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Commentary

Commentary on "Country-specific net-zero strategies of the pulp and paper industry"

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Abstract: The pulp and paper industry is one of the most energy-intensive industries. Achieving net-zero emissions in this industry is crucial for mitigating global warming and reducing environmental pollution. The article entitled "Country-specific net-zero strategies of the pulp and paper industry," published in *Nature,* addressed this issue. Through an in-depth analysis of the historical emission data of the pulp and paper industry in 30 major countries, a series of country-specific net-zero strategies were proposed. This commentary reviewed the main content and views of that article, and the rigor and applicability of its methods are discussed. Then, the potential impacts of economic trade-offs, resource endowments, and technological advancements on the net-zero strategies of the pulp and paper industry in various countries are further considered.

Keywords: pulp and paper industry; net-zero emissions; national strategies

1. Introduction

In the context of global warming, industries are actively seeking solutions to achieve net-zero emissions to meet Paris Agreement targets for limiting global temperature rise. As one of the most energy-intensive industries, the pulp and paper industry accounted for 2% of total industrial emissions in 2022 [1]. Given its significant role in global greenhouse gas (GHG) emissions, reducing emissions within this industry holds great importance for advancing global climate action. Recently, Dai et al. [2] published an article titled "Country-specific net-zero strategies of the pulp and paper industry" in the journal Nature. Through an in-depth analysis of the historical emission data of the pulp and paper industry in 30 major countries, a series of country-specific net-zero strategies were proposed.

2. Analysis of GHG from pulp and paper industry

The study conducted a comprehensive bottom-up assessment of net GHG emissions from domestic papermaking-related industries from 1961 to 2019. The emissions trends and structure of 30 major countries were also explored. This not only provides valuable historical data and deep industry insights but also serves as an important reference for global emission reduction efforts by systematically sorting out and comparing the emissions of different countries.

Figure 1 shows the annual change in GHG emissions from the global pulp and paper industry and the contribution of each stage. It reveals the evolution of the industry's carbon footprint over time and the environmental impact of different stages of production. This echoes the analysis of industrial sector emissions mentioned by

the Intergovernmental Panel on Climate Change (IPCC) in its report, which also highlights the issue of carbon emissions at various stages of the industrial production process [3]. The findings highlighted the importance of a system perspective in identifying emission reduction opportunities. Four stages of S1 (raw material collection), S2 (pulping), S3 (papermaking and printing), and S4 (use and waste management) and their 18 processes were considered. Data in this study showed that S3 contributed the most to cumulative GHG emissions, accounting for 41% of total emissions. The main reason is that this stage is closely related to energy consumption and chemical use. This is an important implication for guiding the industry to optimize energy use and reduce chemical emissions. Apart from S3, other stages also play crucial roles in analyzing pathways for emission reduction. Deforestation-induced forest carbon emissions and pulp timber logging-driven forest degradation constituted 64% (i.e., 6.9 Gt CO_2-eq) of emissions in S1, while the landfill and non-energy recovery in S4 can serve as carbon sinks, leading to negative emissions. The emission characteristics of the pulp and paper industry at the different stages mentioned in this study coincide with the Life Cycle Assessment approach [4]. The study offered a comprehensive analysis of emissions across the pulp and paper industry's lifecycle, including raw material collection, production, usage, and waste management. It provided valuable insights for industry decision-makers, enabling them to pinpoint critical junctures and explore opportunities for reducing emissions.

