Leveraging the Inflation Reduction Act to Achieve 80x30 in the US Electricity Sector

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1. Motivations underlying the research

Under the Paris Agreement, the United States has committed to reducing economy-wide greenhouse gas emissions by 50–52 percent below 2005 emissions levels by 2030. The majority of these emissions reductions are expected to come from the electricity sector, where they correspond to a related sectoral target of reducing emissions to 80 percent below 2005 levels by 2030, which we describe as an "80x30" target.

To help meet these targets, Congress passed the Inflation Reduction Act (IRA)—the most significant environmental policy that the United States has passed since the Clean Air Act in 1970. The IRA aims to decarbonize the power sector by providing subsidies for clean electricity generation. Multiple modeling efforts find that the IRA achieves substantial emissions reductions but that the law is unlikely to reduce emissions enough to reach the 80x30 target. Moreover, the emissions reductions that the law does achieve are uncertain. However, the IRA can be expected to affect the incremental economic effort necessary to achieve the 80x30 target if it were implemented as a new emissions cap in the electricity sector.

2. A short account of the research performed

This paper uses a detailed electricity sector model to examine what would happen if—on top of the IRA—the United States were to adopt an emissions cap that requires the electricity sector to reach the 80x30 target. We compare these results to a scenario that would achieve the 80x30 target without the IRA subsidies. We also model an emissions cap that would achieve the level of projected emissions reductions from the IRA alone (which fall short of the climate targets) to evaluate the cost effectiveness of the IRA.

3. Main conclusions and policy implications of the work

While the IRA is the largest step that the United States has taken so far to mitigate climate change, it does not reduce US power sector emissions to a level that is consistent with the goals in the Paris Agreement, nor are emissions reductions guaranteed. Under different assumptions about gas prices and demand, we find that electricity sector emissions outcomes could vary greatly under the IRA. However, the IRA substantially reduces the incremental marginal cost of an emissions cap set to achieve and guarantee the 80x30 target.

With the IRA in place, the marginal cost associated with the incremental emissions reductions is cheaper than the cost would have been without the IRA. Without the IRA in place, under our central case representation of gas prices and electricity demand, an emissions cap that achieves 80x30 would require an emissions allowance price of $67 per metric ton, while such a cap *with* the IRA would require a cost of only $28 per metric ton.

The IRA provides important subsidies for investment in nonemitting electricity generation but it does not directly penalize emissions. In fact, while we observe under the IRA that investments in clean generation cause overall fossil-fired generation to decline, coal's share of fossil generation increases rel-

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ative to gas. The addition of a relatively low carbon price of $28 per ton under an emissions cap has a big effect in improving the cost-effectiveness of reducing emissions by providing an incentive for the power sector to switch from coal to gas, which would reduce the carbon intensity of fossil fuel–fired electricity generation on the grid, because gas–fired power plants produce less emissions than coal-fired power plants.

We also find that the IRA institutes a cost shift from electricity consumers to taxpayers, resulting in lower electricity prices on average. Achieving the same emissions reductions that are expected through the IRA with only an emissions cap would entail increased electricity prices. With the IRA already in place, adding an emissions cap to achieve the 80x30 target keeps electricity prices below a no-policy reference case. Importantly, lower electricity prices could help promote electrification throughout the economy, which is a crucial part of the US strategy to reach net zero after 2030.

The addition of an emissions cap also would increase the health benefits that are associated with the IRA. These benefits stem from reductions of secondary PM2.5 formed from NO_x and SO_2 emissions from power plants, especially coal-fired power plants. Adding the emissions cap on top of the IRA leads to a greater reduction in coal-fired electricity generation and thus offers greater health benefits.

