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Commentary

High with low: Harnessing the power of demand-side solutions for high wellbeing with low energy and material demand

Masahiro Sugiyama,[1,*] Charlie Wilson,[2,3] Dominik Wiedenhofer,[4] Benigna Boza-Kiss,[3] Tao Cao,[5] Joyee S. Chatterjee,[6] Souran Chatterjee,[7] Takuya Hara,[3,8] Ayami Hayashi,[9] Yiyi Ju,[1,10] Volker Krey,[3] María Fernanda Godoy León,[11] Luis Martinez,[12] Eric Masanet,[13,14] Alessio Mastrucci,[3] Jihoon Min,[3] Leila Niamir,[3] Setu Pelz,[3] Joyashree Roy,[7,15,16] Yamina Saheb,[17] Roberto Schaeffer,[18] Diana Ürge-Vorsatz,[19] Bas van Ruijven,[3] Yoshiyuki Shimoda,[20] Elena Verdolini,[21,22] Frauke Wiese,[23] Yohei Yamaguchi,[20] Carina Zell-Ziegler,[24] and Caroline Zimm[3]

The authors are all devoted energy system and sustainability transformation scholars, who collaborate regularly and actively at global and local levels to advance the knowledge space of demand-side solutions and policies. They are members of a growing bottom-up initiative, the Energy Demand Changes Induced by Technological and Social Innovations (EDITS) network (https://iiasa.ac.at/projects/edits), which builds on various research disciplines to facilitate advances in modeling, data compilation, and analysis of the scope and breadth of the potential contributions of demand-side solutions for climate change mitigation, improved wellbeing for all, and sustainability, complementing supply-side solutions for decarbonizing the energy and material systems.

Introduction

In response to worsening climate change, high market volatility in energy and materials, and geopolitical tensions, policymakers are struggling to ensure the supply of secure, clean, and affordable energy. Complementary demand-side actions can help address climate change and sustainability while improving wellbeing.[1] Too often, however, research, policy, and societal action fail to fully explore the potential of demand-side solutions in energy and materials systems.

We argue that more comprehensive research on demand-side solutions is urgently needed to develop a solid evidence base for scientific assessments and policy recommendations.

We define "demand-side solutions" as policies, interventions, and measures that modify demand for goods and services to reduce material and energy requirements and associated greenhouse gas (GHG) emissions, while also contributing to other policy objectives including improved wellbeing and living standards.[1,2] Demand-side solutions target behaviors, end-user technology adoption, and lifestyles as well as the infrastructures and supply chains. A common classification hierarchy of demand-side solutions distinguishes between

[1]Institute for Future Initiatives, The University of Tokyo, Tokyo, Japan

[2]Environmental Change Institute, University of Oxford, Oxford, UK

[3]International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

[4]Institute of Social Ecology, University of Natural Resources and Life Sciences, Vienna, Austria

[5]Graduate School of Arts and Sciences, The University of Tokyo, Tokyo, Japan

[6]SMARTS Center/Department of Development & Sustainability, Asian Institute of Technology (AIT), Pathum Thani, Thailand

[7]School of Geography, Earth and Environmental Sciences, University of Plymouth, Plymouth, UK

[8]Toyota Motor Corporation, Aichi, Japan

[9]Systems Analysis Group, Research Institute of Innovative Technology for the Earth, Kyoto, Japan

[10]Waseda Institute for Advanced Study (WIAS), Waseda University, Tokyo, Japan

[11]Ghent University, Ghent, Belgium

[12]International Transport Forum (ITF)/OECD, Paris, France

[13]University of California, Santa Barbara, Santa Barbara, CA, USA

[14]Lawrence Berkeley National Laboratory, Berkeley, CA, USA

[15]Global Change Programme, Jadavpur University, Kolkata, India

[16]CDMR IIT, Guwahati, India

[17]OpenExp, Paris, France

[18]Centre for Energy and Environmental Economics (Cenergia), Energy Planning Program (PPE), COPPE, Universidade Federal do Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil

[19]Department of Environmental Sciences and Policy, Central European University, Vienna, Austria

