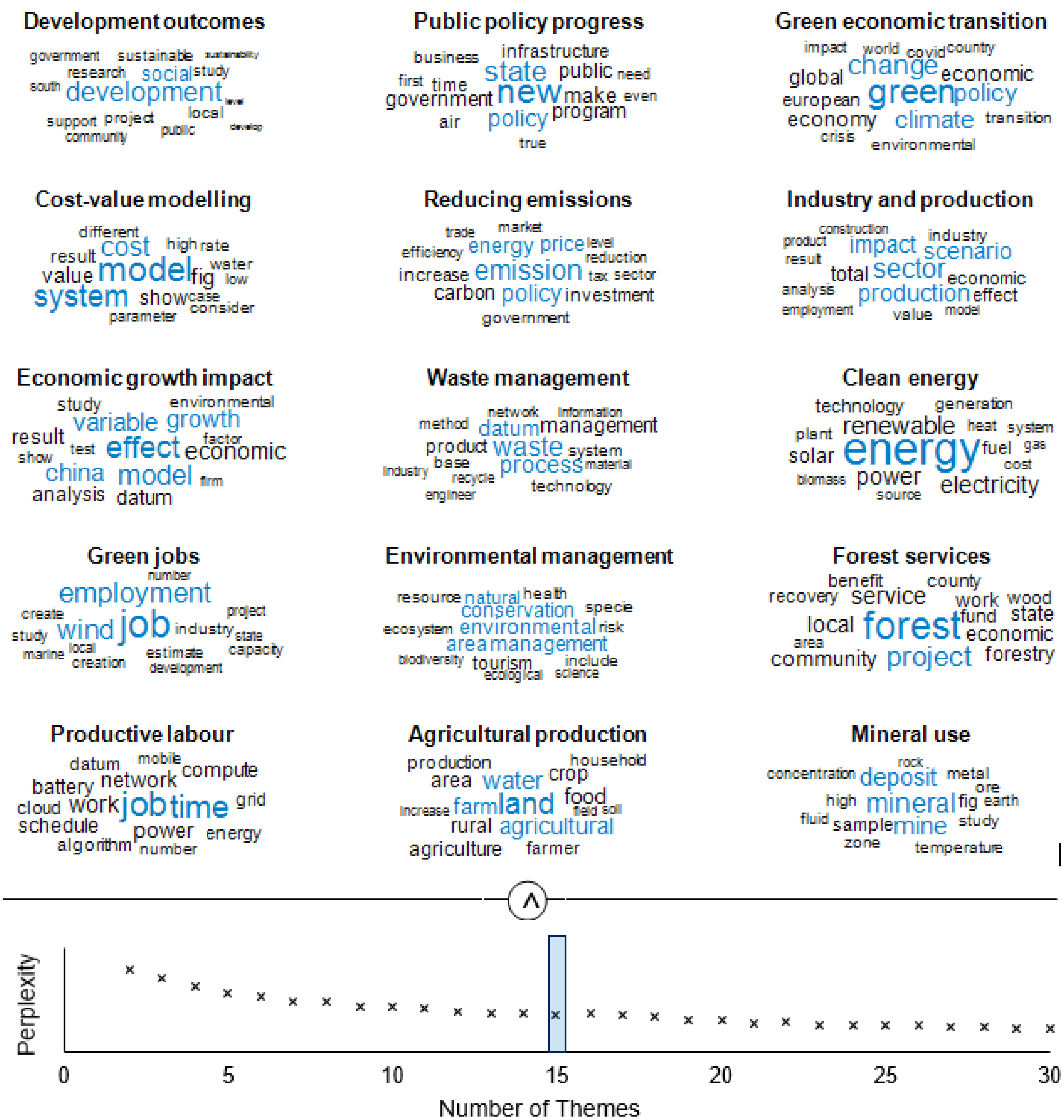

Figure 3. (a) 15-theme Latent Dirichlet Allocation analysis for the full corpus of the economic literature on green investment (lemmatized). Labels defined manually. Topic mixtures across papers are included in the Supplemental Appendixes; (b) relationship between the number of themes and perplexity for the full corpus, derived through iterative testing.

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80.8% of all economic-environmental term pairs related to employment topics, with the balance of economic themes covered by growth terms (8.0%), investment as stimulus terms (7.6%), economic policy assessment terms (2.9%), and policy implementation speed terms (0.8%) (all figures from the context = 100 scenario; see Figure 4). Relative to other economic terms in the category, employment coverage was particularly high for green R&D topics (100.0% of economic coverage), green energy (92.1%), and green skills (76.3%). Meanwhile, economic growth emerged more prominently for clean communications (49.0%),CCS technologies (34.3%),and electric vehicles (26.5%). The greatest proportional coverage of investment as stimulus topics came from sustainable transport (35.8%) and electric vehicles (28.1%).