Instituting an emissions cap alongside the IRA would lock in US emissions reductions, improve the efficiency of the IRA, have no impact on ratepayers, and increase the law's benefits for health. While the IRA does not achieve 80x30 on its own, adding an emissions cap would guarantee that the target is met. At the same time, the IRA reduces by almost 60 percent the marginal cost of achieving the 80x30 target with an emissions cap. The IRA would also prevent the cap from raising retail electricity prices—thereby protecting consumers and supporting emissions reductions in other sectors of the US economy. Adding a cap could raise revenue that partially would offset government expenditures on tax credits for clean energy, and the reductions in coal-fired electricity generation would increase the number of lives saved due to reduced air pollution. In the international context of climate negotiations, adding the emissions cap to the IRA could make the US pledge to reduce emissions more credible, potentially prompting additional effort by other nations.

Evaluation of the Winter Pollution Mitigation Policy in China

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Motivations: The rapid industrialization of China over the past 30 years has led to substantial increases in local air pollution. In response to this environmental crisis, the Chinese government declared a "war on pollution", issuing the Air Pollution Prevention and Control Action Plan in 2013. As part of this effort, the Winter Pollution Mitigation Policy, hereafter the "winter policy", was issued in 2017 to reduce pollution emissions in the winter in Beijing, Tianjin, Hebei and neighboring regions. While a large body of existing work has studied the health costs of air pollution in China, relatively little work has quantified the benefits and public expenditures associated with air pollution *policies* in China.

Research Methodology: This study quantifies the health benefits and public expenditures associated with the Winter Pollution Mitigation Policy of 2017. The policy was implemented to control pollution emissions in the winter months in Beijing, Tianjin, Hebei, and neighboring regions. It included mandates that polluting firms and households reduce pollution levels, which were supported by subsidies from the government. The study used a difference-in-differences approach to analyze the impact of the winter policy on fine particulate concentration levels (i.e., $PM_{2.5}$). In addition, the authors calculated the public expenditures associated with the winter policy in 2017, comparing the implementa-

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tion-cost-effectiveness of the Winter Policy to that of the Air Pollution Prevention and Control Action Plan from 2013-2017.

Main Conclusions and Policy Implications: The paper concluded that the Winter Pollution Mitigation Policy reduced $PM_{2.5}$ concentration levels by an average of 14 μg/m3 or 18% in the Beijing-Tianjin-Hebei region and neighboring areas in the winter of 2017. This reduction in pollution levels led to approximately 19,400 fewer premature deaths due to fine particulate exposure in 2017. The monetized mortality benefit of the winter policy was estimated to be roughly 12 billion USD, and the policy's implementation cost was at least 8 billion USD in 2017. The study found that the ratio of public expenditures to lives saved was significantly lower for the winter policy compared to the overall Air Pollution Prevention and Control Action Plan. This relative implementation-cost-effectiveness may be due to the policy's focus on the most polluted region of China during the season with the highest pollution levels. The winter policy was expanded to include other regions in 2018 and remained in effect as of 2021, suggesting a continued investment in this targeted approach to pollution control in China.

Energy Markets Under Stress: Some Reflections on Lessons From the 2021-2023 Energy Price Crisis in Europe

Michael G. Pollitt[a]

1. Motivations underlying the research

There has been an unprecedented energy crisis in Europe affecting gas and electricity prices over the period since August 2021. Due to a combination of a faster than expected recovery from the COVID-19 pandemic, combined with an initially low level of gas stocks following the winter of 2021-2021, prices began to rise. This rise was then exacerbated by the build-up to the full scale Russian Invasion of Ukraine on 24th February 2022 and the subsequent disruption of Russian gas exports to Europe.

This article discusses the lessons of the crisis with a focus on its implications for electricity markets. The crisis gives rise to two sets of reflections based on the nature of energy policy in wartime and on the actual policies discussed and implemented during the crisis. The experience is rich because many European countries have faced the same shock and there has been a degree of experimentation, co-ordination and learning.

2. A short account of the research performed

We begin by discussing the historical scale of the price shock. The statistics show that the shock to both gas and electricity prices has been historically unprecedented. Next, we discuss how energy policy is different in wartime. This is important because Europe has been in an energy war with Russia, where Europe has attempted to rapidly reduce both its gas consumption and Russian energy dependency, while Russia has strategically restricted gas exports in an attempt to raise gas prices thereby exercising geopolitical leverage. We go on to examine the European Union's (EU) energy policy responses. The EU is responsible for the European single market in electricity and gas (which also formally includes Norway and effectively includes the UK). We then discuss four good and three bad policy responses observed across Europe during the crisis.

