The Economics of Supply-Side Carbon Mitigation

Yuqing Gong

School of Advanced International Studies, Johns Hopkins University, Washington. DC, 20001, United States

ygong38@jh.edu

Abstract. Carbon emission mitigation not only alleviates environmental externalities but also promotes industrial upgrades and facilitates green development. This paper reviews the impact of supply-side carbon mitigation on the economy and explores the pathways to achieve it. Through the study of the historical context of supply-side emissions reduction, case studies of companies, and theoretical pathways of carbon reduction's impact on socio-economic factors, this article asserts that carbon reduction has yielded tangible results and can sustain economic growth through industrial upgrading and changes in production factors. The Cobb-Douglas production function demonstrates that technological innovation can offset the reduction in production factors caused by emission reduction. Further comparative analysis of wind, solar, and hydrogen energy suggests that existing clean energy technologies still require innovation and cost reduction in order to achieve widespread adoption. Technological innovation can be achieved through subsidies for low-carbon technology research and development and policy support for enterprises and industries. This paper argues that, notwithstanding the significant role of energy in economic development, under the context of supply-side carbon mitigation, it is possible to achieve both carbon reduction and economic growth through technological innovation, improved energy efficiency, enhanced production processes, and the adoption of new green energy sources.

Keywords: Carbon Mitigation, Supply Side, Cobb-Douglas Production Function.

1. Introduction

Global warming has increasingly become a significant challenge confronting humanity. The Paris Agreement, an international treaty on climate change, mandates collective action by all nations to restrict the increase of the global average temperature to below 2°C above pre-industrial levels, while striving to further restrict the temperature increase to 1.5°C above pre-industrial levels [1]. Carbon emissions contribute to frequent natural disasters, including typhoons, hurricanes, floods, and fires, which severely impact humanity and the economy, undermining social welfare [2]. Achieving effective carbon mitigation requires coordinated emission-reduction strategies on both the energy demand and supply sides. From the perspective of demand, enhancements in design methodologies, the production of superior-quality goods, and the implementation of circular economy principles have the potential to diminish material demand as well as the related energy consumption within industrial sectors [3]. Carbon emission reduction will alter preferences on the demand side, promote green consumption, and drive the transformation of the consumption structure.

Carbon mitigation on the supply side is also worth noting. It is a significant source of emissions, such as power generation and industrial activities. If solely focusing on demand-side carbon elimination, the overall reduction will have limited, as the energy structure and efficiency on the supply side ultimately determine the final emission levels [4]. Reducing emissions at the supply end can effectively lower overall carbon intensity, thereby alleviating the impact of climate change on social-ecological systems. Economically, it enhances energy efficiency and reduces long-term energy costs. Additionally, it promotes the development of the new energy industry, driving job creation and technological innovations. A low-carbon supply system could improve air quality and public health, and reduce the burden of healthcare, enhancing social welfare.

The significance of reducing carbon emission from the supply side lies in controlling emissions at their source. It not only supports energy conservation on the demand side but also drives the transformation to a green economy. It is not only a need for environmental protection but also a key guarantee for sustainable long-term economic development. It is essential to demonstrate the economics benefits of supply-side carbon mitigation. This paper examines the economic effects and pathways of supply-side emissions reduction, offering a theoretical basis for implementing emissions reductions on the supply side. (cf. remarks on section headings, below).

2. Theoretical Foundations of Supply-Side Carbon Reduction

2.1. Definitions and Reviews

With the growing concerns regarding environmental issues, more efforts are exerted in carbon mitigation. Carbon mitigation can be divided into demand side and supply side strategies. Demand-side carbon mitigation focuses on transferring energy consumption and services through technological innovations and shifts to low-carbon technologies [5]. Supply-side carbon mitigation involves producers reducing greenhouse gas emissions by limiting the supply of fossil fuels, alongside demand-side policies aimed at decreasing fossil fuel consumption [6]. Specifically, during the production process, CO2 emissions can be reduced by optimizing the manufacturing phases and improving production techniques.