Coverage of environmental topics was dominated by clean energy, which represented 60.2% of all environmental terms used in proximity to economic terms, followed by general environmental (18.3%) and CCS technologies (6.6%). This trend was particularly strong in employment topics (68.7% of collocated mentions were with green energy); for investment as stimulus topics, general environmental (43.1%) and clean energy (17.2%) were the most prominent topics. Within the clean energy category, general terms dominated occurrences, accounting for 53.3% of all clean energy mentions in proximity to economic terms; however, wind energy and bioenergy were also major subcategories (20.0% and 17.0%, respectively).[3]

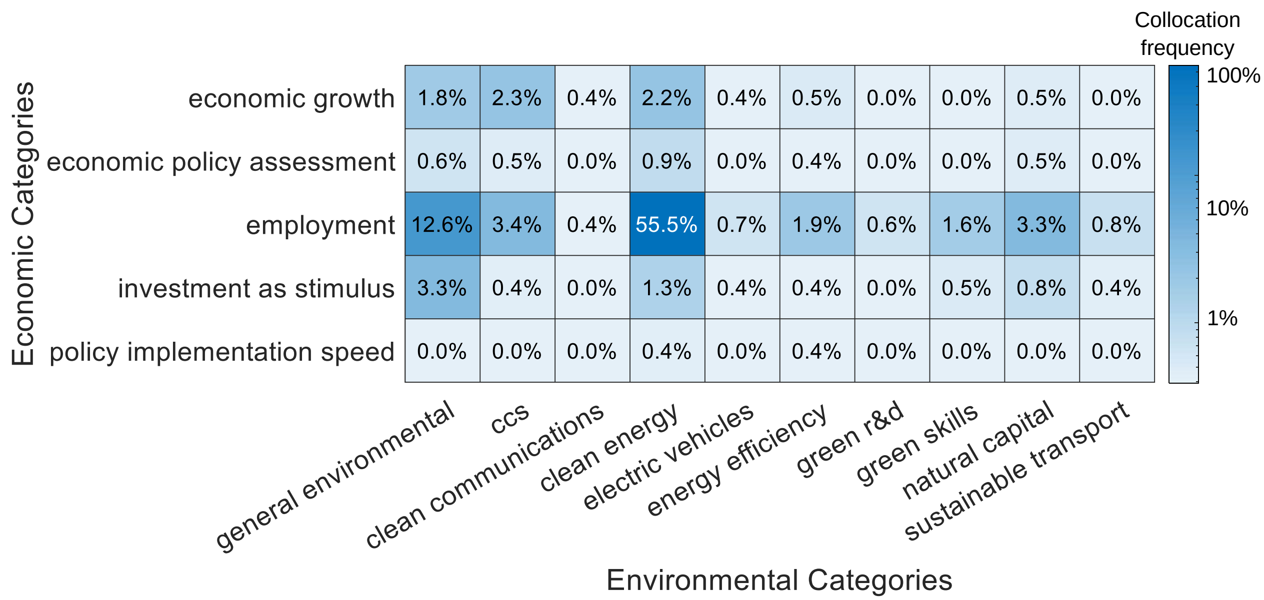

Figure 4. Relative collocation frequency of economic and environmental categories. Results for full corpus (908 papers) and context = 100 scenario. Collocation frequency for the subset of premier journals is included in the Supplemental Appendixes. Abbreviations: CCS, carbon capture and storage; R&D, research and development.

The comparative coverage of environmental categories in the surveyed literature is wildly misaligned with government recovery expenditure observed during the GFC and so far during the COVID-19 pandemic (Figure 5). This trend is similar but less pronounced in premier journals, which deliver a higher proportional coverage of environmental topics outside of clean energy (see the Supplemental Appendixes). In part, these findings are unsurprising because they are

[3] We note that bioenergy terms are frequently used by researchers when clarifying the definition of renewable energy used in their analysis and do not necessarily relate to specific investigations.

backward-looking. Logically, established technologies and practices have garnered comparatively greater research interest than nascent and emerging technologies, particularly for a sector as large as energy. Nevertheless, low research attention for initiatives receiving billions of dollars in taxpayer support is concerning. These findings align with commentary that the field of environmental economic research has not directed sufficient attention to the fastest growing areas of public climate investment, including in so-called hard-to-abate sectors (90, 91).