[20]Graduate School of Engineering, Osaka University, Osaka, Japan

[21]University of Brescia, Brescia, Italy

[22]RFF-CMCC European Institute on Economics and the Environment of the Euro-Mediterranean Center on Climate Change, Milano, Italy

[23]Department of Energy and Environmental Management, Europa-Universität Flensburg, Flensburg, Germany

[24]Energy & Climate Division, Oeko-Institut and TU Berlin, Berlin, Germany

*Correspondence: masahiro@ifi.u-tokyo.ac.jp

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measures that aim to "avoid" demand for certain goods and services, "shift" demand to more resource-efficient forms of provisioning, and/or "improve" the efficiency of provisioning.[1]

The recent Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) for the first time included a dedicated chapter on demand-side measures, services, and linkages to wellbeing. It showed that demand-side solutions have the potential to reduce GHG emissions from end-use sectors by 40%–70% by 2050 without compromising service levels and with improvements to wellbeing outcomes across multiple indicators,[2] demonstrating strong synergies with the Sustainable Development Goals (SDGs).[1,3] Such solutions enable the design of "high with low" (HwL) scenarios,[4] which can promote high inclusive wellbeing with low energy and material demand (LEMD), a resilient economy, and progress in sustainable development (Figure 1).[5] Lowering energy and material demand reduces the size of the biophysical economy,[6] which can be more easily decarbonized with renewables and other granular low-carbon supply technologies, reducing risky reliance on large-scale carbon dioxide removal (CDR).[7]

Demand-side research builds on emerging concepts such as minimum decent living standards (DLSs)[8] for all, a "safe and just space" to address inequalities due to the consumption of the top 10%, as well as sustainable consumption and production corridors. These in turn support the analysis and modeling of HwL pathways toward more equitable societies with higher levels of wellbeing and service provision, achieved via lower levels of energy and material demand.

Nevertheless, demand-side solutions are currently underrepresented and underprioritized in research and policy. Addressing this shortcoming requires improved analytical and modeling capabilities and methodologies, which can be achieved through interdisciplinary research on demand-side solutions.

Accelerating real-world developments

Demand-side solutions are expanding across the world. Progress is being driven by multiple trends,[6] including granular (smaller unit scale) innovations,[9] urbanization, digitalization, sharing and circular economy, increased awareness, more engaged users, and new business models.

For example, over recent decades, the European Union has introduced the 1992 SAVE Directive and the "energy efficiency first principle" in Governance Regulation 2018/1999, which has been incorporated into other policies such as the recasts of the Energy Efficiency Directive. More recently, bans on gas connections in newly constructed buildings have been proposed in several countries, encouraging electrification and more efficient appliances such as heat pumps. The Inflation Reduction Act of the United States also includes several provisions related to demand-side solutions including tax credits for electric vehicles and heat pumps.

Thanks to these policies as well as technological innovation, end-use electrification technologies are expanding. Sales of electric vehicles exceeded 10 million in 2022, representing 14% of global new car sales. Electric heat pumps are also growing rapidly, with record-high growth observed in Europe, China, and the United States.

Other examples of demand-side solutions include sustainable urban planning toward "15-minute cities" that allow citizens to walk or cycle to urban hubs, led by cities such as Paris and Barcelona. On the lifestyle front, Japan has promoted several campaigns, including Cool Biz, which promotes a non-tie style of clothing during the humid summer months to reduce the use of air-conditioning.

Current state of demand-side scenario analysis

Global climate-change-mitigation scenarios, often based on integrated assessment models (IAMs), are a mainstay of international climate policy analysis and feature prominently in scientific assessments.[2] Model-based scenario analyses are useful for comparing and prioritizing alternative options. They can also help to identify synergies and trade-offs and analyze whether current policies are consistent with stated goals.

