**RETHINKING ENERGY DEMAND**
**Discussion Workshop**

**Todaiji Cuture Center, Nara, Japan**
**25-27 September, 2018**

**Workshop Highlights**

# INTRODUCTION

RITE and IIASA convened an expert workshop on 'Rethinking Energy Demand' in Nara, Japan, held from September 25-27, 2018. The workshop was attended by 28 participants from 11 countries (see Appendix I), either in person or through participation via teleconference. The workshop formed part of on-going collaborative research between RITE and IIASA under the auspices of the ALPS collaboration framework in general and of the ALPS 2018/2019 collaboration cycle in particular which has a focus on alternative conceptualizations of energy demand and their implications for future research strategies. The location of the workshop in Nara, Japan, was not a coincidence, instead intended to pay tribute to earlier concepts and emphasis of demand-side solutions pioneered in Japan, such as the 1978 “Moonlight Project”, a prescient precursor to the workshop deliberations reported here.

Over the course of three days, a diverse set of researchers from around the world met to present, discuss and explore their thinking in the reemergent field of energy-service transformation for climate change and sustainable development (see Appendix II for the Workshop Agenda). The aim of the workshop was to further interdisciplinary dialogue on novel conceptualizations of energy demand, and new approaches to data, modelling and analysis.

This report highlights the main points and discussions from the workshop. The full presentations at the workshop are made available on a dedicated workshop webpage that contains the workshops agenda with integrated links to all material presented.
http://www.iiasa.ac.at/web/home/research/researchPrograms/TransitionstoNewTechnologies/event/180925_RED.html

In the following workshop highlights, reference to presentations and discussion statements are made [*with italicized author names shown in brackets*].

Discussion sessions were framed by a summary of the policy context (Paris Climate Agreement and SDGs) and by reflections and syntheses of recent literature and thinking [*Akimoto, Grubler*, *Laitner, Creutzig*], and informed by presentation on a wide range of topics including:

- wellbeing [*Steinberger*], decent living standards [*Rao*], time use [*Gi*], and smart societal visions [*Yamaji*];

- social dimensions [*Lutzenhiser, Moezzi*], psychological explanations [*Steg*], and economic analysis [*Azevedo, Brown*] of energy-related behavior;

- case studies of transformative opportunities in shared urban mobility [*Kaupilla*], residential and commercial buildings [*Urge-Vorsatz*], industry [*Roy*], and consumer-facing goods and services [*Wilson*];

- new data sources [*van Ruijven*], micro-level modelling approaches [*Shimoda*] as well as data and analytical challenges [*Moezzi*].

## BACKGROUND TO WORKSHOP

The Paris Climate Agreement's ambition to limit global warming to 1.5°C above pre-industrial levels has sharpened the focus on transformative change in energy systems. The near-term targets of the UN's Sustainable Development Goals (SDGs) further emphasize the time imperative for a cleaner, affordable, accessible energy services provision for at least minimum standards of decent living for the world's population.

Global scenario and modelling analyses under the auspices of the Intergovernmental Panel on Climate Change (IPCC) share a common assumption of strongly path-dependent growth in energy supply infrastructure against a backdrop of ever-rising energy demand (Clarke et al. 2014). This basic assumption forms the spine of the IPCC's Fifth Assessment Report, the IPCC's recent Special Report on Limiting Warming to 1.5°C, as well as the annual reports by the International Energy Agency (IEA) and the United Nations Environment Program (UNEP) on global progress on decarbonization. These influential publications show that even with dramatic and sustained increases in low-carbon energy supply - whether fossil carbon capture and storage (CCS), bioenergy, renewables, or nuclear - inertia in technological and policy systems means emissions will overshoot the 2°C target and so require massive deployment of negative emission technologies in the longer-term. Yet the prime candidate for negative emissions, bioenergy with CCS, is unproven, costly, detrimental to food security, and requires an accelerated build out of a single-purpose infrastructure equivalent in size that the oil industry has accumulated over the past 150 years (Smil 2010).

Meanwhile on the demand-side of the equation, the body of scenario and modelling analysis assumes energy demand rising in lockstep with incomes, aspirations, and populations. Yet all around us, potentially disruptive changes in the way energy services are provided and consumed are making in-roads into mainstream markets, driven as much by the strength and novelty of their value propositions as by sectorial policies or climate policies.