3. Main conclusions and policy implications of the work

We conclude that wholesale electricity and gas markets work in delivering energy security! Europe's efforts to create genuine single markets in electricity, gas and carbon have proved their worth in the crisis.

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The distributional impact of high prices on European households and industry and the short- run impact on the competitiveness of national industries remains a major concern. Given the prolonged very high prices, intervention of some kind became inevitable.

Moving on to climate policy, we suggest that the crisis is a wake-up call to pay attention to the price impact of net zero policies, where tight linkages between power, heat and transport prices are the consequence of sector coupling *and* high unit prices of energy are also to be expected.

The undermining of world order at the heart of the crisis reduces the prospects for market based decarbonization based on clear definitions of internationally tradeable property rights and reliable international monitoring of the quality of environmental goods (such as carbon, renewables, green and blue hydrogen).

Finally, we argue that what any energy crisis tends to reveal is the need for more, not less, orthodox economic theory to inform energy policy. Wider, deeper, more global markets are the best way to mitigate country specific supply risks *ex ante*. Actually, responding to price spikes by reducing demand and increasing supply are the sensible responses *ex post*. The sad thing is the world often insists on testing the opposite on the real world economy, e.g. by taking actions which increase demand and reduce supply in the face of price spikes. Economists should stand against such theoretically groundless actions.

Towards a Green monetary Policy for Developing Countries: A Climate Rating Mechanism for Funding Sustainable Projects

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(i) Motivations underlying the research

The article falls within the framework of the pressing issue of global warming and its potential economic and social consequences knowing that climate change poses significant risks to economies, financial stability, and the well-being of societies worldwide. Therefore, there is a need for massive and decisive action to be taken by central banks with a view to greening its monetary policy. While developed countries have taken some steps towards green monetary policies, the authors argue that developing countries need specific financing solutions to support their climate projects.

The aim of this research is to propose a mechanism that allows developing countries to integrate climate considerations into their monetary policies, particularly through local development banks. By doing so, these countries can support sustainable projects, contribute to the 2°C objective set by the Paris Agreement, and secure a green future for their economies.

(ii) A short account of the research performed

The research proposes a mechanism for the greening of monetary policy in developing countries, with a focus on supporting local authorities engaged in pro-environmental projects. The mechanism involves a climate-rating model, which assesses the environmental and social risks of various investment projects seeking funding from local development banks. Central banks play a crucial role by providing liquidity to local development banks, contingent on their financing of low-carbon projects. The central

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bank can play a key role in financing green projects by providing liquidity to local development banks specifically channelled, as a collateralized loan, to "local authorities" that undertake environmentally friendly actions.

The climate rating model evaluates the creditworthiness of local authorities and the environmental parameters of the projects. It categorizes projects into four risk levels: A, B, C, or D, with D representing projects with the highest environmental and social risks and being systematically rejected. The local development bank's counterparty risk is determined by a combination of both the municipality's and the project's rating, ensuring that only green projects with appropriate ratings receive funding. The proposed mechanism aims to foster green financing by local development banks, incentivizes the development of ~~the~~ green securities markets, and ultimately green the central bank's balance sheet.

A concrete case study has been presented showing how our suggested mechanism is contributing to the greening of the monetary policy by funding sustainable projects through a local development bank. By integrating climate considerations into their monetary policy, developing countries can enhance the sustainability and profitability of green projects and contribute to the global fight against climate change.

(iii) The main conclusions and policy implications of the work

The research concludes that a pro-climate monetary policy is essential for developing countries to combat climate change effectively. Central banks can encourage local development banks to fund sustainable projects, by incorporating climate ratings into the financing decision-making process. The proposed mechanism promotes a societal shift, recognizing the environment's central role in the economy, and fostering urgency in achieving the 2°C objective.

Overall, the proposed mechanism provides a path for developing countries to navigate the challenges of climate change while maintaining financial stability and economic growth.

