Energy System Transformation for a 1.5°C Future

Using Climate and Energy Scenarios to Inform Strategy and Policy

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Businesses, governments, and other institutions are facing increasing pressure to mitigate the worst impacts of climate change by dramatically reducing emissions in line with the Paris Agreement. However, the strategists, analysts, and decision makers whose actions will shape the necessary market and policy transformations may be challenged to see past legacy modeling approaches and assumptions. These approaches and assumptions capture neither the massive economic opportunities for early movers nor the compounding risks of being left behind.

To strengthen this interface, Rocky Mountain Institute is releasing a series of insight briefs to help demystify the available tools for 1.5°C alignment, identify critical gaps that require complementary approaches, and highlight emerging opportunities to reinvent the future. **These insights are bound by our assessment that a rapid transition to a low-carbon energy system is not only achievable, but also a source of growth, prosperity, and benefit for all.**

This insight brief introduces the role of climate and energy-economic scenarios in informing climate-aligned policy and strategy. Forthcoming briefs in this series will address a range of topics that contribute to our commitment to a beneficial clean energy transition, including the interplay between efficiency and growth, as well as exploring individual catalysts for non-linear systems transformation.

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In this series of insights, we discuss a suite of tools and perspectives that can help guide strategies that align with a 1.5°C future. We begin with an introduction to climate and energy-economic scenarios. These are a critical tool for target setting, but one with limitations that can obscure or undervalue some avenues for energy system transformation.

We discuss how these scenarios, considering their strengths and limitations, should be used to inform planning by a diverse set of institutions, from large corporations to subnational governments. We then conclude with recommendations for how strategists and decision makers can use scenarios in tandem with other information and approaches to translate climate commitments to appropriately scaled and advantageous action.

Aligning 1.5°C Ambition through Scenarios

Limiting global temperature rise to 1.5°C is achievable, affordable, beneficial, and necessary. A growing number of institutions are committing to 1.5°C alignment and must now translate those targets into action. This will be challenging. The world has already warmed approximately 1°C, and growing evidence indicates Earth-system feedback loops, such as the melting of permafrost, could be triggered around 2°C, preventing stabilization at intermediate temperatures.[1]

But there are plenty of reasons to be optimistic about the journey ahead. Recent changes in the energy system provide evidence that a full-scale clean-energy transition is not only possible but also affordable. Furthermore, successful climate mitigation can meaningfully contribute to a better world. Targeting 1.5°C can create a reimagined future with an energy system that is dramatically more sustainable for more people. The question is, where are the greatest opportunities that will allow people to lead healthier, more prosperous, and secure lives?

Climate and energy system scenarios have played a crucial role in the search to answer this question. They are responsible for pegging that a 1.5°C future means achieving net-zero global emissions by 2050.[2] They have also been instrumental in informing recent commitments to net-zero goals by the European Union, China,[3] and Japan, as well as other institutions' participation in the Race to Zero campaign and Science-Based Targets Initiative.[4] Yet these scenarios provide only a starting point from which we must apply other tools for translating commitments to action.

A Shared Lexicon for Targeting 1.5°C

In the parlance of energy and climate, terms like scenario, pathway, and roadmap are often used interchangeably, but they are not the same thing. Here are summaries of the definitions put forth by the International Futures Forum.[5]

Scenarios inform goals. Individually, they provide a snapshot of what the future could look like; collectively, they help define a landscape of opportunity. While scenarios are excellent tools for highlighting areas of uncertainty and challenging the status quo, they do not help enhance the identification of specific decisions that stakeholders must make.

Pathways inform strategy. They chart a course from what is happening today to the landscape of a future scenario while being adaptive to major global disruptions and economic shifts. Pathways share scenarios' ability to highlight uncertainty and go further toward assisting decision-making by acknowledging uncertainty and allowing for the exploration required for transformational change.

Roadmaps inform methods for achieving intermediate goals. They provide a specific outline for how an institution will align with a pathway. Roadmaps are helpful when uncertainty is controlled or low, and therefore are good for reaching manageable, intermediate goals. They are deterministic and do not allow for the same flexibility for disruption as do pathways.

Scenarios are plentiful today. However, the implied or explicit pathways and roadmaps to arrive at these 1.5°C futures should be developed and improved to leverage feedbacks and synergies that can make the admittedly daunting trip more feasible.