The most striking example is in passenger transport. Less than five years ago, transport was framed as the hardest end-use sector to decarbonize (Creutzig et al. 2015). Generations of low-emission vehicles using biofuel, fuel cell, natural gas propulsion failed to dent the market dominance of the internal combustion engine, and alternatives to private car ownership and use failed to offer mobility with the same versatility, autonomy, and lifecycle cost. Now, exponential cost declines in modular battery technology aligned with air pollution concerns, particularly in emerging economy cities, have seen strong deployment of electric vehicles at the margins of the auto industry, and a range of new sharing-economy and digitally-enabled business models are increasingly available to increase occupancy and utilization rates of passenger vehicles. A series of influential studies by the OECD's International Transport Forum *[cf. Kauppila]* have simulated the dramatic reductions in emissions which this combination of electrification and on-demand shared mobility are now making possible at a urban scale (ITF 2016; ITF 2017a; ITF 2017b).

More broadly, opportunities for accelerated transformation in energy-service provision are rapidly opening up at the interface between the digital and energy worlds, with tech sector software expanding and integrating into traditional energy, transport, and buildings hardware. The innovative possibilities are combinatorial and business model-centered, delivering new sources of value, and new bases for consumer appeal. As the ITF observe: "*The nexus of digitalization, new business models, ubiquitous computing and platform-based* *supply/demand matching is already beginning to have an impact on many aspects of modern life, including the way in which people and goods move about cities*" (ITF 2017b).

These 'mega-trends' shaping energy service provision are far from business-as-usual.

First, the most influential innovation testbeds are now in major emerging economies, particularly China, with pressing challenges associated with rapid urbanization, chronic air pollution and congestion, and rising incomes ratcheting up expectations for more livable cities.

Second, the most influential demographic cohort in both the global North and South are now the Millennials generation in their 20s and 30s who have grown up with digital, mobile, smart technologies integrated into their daily lives and for whom accessing services rather than owning goods is fast becoming the new norm. This shift from ownership to 'usership' has most clearly taken place in the media and entertainment, but similar patterns are emerging with mobility, consumer goods, working and living spaces, and other energy-intensive services.

Third, the most influential innovation actors are now data-driven service providers and tech companies introducing software, algorithms, and big-data analytics, to repurpose energy-using hardware and infrastructure. More broadly, the constellation of innovation actors driving change in the energy domain - from IT companies to cities and Millennials as adoption pioneers - pose an existential challenge to the long-incumbent centralized energy utilities and resource-extraction companies (Graffy and Kihm 2014).

Fourth, the most influential social enabler for energy-service transformation revolves around data availability, accessibility, privacy and protection. New services are invariably data service providers is shaping innovation outcomes. The divergent trajectories of stricter data-protection legislation in post-Snowden Europe are in stark contrast with the digital citizenship system implemented in China, drawing on and synthesizing a wide range of data to score citizens' trustworthiness and behavior in a digital, socially-networked contemporary world.

There is much hype around the "disruptive trends that may change the world" (McKinsey 2013), and in the context of climate change and sustainable development, there is much need for careful empirical research on the transformative potential of new consumer-facing goods and services. Much of the evidence base comes from simulation modelling (ITF 2016), exuberant market projections (Arbib and Seba 2017), techno-economic estimations of market potentials (Buscher et al. 2014), as well as early-adopting niches (Wilson et al. 2018).

The generalizability, robustness, and durability of emission reductions require comprehensive real-world testing and verification as the potential benefits are enormous. A recent global scenario study found that transforming energy services through new consumer innovations working alongside an aggressive strengthening, implementation and enforcement of efficiency and performance standards could deliver on the Paris Climate Agreement's 1.5°C ambition without relying on any CCS technology (Grubler et al. 2018). Central to this analysis is the basic insight that downsizing demand in turn makes transforming supply less infrastructure-intensive, less investment-intensive, and so more feasible as a way of rapidly escaping the path-dependency in which the conventional wisdom is trapped (Figure 1).

Amory Lovins, who has spent over 40 years arguing the case for an efficiency-driven future, describes this systems thinking as 'integrative design': sizing the system appropriately leverages many-fold improvements in system efficiency throughout the residential, commercial, transportation, and industrial sectors (Lovins 2018).