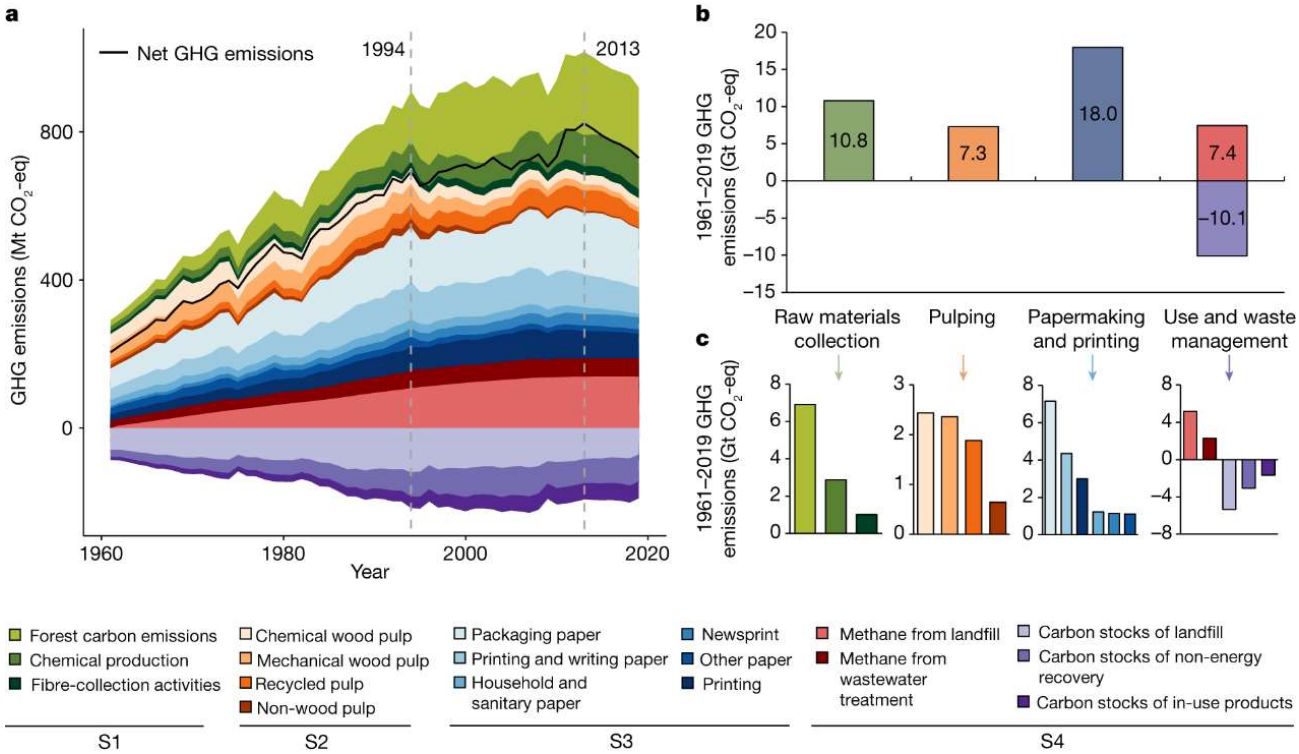

Figure 1. Global GHG emissions of paper-related sectors between 1961–2019 [2].

3. Geographical shift and difference of GHG emissions

Although the carbon emissions from the pulp and paper industry in each stage were analyzed, the results did not reflect the emission characteristics of countries and regions. Therefore, the geographical shift of global GHG emission hotspots is further

explored. The geographical shift highlights the need for global emission reduction efforts to consider regional differences and stages of development to achieve fair and effective climate governance. Furthermore, GHG emission trends and structural differences in various countries are presented, providing a framework for comparing emission reduction challenges and opportunities in different scenarios.

From 1961 to 2019, global GHG emission hotspots shifted from North America and Europe to Asia and Latin America, reflecting the shift in the production focus of the global pulp and paper industry over time. This shift was related to changes in the global economic landscape and the speed of industrialization across countries. For example, the growth of emissions in Asian and Latin American countries is closely related to the rapid economic development and changes in consumption patterns in these regions. Furthermore, from a national perspective, S2 and S3 are the main carbon sources for most countries. However, in tropical regions with abundant forest endowments, S1's forest negative carbon emissions are large, accounting for more than half of total GHG emissions in some countries. It is mainly caused by plantation expansion, unsustainable selective logging, and unsustainable clear-cutting. The data in this study also revealed the success of some countries in reducing emissions in the pulp and paper industry. For example, Nordic countries significantly reduced GHG emissions by using biomass as fuel and improving energy utilization efficiency. These success stories provide lessons for other countries, while also pointing out that some countries still need to strengthen forest management and waste disposal.