Best Practices for Using Climate and Energy Scenarios

An immense amount of work has been done by analysts from many different institutions to create climate and energy-economic scenarios. While these scenarios do not provide all the answers, the knowledge they contain is useful for informing goals in the context of other planning priorities. This section lays out some best practices for using these scenarios to inform policy and strategy development.

Develop a broad view of the opportunity space by comparing future snapshots described by several scenarios.
Although it may be practical to work with just one scenario, no one can provide a certain, singular vision of the energy system of the future. Indeed, looking across several scenarios reveals diverse portfolios of solutions that could potentially contribute to achieving 1.5°C. Surveying this space provides useful context for choosing scenarios with which to work and identifying key solution options and tradeoffs that fit with other strategic goals. Exhibit 1 compares the diverse landscape of 2050 results from select scenarios achieving 1.5°C–1.8°C on the basis of carbon sequestration, end-use electrification, and final energy demand.

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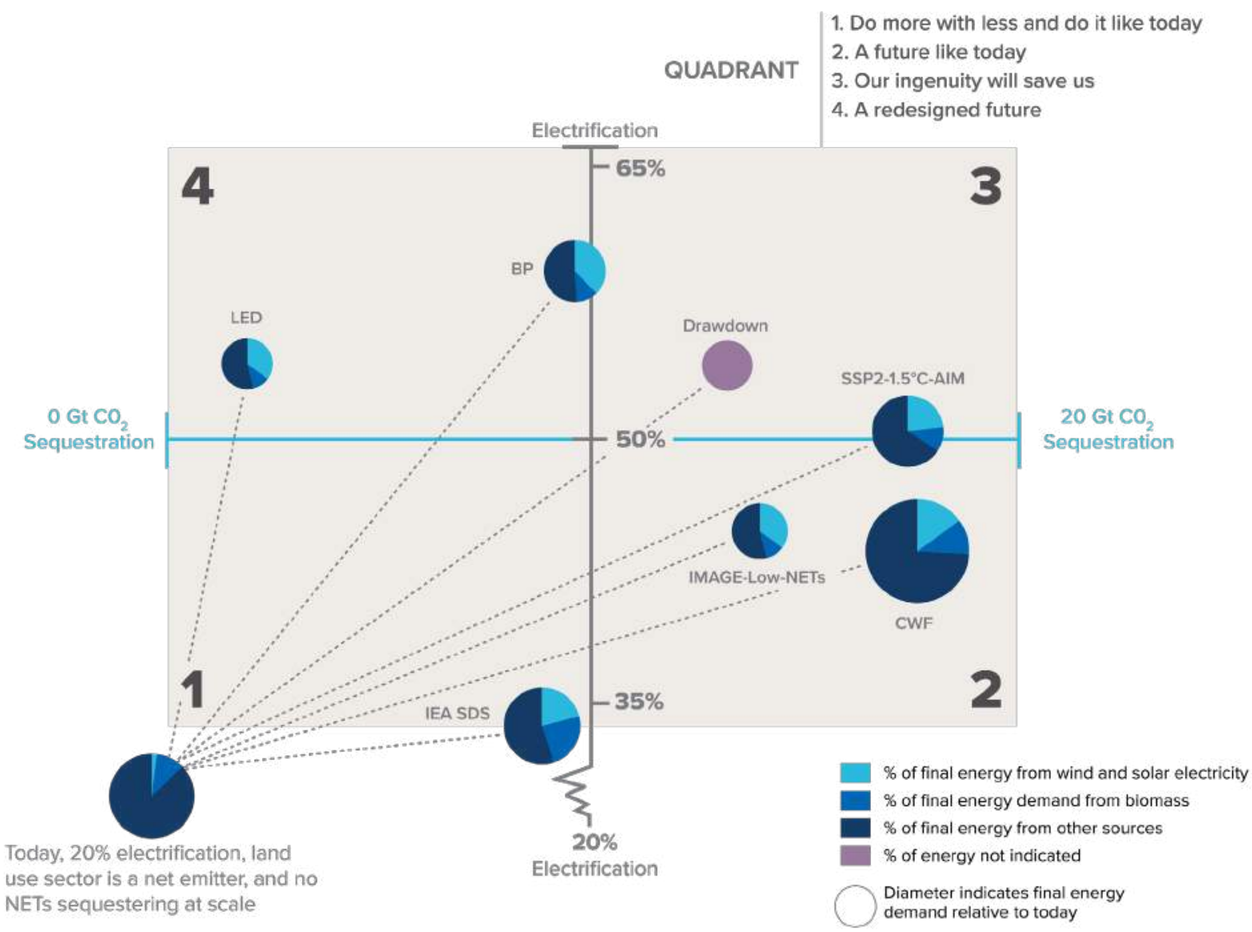
In Exhibit 1,[i] the x-axis represents the magnitude of carbon sequestration in 2050, combining land sinks, carbon capture and storage (CCS), and negative emissions technologies (NETs). Since CCS and NETs do not currently remove a significant amount of CO_2 from the atmosphere, and land use is likely a net emitter presently (according to ClimateWatch 2016 data[6]), all of these scenarios represent a large divergence from the status quo.". The y-axis represents the degree of electrification achieved globally across all end-use sectors.