These arguments for energy-service transformation through disruptive consumer innovations could risk marginalizing the imperative of raising living standards in the global South in line with the poverty-alleviation agenda of the UN's Sustainable Development Goals. Decent living standards can be defined as minimum thresholds of comfort, living space, consumer goods, mobility, and nutrition as well as the land, buildings, transport and industrial infrastructures which provision these goods and services (Rao and Min 2017). And yet, as Grubler and colleagues demonstrated in their scenario study, these minimum standards can not only be provided but even exceeded through an end-use, service-oriented model of provision while remaining consistent with the overall scenario narrative of accelerated supply side transformations, leveraged by a downsized final energy use (Grubler et al. 2018). In other words, the increased provision of energy services does not necessarily require more energy inputs, as there are enormous potential efficiency gains that can be tapped by changing the ways of energy services are provided. These are currently highly inefficient, with some estimates showing that only 5% of global primary exergy harnessed is delivered as useful energy services, with 95% being wasted (Gilli et al. 1996; Grubler et al. 2018).

The traditional association of ever-increasing levels of energy inputs with increases in human welfare is thus neither empirically supported [*cf. Steinberger]* nor a thermodynamic 'law of energy development'. At the same time, we should recall that energy services are themselves an intermediate good: a means of providing the end of human wellbeing, welfare or decent living.

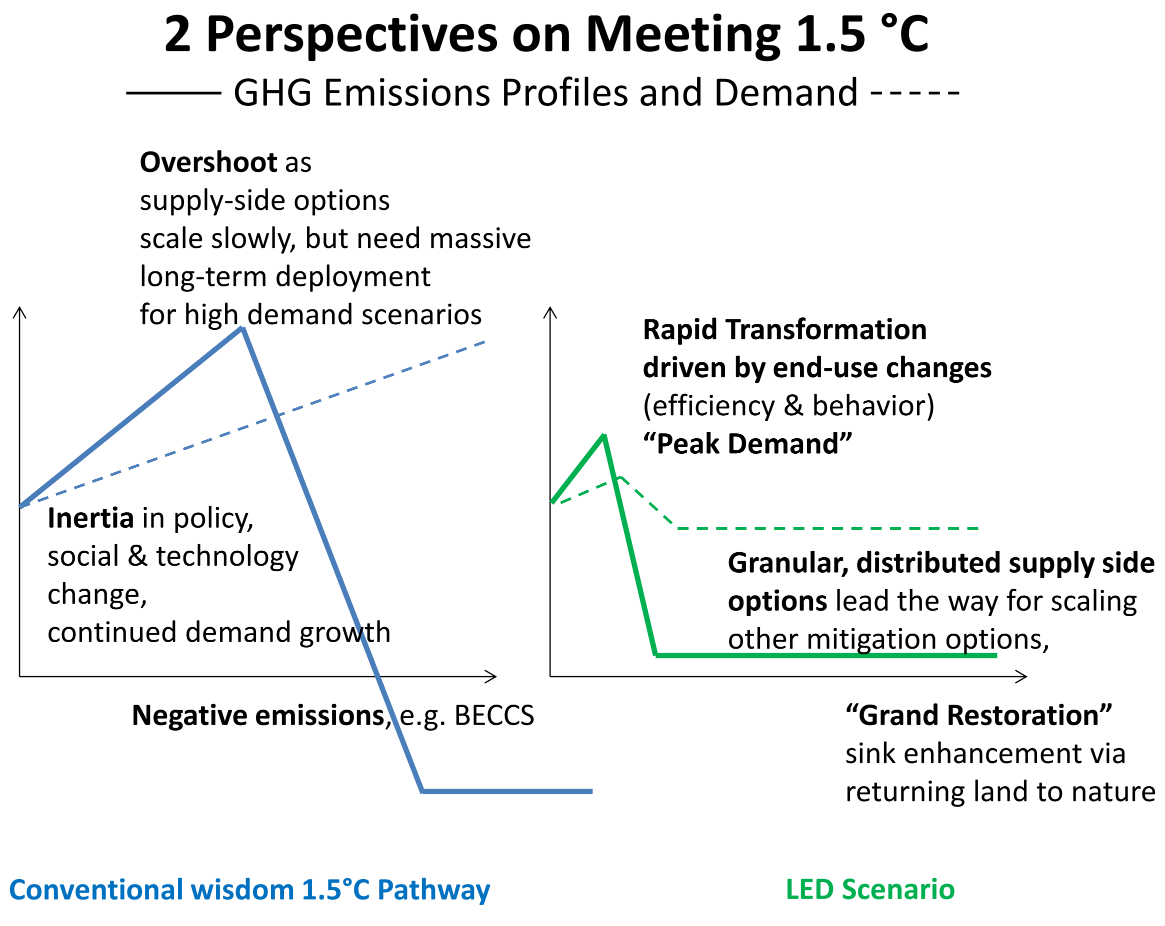


Figure 1. Two contrasting perspectives of meeting a 1.5 °C climate goal.

