How are we Doing with the Energy Transition? Two Simple Metrics to Understand and Track Progress

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Transitioning our energy system to meet the emissions reductions requirements of our climate change goals is a complex process that will touch all parts of our society and all corners of the world because energy is fundamental to most of what we do, day in and day out. It is an integral part of people's daily lives, whether rich or poor; it supports the most basic needs such as cooking, to less accessible ones such as air travel, as well as all levels of economic activity, from a shop to a steel factory. By design or disorder, the energy transition will change the forms in which, and how and for what, we use energy.

So, how are we doing in transitioning our energy system to meet our climate goals?

What are the goals?

The Paris Agreement, by its terms, speaks of two climate goals limiting global temperature increase. The first is "well below 2ºC."[1] The second, is "pursuing efforts …to 1.5ºC," a more ambitious goal designed, among other things, to limit the sea rise that threatens various island states and the hundreds of millions living in low-lying areas (particularly in numerous poorer developing countries).

Energy sector emissions constitute the vast majority of global greenhouse gas emissions (e.g., 75 percent in 2019[2]). Accordingly, we focus on how to understand and assess the transition specifically of the energy sector and the related evolution in its emissions relative to our climate goals.

Although there is much discussion about whether we are adequately transforming our energy system (e.g., from the global carbon project[3] or the UN Emissions Gap report[4]), there remains an absence of easily accessible metrics to help measure our progress. We know we need to dramatically reduce emissions; but how are we doing in changing our energy system to effect that reduction, particularly as compared to modelled pathways designed to achieve our climate goals?

To support a broader understanding of this issue, we propose two simple metrics to help measure how we are doing in advancing the energy transition. We hope in this way to make the complex energy transition more easily accessible to a wide range of stakeholders – all of whom, as noted above, will as energy users not only be touched by, but will also influence to some extent, the transition itself.

How do we measure progress? Two metrics

Energy emissions are the product of two factors: (i) the carbon intensity of the energy we use -- namely, how much carbon is emitted per unit of energy consumed, and (ii) the total amount of energy used. Building off these two factors, we propose two metrics to track progress in implementing the needed energy transition.

i. The first metric assesses the carbon intensity of system-wide energy consumption ("CISEC"). We will measure total CO_2 emissions from energy combusted or otherwise consumed as part of industrial processes, relative to the total amount of energy used system wide (i.e., emissions divided by energy consumption, expressed as tons of CO_2 per terajoules (TJ) of total energy supply). This includes:
   - in the numerator, CO_2 emissions from all fossil fuels and non-renewable waste, such as gasoline used in cars, natural gas used for heating, and coal consumed in power plants to produce electricity or used in the chemical processes to manufacture cement and other products;[5] and
   - in the denominator regarding system-wide consumption, we use total supply energy figures as generated by the IEA, which includes, for example, natural gas used either for heating (which generates emissions) or as feedstock in petrochemical production (which has no direct combustion emissions), as well as energy produced from other fossil fuels, nuclear, hydropower and renewables as well as traditional use of biomass.

ii. The second metric tracks the level of and changes in system-wide energy consumption ("SEC"). The metric is the same as the denominator used in the CISEC (expressed as TJ of total energy supply). The volume of energy consumed, and particularly of fossil fuels, is the second lever that affects total emissions. The definitions and measures of SEC can vary from one institution to another,[6] and we have chosen the commonly accepted approach of IEA supply data.

To calculate and illustrate the proposed metrics, the following three climate scenarios from the IEA's World Energy Outlook 2021[7] have been used: (i) the Sustainable Development Scenario ("SDS-2021") designed to meet the Paris Agreement goal of keeping tempera-

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tures "well below 2°C"; (ii) the Net Zero Emissions by 2050 scenario ("NZE"), which captures the more ambitious 1.5°C target of the Paris Agreement; and (iii) the Stated Policies Scenario (STEPS-2021), which uses each country's stated policies – not Paris-related pledges -- to forecast the current trajectory of the energy system.

The analysis focuses on global-level metrics, in part because it is global level emissions that drive temperature change. At the same time, the largest energy systems are responsible for the majority of energy emissions, notably China, the US, the European Union, and India. Given that much of climate and energy policy is made by governments at the country-level (taking the European Union as a single unit for these purposes), it is also useful to look at these metrics at this level in addition to global figures.