Currently, about 20% of final energy demand comes from electricity, but scenarios diverge significantly in the role it will play in getting to net zero by 2050. The scenarios shown here achieve 35%–60% electrification of final energy demand in 2050. The size of the circles indicates final energy demand in each scenario relative to today (421 exajoules [EJ] in 2019 according to the 2020 International Energy Agency's [IEA] *World Energy Outlook*). Within each scenario's circle is an estimate of final energy demand breakdown.

EXHIBIT 1

Scenarios Represent Diverse Snapshots of a Transformed Energy System in 2050



[i] The appendix includes a table with the primary quantitative information used to map the scenarios in Exhibit 1, along with assumptions.

The four quadrants categorize the different futures described in each of the scenarios.

- In quadrant 1, scenarios with moderate sequestration and a relatively low share of energy demand from electricity are like today but would require the world to do more with less. For example, the IEA Sustainable Development Scenario (SDS) achieves universal energy access with less sequestration than most scenarios and sustained levels of natural gas use (note however that IEA SDS results in 1.8°C global temperature rise).

- In quadrant 2, scenarios with high sequestration and moderate electrification are the most structurally similar to today. Specifically, relying heavily on NETs would allow for much of our existing, fossil-fueled energy infrastructure to remain the same, but this avenue is both costly and unproven.

- In quadrant 3, scenarios with high levels of electrification and high sequestration arguably require the greatest surge in technological innovation and adoption. Thus, these are futures where our ingenuity will save us. NETs technologies are still in immature stages, and electrifying some end-uses may require very different technologies compared to today (e.g., for carbon-free cement).

- In quadrant 4, scenarios in the redesigned future territory generally require behavioral changes in order to achieve high levels of electrification and lower energy demand relative to today with moderate sequestration.

Compare scenarios that make use of different methodologies. The scenarios shown in Exhibit 1 use a variety of methodologies that generally fall into two main categories: top-down models and bottom-up assessments. Characteristics of each methodology are summarized in Exhibit 2. Top-down models typically provide greater context for each sector's role in mitigating climate change, while bottom-up assessments can help fill in missing sectoral details and emerging trends.

EXHIBIT 2

Scenarios Are Made through Two Main Approaches: Top-down Models and Bottom-up Assessments

Methodology for Creating Scenario	Description	Types	Examples
Top-down model	Represents holistic system interactions, producing results on emissions and economic activity that "add up" to a whole	Integrated assessment models (IAMs)	Shared Socioeconomic Pathways
		Detailed energy system models	IEA World Energy Outlook
Bottom-up assessment	Describes details and latest advancements in individual sectors	Can cover several sectors or take a deep dive into one sector	McKinsey Climate Math; ETC Mission Possible Sectoral Focus: Steel