# SUMMARY AND HIGHLIGHTS OF PRESENTATIONS

## Session I: Opening and Welcome

The workshop was opened by **Arnulf Grubler**, who summarized the motivation and agenda of the workshop as well as its research context. In particular he highlighted the hope this workshop would be the start of a more regular series of interdisciplinary exchanges that would ultimately lead to new research collaborations and an improved understanding of demand issues in energy, climate, and SDG policy contexts.

***Keigo Akimoto*** as the local host welcomed all participants and gave an overview of RITE (the Research Institute for Innovative Technologies for the Earth), its research mission, and methods and tools being developed for assessing “deep” decarbonization options. He emphasized one reason for a renewed interest in energy end-use and demand issues, namely the challenges (reliance on unproven technological options such as negative emissions technologies, extremely high mitigation costs) associated with drastic carbon reductions required with a 1.5 $^{0}$C climate target under “business as usual” demand trends. He also stressed the increasing need to integrate climate mitigation analysis into the broader SDG context, requiring to revisit social welfare and distributional issues of alternative development pathways which put end-use and demand considerations into the center of the interlinkages among various SDGs.

***Skip Laitner*** opened the workshops discussion by an overall framing and motivational statement. He argued that the traditional “silos” in the framing, conceptualization, as well as policy interpretation of energy issues are a reality, but need to be overcome by enhanced dialogue and interaction, not at least due to the increasing recognition of diminishing returns on current dominant infrastructures, technologies, and practices calling for a major transformation. “The interactive, productive, and more efficient use of all resources – capital, materials, food, water and especially energy- must underpin this transformation” according to Laitner. He provided three intermediary perspectives as a useful strategy forward, including: 1) tracking the array of wastes, from current systems and practices; 2) complementing the traditional energy (commodity/products) metric by useful work (or exergy) considerations (that provide a more direct linkages to services and welfare); and 3) integration of various potential productivity gains (efficiency, waste reduction, clean supply systems) into an overall energy productivity measure linked to social, economic and environmental welfare. Laitner concluded with a plea for a paradigm shift in the discourse departing from traditional conceptualizations and compartmentalization while encouraging new, but also rigorous thinking and analyses.

## Session II: Multiple Science Perspectives on Demand

***Loren Lutzenhiser***, a pioneer in the sociology of energy demand, reminded participants about the ambiguity of the very concept of “demand” in various social science disciplines when discussing also the evolution of the concept since the 1970s. The “demand” concept as framed in economics (whether considering intermediary economic goods like energy, or service provisions enabled by energy use such as mobility, communication, thermally comfortable housing, etc.) actually does not exist in other social sciences such as sociology and anthropology. Lutzenhiser expressed his view that demand should be seen as the co-evolutionary product (in Lutzenhiser’s term the “co-production”) of persons, households, communities, businesses, regulators, media, and social movements. (While these are highly variable and in constant flux, there might nonetheless be opportunities for improved understanding by developing typologies or typologies of trajectories of their co-evolution.)

Lutzenhiser considered social practice theory “as close to formalizing a social perspective on people, energy, technology and environment as we have come so far” but cautioned also the theory remains as essentially European project, complemented by different research approaches elsewhere, including his own work on empirical surveys of household energy use and developing narratives and scenarios of multi-dimensional changes at the state level (California). He concluded with wishing all participants and the workshop a most fruitful dialogue.