How have we done on carbon intensity and where do we need to go

Before looking into the future, it is useful to assess our past and how these metrics have evolved over time, both at a global level and country/regional levels.

It is sobering among the current rhetoric of ambitious net-zero targets that the data shows there has been little improvement over the last several decades in decarbonizing our energy system at a global level. In fact, the consistency of the global CISEC is striking, having dropped less than 2 percent when comparing 2019 to 1990.

Having looked at the past, now we explore where the CISEC would need to go over the next 30 years, through 2050, to meet our climate goals. What is notable is that in contrast to the largely unchanged historical CISEC of the last 30 years, we will need to see dramatic reductions going forward. Some of that reduction has already started to occur, as reflected in the slight but visible downward slope of the CISEC since 2015 (NB, following the Paris Agreement), as reflected in figure 1. This trend continues under the STEPS-2021 scenario. But a much larger reduction is needed to achieve the "well below 2°C" (cf. the SDS-2021 scenario in figure 1), let alone the more ambitious 1.5°C threshold (cf. the NZE scenario).[8]

Looking more closely at the world's largest emitters, figure 2 shows the type of change in carbon intensity China, the EU, the US, and India would need to achieve to meet the "well below 2oC" temperature goal of the Paris Agreement. Once again, the data indicates that the current levels of carbon intensity would have to accelerate substantially. For example, while China's CISEC declined by 0.8 percent between 2015 and 2020, the SDS-2021 scenario requires an acceleration of that decline. Specifically, under the SDS-2021 scenario, the annual drop in China's carbon intensity would have to top 2.2 percent per year by 2030, and then accelerate further through 2050. The US and EU would need to double the decline rate of their CISEC by 2030 to -3.9 percent and -4.4 percent, respectively, under this same scenario.[9]

What has happened with energy use and where do we need to go

While global energy carbon intensity has remained fairly flat over the last 30 years, energy consumption has grown by 65 percent, led by significant growth from emerging economies such as China (over 250 percent).

Looking ahead, the SEC is projected to rise by over 25 percent by 2050 under the STEPS-2021 scenario.