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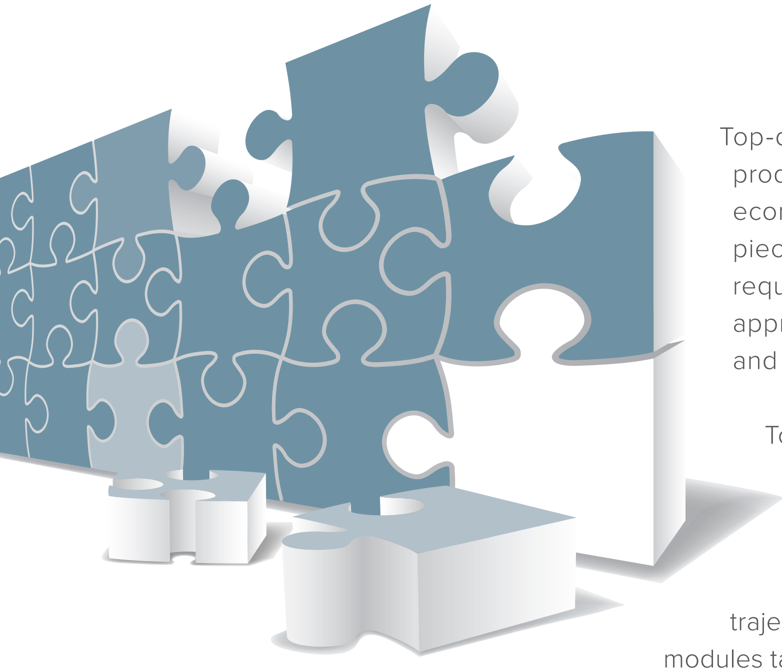

Top-down models represent holistic system interactions, producing a comprehensive set of mathematical results on economic activity and emissions that fit together like puzzle pieces. Due to the complexity and computing power required to model such a full-systems view, this top-down approach often fails to incorporate recent emerging trends and sector-specific details.

Top-down models can be further categorized as integrated assessment models (IAMs) or detailed energy system models. The IAMs consist of an Earth system module (more on this later) and an economic module that calculates anthropogenic greenhouse gas (GHG) emissions trajectories based on how sectors interact. These IAM economic modules take external data on future gross domestic product (GDP) and population as inputs and calculate the impact of economic transactions at the global level, with varying levels of geographic resolution. They usually include significant detail on the legacy energy system and how it links with the rest of the economy.

Like IAMs, detailed energy system models also present a whole-systems view and could be considered more detailed versions of an IAM economic module. The scenarios included in the Shared Socioeconomic Pathways,[7] a cornerstone of the Intergovernmental Panel on Climate Change's (IPCC) upcoming Sixth Assessment Report, are from IAMs. The IEA's World Energy Model (WEM) used to produce the annual *World Energy Outlook* is one example of a detailed energy system model.[8]

Bottom-up assessments produce more narrative-driven scenarios based on an extensive literature review of the latest advancements across many sectors in great detail. However, quantitative results from a bottom-up assessment are not guaranteed to fit together like puzzle pieces in the same way a top-down model provides a comprehensive set of results on economic activity and emissions.

For example, a bottom-up assessment will not necessarily provide the amount of final energy consumed by the building sector in a future year. But it could explain implications of the latest trends in building insulation and smart thermostats,[ii] levels of detail unlikely to be included in a top-down model. Examples of scenarios created from bottom-up assessments include Project Drawdown and McKinsey Climate Math.[9]

Comparing scenarios with different methodologies can provide more ideas on how a given sector might evolve or co-evolve with adjacent sectors. This can serve as a foundation for exploring collaboration opportunities with potential partners in complementary sectors, vertical integration strategies, or entirely new business models. For example, a decision maker interested in passenger transport may explore what scenarios' results on electric

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[ii] For more information on insulation and smart thermostat solutions, see Project Drawdown, **https://www.drawdown.org/solutions.**

vehicles (EVs) imply for electricity demand from transport. These could also reveal what other advancements must be made in the energy system for EV deployment to be successful and how an EV manufacturer might address (or capture value from) those opportunities.

Consider the rigor of global temperature rise calculations and associated assumptions. It is important not to confuse the amount of GHG emissions being added to the atmosphere in any one year with the underlying challenge that GHGs, especially long-lived gases like carbon dioxide, have been slowly accruing for decades. Furthermore, significant levels of GHGs are emitted not only from the energy system but also from agriculture and land use. The robustness of a scenario's global temperature rise claim can thus vary depending on its methodology (summarized in Exhibit 3) and the degree to which it considers all sources of anthropogenic GHGs. It is crucial to understand the total emissions budget (i.e., how much cumulatively can be emitted over a time period) when setting emissions targets for future years.