By examining national emission trends, the study uncovered the disparities in pulp and paper industry emissions across various countries and regions. These variations align with the principle of "common but differentiated responsibilities" in global environmental governance. This principle asserts that nations should bear distinct responsibilities and obligations in addressing climate change, given their differences in historical emissions and economic development levels [5]. The study's findings supported this principle empirically and offered a data-driven foundation for crafting country-specific strategies to reduce emissions.

4. Analysis of future emission reduction scenarios

The study delineated future carbon emission scenarios based on the distinctive features of the paper industry across various stages and regions. It constructed a framework for the prospective analysis of greenhouse gas emissions in the pulp and paper sector and explored potential trajectories for future emissions. This segment of the research offered not only a predictive outlook for the industry but also a spectrum of alternatives for devising emission reduction strategies.

The GHG emissions of each country in 2050 and the likelihood of achieving net-zero emissions under different mitigation measures are shown in **Figure 2**. The result revealed the potential impacts of different measures on reducing GHG emissions and also highlighted the complexity and challenge of achieving the net-zero emissions target. **Figure 2a** shows the rate of change in GHG emissions across countries under a single measure compared to the business-as-usual scenario. These data confirmed that energy mix and efficiency improvements are the most effective measures and can significantly reduce emissions. However, the effectiveness of other measures varies

significantly across countries, suggesting that emission reduction strategies need to be tailored to individual country's circumstances.

Figure 2b, on the other hand, shows the GHG emissions of each country in 2050 and the likelihood of achieving net-zero emissions under 2160 scenarios. For example, some countries can achieve significant carbon sink growth after implementing all the best measures, while others will require simultaneous action in several areas to reach net-zero emissions. In addition, the likelihood of achieving net-zero emissions also varies significantly between countries, depending on the mix of measures taken and how strongly those measures are implemented. These analytical results in this study are consistent with other findings from research on global climate change. For example, the IPCC has also highlighted multiple pathways to net-zero emissions in its reports and the impacts of these pathways on different countries and regions [3]. The findings of this study further confirmed the IPCC's views and provided specific guidance for various countries to take action.