As policy implications, the adoption of this mechanism by central banks of developing countries can stimulate the generalization of climate rating, leading to increased investments in low-carbon projects. Furthermore, it will strengthen the development of the green finance market, enabling the alignment of financial strategies with climate objectives. The authors advocate for a paradigm shift which entails a seamless integration of climate considerations into monetary policy guiding investment decisions, and, in turn, fostering a holistic framework for sustainable economic development.

By embracing green monetary policies, developing countries can contribute meaningfully to the global effort to combat climate change and ensure a sustainable future for generations to come.

Regional Electricity Trade in Latin America Without Expanding Generation Capacities

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Regional or cross-border electricity trade entails several economic and environmental benefits, including optimal use of electricity generation resources across the borders; hourly cross-border electricity trade utilizing differing load curves between the countries; sharing peak load and reserve margins, enhancing the system reliability; facilitating clean energy trade to reduce emissions of greenhouse gases (GHGs) and local air pollutants and finally reducing the cost of electricity supply. Limited regional electricity trade has been exercised in Latin America (LAC region), multilaterally in Central America (SIEPAC) and multilaterally or bilaterally in other parts, such as Brazil-Uruguay-Argentina. However,

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the volume of cross-border electricity trade in the region accounts for less than 5% of the total regional generation. Several countries in the region have excess capacities; their load profiles differ significantly, indicating cross-border electricity trade opportunities without adding new capacities for electricity generation. This study estimates the gains from sub-regional and regional electricity trade in Latin America utilizing existing generation capacities (e.g., day-ahead, intra-day, and balancing services).

The study uses the World Bank's electricity planning model (EPM) to simulate hourly electricity generation and trading potential at the sub-regional and regional levels. It develops three scenarios – Baseline, Sub-Regional trade and Regional trade. Under the baseline scenario, each country dispatches its power plants following the merit-order rule and meets its demand in 2020. It also accounts for existing cross-border electricity trading facilities. The Sub-regional trade scenario assumes unconstraint cross-border electricity between the countries within three sub-regions: Andean sub-region (Bolivia, Colombia, Ecuador, Guyana, Peru, Suriname and Venezuela), Central sub-region (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua and Panama) and Mercosur sub-region (Argentina, Brazil, Chile, Paraguay and Uruguay). The regional trade scenario considers unconstraint electricity trade across all countries in the LAC region. We collected hourly load data in 2020 (8784 hours) for 20 LAC countries to develop hourly load profiles. Other data used are fuel and electricity prices, peak loads, generation capacities by technology type (10 types of technologies) and existing cross-border interconnection capacities.

The study finds that the existing volume of electricity trade (baseline scenario) in LAC is approximately 4% of the regional generation. It would increase to 13% and 29% under the sub-regional and regional scenarios, respectively. The Andean region realizes the highest increase in electricity trade volume; the traded volume of electricity in this sub-region accounts for 0.2% and 33% of the total sub-regional generation in the baseline and sub-regional scenario, respectively. The ratio of traded electricity to total generation would almost double from the baseline scenario to the sub-regional scenario in the Central and Mercosur sub-regions. In terms of trade value, the region as a whole would gain US$1.5 billion annually under the sub-regional scenario and almost US$2 billion under the full regional scenario. More than half of this gain would be realized by the Andean sub-region under both scenarios. About one-third of the total regional gains would go to the Mercosur sub-region. The Central region would gain 12% and15% of the total regional gains under the sub-regional and full regional scenarios. Note that these are short-term benefits by utilizing existing capacities in different countries. The size of the total benefits would be larger in the long run.

This study estimates the potential savings on electricity supply costs if 20 Latin American countries allowed unrestricted trade of electricity between the borders without expanding their current electricity generation capacity. The study shows that the volume of cross-border electricity trade would increase by 13 and 29 percent under the subregional and regional scenarios, respectively. The region would gain US$1.5 billion annually under the subregional scenario and almost US$2 billion under the full regional scenario. More than half of this gain would be realized by the Andean subregion under both scenarios. These are short-term benefits without expanding the current electricity generation capacities. In the future, when countries add more generation capacity to meet their increasing demand, the potential benefits of electricity trade would be higher.