EXHIBIT 3

Methodologies Used in Scenarios to Determine Global Temperature Rise

Approach	Pros	Cons	Example
Carbon budget	Sound scientific basis considering Earth system feedbacks	Requires analysis or assumptions on all anthropogenic sources of GHGs	IRENA 2019 Global Energy Transformation ReMAP scenario
Annual emissions checkpoint	Fast check and can be performed on a sector-by-sector basis	Does not acknowledge what must happen in other sectors	IEA 2020 WEO Net Zero Emissions by 2050 mini-scenario

Creating a scenario with a model that includes an Earth system module or calculating cumulative GHG emissions over the duration of the scenario timespan are preferred gold standard methods. These methods provide the soundest scientific basis for global temperature rise, ultimately based on the latest climate science. An Earth system module, usually a main component of an IAM, is a reduced-form general circulation model—basically the climate in a box. It converts emissions trajectories to atmospheric concentrations, and calculates global temperature rise by analyzing Earth system feedbacks like the carbon cycle and atmosphere-ocean interactions.[10]

Adding up annual emissions each year from a scenario that utilizes an Earth system module and considers all sources of GHGs to a cumulative value provides an emissions budget that corresponds to a global temperature rise. Cumulative emissions from scenarios created without an Earth system module can be compared to those budgets to determine estimated global temperature rise, if one considers the degree to which all GHG emission sources are represented and makes assumptions for any missing sectors like agriculture. Such an approach was taken by IRENA in its 2019 Global Energy Transformation ReMAP scenario.[11]

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Other scenarios use a less rigorous method that checks for adherence to a global temperature rise goal by comparing annual emissions from one or two points in time to another scenario that uses one of the gold standard methods. This is the approach taken by the IEA 2020 WEO Net Zero Emissions by 2050 mini-scenario.[12] However, the shape of an emissions trajectory matters, and choosing a few years in the future as benchmarks does not consider the total GHGs released to the atmosphere over a given time period. This method is less rigorous than the emissions budget approach. In either case, policy and strategy analysts should verify that the underlying methodology of a referenced scenario truly aligns with any stated goals.

Compare data from recent energy system developments to results and assumptions inherent in a scenario's methodology. Scenarios tend to be rooted in the history of what's happened so far in the energy system without much consideration of emerging trends and system shifts. It is therefore important to understand how the latest developments might affect a scenario's results.

Some scenarios created from top-down models are so complex that they cannot be updated quickly enough to keep pace with recent technological advancements, price changes, and geopolitical developments. For example, a slew of good news has recently emerged on electric vehicles in the United States. This includes cheaper battery technology from Tesla (projected to cut its models' projected cost in half by 2023), increased demand from California as the state phases out internal combustion engine sales by 2035 (with New Jersey expected to follow), and supportive policy signals for charging infrastructure.[13]

Tesla's announcement puts the company on track to provide EV batteries at significantly lower cost than DNV-GL's 2020 Energy Transition Outlook. DNV-GL acknowledged this development in a recent short analysis,[14] providing an excellent example of how real-life energy system happenings can be used in concert with scenarios.

Don't let scenarios constrain ideation and recognize that more layers of opportunity rest in the gaps left by scenarios. Used alone, climate and energy scenarios may actually constrain imagination that could otherwise recreate markets and industries as we know them. Such changes can open new forms of value creation, increase prosperity, and improve lives as well as mitigate climate change. Like an abstract painting making shapes from negative space, the gaps left by the limitations of scenarios are one of the best places to look for scalable opportunities to improve the future of the energy system. The next section provides an overview of the types of limitations in scenarios that can be used for identifying areas of opportunity.

Finding Opportunity in Climate and Energy Scenario Limitations

Becoming a wise user of scenarios requires at least a basic understanding of their mechanics. This includes the white space left by their limitations, especially those that cause scenarios to neglect opportunities that could help the energy transition be faster, more prosperous, and more beneficial for more people. Fortunately, existing and emerging tools and approaches can be used to complement scenarios to identify transition pathways. This section highlights some of the hidden layers of the solution space to be considered in formulating climate-aligned policies and strategies.

Einstein is famously credited with having said, “We cannot solve our problems with the same thinking we used to create them.” Unfortunately, this is the most common approach to developing scenarios, as many use historical data and then “press play” to project the past for the future. The approach is a logical extension of many scientific institutional norms and global Earth system modeling processes but is not appropriate for planning in an evolving energy system.