As society increasingly focuses on environmental issues, many enterprises have proactively adopted measures to reduce carbon emissions and have achieved positive outcomes. At Bosch, the optimization of the supply chain facilitates close collaboration between purchasing and logistics functions to establish resilient and sustainable supply networks. This integrated approach enables Bosch to effectively convey its standards and requirements to suppliers, thereby ensuring a high degree of sustainability and regulatory compliance. Additionally, smart utility systems including efficient heating systems, advanced cooling systems and AI-driven control systems are employed to allocate energy consumption more efficiently [7]. Schneider, as a practitioner of sustainable development, has deeply integrated sustainability into its manufacturing process. On the Wuxi campus, it has the highest number of Sustainable Lighthouses where it achieved net zero for Scope 1 and 2 emissions, eight years ahead of its goal in 2022. AI is utilized to manage product assembly and develop business models, significantly reducing carbon emissions [8]. At the power generation plant in Ulanqab, Inner Mongolia, the Three Gorges Group has optimized energy storage facilities and implemented digital management systems, successfully integrating wind power, solar energy, and energy storage into the power grid. This approach has effectively improved power generation efficiency while utilizing clean energy sources [9]. With advancements in technology and growing awareness of environmental issues, it is anticipated that in the future, more enterprises will embrace the concept of low carbon practices.

2.2. Background and Theorems

Related research has examined the relationship between energy and the economy from various perspectives. One important aspect regarding this is environmental externalities, which occurs when one part of the economy affects the environment without direct involvement, resulting in negative impact remains uncompensated. The impact of externalities on the economy manifest through the following pathways [10].

Firstly, externalities that occur within the same industry, commonly known as intra-industry spillovers, or Marshall-Arrow-Romer (MAR) externalities. MAR externalities can be classified as positive externalities and negative externalities. Positive externalities facilitate industrial upgrading; for example, industrial agglomeration can enhance the spillover of knowledge and technology, thereby improving total production efficiency.

Negative externalities arise when an economic entity affects other entities without accounting for the associated costs. For example, in the resource recycling industry, industrial agglomeration may prompt companies to adopt outdated technologies in pursuit of profit maximization, leading to increased energy consumption and pollution emissions.

Furthermore, externalities occur between different industries, known as inter-industry spillovers or Jacobs externalities. In the industrial chain of secondary resource recycling, producers and consumers often do not assume responsibility for waste treatment but instead transfer the waste to recyclers. When products are not designed with environmental considerations—such as composite materials being difficult to disassemble—even diligent efforts by recyclers result in low recycling rates. Consequently, more materials are incinerated or landfilled, leading to increased carbon emissions.

Finally, externalities occur at the regional or national level and are commonly referred to cross-regional spillovers or Krugman externalities. These externalities can be classified into two types: transferable and non-transferable. Transferable externalities refer to waste that, after it is generated, can be transferred to other regions by those affected, thus transferring the externality. In contrast, non-transferable externalities pertain to pollution sources fixed in a certain area, where emissions can only be mitigated through treatment and cannot be transferred to other regions.

Despite the environmental issues and externalities caused by carbon emissions, an upgrading industrial structures may mitigate these negative effects. One key aspect is technological advancement. In 1934, Schumpeter characterized innovation as the process through which entrepreneurs implement novel combinations of production factors and conditions within the production, thereby driving economic development [11]. Later on, drawing upon labor market analyses, Clark substantiates Petty's hypothesis that economic development induces a progressive transition of the labor force from the primary sector to the secondary sector, and ultimately to the tertiary sector [12]. In economic statistics, total factor productivity (TFP) quantifies an economy's capacity to utilize technology and innovation beyond the inputs of labor and capital. Technological shocks exert significant and long-lasting impacts on the trajectory of economic growth [13]. In the low-carbon economy, increasing investment in the research and development of green industries can promote economic development while achieving industrial transformation. This transformation encompasses both the adoption of renewable energy to replace fossil fuels advancements in technological innovation [14]. These studies demonstrate that although low-carbon requirements may pose challenges to traditional industries, economic growth can still be achieved growth can still be achieved through industrial upgrading and changes in production factors.

