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Perspective

Carbon Neutrality and Life Cycle Thinking

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ABSTRACT: Climate change is one of the most critical sustainability challenges facing the humanity. International communities have joined forces to mitigate climate change impact and aim to achieve carbon neutrality in the coming decades. To achieve this ambitious goal, life cycle thinking can play critical roles. Specifically, life cycle thinking helps evaluate the true climate impacts to avoid shifting emissions across processes in a product life cycle. It can also help inform consumers with carbon footprint information to make climate-conscious choices. Finally, it can help identify key processes dominating the carbon footprint of a product so that future improvement can set priorities. High quality data is required for accurate and timely carbon footprint accounting and critical challenges exist to obtain and share such data.

Keywords: Carbon Neutrality; Life Cycle Thinking; Carbon Footprint; Life Cycle Assessment

1. Carbon Neutrality

According to the Intergovernmental Panel on Climate Change (IPCC), the global surface temperature in the first two decades of the 21st century was approximately 0.99 °C higher than that in 1850–1900 [1]. To tackle climate change, the 2015 Paris Agreement aimed to hold global warming to levels well below 2 °C and pursue efforts to further limit it to 1.5 °C. The international community has joined forces to develop policies, initiatives, and programs to reduce anthropogenic greenhouse gas (GHG) emissions and mitigate its impacts for carbon neutrality. Specifically, carbon neutrality means reducing and neutralizing anthropogenic GHG emissions so that no net emission of GHG is released to the atmosphere [2]. As a global consensus, 139 countries have announced carbon neutrality goals, which cover 80% of global population, 83% of global GHG emissions, and 91% of global GDP [3].

Achieving carbon neutrality requires emission actors to take actions to reduce or neutralize their emissions. To do so, incentives need to be available to the emission actors. Broadly speaking, there are two types of drivers to incentivize emission actors. On the one hand, there are mandatories such as government policies that force emission actors to reduce or neutralize emissions. For example, carbon emissions trading has been widely implemented in many countries as a key policy tool for emission mitigation. Specifically, emission actors are given emission allowances based on various criteria. Ones that have less emissions than the given allowance can sell the unused allowance on the carbon emissions trading market, while ones that have more emissions than the given allowance can buy unused allowances from the market. The market exists only to efficiently allocate the emission allowances among emission actors. However, the whole carbon emissions trading system is based on the mandate of emission allowance imposed by the policy. Therefore, carbon emissions trading is essentially a policy-driven, mandatory mechanism to incentivize emission actors to reduce and neutralize their emissions.

On the other hand, emission actors may take voluntary actions facing market pressures. Such pressure may from their customers or even further downstream the supply chain (e.g., final consumers). For whatever reason, consumers have a preference towards low-carbon or even zero-carbon products or services. As a result, such consumer preference is passed on to emission actors in the supply chain which will have the motivation to reduce and neutralize their emissions to meet the consumer demand. For example, many products now carry a carbon footprint label which provides

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critical information for consumers to make climate-conscious purchase decisions. When more consumers choose products with lower carbon footprint, producers will have incentives to invest to reduce the carbon footprint of their products to gain market competitiveness. In turn, emission actors upstream the supply chain are pressured to reduce their emissions as well. Another example is that, on April 25, 2022, General Motors asked its suppliers to achieve carbon neutrality for their Scope 1 and 2 emissions—emissions from the supplier's own operations and its purchased electricity and heat—by various dates based on their respective industry [4].

Carbon footprint is the key lever in the market-based, voluntary mechanism to incentivize emission actors. Increasingly, carbon footprint accounting, disclosure, and tracking have become mainstream. Many producers are disclosing the carbon footprint of their products and tracking the progress of their reduction, such as Apple [5], Amazon [6], and Toyota [7]. Many organizations are reporting their carbon footprint regularly through platforms such as Carbon Disclosure Project [8]. Specifically, based on life cycle thinking, carbon footprint is the amount of GHG emissions generated from the life cycle of a product from raw material extraction, material processing, manufacturing, use, and end-of-life treatment.

2. Life Cycle Thinking

Life cycle thinking is to consider the entire life cycle of a product when evaluating its environmental impacts. It is a specific implementation of systems thinking. The typical life cycle of a product includes raw material extraction, material processing, manufacturing, transport, use, recycling/reuse, and disposal. Using a life cycle thinking, one can compare the environmental impacts of different products with the same functionality. A classic example is the comparison between paper and polystyrene foam used for hot drink containers. From the life cycle perspective, polystyrene foam cups use less energy and generate fewer air pollutants compared to functionally equivalent paper cups [9].

Life Cycle Assessment (LCA) is a methodological framework to implement life cycle thinking in practice to quantify life cycle environmental impacts. The earliest LCA study is generally considered as the one done by Midwest Research Institute (MRI) commissioned by Coca Cola in 1969 to compare the environmental impacts of glass and plastic beverage containers [10]. Later, the International Organization for Standardization (ISO) developed a common framework for LCA with standardized methods and procedures [11]. Today, LCA is widely used in both academia and industry to support decision making in a variety of sustainability fields.