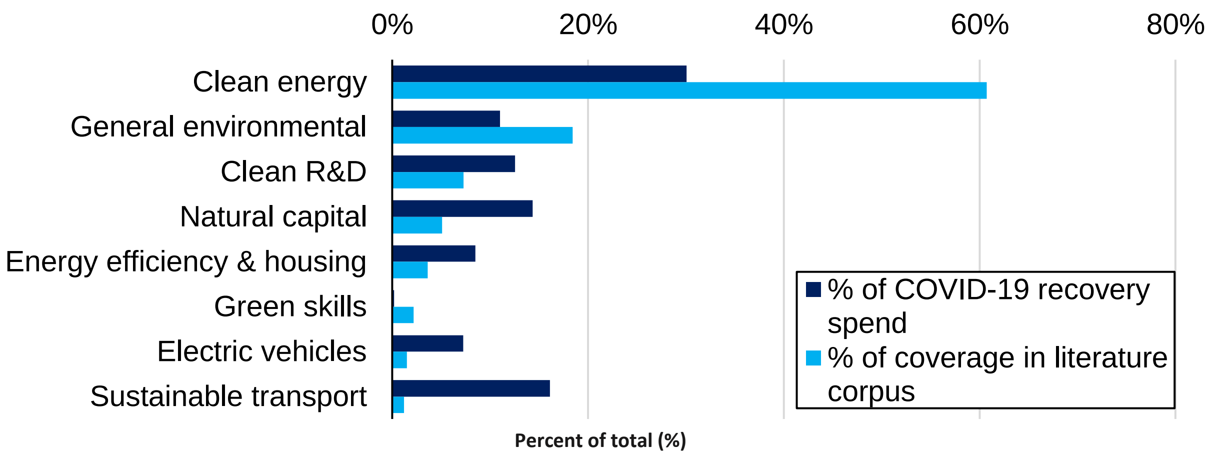

Figure 5. Research spread versus green stimulatory investment patterns. CCS combined with R&D for comparison. Clean energy includes relevant market creation initiatives. Source: literature data from this article; COVID-19 data to October 2021 from the Global Recovery Observatory (59). Abbreviations: CCS, carbon capture and storage; COVID-19, coronavirus disease 2019; R&D, research and development.

4. MACROECONOMIC IMPACTS OF GREEN STIMULUS

This section builds on the quantitative analysis above to provide an assessment of the literature on the economic characteristics of green fiscal spending in terms of speed of implementation, job creation, and national income multipliers. Overall, although there are some quality studies offering initial guides on the characteristics of stimulatory green investment, there are also large gaps in the literature where progress appears both valuable and possible.

The characteristics of green fiscal spending could be evaluated across at least eight important dimensions, namely (*a*) boosting employment and doing so in areas of greatest need, (*b*) optimizing the time of action, (*c*) maximizing the economic multiplier, (*d*) ensuring fiscal affordability, (*e*) reducing inequality and meeting other social prerogatives, (*f*) supporting the natural environment, (*g*) achieving simplicity for implementation, and (*h*) political considerations. This review focuses on the first three listed objectives, each of which is an essential economic consideration for policymakers.

4.1. Job Growth

Perhaps the most oft-cited objective in stimulatory/expansionary fiscal policy is job protection and creation, as contractionary economic periods tend to induce unemployment. It is unsurprising then that the employment characteristics of green investment receive disproportionately higher coverage in the literature than studies of timeliness or Keynesian multipliers, as seen in Section 3.[4] In this section, we focus on modeled and measured green job creation effectiveness and job multipliers from public green investment programs. A complementary and growing literature investigates green job potential from all kinds of investment (96, 97).

One class of literature focuses on absolute job creation. Blanco & Rodrigues (98) assess job creation from nascent wind energy deployments in the EU, finding that early investments created many jobs as other segments of the energy sector were shrinking. Scholtens (99) estimates that the Netherlands' Green Projects Facility created approximately 21,500 FTE job years. Pollitt (52) and Mundaca & Damen (48) respectively present figures for post-GFC measures in EU member states and South Korea, again demonstrating strong job creation characteristics. In the US, ARRA renewable energy investments were identified as particularly strong for job creation (41–43, 45, 56). For example, Steinberg *et al.*'s (45) analysis shows that $US 9 billion in incentives under the Section 1603 Grant Program of the American Recovery and Reinvestment Tax Act generated 150,000 to 220,000 job years just in renewable energy construction, and a further 5,100 to 5,500 job years in operation. Popp *et al.* (56) consider total jobs rather than job years, finding that every $US 1 million in green ARRA spending created 15 new jobs. For COVID-19, ex ante models also predict strong employment impacts from green investment across geographies (see 68 for global coverage, 70 for ten case study countries, and 66, 69 for South Africa).[5]