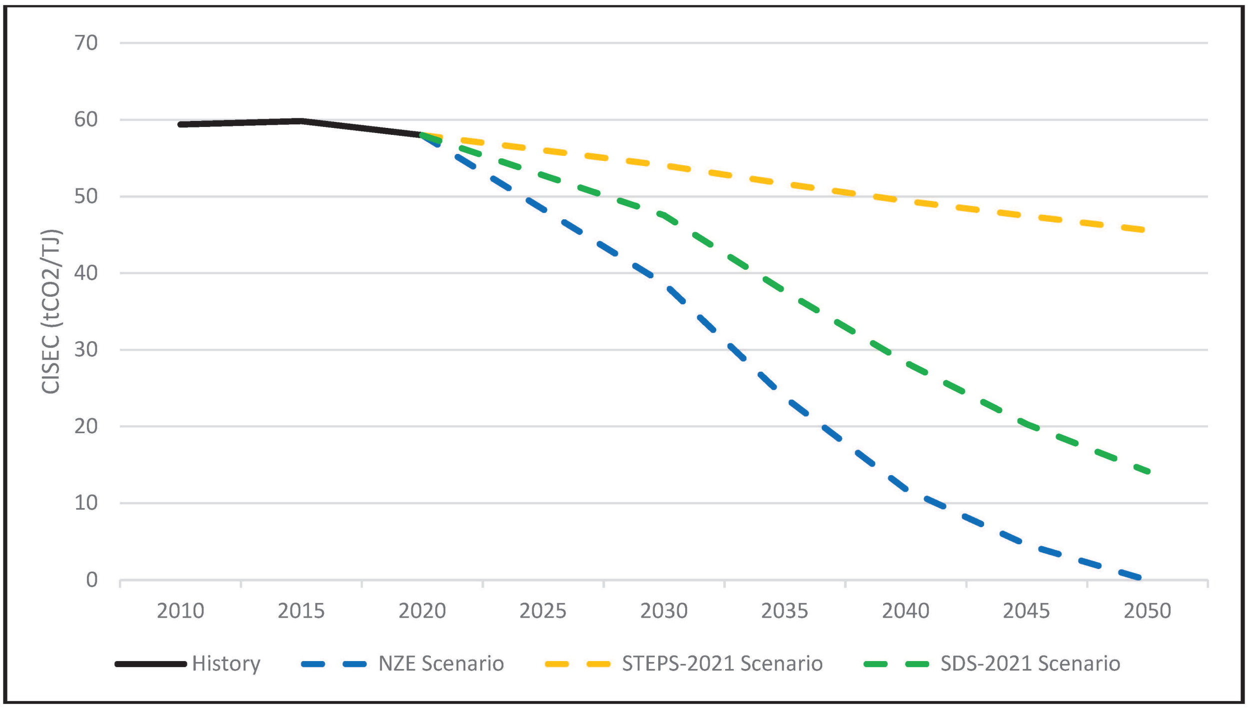

Figure 1: Where the World CISEC is now and needs to go to meet the Paris climate goals
Data source: IEA World Energy Outlook 2021 Extended Data set

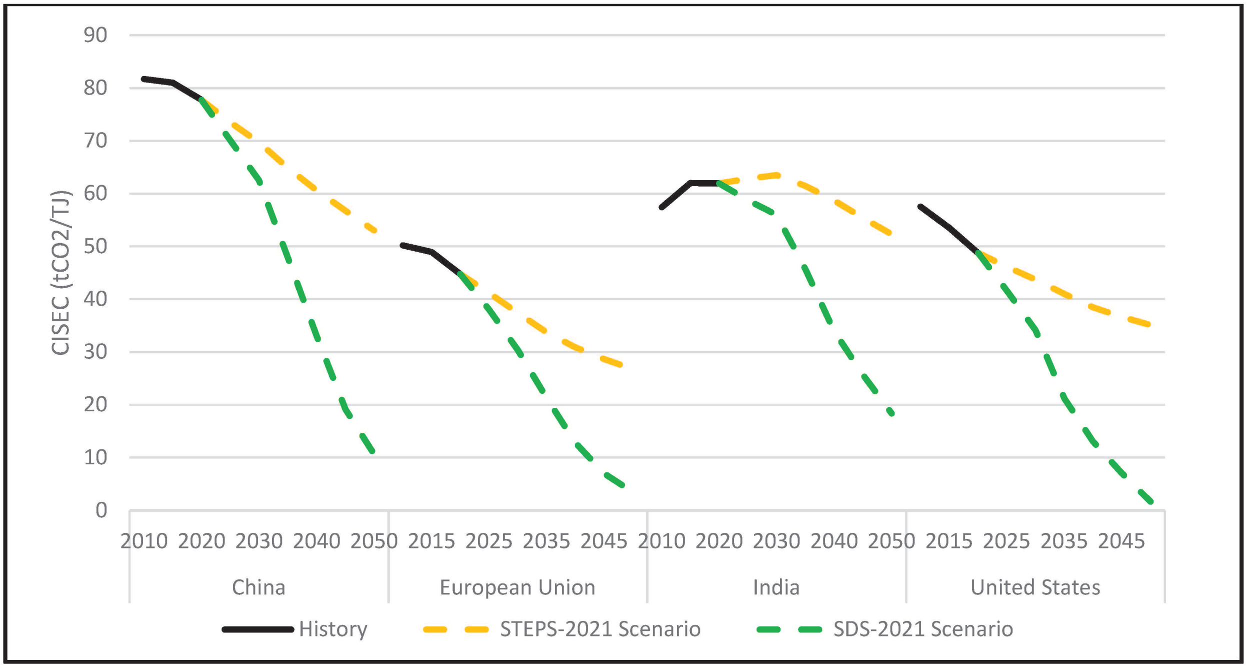

Figure 2: Carbon intensity pathways for key countries
Data source: IEA World Energy Outlook 2021 Extended Data set.