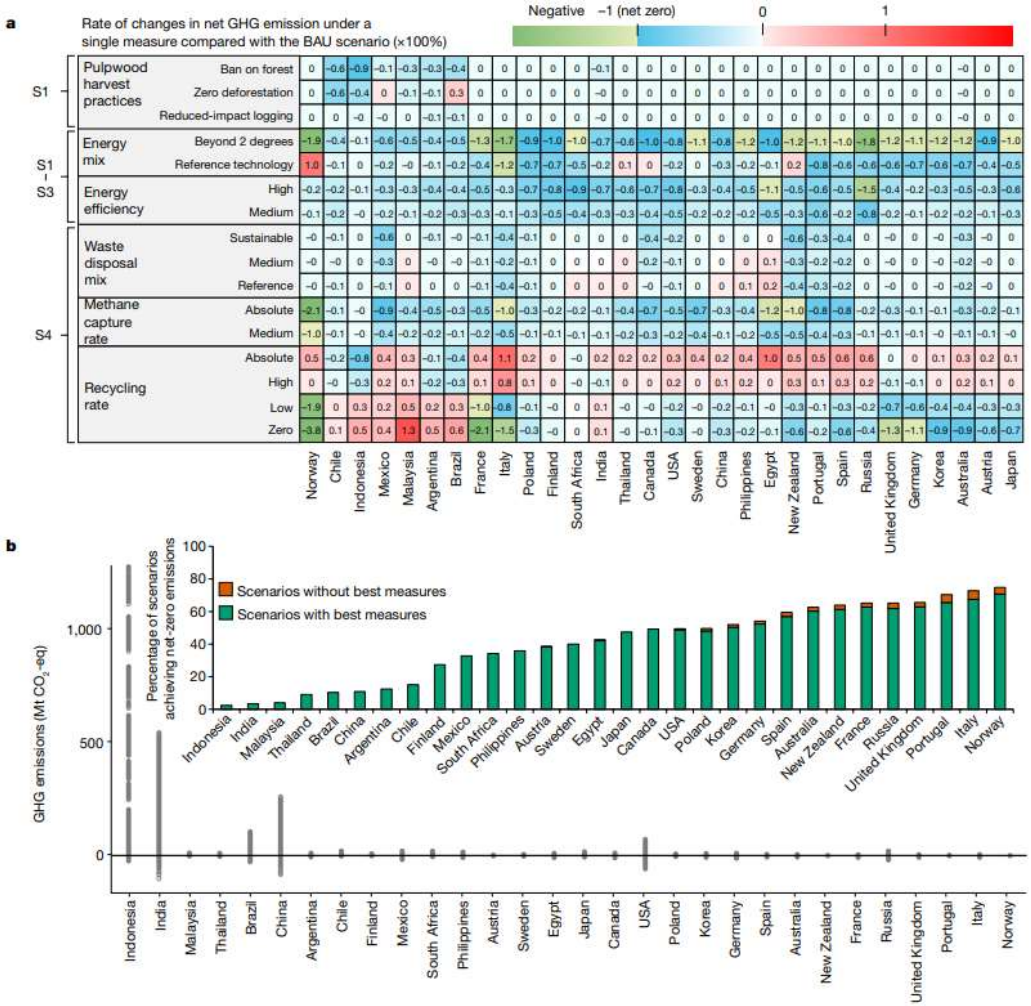

Figure 2. Effects of single measures and all scenarios in 30 countries [2].

The findings underscored that while scenario analysis presents optimistic prospects, realizing these aspirations necessitates a unified global initiative and resolute action. It resonates with the United Nations Framework Convention on Climate Change report's [6] critique of current global emission reduction efforts,

which, despite advancements, are insufficient to mitigate the most severe consequences of climate change. Scenario analysis incorporates a multitude of economic, social, and environmental factors, embodying a holistic analytical approach. This paradigm acknowledges that attaining net-zero emissions transcends technical challenges, encompassing economic restructuring, societal progress, and environmental stewardship. Consequently, achieving the pulp and paper industry's net-zero emissions hinges on the collaborative endeavors of governments, corporations, and societal stakeholders to surmount impediments and realize sustainable development objectives.

5. Discussion on customized national strategies

Supported by previous conclusions, a set of national strategies for the pulp and paper industry to achieve the 2050 net-zero emissions target was put forward. This part of the study demonstrated a deep understanding of the emission reduction challenges and provided countries with concrete action plans to achieve their emission reduction targets.

According to the classification of different countries' efforts to reduce emissions, the countries were divided into "hard", "medium", "easy", and "very easy" groups for achieving net-zero emissions. This classification was based on the countries' level of economic development, technological capacity, state of forest resources, and existing energy mix and waste management practices. The study found that the pulp and paper industry can achieve net-zero emissions by 2050 through country-specific strategies. These strategies include improving energy efficiency, optimizing the energy mix, improving forest management, enhancing methane capture and recycling rates, etc.

The "hard" group, made up mostly of developing countries, faces a huge challenge in achieving net-zero emissions by 2050. Only 2%–49% of scenarios in the "hard" group could achieve net-zero emissions, and there are no single-measure scenarios or medium-measure scenarios. Achieving net-zero emissions in these countries requires at least one best measure and one or more medium measures. Improving methane capture rates, energy mix, and energy efficiency are critical for "hard" countries. Countries in the "medium" group would need to make improvements in some key areas, but overall would have an easier time achieving net-zero emissions than countries in the "hard" group. For example, Sweden, the Philippines, South Africa, Japan, Spain, and New Zealand could achieve net-zero emissions simply by optimizing their energy mix. Countries in the "easy" and "very easy" groups are likely to already have a good basis for achieving net-zero emissions and to do so with a few small adjustments or continuous improvements to their existing base.

The diversity and complexity of achieving net-zero emissions are highlighted in this section, with each country needing to develop and implement emission reduction strategies tailored to its own specific circumstances. In addition, the strategies in the study considered the impact of technological innovation, policy changes, market demand, and other factors on the emission reduction path. Overall, this study provided a comprehensive, systematic, and country-specific strategic framework for net-zero emissions in the pulp and paper industry. It made an important contribution to global climate action by conducting an in-depth analysis of historical emissions data,

considering country-specific circumstances, and proposing practical measures to reduce emissions.