Without a counterfactual, the relative job creation potential of green investment is difficult to ascertain. Kammen *et al.* (100) perform a meta-analysis of 13 studies, concluding that renewable energy policy portfolios generate more jobs than fossil fuel–based portfolios, per unit of energy delivered. Wei *et al.*(92) build on this, including more studies to find that clean technologies, from renewable energy and energy efficiency to CCS, can form energy portfolios with considerably more FTE jobs per unit energy than coal and natural gas. Blyth *et al.* (93) estimate that a shift toward renewable energy and energy efficiency investment can increase the labor intensity of energy by up to 1 FTE job per annual gigawatt hours above the previous average of 0.4.

Other studies use jobs per unit capital investment and direct job multipliers to compare the economic advantages of green spending against other investments. Spencer *et al.* (101) use French data to show that a million Euro of expenditure created 17 jobs in energy efficiency and 10–14 jobs in renewable energy, versus 2.4 in oil and 3.6 in gas. Using an input-output model, Garrett-Peltier (102) finds that, in the United States, US$1 million in spending creates 7.49 jobs in renewable energy,7.72 in energy efficiency, and 2.65 in fossil fuels. However, Huntingdon (103), including data from Kammen *et al.* (100) and others, finds that green job creation is only cheaper where there are pre-existing advantages for green power sources, such as a facility located close to the power grid. Huntingdon concludes on average that, up to 2009, green jobs were not clearly cheaper than conventional energy jobs; however, Huntingdon does not consider spillover effects

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[4] Job creation is often reported as full-time equivalent (FTE) jobs or job years (92–95) to standardize across full time and part time jobs and to account for the temporary nature of some types of employment (e.g., in the construction sector) compared to the more permanent employment generated in roles like maintenance and research. In this study, jobs refers to FTE jobs and job years to FTE job years.

[5] Higher modeled employment benefits of green spending might be explained by technological progress, a more complementary macroeconomic environment, and/or better data availability. In the case of technological progress, lower costs for green technologies might lead to a smaller portion of investment spent on materials and a higher portion on labor.

and refrains from commenting on possible future job multipliers. Additional commentaries point to the sizeable risks of offshoring capital to fund import-heavy renewable technology while losing corresponding fossil energy jobs (104).

Induced jobs and other employment spillover effects on green investment are considered by a small group of authors, including Nair & Rutt (94), who estimate that one additional job in forestry generates an additional 1.5 to 2.5 FTE jobs in the wider economy. Vona *et al.*(44) find that one additional green job is associated with 4.2 new local jobs in non-tradable, non-green activities, only falling to 2.2 in crisis periods—this is considerably higher than previous studies. Houser *et al.* (95) partly associate these benefits with savings in energy costs—every US$1 billion on building efficiency is estimated to create 30,100 FTE jobs and save US$450 million in energy costs, of which approximately 50% is reinvested in the economy and creates further jobs. Kronenberg *et al.* (57) further consider the significant avoided cost of unemployment, in the example of a German building rehabilitation program. O'Callaghan *et al.* (69) note that the mutually supportive characteristics of green industries are difficult to account for in modeling—consider, for example, the role of cheaper electricity in strengthening the economic appeal of consumer products like electric vehicles and emerging innovations like artificial proteins.

There are also negative effects to consider. For instance, although renewable energy spending boosts employment while the asset is being built, in the longer run, keeping net capacity equal, the transition from fossil electricity to renewable electricity could reduce total direct employment, as renewable infrastructure has comparatively minor maintenance requirements (105, 106). Indirect effects may be significant, however: Energy savings from cheaper renewable electricity could be reinvested into the wider economy, leading to job growth, as Houser *et al.* (95) suggest. Jacobson *et al.* (107) calculate private energy cost savings of US$10.9 trillion a year (61%) across 143 countries, from an energy transition of this kind. If reinvested, this could bring many new jobs globally. More widely, it remains imperative that green fiscal stimulus programs are tailored and well implemented to minimize harm to overall employment—policy design remains crucial (2, 108, 109).