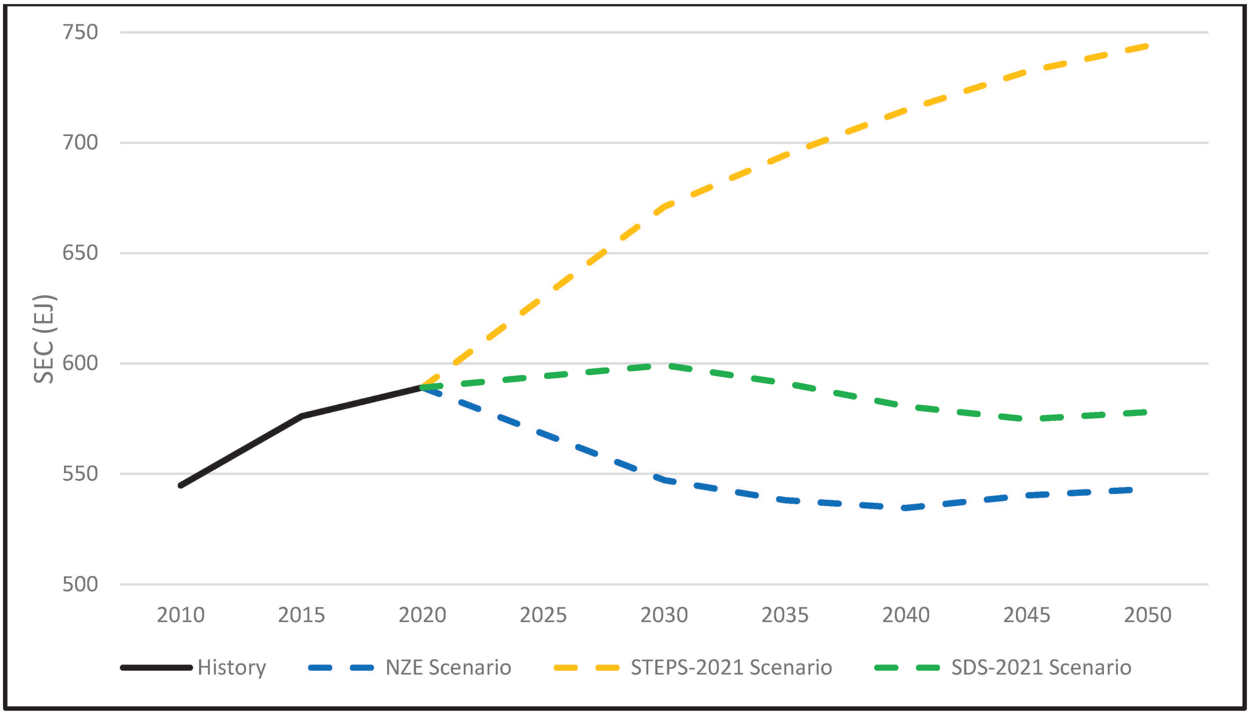

Figure 3: Where the World System-Wide Energy Consumption needs to go to meet Paris climate goals
Data source: IEA World Energy Outlook 2021 Extended Data set.

The climate scenarios require a significant break from both historical trends and the projections of the Stated Policies Scenario (figure 3). For example, under the SDS-2021 scenario designed to limit global temperature increase to "well below 2°C", the global SEC is essentially the same 30 years onwards. The 1.5°C goal embedded in the NZE scenario requires a drop of 8 percent as compared to current levels. The changes of the SEC under both these climate goals are substantially smaller than the decarbonization of the energy sector as reflected in the corresponding CISEC (figure 1). However, even those small changes in the SEC will require reversing the established upward trend in global energy demand and represent global energy demand levels in 2050 that are nearly 25 percent lower than that of the STEPS-2021 scenario.