Are energy performance certificates a strong predictor of actual energy use? Evidence from high-frequency thermostat panel data

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Motivations underlying the research

Improving energy performances of buildings is widely cited as one of the cost-effective approaches to address climate change, with building Energy Performance Certificates (EPCs) serving as benchmarks. For example, the Government of Ireland in its Climate Action Plan 2023 set a target of upgrading half a million existing homes, nearly a quarter of the housing stock, to a 'B2' Building Energy Rating (BER; the Irish EPC standard) by 2030 as part of the building decarbonization strategy. Similar EPC policy benchmarks are used in other countries, including the European Union and the USA.

National-level policies defined relative to certain EPC benchmarks implicitly incentivize households to target the specified EPC rating when investing in improving the energy efficiency of their dwellings. However, EPCs are generated based on projections from engineering models using standardized values for the number of occupants, energy use schedules, and other model parameters. Thus, the optimality of EPC related investment is determined by the accuracy of EPC in capturing actual dwelling-specific energy performance. Should a discrepancy exist, then household investment benefits and future emission targets might not be realized. This research evaluates the extent with which EPCs reflect observed energy demand for home heating, by focusing on building fabric performance while excluding occupants' behavioral effects.

2. A short account of the research performed

Our analysis exploits variations in boiler operation for home heating while the indoor temperature is within a small threshold of the thermostat's set point temperature during the main winter heating months in Ireland. This serves as a proxy measure of the variations in energy use for home heating across building energy ratings, attributed to building fabric performance alone.

The availability of high-frequency panel data (approximately every three minutes) on household thermostat set point, indoor temperature, and heating unit operating status from a smart thermostat company allows us to clearly identify the sole effects of building fabric performance across dwellings with different EPC ratings. This rich data enables us to capture the duration a home heating unit was in operation in the neighborhood of the thermostat set point temperature. In addition, we obtain access to hourly local weather variables and detailed data on building characteristics. We finally model the relationship between the duration a boiler operates and EPC ratings, conditioning on hourly outdoor temperature, relative humidity, windspeed, levels of the thermostat set point, several building characteristics, and type and efficiency of the main home heating unit.

3. Main conclusions and policy implications of the work

Our results indicate that improving a building's energy performance, as measured by EPCs, reduces energy use, but the difference in energy use attributed to the EPC ratings is modest, considerably lower than projected. This does not imply that upgrading a dwelling's energy efficiency is not beneficial. Rather, the findings underscore that EPCs are poor predictors of actual energy use and consequently cast doubt on the efficacy of public energy efficiency targets that are aligned to a specific EPC standard.

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Total factor productivity and tax avoidance: An asymmetric micro-data analysis for European oil and gas companies

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1. Motivations underlying the research

The accelerated growth in energy productivity recorded globally between 1990 and 2010, which was mainly driven by technological progress, started to fade during the last decade. This changed the behaviour of energy companies, in particular the multinational ones, in their pursuit of after-tax profits. Although tax avoidance is a common practice of multinational companies, its implications for productivity are unclear. Against this background, the main purpose of this paper is to investigate the impact of tax avoidance behaviour of European energy companies on their total factor productivity (TFP). The second objective of the paper is to show that this relation is asymmetric, being influenced by the level of firm productivity.

2. A short account of the research performed

To this end, we use firm-level data for 141 European oil and gas companies (NACE code 06), covering the period 2007 to 2015. Firstly, we rely on Rovigatti and Mollisi (2018) to compute firms' TFP. Secondly, we resort to Canay's (2011) panel data fixed-effect quantile approach to assess the nonlinear, asymmetric effect that tax avoidance has on a firm's productivity. As novelty, we use two proxy variables to estimate tax avoidance, namely companies' holding structures and tax haven location. These proxy variables are identified starting from the main international tax avoidance channels advanced by Beer et al. (2018), namely transfer mispricing, international debt shifting, tax deferral and locating asset sales in low-tax jurisdictions. For robustness purpose, we resort to different approaches to compute firms' TFP. In addition, we draw a comparison between SMSs and large companies' samples.