2.3. Economic Modeling

The conventional Cobb-Douglas production function typically includes only capital (K) and labor (L) as inputs. However, to achieve a more thorough analysis of economic dynamics and carbon mitigation strategies, it is imperative to extend the model by integrating energy consumption (E) and technological advancement (A) as additional factors. The revised Cobb-Douglas production function could be expressed as:

$$Y = AK^{\alpha}L^{\beta}E^{\gamma} \tag{1}$$

Assuming the return of scale is constant, $\alpha+\beta+\gamma=1$.

To find out the equilibrium point of the economic model, a few symbols are denoted as follows:

$$\dot{K} = sY - \delta K \tag{2}$$

This represents the capital accumulation formula. $\dot{K}$ is the rate of change of capital stock, s is the savings rate, δ is the capital depreciation rate.

$\frac{\dot{L}}{L} = n$. This represents the change of labor, and n is the change rate.

$\frac{\dot{E}}{E} = e$. To simply the model, assume that the growth of energy is exogeneous. The supply or usage of energy grows at a certain fixed rate or is proportional to the output.

$\frac{\dot{A}}{A} = g$. Assuming the growth rate of technology is constant.

The equilibrium should be somewhere the per capita variables are constant. Per capita variables are defined as:

Per capita capital: $k = \frac{K}{L}$; Per capita production: $y = \frac{Y}{L}$; Per capita energy: $e_L = \frac{E}{L}$

First, divide the function by L:

$$y = Ak^{\alpha}L^{\beta\text{-}1}E^{\gamma} = Ak^{\alpha}(E/L)^{\gamma} = Ak^{\alpha}{e_L}^{\gamma} \tag{3}$$

Also, convert capital accumulation form to per capita form., denote as:

$$\dot{k} = \frac{\dot{K}}{L} - \frac{K\dot{L}}{L} = \frac{sY}{L} - \frac{\delta K}{L} - nk = sy - (\delta + n)k = s(Ak^{\alpha}{e_L}^{\gamma})\text{-}(\delta+n)k \tag{4}$$

When reaching the equilibrium, $\dot{k}$ no longer changes and equals 0, thus

$$s(Ak^{\alpha}{e_L}^{\gamma}) = (\delta+n)k \tag{5}$$

$$sA{e_L}^{\gamma} = (\delta+n)k^{1\text{-}\alpha} \tag{6}$$

$$k = \left(\frac{sA{e_L}^{\gamma}}{\delta+n}\right)^{\frac{1}{1\text{-}\alpha}} \tag{7}$$

This equation represents the per capita capital stock in a steady state. When energy supply is constrained or prices rise, the per capita capital and output levels in equilibrium will be negatively affected, thereby slowing economic growth. At the same time, technological advancements play a crucial role in enhancing energy efficiency, which can alleviate the adverse effects caused by energy constraints.

3. Structural Pathways for Achieving Supply-Side Carbon Reduction

3.1. Energy as a Pathway

Energy is a crucial component of economic activities. To achieve low carbon emissions, the transition of energy from fossil fuels to renewables is important. This transition requires not only the consumption of energy to be renewable, but also that the production and distribution of energy be sustainable [15], emphasizing improved energy efficiency. Among all renewable sources, wind energy remains at the forefront of the energy transition. Since wind resource is abundant globally, wind energy is accessible worldwide and it has great potential. It doesn't generate pollution when producing electricity. The main challenges of wind energy are storage issues and impacts on ecosystems [16]. Due to the intermittent nature of wind energy, which varies across different times, the storage of wind energy is particularly important. These challenges can be addressed through technological innovations.