There is an older and relatively limited literature critiquing green jobs (e.g., 110–114), drawing attention to definitional issues and data comprehensiveness, querying the public expense of such job creation, and observing that labor-intense output is not necessarily economically superior to output that involves higher labor productivity (and hence fewer jobs). These specific critiques and questions are useful. Overall, however, the literature examining the role of green job creation during an economic recession remains limited and partial at best. Álvarez *et al.* (106) claim that green jobs investment in Spain destroyed nine jobs for every four created, before accounting for the opportunity cost of the investment. This work is directly countered by Lantz & Tegen (115), who identify inappropriate use of metrics and failure to account for economic variability, among other critiques. Marsh & Miers (116) find that, in the United Kingdom, 3.7 jobs are foregone for every job created in renewable energy. Böhringer *et al.* (117) observed a similar decline in overall labor force participation because of Ontario's feed-in tariff policy to promote renewable energy. This finding opposes other studies conducted in Germany (118, 119), and the EU more widely (120). Hillebrand *et al.*(121) suggest that short-term gains in net employment are eventually offset by falls in domestic production if energy costs rise, leading to a negative employment balance in the long run. Yet even this is of limited relevance today, 15 years later, where the levelized cost of energy of solar has fallen 89% and onshore wind 55% (globally representative figures) (122, with data from 123 and 124). Broader, elemental criticisms from the literature question the political fixation on jobs—they contend that if the objective is to spend efficiently then perhaps the focus should be to minimize costs rather than create jobs. Some suggest that the goal should be more productivity rather than more jobs (113), whereas others warn against conflating labor-intensive energy provision with efficient climate protection (104).

Four clear findings emerge from the literature on job creation through stimulatory green investment:

- First, clean energy investments and energy efficiency retrofits can outperform traditional energy investments on direct and indirect job creation and labor intensity.
- Second, there is insufficient evidence to definitively comment on the comparative labor impacts of other green investments; however, emerging COVID-19 analyses suggest that these might also be more favorable than traditional alternatives. These investment archetypes require particularly urgent attention and include natural capital investment, green agriculture, sustainable transport, and clean R&D (particularly green hydrogen and CCS). Across each archetype, particular focus is required in emerging markets and developing economies.
- Third, the induced labor impacts of green investment are poorly understood and would benefit from more research.
- Fourth, minimal research has considered the key enablers of green job creation—namely, availability of sufficient and suitable green skills, existing baseline green business ecosystems and contractor capabilities, and appropriate absorptive capacity in R&D.

For findings two, three, and four, US$470 billion (and growing) in COVID-19 investment that is geographically and sectorally spread provides the ideal testbed for future research. In this, it will be important for researchers to coalesce on consistent definitions and methodologies in green job impact assessment.

4.2. Time of Action

A key attribute of fiscal stimulatory spending is its timeliness—governments aim to deploy investment rapidly to reduce economic harms (125). Quickly deployed stimulus can counter consumer and business uncertainty, acting to restore aggregate demand and make use of idle labor in the period of higher unemployment associated with recession (4). If fast enough, spending can also arrest a fall in jobs by replenishing revenue for companies in target sectors with new contracts, allowing them to meet wage obligations (126). If dispersed in a favorable low-interest rate environment, which might follow a period of economic contraction, well-timed investment could also more easily catalyze business investment and thereby support higher economic multipliers (4, 9, 127).

But faster is not necessarily better—combining policies of varied timeframes into a policy portfolio might enable a smoother recovery path. Rapid measures can bring forward established consumer demand without necessarily increasing total demand over the medium term (128,129). This possibility raises concerns about arrested growth or industry slowdown in the period following the stimulus action but also might resolve concerns about excessive overheating and inflation in the event of a strong rebound.

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Incorporating policies with medium-term effects into stimulus packages can complement rapid action measures. Such policies can deliver a permanent upward shift in the demand curve to establish new industry and long-term jobs. However, any medium-term spending must be considered for its impact on the national debt and resulting effects (positive or negative) on business confidence. Reduced business confidence in a high-debt environment could feasibly constrain private investment, increasing long-term interest rates and countering the intended effect of the stimulus program (see 125). As economic recovery itself takes place over several stages, packages incorporating policies that exhibit economic benefit at different stages of recovery could ensure that this takes place completely and gradually.

Pollitt (52) conducts a high-level analysis of the timeliness of recovery packages from EU member states, the United States, Australia, China, and South Korea following the GFC. Pollitt concludes that stimulatory green investments have generally been timely, although as in the Australian roof insulation experience, attempts to take shortcuts can have severe negative consequences. He finds that energy efficiency investments, including building retrofits, are particularly quick—this finding is supported across the literature (see 95, 101, 130–132). However, this is contingent on overcoming barriers such as up-front costs, cost of finance, and informational barriers (55). These policies can be particularly fast-acting when supported by direct loans (101). Alberini *et al.* (133) may offer some explanation for the speed of these policies, demonstrating that in addition to having low planning requirements, a successful Swiss retrofit program was spurred by high levels of household responsiveness to simultaneous cost, comfort, and climate benefits from retrofitting.