However, within the existing corpus of scenario analyses and models, there is fierce debate about the emphasis—and hence the limitations—of supply-side solutions and CDR options, such as bioenergy with carbon capture and storage. Bioenergy production is a land-intensive activity, and large-scale removal of CO_2 from the atmosphere on the order of 10 $GtCO_2$/year forces complex trade-offs, including competition for land between food and bioenergy.[10]

LEMD scenarios, which minimize such trade-offs, are explored only in a small number of studies (see Figure 2A for IPCC scenarios; Figures S1–S3 in the supplemental information for a more detailed discussion; see Mastrucci et al.[11] for a review of the buildings sector). In addition, models tend to lack sufficient resolution to analyze demand-side transformation. For example, energy services are reported >4 times less frequently than primary energy in the IPCC scenario analysis (Figure 2B).

Demand-side research does not easily lend itself to the standard techno-economic approaches used in forward-looking models to identify cost-effective pathways, as it requires interdisciplinary insights from various disciplines. For example, solutions to reduce "energy efficiency gaps" (between technically optimal and actually realized potentials) and "rebound effects" (induced increases in energy service demand as efficiency measures reduce the cost of energy

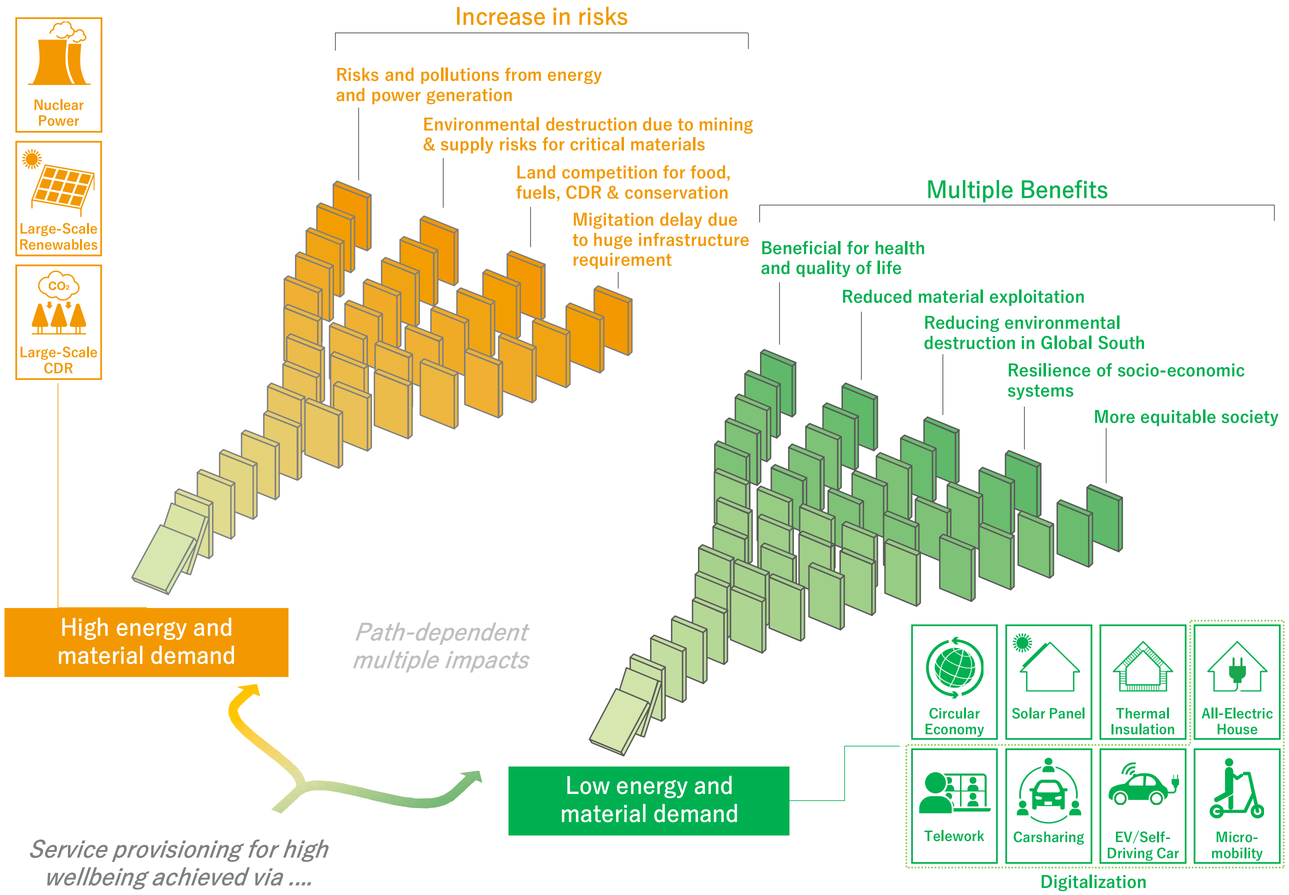

Figure 1. "High with low" (HwL) scenarios—High wellbeing and service levels with low energy and material demand (LEMD)—offer multiple benefits at low costs and risks

LEMD pathways can enable the achievement of high and inclusive wellbeing as well as the contextual achievement of multiple SDGs. In contrast, supply-side solutions with high energy and material demand carry risks associated with higher resource use. LEMD complements supply-side decarbonization, for example, through the deployment of renewables and other clean energy. High demand scenarios do have benefits, including fewer transition barriers and stranded assets, and large-scale projects may bring about economic benefits. The distinction between the two scenarios is not binary but illustrative.