The reason is this approach generates tunnel vision and creates the illusion that the transition must happen slowly. It neglects the fact that humans learn, innovate, and engage in collective action toward desired goals, fundamentally different from the laws of physics governing the climate. In future insight briefs, we will discuss opportunities that lie in critical drivers of change in the energy system that are often omitted from scenario methodologies. We offer here a preview of a few such solutions spaces.

Stakeholders

The lack of stakeholder diversity and inclusion in climate and energy scenario development has contributed to tunnel vision about the future; obscuring identification of areas where transformative opportunities and synergies exist. Many critical stakeholders that need to take action vital for transitioning the energy system—the steel industry, automakers, civil society, subnational governments, and investors, for example—are usually missing from scenarios and are generally not asked to participate in or provide input to the scenario creation process.

The result is that scenarios can continuously depict a future state that seems all but impossible to achieve without a top-down mandate from national governments. Yet these stakeholders have immense collective influence on the speed and direction of change in the complex systems of the energy transition. There is so much more value presented by a transformed energy future than scenarios can provide, and decision makers need to seek other tools to bring these additional opportunities into focus.

Equity and Other Non-emissions Benefits

The omission of so many stakeholders also means that scenarios do not provide enough information about what a desirable future looks like in non-carbon terms like equity. They also may not show where the real innovations and opportunities exist for people to have healthier, more prosperous, and secure futures. A 1.5°C future need not be an unjust one.

Some scenarios do include results on the non-emissions benefits that come from mitigating climate change—typically relegated to "co-benefits." For example, IEA reports premature deaths avoided from climate change solutions that also reduce air pollution, and the Low Energy Demand scenario tracks its results to the Sustainable Development Goals. But the parameters on which a scenario is optimized tend to focus strictly on economics, like least-cost solutions for reducing emissions and achieving 1.5°C.

For many stakeholders, climate change is a secondary concern to more immediate problems. A holistic view that considers public health, poverty, jobs, energy access, running a viable business, and other concerns alongside climate change creates a virtuous cycle, with solutions for one problem amplifying the solutions to others.

Data and Transparency

We have discussed several examples of promising emerging developments in the energy system to which scenarios often fail to react in a reasonable timeframe. Unless one has dug into scenario methodologies, it might not be obvious that they may be based on old data. Additionally, some scenarios, like those released by BP and Shell, are published with little information on the methodologies used to create them.

While this is ostensibly for proprietary reasons, transparency is crucial, and it is vital that users are given the opportunity to understand (and challenge) the methods and assumptions inside the "black box." How stakeholders choose to journey toward this future will certainly influence human lives, and arguably they bear a similar burden of responsibility as an engineer constructing a bridge. In engineering circumstances, a challenge of all assumptions in an analysis is vital given the potential direct loss of life involved.[15]

Apart from the transparency of these scenarios themselves, new applications of data also provide a crucial source of disruptive and transformational potential that is difficult for such analyses to represent. A veritable boom in data collection and analysis techniques, enabled by technologies like remote sensing, satellites, social media, and machine learning has transformed existing businesses and paved the way for new ones.

How can these potential disruptive developments be monitored, or better yet, anticipated and leveraged by businesses and policymakers to support 1.5°C pathways? The new suite of data-enabled tools is highlighting previously invisible consequences of individual and institutional decision-making that can impact emissions and enabling more incisive action that benefits both businesses and the climate.

Technological Innovation

The IEA has famously and consistently underestimated the global expansion of solar PV capacity, predicting relatively flat or linear growth and stagnating prices in the *World Energy Outlook* series for more than a decade,[16] even as the cost of solar PV has fallen exponentially. This is a common theme across scenarios, as the IEA's methodologies often define technology cost as strictly a function of time.

However, the impact of cumulative production, a metric of experience, on a technology's cost can be described by the mathematical formulas of learning curves that are independent of time. Experience accumulated throughout the innovation process plays a critical role in scaling a new technology and reaching cost parity with incumbents. Experience, and not time, can be a better predictor of progress, presenting an opportunity for both policymakers and businesses to advance disruptive technologies and strategies that create economic gain and address climate change.