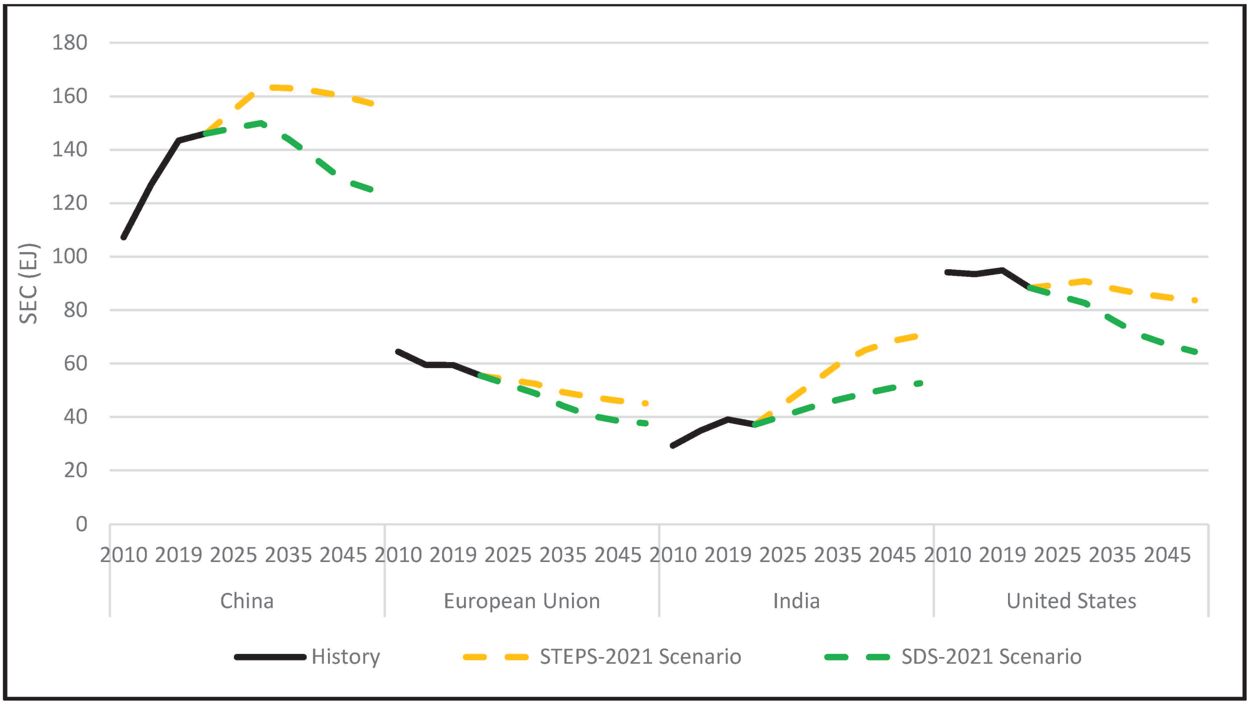

Figure 4: SEC pathways for key countries

Data source: IEA World Energy Outlook 2021 Extended Data set.

These smaller changes in SEC reflect in part a dynamic (arguably a recognition) of upward pressure on energy demand flowing from the growing populations across the developing world and their need to improve inadequate standards of living and generate further economic development.[10] Given the development status of these countries, their call for more housing, schools and hospitals, expanding infrastructure and various other similar energy intensive activities required to alleviate poverty and generate economic and social improvements will work against efforts to reduce energy consumption, in contrast to the ability of advanced economies to implement reduction targets.[11] Consequently, even stabilizing demand at a global level will require a massive effort.

Likewise, while the amount of emissions is the product of the CISEC and the SEC, it is the former that emerges under the climate scenarios as the dominant lever to effect the needed deep reductions in emissions at a global level.

Once again, it is also revealing to look at the type of effort that will be required by the world's largest energy systems (figure 4). The SEC under the SDS-2021 scenario is substantially lower than where countries are currently headed under their stated policies,[12] requiring investments in energy efficiency and other demand side management actions.[13] However, in contrast to the CISEC, not all countries move in the same direction under this scenario.

Notably, and in contrast to reductions in China, the EU and US, the SEC for India in the SDS-2021 scenario is higher in 2050 than the current level, albeit smaller than where its policies are projected to take consumption. This is consistent with the developing country dynamics described above, and also accommodates a rise in energy consumption per capita that is currently markedly below that of advanced economies or the global average (figure 5).

Identifying some of the dynamics affecting the metrics

It is also useful to identify some of the dynamics likely to drive changes in these metrics and related insights.

- There is an important lag with data availability, especially for many large energy consuming countries outside the OECD. As a result, the analysis will tend to capture where we recently stood, rather than where we currently stand. Unfortunately, efforts to estimate where we currently stand (or even to project how a year will turn out during the course of the year) can also prove to be inaccurate, as the disruptive impact of COVID-19 in 2020 or the current energy crisis unfolding since late 2021 demonstrate.
- A more complete CISEC would include other greenhouse gases from the energy system, notably methane emissions. As better data is produced (including through new satellite tracking systems), methane should be added to the CISEC calculation.
- The SEC can change without altering end-user energy service consumption patterns, notably through the substitution of thermal power generation with renewables (e.g., because of differences in efficiency and accounting methodologies). This becomes more significant given efforts to increase the weight of electricity in the energy mix, includ-