Solar energy, harnessed through photovoltaic systems, can partially replace certain fossil fuel power generation by constructing transmission networks, optimizing the distribution of solar field, and advancing technologies to improve conversion rates [17]. However, its reliability is limited by weather conditions and solar resources. The distribution of solar energy is uneven across the globe.

Hydrogen is regarded as a promising clean energy source for the future due to its combustion resulting solely in water vapor, without the emission of climate-impacting carbon dioxide (CO2). The production of hydrogen typically involves the use of electrical energy to electrolyze water molecules, thereby separating hydrogen atoms from oxygen and extracting hydrogen from H2O. The key issue of hydrogen production is that the electricity producing hydrogen should also be green, namely generated from renewables. However, the high cost of separating hydrogen from water prevents the widespread adoption of hydrogen energy [18]. In the future, it will still be necessary to reduce hydrogen production costs through technological innovation.

3.2. Innovation as a Pathway

Innovation is crucial for countries to achieve low-carbon and carbon neutrality goals. Technology can drive low-carbon industrial upgrading by developing new products and providing innovative services, as well as reducing emissions through improved production processes and enhanced energy consumption efficiency. One method to encourage innovation is R&D funding investment. By supporting corporations in investing in low-carbon technologies, carbon emissions can be lowered while the gross productivity could increase [19], indicating that emission reduction and production are not mutually exclusive. The innovation and development of low-carbon technologies not only enhance overall energy efficiency but also promote the convergence of energy efficiency between regions, thereby reducing regional disparities [20].

The innovation underpinning this process is intrinsically connected to policy support and market dynamics. Robust policy frameworks can effectively steer enterprises and industries toward the expedited research and development of low-carbon technologies. For example, in China, the low-carbon city pilot policy plays a crucial role in accelerating China's low-carbon transition. This policy not only promotes urban green technological innovation across all regions, city classes and energy types [21]. Market forces are also significant in the energy transition. In most cases, if low-carbon capital is cheaper than traditional capital, the market will naturally shift toward low-carbon options. Whenever a new low-carbon technology is proven cost-effective, it will diffuse and accelerate upgrades in supply-side manufacturing. Additionally, under market competition, producers who improve production efficiency or reduce production costs through low-carbon innovations, they will gain market advantages, further encouraging such innovations. In conclusion, as previously derived in the formula, innovation can enhance energy utilization and efficiency.

4. Conclusion

Both the demand for and supply of energy consumption play crucial roles in carbon mitigation. Given the significant emissions originating from the supply side, this paper analyzes how supply-side carbon mitigation affects the economy, derives the formulaic relationship between energy consumption and economic growth, and reviews strategies through which the supply side can achieve carbon mitigation. Carbon emissions from the supply side contribute to pollution and generate negative externalities; however, industrial upgrading and technological innovation can alleviate these adverse effects. Furthermore, with the advancement of the green economy, many enterprises are actively pursuing green transformation and upgrading by optimizing their production processes and reducing carbon emissions.

This paper demonstrates how energy, as a crucial component of economic growth, influences the overall growth of the economy. By adopting an improved Cobb-Douglas production function, the model shows that energy determines the per capita accumulation rate of a country's economic capital, thereby affecting the economy's overall growth rate. To achieve carbon mitigation, it is essential to improve and optimize the supply side—particularly the ways in which energy is utilized within economic activities. Given energy's vital role in economic growth, the supply side must ensure efficient energy utilization while also reducing emissions. This requires enhancing the supply side to improve energy efficiency, adopting new energy sources, and fostering technological innovation to optimize energy consumption.

As a key role in carbon reduction, the supply side can decrease carbon emissions by adopting clean energy and fostering innovation. Whether wind, solar, or hydrogen energy source, each green energy has distinctive characteristics that contribute to carbon mitigation. However, given the limitations of existing technologies, further innovation is required for the widespread adoption of these new energy sources to replace fossil fuels. For industries and corporations on the supply side, low-carbon R&D funding and market support are essential to drive technological innovation during the low-carbon transition. Effective policies and a market-driven economy can motivate the supply side to actively pursue green upgrades while ensuring sustained economic growth.