6. Ideas for future works

This study provided detailed simulations and analyses for future emissions scenarios and strategies to achieve net-zero emissions, which also has strong guiding significance for other light industries. In terms of future scenario analysis, the impacts of different emission reduction measures in different countries were analyzed in detail. In terms of strategy research, different combinations of strategies were proposed for each country. However, there are still opportunities for further studies from a development perspective on the economic, resource, and technological factors:

1) Achieving net-zero emissions in the pulp and paper industry is a complex and arduous task that requires not only technological innovation and policy support but also a large amount of economic investment. In this process, the trade-off between economic inputs and emission reduction measures is particularly critical. Economic investment includes direct capital investment and also involves the allocation of human resources, the adjustment of the market, and a change in consumer behavior. In order to ensure the economy and effectiveness of emission reduction strategies, a detailed cost-benefit analysis of each emission reduction measure can be carried out in future studies. This includes an assessment of the initial investment in emission reduction measures, operating costs, maintenance costs, and expected emission reductions. At the same time, it is also necessary to consider the impacts of policy support on the economics of emission reduction measures, such as tax incentives and subsidy policies. For example, according to the International Energy Agency, although the cost of renewable energy is falling, the deployment of emission-reducing technologies still faces high initial investment and policy barriers in certain regions and industries [7]. An in-depth analysis of the cost-effectiveness of each measure can ensure that emission reduction strategies are both economical and effective.
2) In addition to the forest resources considered in this study, other resource endowments of countries, such as water resources, mineral resources, and renewable energy, will also have impacts on the net-zero emissions path of the pulp and paper industry. For example, the availability and management of water resources will directly affect the efficiency and environmental impacts of pulp production. Paper mills in water-scarce regions may need to invest in water recycling and water-saving technologies. The environmental impacts and sustainability of mining and the use of mineral resources, such as calcium carbonate used in paper manufacturing, also need to be considered [8]. In addition, renewable energy sources, such as solar, wind, and biomass, offer clean energy options to the pulp and paper industry. By installing solar photovoltaic panels or wind turbines inside paper mills, it is possible to directly utilize on-site renewable energy and reduce dependence on fossil fuels. Therefore, a comprehensive consideration of the diversity and availability of national resource endowments is decisive in achieving net-zero emissions from the pulp and paper industry.

3) In analyzing future scenarios, more attention should be paid to the potential impacts of technological advancements. Advanced technologies, such as digital twins and biorefinery complexes, may significantly change the energy consumption and emission characteristics of the pulp and paper industry. Digital twin technology allows production processes to be simulated and analyzed in a virtual environment by creating high-precision digital copies of physical systems. This technology can help companies optimize process flows, predict equipment failures, and adjust production strategies without affecting actual production. By monitoring and analyzing production data in real time, digital twins can guide companies to implement more precise and effective energy management measures, thereby reducing energy waste and lowering GHG emissions [9]. The biorefining complex is a new industrial model that integrates traditional pulp production and bioenergy production. Through this model, by-products and waste from the pulp production process can be converted into valuable bioenergy, such as biodiesel, bioethanol, and thermal energy [10]. It can improve the efficiency of resource use and reduce the cost and environmental impacts of waste disposal. In future studies on emission reduction strategies, more attention should be paid to the potential of these innovative technologies and their impacts on emission reduction strategies.

7. Conclusion

In general, in this commentary, the main contributions and methods of the work of Dai et al. [2] were summarized and discussed. The study provided a valuable roadmap for the pulp and paper industry in different countries to achieve net-zero emissions. Moreover, on the basis of this work, ideas for future research directions were explored. Future works can further comprehensively explore how economic, resource, and technological factors affect the net-zero emission path. This comprehensive analysis provides a better understanding of the complex challenges facing the pulp and paper industry to achieve net-zero emissions, thereby facilitating their successful implementation.

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