Depending on the type of program, natural capital investments can also be relatively fast-acting (130). Some jobs in ecosystem services are considered lower-skilled, meaning project lead times can be shorter than in other industries if skilled labor is scarce. Additionally, as these projects often rely on primary goods and domestic supply chains, input material sourcing can be comparatively streamlined. However, without apt consideration of biodiversity, local populations, and other practical needs, rapid and poorly planned investment in natural capital risks inadvertent but severe human and environmental externalities (134).

Whereas energy efficiency and natural capital investments stand out as fast-acting policies, clean energy infrastructure and clean transport infrastructure investments are typically considered to be slower-acting policies (101, 130). The speed of action in these investments depends on the availability of so-called shovel-ready projects, particularly those that have already passed planning and approval processes, or perhaps are already underway and would benefit from acceleration (131). The prioritization of shovel-ready projects in the ARRA during 2009 allowed for rapid US deployment of both the Weatherization Assistance Program and tax credits for wind and solar (43). In some nations, provided that appropriately skilled labor is available, a backlog of existing shovel-ready projects might guide investment—for instance, ecological conservation projects and local bike infrastructure projects in the United Kingdom following COVID-19 (135).

Despite the labor intensity of many rapid action projects, and the relatively low training requirements of associated jobs, induced labor demand from significant fiscal investments is often not fulfilled (132). Instead, the wider economic impacts of targeted worker retraining programs are likely to only be fully realized in the medium and long run. This is because maintenance demands increase over time, while dynamic innovation effects and skill-biased technical change creates jobs through R&D (136). Relatedly, stimulus through clean R&D investment is expected to have a delayed effect. In the past, depending on the industry, regulatory hurdles and scaling timelines have seen new fiscal allocations dispersed to research teams two or more years after initial funding (95, 130, 137).

Compared to employment impacts, research on the timeliness of stimulatory green fiscal spending is relatively shallow and skews to qualitative descriptions over technical analysis. Rather than quantifying the time spans over which economic benefits play out, most studies use broad descriptors, for instance, “fast,” “medium,” and “slow” (9,52,95). Overall, a greater understanding of when different policy archetypes exhibit economic benefit will be beneficial to design balanced green stimulus packages that both provide an immediate economic boost and set the economy on a path toward long-term sustainability and prosperity.

4.3. National Income Multipliers

Comparing the economic benefit of fiscal investment alternatives is traditionally completed with reference to national income multipliers or so-called Keynesian multipliers (4,9,138,139). Sometimes these are “true” Keynesian in that they consider both private and public spending, but frequently they focus only on public investment and are better termed fiscal multipliers. The intertwined nature of economy and environment in our current system of production questions whether economic growth should be analyzed in isolation from its environmental consequences. Yet, mainstream policy discourse continues to consider the two as separate today (2, 52, 71, 101, 108). In the simplest form, the direct job creation and consumption impacts of government spending are expected to induce additional consumption and investment, further adding to national income and creating a multiplier effect. Short- and long-run multipliers are both known to be higher in demand-deficient macroeconomic environments, for instance, during and directly following a recession (140). This being said, fiscal multipliers are notoriously difficult to estimate, and green multipliers represent a particularly understudied area (9, 71, 138).

Given a lack of appropriate data, various directional estimates of green multipliers have informed policy decision making. Estimates employ three-point scales, judging multipliers from high to low or best to worst. In these schemes, policies including energy efficiency retrofits, CCS programs, vehicle scrappage schemes, and afforestation are reported to have high fiscal multipliers (101, 130, 141). Conversely, smart metering stands out as a policy considered to have a particularly low multiplier (130). The multiplier potential of renewable energy promotion and capacity construction is debated, with some studies claiming both high absolute multipliers and high multipliers relative to other green technologies (130), and others estimating high absolute but low relative multipliers (101, 141).