References

[1] United Nations Office of Legal Affairs, Paris Agreement, 2015, https://legal.un.org/avl/ha/pa/pa.html.

[2] Meng, Weizhen, Shilin Li, and Jinqiang Yang. Mitigating disaster risks caused by carbon emissions. Economics Letters, 2024, 241: 111817.

[3] Khanna, Nina Z., et al. Conceptualizing demand-side technological and social innovations in modeling pathways to carbon neutrality. Energy Research & Social Science, 2023, 100: 103115.

[4] Nguyen, Hai-Tra, et al. Smart multi-stage energy-emission nexus framework for sustainable supply-demand management and CO2 mitigation. Renewable and Sustainable Energy Reviews, 2025, 214: 115551.

[5] Scott, Kate, et al. Demand vs supply-side approaches to mitigation: What final energy demand assumptions are made to meet 1.5 and 2° C targets? Global Environmental Change, 2022, 72: 102448.

[6] Gaulin, Nicolas, and Philippe Le Billon. Climate change and fossil fuel production cuts: assessing global supply-side constraints and policy implications. Climate Policy, 2020, 20 (8): 888-901.

[7] Bosch. Bolstering green manufacturing- one plant at a time,2025, https://www.bosch.com/sustainability/.

[8] China factory as a Sustainability Lighthouse. World Economic Forum recognizes Schneider Electric's Wuxi, 2025, https://www.se.com/ww/en/about-us/newsroom/news/press-releases/world-economic-forum-recognizes-schneider-electric%E2%80%99s-wuxi-china-factory-as-a-sustainability-lighthouse-6786009aad70016b280e06f4.

[9] National Energy Administration. The National Energy Administration has published typical cases of green and low-carbon transformation in the energy sector, 2024, https://www.nea.gov.cn/2024-05/19/c_1310775206.htm.

[10] Tian, Xi, et al. Secondary resource curse's formation and transmission mechanism based on environmental externality theory. Resources, Conservation and Recycling, 2020, 161: 104958.

[11] Schumpeter, Joseph A. The Theory of Economic Development. Harvard University Press, 1934.

[12] Colin, Clark. The condition of economic progress. Macmillan, 1940.

[13] Xiao, Anran, et al. Technological progress and economic dynamics: Unveiling the long memory of total factor productivity. Economic Analysis and Policy, 2024, 84: 326-343.

[14] BOUATTOUR, Afef, et al. Relationships between green technological innovation, renewable energy, circular economy, and green growth. Journal of Innovation & Knowledge,2025, 10 (4): 100748.

[15] UNDP. What is the sustainable energy transition and why is it key to tackling climate change? 2025, https://climatepromise.undp.org/news-and-stories/what-sustainable-energy-transition-and-why-it-key-tackling-climate-change.

[16] McKenna, Russell, et al. System impacts of wind energy developments: Key research challenges and opportunities. Joule,2025, 9 (1).

[17] Wang, Lunche, et al. Carbon emissions and reduction performance of photovoltaic systems in China. Renewable and Sustainable Energy Reviews, 2024, 200: 114603.

[18] MIT Climate Portal, How clean is green hydrogen? 2024, https://climate.mit.edu/ask-mit/how-clean-green-hydrogen.

[19] Zhang, Yuechi, Zhuang Miao, and Yangyang Sun. Impact of green and low-carbon technological innovation on green total factor productivity of industrial sector: An analysis based on BAM-DEA model. Sustainable Futures, 2025, 10: 101036.

[20] Fu, Mengyu. Can low-carbon technology transfer accelerate energy efficiency convergence. Energy, 2025, 137365.

[21] Cao, Xiaojuan, Fangyuan Zhong, and Mengbing Du. Can Climate Policy Promote Urban Green Technology Innovation in China? - Evidence from China's Low-Carbon Pilot Initiatives. Sustainable Futures 2025, 100939.