services) require interdisciplinary approaches.[12] Moreover, there are multiple perspectives on service provisioning, demand, and human wellbeing,[13] and the choice of indicators (whether as model inputs or outputs) is normative and has direct consequences for modeling. Improved representation of granularity (scale characteristics) and wellbeing indicators further increases the complexity of models and linkages, presenting a fundamental research challenge.

Research priorities for demand-side analysis

Addressing this challenge requires interdisciplinary knowledge integration, modeling and scenario analysis, data collection, and policy research. We identify three main research priorities for advancing interdisciplinary demand-side research on HwL pathways (Table 1).

A wider scope and greater variety of models and scenarios

Methodological innovation is needed to bring the analysis of demand-side solutions into the mainstream of mitigation pathway modeling at local, national, and global scales. A variety of detailed sectoral and bottom-up models, including engineering and agent-based traditions, already exist (e.g., for analyzing energy demand in buildings[11]). Though IAMs have historically focused on supply-side modeling, they can also be fruitfully extended to improve their resolution of processes in multiple sectors, and/or they can be coupled with, linked to, or parameterized after more detailed models. The complementary use of a variety of models is urgently needed to understand the impact of digitalization, changing practices, and policy mixes in HwL pathways.[11]

Scientific assessments should engage with multiple research communities to incorporate insights into demand-side solutions. The IAM research community is organized around the IAM Consortium