We find that the reduction of tax liabilities provided by holding structures have a mixed effect on TFP, being influenced by the sample composition. However, being located in a tax haven enhances the productivity for all categories of companies. At the same time, we discover that the impact of tax avoidance on TFP is stronger at higher quantiles, that is, for higher levels of productivity. This means that energy firms migrate to tax havens not to compensate a lack of productivity, but to increase their productivity level through tax avoidance.

3. Main conclusions and policy implications of the work

Our findings are robust to different TFP specifications and have several policy implications. First, our results enrich the microeconomic understanding of the consequences of tax avoidance. We discover that the implications of tax avoidance for productivity are influenced by the way the tax avoidance is calculated. Second, our evidence could potentially provide lessons to energy firms' decision makers to deal with aggregate productivity shortfalls. Third, we document that tax avoidance helps the energy firms to record and maintain a productivity above the average.

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Time and frequency domain connectedness between Green Bond Index and Financial Markets. Are there any diversification benefits?

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1. Motivations underlying the research

The main motivation of this research is the emerging interest of green investments, especially green bonds. This interest is rooted in the growing awareness of sustainability, environmental challenges and climate change. The Paris Agreements of 2015 marked a shift in global environmental awareness and lead the way to international collaboration with focus on reducing gas emissions and overall, a sustainable development. Green investments not only provide financial returns, but also contribute to social and environmental goals.

2. A short account of the research performed

The researchers undertook a comprehensive empirical analysis to assess the connectedness between the S&P Green Bond Index and the stock market indices of four major markets: S&P 500 (USA), FTSE 100 (UK), Nikkei 225 (Japan), and ASE (Greece). They used daily data from January 7, 2014, to June 24, 2022, covering key events like the signing and implementation of the Paris Agreement in 2016 and significant global crises such as the COVID-19 pandemic and the Russo-Ukrainian war. The research was conducted using three econometric methodologies: i) VAR (Vector Autoregression) and Granger Causality Analysis to detect the dynamic relationships between variables and potential causal effects. ii) Dynamic Conditional Correlation (DCC), a multivariate model used to estimate the time-varying co-movement between Green Bonds and the stock market indices. iii) Wavelet Coherence Analysis as a robustness check. Wavelet coherence analysis investigate the coherence and interaction between time series in both time and frequency domain.

3. Main conclusions and policy implications of the work

The result of the study highlighted the growing integration of Green bonds in financial markets, especially after the implementation of Paris Agreement. This outcome supported by the increasing co-movement between Green Bonds and major stock indices. Moreover, Green Bonds offer diminished diversification benefits when combined with traditional financial assets, in contrast to the results of previous literature. Up to now, research has highlighted the significant diversification benefits of including Green Bonds in a portfolio consisting of traditional assets. Our findings indicate that Green Bonds are closely linked to financial markets, as the correlations between Green Bonds and financial markets increased during the Covid-19 pandemic. These results lead to several policy implications that stakeholders should take into consideration when implementing policies in green finance. Specifically, green bonds should remain a tool used for environmentally beneficial project while being carefully to not overly connect those investments with broader financial markets. In this case, green bonds will not present its distinctive advantages in promoting sustainability but rather retain the correlation with financial markets and fluctuate accordingly.

Another important aspect that should be taken into consideration is the transparency associated with green investments. Post-Paris agreement period reveal a strong connection between green investments and financial markets. In this case, all involved parties should ensure that the green investments they participate in are genuinely positively affecting the environment and not merely marketed as such. Moreover, this research calls for implementing incentives to promote further investment in green finance. Some of these incentives may include tax incentives, risk-sharing mechanisms, and direct sub-

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sidies to lower the cost of issuing green bonds. This measure could help sustain investors' interests and continue the beneficial outcomes in sustainable development. Finally, the evolution of green bond market should continue to be examined and carefully monitor, especially because of the results in post-Paris agreement period, to ensure that they are indeed beneficiary for sustainable development and the policies are accordingly adapted to the given situation in each case.