3. Roles of Life Cycle Thinking Playing in Carbon Neutrality

Life cycle thinking is essentially an implementation of systems thinking in the environmental sustainability field. It can also play critical role in helping achieve carbon neutrality.

3.1. Avoiding Shifting Emission Burdens across Life Cycle Processes

Life cycle thinking helps evaluate the true climate impacts of products, so that we can avoid shifting GHG emissions from one process to others. The life cycle of a product consists of various processes with distinct emission profiles. If mitigation is only focused on specific processes without considering the entire life cycle, emissions can potentially be shifted to other processes in the life cycle. As a result, process-focused mitigation actions may not actually lead to emission reduction in the product life cycle.

Take electric vehicles (EVs) as an example. For a long time, EVs were regarded as a more climate-friendly choice compared to internal combustion engine vehicles (ICEVs) because it does not have tailpipe emissions. However, GHG emissions, in fact, can be generated from other processes in the life cycle including the vehicle production, use, and end-of-life as well as those for fuels. From a life cycle perspective, using EVs is equivalent to shifting the ICEV tailpipe emissions to the power generation process. Hawkins et al. showed that the life cycle GHG emissions of EVs using coal-fired power are approximately 1.2 times those of ICEVs using gasoline for the same distance traveled [12].

Using life cycle thinking, we can assess the GHG emissions of a product from its entire life cycle. As a result, we can avoid reducing emissions in one process but increasing in others to ensure actual emission reduction happens.

3.2. Informing Consumer Choices and Public Policy

Life cycle thinking allows informing consumers regarding the carbon footprint of their purchases. With appropriate market mechanism and public policy, products with lower carbon footprint can be incentivized. As a result, producers will have pressures or motivations to reduce the carbon footprint of their products or introduce new products

with lower carbon footprint. Since the carbon footprint covers the entire life cycle of a product, emission actors in the supply chain in turn will have pressures or motivations to reduce emissions.

Carbon footprint labeling is an effective strategy to provide consumers with carbon footprint information. As consumer preference is largely consistent with their understanding [13], there are great potentials for carbon footprint labeling to empower consumers to make climate-conscious choices. According to a study done in China, consumers are in favor of low-carbon products partially through the recognition of environmental value and carbon neutrality [14].

Many international organizations are taking efforts to promote carbon footprint accounting and disclosure. British Standards Institution (BSI) published the Publicly Available Specification 2060 (PAS 2060) standard to provide a framework for accurate carbon footprint accounting and certification [15]. To ensure the robustness of carbon footprint accounting, high-quality data are required. However, data transparency and consistency still remain to be critical challenges in carbon footprint accounting. Many data are proprietary and not available for public use. Information about the geographical or temporal validity of data is extremely rare. Significant efforts are urgently needed to address these issues for better carbon footprint accounting.

3.3. Identifying Key Processes to Guide Emission Reduction

Life cycle thinking can also help identify key processes in a product life cycle that dominate the carbon footprint. Those dominating processes can be considered as priorities for improvement with larger potentials for emission reduction.

For example, bioenergy uses biomass to produce electricity or liquid fuels to replace fossil fuel uses. To understand which processes in the bioenergy life cycle dominate its carbon footprint, a study was conducted to analyze the bioelectricity and biofuel pathways for cellulosic bioenergy using switchgrass as the feedstock [16]. The results show that the agriculture process and feedstock logistics are the two key processes dominating the carbon footprint of both switchgrass-based bioelectricity and bioethanol. It further identifies nitrogen fertilizer production and field application are the key processes to life cycle GHG emissions. To further reduce the carbon footprint of switchgrass-based bioelectricity or bioethanol, those key processes should be the priorities for improvement.

4. Conclusions and Outlook

Life cycle thinking originates from assessing environmental impacts of products and services. It provides a system-based framework to characterize the life cycle of a product and analyze its life cycle environmental impacts.

As carbon neutrality has become a global consensus, life cycle thinking starts to play critical roles to help the global efforts towards carbon neutrality. Specifically, it helps evaluate the true GHG emissions associated with a product to avoid shifting emissions from one process to others. It also helps inform consumers with carbon footprint information of products or services so that consumers can make climate-conscious purchase decisions. As a result, emission actors upstream the supply chain will have incentives and motivations to reduce their emissions, so that the emissions of the entire supply chain can be reduced. Finally, it helps identify critical processes in a product life cycle that dominate the carbon footprint so that future improvements can set priorities accordingly.

The implementation of life cycle thinking in carbon neutrality requires rigorous carbon footprint accounting which is done by using LCA. LCA is data intensive. Critical data challenges exist for carbon footprint accounting which are also common challenges in LCA. Specifically, LCA studies rely on industry-representative inventory data which are not widely available. Existing databases are hidden behind a paywall, or data sources are not entirely transparent. Also, the geographical coverage and temporal timeliness are very limited. Proprietary data are often of higher quality but are not easily shared and accessed. Significant efforts are required to address these issues to provide a transparent, open, comprehensive, and regularly updated life cycle inventory database to support carbon footprint accounting and decision making to achieve carbon neutrality.

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Not applicable.

Informed Consent Statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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