Batini *et al.* (71) provide a direct analysis of green national income multipliers, using factor augmented panel vector-autoregressive models to interpret the impact of clean energy spending and biodiversity conservation spending on GDP. They find that the output response of green investments is much more persistent when compared to their non-green direct corollaries (e.g., dirty energy and industrial farming, as Batini *et al.* describe). In their model, whereas the output response of non-green spending dies within five years, the green spending response continues beyond five years. This translates to an impact multiplier of 1.19 for clean energy (five-year multiplier of 1.11), compared to 0.65 for dirty spending (five-year multiplier of 0.52). The authors explain the following:

In other words, when an additional dollar of public or private money is spent to build more fossil fuel energy infrastructure and power generation plants, this expenditure crowds out some other component of GDP (investment, consumption, or net exports) by 48 cents in the medium run. When the same dollar is spent on solar, wind or geothermal, 11 cents are instead crowded in. (71, p 24)

On biodiversity conservation, the study is unable to derive a statistically significant short-term impact multiplier. However, at the five-year horizon, biodiversity conservation is shown to be even more persistent in its output response with a growth multiplier of 6.67. This compares to a five-year multiplier of 0.94 for industrial farming.

Hasna (142) estimates local green energy multipliers in the United States using state-level annual data over 16 years. Hasna finds a multiplier of 1.1 contemporaneously, 2.5 within one year, and up to 4.2 within two years of implementation. These figures are significantly higher than comparable traditional energy investments. Hasna shows that 86% of the variation between the green and non-green multipliers is due to differences in the initial stock of public capital, with green "further away from the steady-state."

Pollitt (52) provides a quantitative estimate for domestic short-term green multipliers for EU member states, using the E3ME macroeconometric model. Pollitt concludes that green multipliers range from 0.5 to 1.1 domestically and that multipliers vary more between countries than they do between green policy types. Notedly, Politt shows that whereas average multipliers might be 0.75 when measured at a national level, at the regional EU level they can be as high as 1.5 due to captured imports and the integrated nature of the Union. At the national level, spending on buildings is estimated to be slightly higher than 1 due to the domestic nature of construction. For other green initiatives, trade and importing impact national fiscal multipliers to a greater extent.

A valuable case study in the variability of green fiscal multipliers is that of vehicle scrappage, or "cash-for-clunkers" programs. Although, theoretically, these initiatives might bring large economic returns on account of their propensity to mobilize private savings (52), the size of impact depends on how these private funds might otherwise have been used to purchase another, perhaps less expensive, vehicle, or any other good or service. Ex post analyses return mixed findings. Analysis of the US Car Allowance Rebate System program suggests high economic effectiveness, wherein the probability of a household exchanging their old vehicle for a new one increased by a factor of four and the average spent on a new vehicle increased by US$320 (143). However, analysis of a German vehicle scrappage program identified high leakiness on the account of rapidly increased Czech automobile imports (144). Additionally, relevant for all cash-for-clunkers programs, Li & Wei (145) have demonstrated the inherent economic-climate trade-offs of vehicle scrappage programs, whereby rational consumers might purchase bigger and more luxurious vehicles than they otherwise would have. Such vehicles are often less fuel efficient.

Apart from Batini *et al.* (71) and Hasna (142), quantitative studies do not attempt to compare the multiplier characteristics of green investments with traditional forms of spending. In response to COVID-19, Hepburn *et al.* (2) partially addressed this gap, using a survey of 231 participants from central banks, finance ministries, and academic institutions to indicatively categorize subjective perceptions of the relative long-run multipliers of 25 fiscal spending options. Green policies with comparatively high long-run perceived multipliers include clean energy infrastructure investment, clean R&D spending, and connectivity infrastructure.

One challenge to making robust progress on stimulatory green multipliers is that most studies (including those mentioned here) adopt at best a Bayesian approach with the assumption of constant parameters. By definition, however, an economic crisis brings significant and unanticipated shifts. In general, diffuse priors can distort outcomes, especially if outliers and shifts are not appropriately handled. A next step would be to derive results from other (non-Bayesian) modeling approaches that can handle distribution and parameter shifts (146, 147).

Despite useful initial works, there remain many gaps in the academic literature on green multipliers:

- First, all green policy archetypes identified in this review could benefit from further analysis, with particular consideration required for sustainable transport, natural capital investments, electric vehicles, energy efficiency programs, clean R&D, and green skill-building and retraining programs.
- Second, in the absence of long time series data, which is often required for multiplier computation, unique methodologies in data collection and processing might be needed to reach empirical insights beyond Batini *et al.*'s (71). Artificial intelligence solutions could unlock particularly promising opportunities.
- Third, new (non-Bayesian) modeling approaches should be considered to appropriately tackle distributional and parameter shifts, which are inherent in times of economic crisis.
- Fourth, multiplier assessment terms need to be better defined and linked to other assessments of economic impact, for instance, labor market impact. To enable comparison across studies and national contexts, a consensus is needed on definitions for short- and long-term multipliers, as well as definitions for green policy archetypes.