Understanding Indicators for Circular Economy Application in Manufacturing

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1. Motivations underlying the research

The concept of the circular economy (CE) is gaining prominence as a pivotal economic model, designed with the objective of preventing resource depletion and promoting sustainability. The CE places an emphasis on cyclical and regenerative innovations that are environmentally sound, a concept that is gaining traction among businesses and manufacturers. This model effectively links economic growth with environmental stewardship by decoupling economic development from the consumption of finite resources. As awareness of environmental issues escalates, organizations are increasingly adopting CE principles, demonstrating a commitment to environmental responsibility and sustainability. This shift often prompts companies to seek alternative operational methods that reduce their ecological footprint.

While the circular economy offers significant promise, the lack of standardized measurement indicators represents a significant challenge to its effective implementation in manufacturing. The research conducted by Saidani et al. (2019) and Ormazabal et al. (2018) has shed light on the intricate challenges associated with evaluating the implementation of CE at various levels and in diverse contexts. Nevertheless, a significant gap remains in the existing literature with regard to the design of indicators that can effectively assess the performance of a manufacturing company within the context of the circular economy. This gap presents a challenge for researchers, namely distinguishing between proven, certified indicators and those developed solely for academic purposes. By conducting further research, scholars can make a significant contribution to the advancement of knowledge and understanding of circular economy performance measurement in manufacturing, thereby supporting more effective and sustainable decision-making processes.

The principal objective of this paper is to furnish manufacturing stakeholders—including industry professionals, policymakers, and researchers—with a comprehensive understanding of the multifarious indicators available for the assessment of circular economy practices within the sector. This article provides readers with the requisite knowledge to evaluate the performance of CE at the firm level. It offers an exhaustive overview of the various indicators, along with an analysis of their respective advantages and disadvantages. This comprehension empowers stakeholders to select and categorize suitable metrics for efficacious evaluation.

2. A short account of the research performed

In their analysis, the authors identified 32 indicators that are particularly pertinent to manufacturing companies. Following an initial evaluation conducted with the assistance of a focus group, four indicators were excluded on the grounds that they failed to align with the requirements of the manu-

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facturing sector. In the subsequent phase of the study, the remaining indicators were organized into six functional groups, and a framework was constructed to assist entrepreneurs in selecting the most appropriate indicators. Furthermore, this indicator-based framework examined the interconnections among these groups within the manufacturing context. The presented framework offers a novel perspective on the categorization and assessment of CE indicators, which are now organized into single and multiple indicator categories.

3. Main conclusions and policy implications of the work

The principal outcome of this research is the development of the CE Indicators Framework and the interconnectivity of CE Group Classifications in the manufacturing sector.

The study elucidates the discrepancies in the establishment of these indicators or methods and their frequency of use. The more established indicators (e.g., LCA, M/SFA, DEA) are readily accessible to practitioners, whereas the newer indicators that integrate sustainability issues, such as EPICE and CP, are less commonly applied in manufacturing or are still in the early stages of development. Moreover, this framework enables practitioners and decision-makers to select CE indicators that align with their more nuanced understanding of circularity, which extends beyond mere material recirculation and encompasses a range of environmental impacts. The effective implementation of these indicators necessitates collaboration between businesses and consumers, as well as a comprehensive understanding of the broader circular economy. This encompasses insights into consumer behavior and the rapid evolution of trends.

Despite the inherent challenges in establishing universal indicators or standards for manufacturing, given the distinctive nature of each business, an open and creative approach that is informed by a robust knowledge base is essential for CE implementation. Nevertheless, the successful implementation of CE also necessitates a cultural transformation within companies and a shift in mindset. It is of paramount importance to conduct organizational culture assessments, profiling, and understanding worker characteristics in order to facilitate the transition to CE. Furthermore, the collection of data from social networks and the analysis of statistical information pertaining to the social dimension are becoming increasingly crucial in this context.