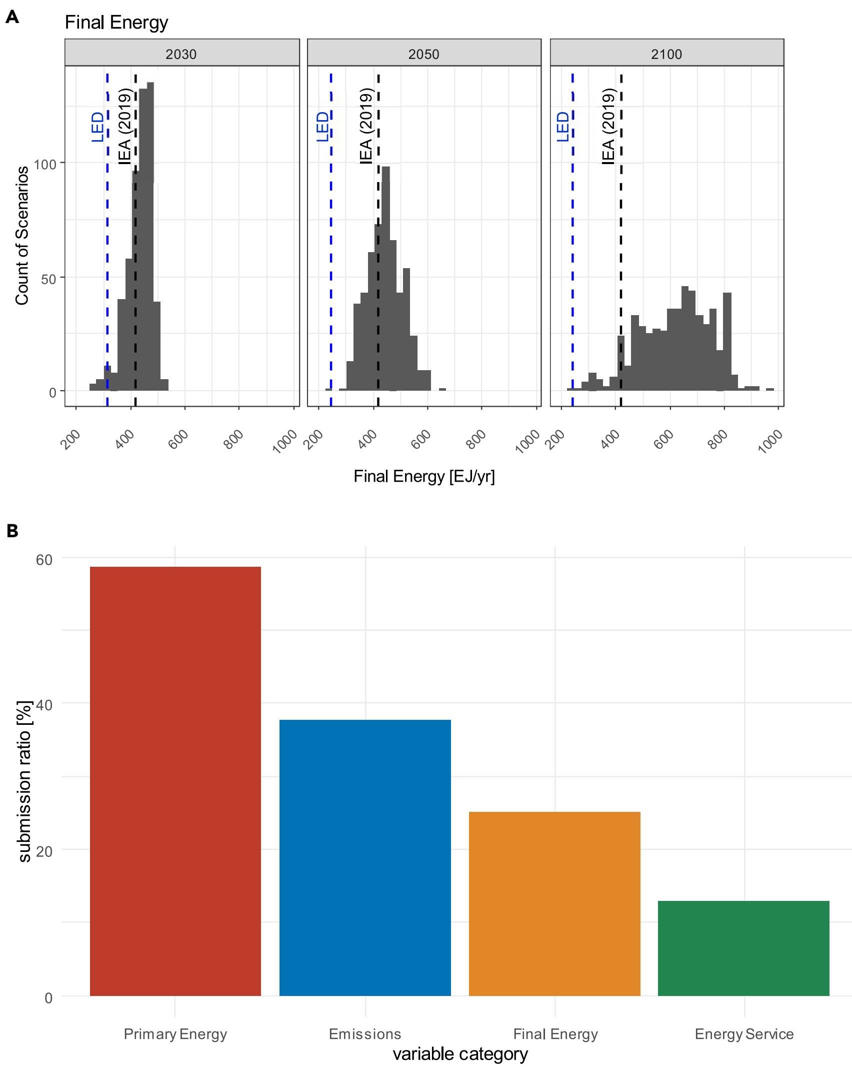

Figure 2. The IPCC scenario database contains only a small number of LEMD scenarios, and it does not provide sufficient granularity for demand-side analysis

(A) Distribution of final energy consumption in the IPCC AR6 scenario database for 2030, 2050, and 2100. The blue dashed vertical line indicates the original LED scenario,[6] which was also presented as an illustrative mitigation pathway in the IPCC, and the black dashed vertical line represents the total final energy consumption in 2019 from the International Energy Agency statistics. See Figures S1–S3 for sectoral breakdowns.

(B) Submission rate of variables to the IPCC AR6 Scenario Explorer, defined as the number of the variables submitted, divided by the number of unique models times the number of unique variables. For both (A) and (B), only the scenarios consistent with the Paris Agreement (peak warming of 2°C or less with >67% probability; scenario categories C1, C2, and C3) are used.

(IAMC) (https://www.iamconsortium.org/), to which, for example, the IPCC has easy access. Open calls for sectoral scenarios (buildings and transport) were made during the IPCC AR6 cycle, but the submissions were few. More effort is needed to solicit valuable contributions from other types of modeling traditions[15] to improve the usefulness of the next IPCC assessments including the Special Report on Cities. The Energy Demand Changes Induced by Technological and Social Innovations (EDITS) network, for instance, is facilitating a broadening and a deepening of demand-side modeling contributions by expanding the IAMC scenario data template and fostering new interdisciplinary collaborations.

Scenario design should also promote efforts to model LEMD based on the HwL narrative and novel scenario frameworks. Such frameworks should also incorporate the effect of rapidly developing, supply-side granular technologies.[7,9]

Better data on demand, services, and wellbeing

Modeling wellbeing, service provisioning, and energy and material demand requires data that are dispersed across different locations and research communities (which are increasingly interconnected),[14] as well as new datasets and frameworks. Even basic energy datasets such as national energy balances need to be updated to better reflect energy services and useful energy. It would therefore be crucial to bring research communities together in an interdisciplinary effort in order to arrive at compatible ontologies and systems definitions.

National panel surveys can help in this respect. For example, in 2014, Japan's Ministry of the Environment launched a household survey on energy consumption patterns and CO_2 emissions, similar to the long-standing Residential Energy Consumption Survey (RECS) in the United States. This novel data source has spawned numerous studies, providing a baseline for further exploration of demand-side solutions. Similar survey efforts are emerging in the Global South (e.g., in India and Mexico). Artificial intelligence and big data (e.g., bibliometric analysis,[14] remote sensing, and social media data) can be fruitfully exploited. Improved methodologies for developing data on the energy-material nexus (e.g., embodied emissions of materials production, accumulated material stocks) are also needed.