5. CONCLUSION

The encouraging conclusion of this review is that although the field is nascent, the overall economic characteristics of green fiscal investment appear positive and are likely superior to dirty investment options. This is before essential cobenefits are considered, which range from improved health outcomes to reduced environmental degradation and a stabilized climate. The time to conduct higher quality research in this area is now—before levels of interest fall away and memories of the COVID-19 crisis fade. The results may not be needed for another decade, but when they are needed, they will be urgently needed.

In a sense, therefore, we hope that policymakers are not turning to the synthesis on green fiscal policy in this article for advice when subsequent crises hit. However, history suggests they may do this, so we summarize the key recommendations for policymakers emerging from the literature at this stage:

- **Green stimuluses can indeed be stimulating.** The economic properties of recovery spending on the environment appear (on relatively weak evidence) to be relatively strong. Given that huge investments are required to achieve the world's climate and biodiversity goals, wise governments will seize the opportunity to progress two objectives with one intervention.

- **Plan ahead as policy design is important.** As with all recovery spending, the impact of green investment depends on the archetypes used, the national context, and specific design features. Among other factors, the financing, delivery mechanism, and target beneficiaries of a policy can significantly impact economic, social, and environmental returns. To get it right, policymakers must invest time in policy design—either by beginning as soon as a crisis hits or ideally preparing investment options in advance of a crisis. We prepare for rainy days with food banks and oil stockpiles—why not cache and refresh shovel-ready projects too?
- **Invest in policy impact assessment.** Policymakers often lack sufficient evidence to make the necessary design decisions for green investment. To build an evidence base to inform future decision making, policymakers should commit to policy impact assessments, with a portion of every fiscal investment reserved for ex post analysis. We did not learn sufficiently from GFC policy responses—we should not repeatedly make the same mistake.

Periods of economic crisis provide an opportunity for fiscal investment to reorient economic production and growth trajectories; the immense and growing risks of climate change require that this reorientation is toward green industries. It is imperative that we learn from the GFC and the COVID-19 pandemic so that during the next crisis we have a well-evidenced understanding of the benefits and trade-offs of green investments and can act to maximize shared prosperity.

SUMMARY POINTS

1. Green stimulus has a strong capacity to create jobs, to boost economic growth, and to do so in a timely manner.
2. Green investment for stimulus has grown with the resurgence of Keynesian narratives for public spending in economic recovery, seen in responses to the 2008–2009 Global Financial Crisis and the coronavirus disease 2019 (COVID-19) pandemic.
3. As of October 2021, green COVID-19 investment continues to lag behind spending in the Global Financial Crisis, despite a deeper recession and more advanced green technologies.
4. The research field of stimulatory green investment is nascent and contains many gaps. Gaps exist heterogeneously across archetypes, with greater existing coverage for energy efficiency and renewable energy policies; geographies, with greater existing coverage for Northern America and Europe; and methodologies.
5. Research critical of green stimulus policies focuses on the job creation aspects of green stimulus. It broadly fails to consider positive long-run spillovers and falling green technology costs.
6. Research patterns are unaligned to government spending patterns. Some poorly researched topics receive significant public investment, leaving policymakers to design policy without sufficient academic guidance.
7. In terms of methodology, for literature identification, we use a bespoke supervised machine learning algorithm based on the word2vec neural network model.
8. In terms of methodology, for literature synthesis, we use a structured qualitative review and several machine learning models, including Latent Dirichlet Allocation, t-Distributed Stochastic Neighbor Embedding, and collocation analysis.

FUTURE ISSUES

1. All green archetypes are understudied, with particularly low coverage of natural capital, green agriculture, sustainable transport, clean research and development (R&D), and green skill-building.
2. All fiscal recovery programs should designate funds to ex post impact assessment based on appropriate standards—these standards need to be designed and uniformly adopted.
3. A universal taxonomy for green investment archetypes should be used in ex post assessment and commentary. Recovery policy taxonomies need to be expanded.
4. Enhanced focus is needed for regions outside of Northern America and Western Europe.
5. Particular gaps for job creation should be addressed, including in induced job impacts, sufficiency and suitability of existing and future green skills, green business ecosystems capabilities and requirements, and appropriate absorptive capacity in R&D.
6. Particular gaps for timeliness should be addressed, including in quantitative analyses and trade-offs with other economic impacts.
7. Particular gaps for fiscal multipliers should be addressed, including in methods for acquiring adequate data, new (non-Bayesian) modeling approaches, and definitions of multiplier terminology.

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