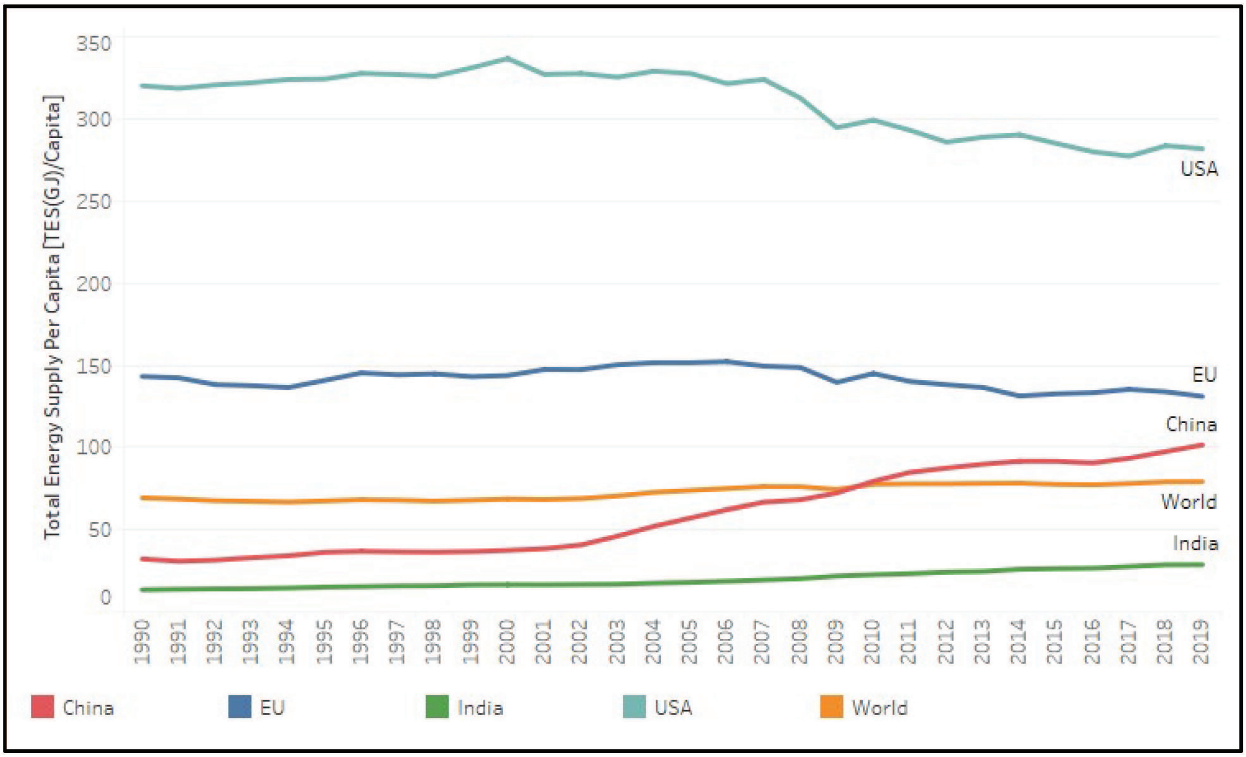

Figure 5: Total energy consumption per capita over time since 1990
Data source: IEA Energy Balance Indicators 2021

ing through electrification of end-use (e.g., electric vehicles). Under the methodology of the IEA and various other agencies, substituting renewables for thermal power lowers the SEC, all else being held equal. However, other analysts use a different approach in comparing thermal to renewables power generation, which could generate different SEC pathways to achieve the same climate goals.