A significant step toward synthesizing concepts and data related to demand-side solutions was undertaken by the Working Group III of the IPCC in the

Table 1. Research priorities for HwL pathways

Domain	Priorities	Examples
More diverse models and scenarios	models representing demand-side solutions based on interdisciplinary methodological frameworks can complement IAMs for scenario analysis	• LEMD scenario modeling implementing the HwL[4] or similar narratives • IAM coupling with high-resolution demand-side models • updating the IAMC scenario data template for demand-side analysis
Better data	expanded and improved data on demand, services, and wellbeing can improve the design and calibration of models for demand-side solutions	• metadata collection and gap analysis of demand-side data • energy demand surveys in wider areas OECD (Organization for Economic Cooperation and Development)'s "How's •Life" compilation of wellbeing indicators • big data[14] and new datasets
Evidence on policies, societal actions, and business models	incorporating demand-side characteristics (e.g., elasticities) can bridge the gap between model-based analysis and concrete actions	• energy services and wellbeing-driven analysis (e.g., DLSs) • sufficiency policy database

AR6 (Chapter 5). Looking ahead, this evidence should be bridged with modeling. Importantly, demand-side modeling is more data intensive than supply-side modeling, and updating data is a significant challenge. To overcome these challenges, the EDITS network is working on meta-datasets and data collections for modeling teams, as well as conducting reviews of models and scenarios[11] and identifying gaps between existing and required data.

Linking analysis to policy, society, and business

Alongside model development, demand-side policy analysis is crucial for ex-post evaluation and the design of new scenarios. A recent review[16] outlined the need for demand-oriented policies based on transitions research, energy technology innovation systems, conventional policy analysis, and the need to take into account the specificities of demand-side solutions: endogenous and heterogeneous preferences, peer effects, granular technologies, and the roles of different actors and intermediaries[3] involved in the implementation of demand-side options.

While there is a long history of demand-side policies, research has not yet systematically synthesized their potential for the current challenges. The new agenda for policy analysis includes (1) the link between climate change and other SDGs; (2) wellbeing implications; (3) interdependencies between energy, materials, and other resources; (4) relationships among sufficiency, upper ceilings, and planetary boundaries; and (5) spatially explicit interactions with the built environment. Ex-post policy evaluations can go hand in hand with scenario analysis to provide valuable insights for effective policy interventions across regions and sectors. Policymakers also need clear communication strategies and bundled policy packages or policy mixes to implement such solutions.

To effectively support different actors, the evidence base should go beyond government policies to include new business models and societal actions. These will be critical for promoting sufficiency, sharing and circular economies, digitalization in line with the Industry 5.0 paradigm, and other broad demand-side strategies. The scenarios in the IPCC reports have also not explicitly addressed digitalization, which involves new business models and services with potential contributions to HwL futures. Lessons from sustainability transitions research, which describes the co-evolution of social and technical systems, are highly relevant and can be mobilized to inform further quantitative modeling.

Conclusion

The pressing need for more robust evidence and analysis of HwL futures creates research priorities that should be addressed through interdisciplinary collaboration to inform policy and support societal changes required for a transition to sustainability. This has support at the highest political level, as evidenced by the 2023 G20 communiqué and the decision at the 28th Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). The international EDITS network is an initiative to mobilize research in this area, but much more is needed from both the scientific community and the IPCC to improve the linkage between scenario and demand-side research. We call on researchers, governments, statistical offices, funding agencies, and other interested stakeholders to join forces to strengthen the evidence base for demand-side solutions.

Data and code availability

The dataset used for Figure 2 is publicly available from the IPCC AR6 Scenario Explorer (https://data.ece.iiasa.ac.at/ar6/). The code to generate the charts is available upon request.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.joule.2023.12.014.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work the authors used DeepL in order to improve the clarity of the English writing. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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