Demand-side Efficiency

Scenario methodologies' focus on the legacy energy system neglects the role of demand and efficiency since supply infrastructure buildout has historically driven the system's evolution. But energy demand and efficiency are powerful levers, and there are well-documented beneficial feedbacks between the supply side and demand side of the energy system.[17]

For example, demand-side flexibility can go a long way toward balancing electricity systems with high renewable penetration.[18] Aggregating demand-side procurement can also be a powerful lever for change. India's Energy Efficiency Services Limited (EESL) serves as a model for the power of aggregated procurement that could have even more potential if implemented by several regions in tandem.[19] To date, EESL has purchased and deployed over 360 million LED light bulbs as part of its UJALA program, providing economies of scale to the industry and contributing to price reduction.[20]

Conclusion

Energy and climate scenarios play a critical role in providing a landscape of what mitigating climate change *could* mean, but they also have their limitations. However, even in the white spaces of their omissions, scenarios can reveal enormous economic and social opportunity in aligning government policies and business strategies with climate mitigation targets. They will continue to be valuable, provided they are used in context with other tools that acknowledge the realities of policy and strategy planning and that must grapple with the more immediate pressures of human welfare and economic growth.

APPENDIX

EXHIBIT 4

Quantitative Data and Assumptions for Exhibit 1

2050 scenario metrics	BP Net Zero[21]	Drawdown[22]	SSP2-1.5°C AIM[23]	LED[24]	IMAGE[25]	IEA SDS[26]	CWF[27]	Today[28]
% final energy from electricity	59%	54%	50%	54%	45%	35%	44%	19%
Total final energy demand (EJ)	300	245	399	245	280	385	473	421
Total carbon sequestration from CCS, NETs and land sink (Gt CO_2)	9.7	13.3	17.5	2.4	13.9	9.2	17.6	See note h
% of final energy from wind and solar electricity	38%		29%	38%	35%	21%	15%	2%
% of final energy demand from biomass (electricity and all other end-uses)	11%		14%	10%	11%	15%	11%	11%
% of final energy from other sources	51%		57%	52%	54%	64%	74%	88%
Notes	a, j	b, c				d, e, f, g		h, i

Notes

a. BP does not explicitly analyze land sink emissions. In its net zero scenario, the company states that 6.9 Gt CO_2 are emitted from the combustion of fossil fuels before carbon capture and storage (CCS). 5.5 Gt CO_2 are explicitly removed by CCS. We assume land-sink sequestration in BP is equal to the median IPCC scenarios they present for comparison.

b. Drawdown reports results as cumulative CO_2e sequestered from 2020 to 2050. In order to compare to the other scenarios, we calculated the average annual sequestration from Scenario 2.

c. Drawdown only provides results on reduction of CO_2e relative to today and investments required to achieve solutions. Therefore, it’s difficult to compare it to other scenarios. Many solutions presented in the end-use sectors are creative and involve a transformation of how we do things today (e.g., carpooling and telepresence as a solution to transportation, emphasis on recycling and utilizing waste gases in industry, and changing cooking methods in developing countries). Because its suggestions are aligned with a redesigned future similar to the LED scenario, we assign it the same percent electrification and final energy demand as in that scenario.

d. Section 3.4.5 of IEA WEO 2020 states primary energy demand falls globally by 5% 2030–2050 in the Sustainable Development Scenario; we assume the same is true for final energy consumption.

e. Section 3.4.5 states that global electricity demand expands by 2% per year 2030–2050.

f. 10 Gt CO_2 total is emitted from energy and industrial processes in IEA SDS in 2050. None of IEA's WEO scenarios consider agriculture or land use emissions. Approximately 7 Gt CO_2 is emitted from energy and industrial processes in BP Energy Outlook. SDS is not a net-zero scenario; it achieves about 1.8°C temperature rise. Section 3.4.5 of IEA WEO 2020 states 5 Gt CO_2 is captured from energy and industrial processes in the Sustainable Development Scenario. Assume the same amount of land sequestration occurs as in BP Net Zero scenario (see Note a). Note that IEA's WEO scenarios do not consider the agricultural sector, land use, or GHGs besides CO_2.

g. Electricity generation and final energy demand from bioenergy are extrapolated to 2050. IEA WEO 2020 provides results for these sectors until only 2040.

h. Today, global land use that can be influenced by humans is likely a net emitter presently (according to ClimateWatch 2016 data).[29]

i. Sums for final energy percentages may not total 100 due to rounding.

j. We use BP's result on final consumption that excludes non-combusted resources.

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