- It is interesting and revealing to compare the relative impact of the CISEC and SEC metrics on overall emissions. As noted above, initial analysis seems to point to greater use of the carbon intensity lever than the demand one, and their relative contribution also seems to change over time. For example, as the CISEC nears low intensities consistent with net-zero emissions, changes in SEC have a smaller impact on emissions. Put another way, the SEC level loses weight to the extent we successfully decarbonize as we near net-zero emissions -- i.e., at an energy system that is near net-zero, the amount of energy consumed is less weighty in driving emissions than at higher levels of carbon intensity. Further analysis of the relative impacts of these two metrics over the energy transition would be revealing.
- The modelled differences in the contributions over time of the CISEC and SEC under the scenarios often will largely reflect the different costs of using each lever (e.g., cost of energy efficiency versus additional renewables generation). However, in deciding how to transition the energy sector, it may also be appropriate to consider other factors, such as differences in feasibility, geopolitical considerations, issues of equity (NB, the different per capita consumption levels presented in figure 5), and economic and developmental factors.
- Beyond metrics (including those presented in this article) that try to decompose, and thereby reveal, some of the dynamics driving emissions, the critical factor remains the cumulative level of emissions themselves. Accordingly, the carbon budgets used to drive the temperature scenarios are significant indices. For example, the 1.5°C target has a carbon budget that is about 750 $GtCO_2$ smaller than what the 2°C threshold (used prior to the Paris Agreement) can absorb.[14] At the end of the day, we are much more concerned about how much emissions we produce in total.
- Similarly, while "destination" targets (such as net-zero by a defined year) are important, the pathway of emissions in the intervening years (i.e., the "journey") is just as, if not more, important. What matters is the aggregate level of emissions over a defined period. Maintaining emissions at 2020 levels and then dropping them to net-zero only in the target year is inconsistent with our climate goals (as reflected, for example, in the carbon budget concept). This is why tracking how the metrics evolve over time as compared to a defined scenario is critical to understanding and evaluating how we are doing in achieving our climate goals.

Tracking Progress in the Future

In many cases, scenarios and the corresponding emissions pathways are updated every year, as new historical information about the evolution of fuel demand and emissions for the previous year(s) becomes available. However, a side effect of updating historical data and the starting year for model runs is that it is difficult to analyze and evaluate how the energy system changed relative to the analysis from earlier years. This modeling setup moves the goalposts each year and it does not assess how far off track the energy system is relative to previous outlooks. To counter this, it would be useful to establish a frozen benchmark for historical tracking purposes, to assess how the global community has performed and signaling whether the world is moving towards a delayed and chaotic transition or moving on an orderly pathway consistent with the Paris Agreement goals.

Conclusions

Presenting information as to how our energy system is evolving, and how that evolution is impacting greenhouse gas emissions and the prospect for success in achieving our climate goals, is becoming increasingly important. The numerous extreme weather events (floods, heatwaves, etc.) that have marked 2022 are an indication that we need to do a better job at understanding what is happening and, importantly, in making both the ongoing and prospective evolution in energy system emissions accessible to more people. Better metrics can help. This article represents a small step in that effort.

Footnotes

[1] Paris Agreement, 2015, Article 2-1(a)

[2] https://www.climatewatchdata.org

[3] https://www.globalcarbonproject.org/

[4] https://www.unep.org/resources/emissions-gap-report-2021

[5] NB, given current data limitations, we are not including methane emissions from oil, gas, and coal-related activities. These emissions could be included in subsequent analyses depending on improvements in data availability, as discussed later.

[6] For example, different approaches to valuing the heat loss in thermal power generation that does not occur in the same way with renewables plants.

[7] For a more detailed definition of the IEA's climate scenarios, see the World Energy Outlook 2021, p. 327.

[8] Note that we have interpolated for intermediary years between 2020 and 2030 and during five-year segments thereafter using a straight-line approach. It is actually likely that the transition might follow more of a curved trajectory between points, accelerating in particular from 2020 into 2030 as countries take the time initially to ramp up the changes they require to advance their respective energy transitions.

[9] NB, we have not provided country-specific calculations for the NZE scenario as country-level figures are not available.

[10] See, e.g., figure C.3 in "Is China still a developing country and why it matters for energy and climate" which illustrates how energy consumption per capita increases with rising income per capita for all countries except high-income ones.

[11] For example, the EU and Japan have explicit energy consumption targets, including ones that predate the current European energy supply crisis.

[12] NB, country breakdowns of the SECs under the NZE Scenario have not been published and so are not analyzed in this article.

[13] See, e.g., IEA's Energy Efficiency 2020 and World Energy Investments 2021 reports.

[14] See, for example, the carbon budget estimates presented by the Mercator Research Institute on Global Commons and Climate Change (https://www.mcc-berlin.net/en/research/co2-budget.html).