***Ines Azevedo*** summarized recent economic research with a focus on improved analytical techniques for improved decision making and policy. First, she introduced a technique for assessing (the endemic) uncertainties in energy projections differentiating between projection errors (unpredictability) and year-to-year overall changes (volatility) for the US over the period 1949 to 2014, concluding that both unpredictability and volatility have increased in the last decade, compared to earlier periods (most likely the result of changes in fundamental drivers and variables in the social, economic, and technological realm). Second, she presented a range of recent studies on the “rebound” (or take-back) effect, a frequently discussed (and often overplayed) phenomenon, concluding that the empirical quantification of the effect shows that it is as real as relatively modest, even considering variability across different markets and geographical environments in the US. Lastly, she demonstrated new analytical techniques combining smart meter data with household, demographic and weather “big data” to assess the impacts of (electricity) efficiency policies via appliance rebate programs, opening new avenues to validate the impact of policy interventions affecting energy demand.

***Narasimha Rao*** introduced the novel concept of “Decent Living Standards.” The approach aims to derive a quantitative framework of human wellbeing that includes also material living standards. This framework is argued not only to have a greater explanatory power for energy demand (e.g. compared to traditional aggregate variables such as income) but also to allow addressing broader sustainability issues. Currently the concept comprises ten group of indicators centered around housing, nutrition, water/sanitation, health, education, as well as communication and mobility, including always also energy services (e.g. thermal comfort, cooking, transport, etc.). Energy quantifications consider both embodied as well as operational (and associated upstream) energy use. Illustrative quantifications for Brazil, India, and South Africa indicate that minima energy demand for providing decent living standards with current technologies and practices would range in the longer-run (after completing energy-intensive infrastructure build-up) between 15 to some 25 GJ/yr/capita, which can be considered a kind of SDG “floor” of resource use, with mobility being generally the most resource intensive activity. This suggests to explore alternative models of mobility provisions, e.g. shared mobility, with a particular focus on the poor and lower income households.

***Linda Steg*** summarized recent research in psychology including European opinion surveys on climate change as well as empirical research on behavior change strategies. The surveys confirm that a vast majority of the European population thinks that the climate is actually changing, with a large majority attributing it to human activity. Given this high degree of problem awareness, Steg summarized the main areas of psychology research as relating to energy policy, including the following group of questions: Which behavior is at the cause of a given problem? Which factors influence behavior? Which strategies can be implemented to change these factors and behaviors? And what are the impacts of changes implemented on wellbeing? She also identified three major strategies for behavioral change: 1) changing perceptions and evaluations; 2) changing the (financial, legal, infrastructural) context in which decisions are made; as well as 3) considering the psychological implications of strategies. She illustrated the impact of psychological experiments in which different communication strategies addressed various behavioral motivations (concern for environment, money, or control respectively). The major insight emerging from this body of research is that a “one size fits all” policy approach is unlikely to succeed, instead differentiated communication strategies, incentives, and policies need to target different motivations of behavior to ultimately lead to behavioral change. She also argued that an important aspect to also consider to target extrinsic motivations, introducing the concept *Eudaimonia*, where acting pro-environmentally provides a positive self-reinforcing mechanism via its perception as being meaningful, leading to “feeling good”, which in turn further reinforces the original pro-environmental behavioral motivation.

**Session III: Multiple Scales: Perspectives from the South and the Urban Scale**

***Joyashree Roy*** framed the demand discourse from the twin perspectives of emerging economies (the Global South) and two ongoing transformations which she termed “demand for efficiency” (decoupling resource use from GDP growth via price mechanisms and adoption of energy efficiency technologies and practices) as well as “demand for sufficiency” (enabling increases in wellbeing with less waste, less inequality and while respecting planetary boundaries). Drawing on recent empirical and scenario analysis in India she illustrated evolving trends in both types of transformations. She showed evidence that due to increasing factor substitution in the Indian economy, the price elasticity of energy has doubled (from -0.6 to -1.2) between the 1973-1986 and 2000-2010 periods suggesting ever large impacts from price-based policy interventions. At the same time, also the influence of non-price incentives for both energy efficiency and for renewable energy in India is increasing in importance as well as in impact. She also argued that disruptive behavioral changes that are emerging could further reduce barriers to resource efficiency policies and fuller realization of efficiency improvement potentials. Rebound effects are expected to decline with increasing evidence of reductions in optional (unmet) demands, paving the way to increasingly consider “demands for sufficiency”, i.e. the energy-welfare-ecological interactions in an Indian policy context.

***Felix Creutzig*** presented his current conceptualization of the structure, contents and research gaps for the forthcoming Chapter 5 of the IPCC 6$^{th}$ Assessment Report. He emphasized first the interdisciplinary efforts required to address demand side solutions in a climate mitigation context and then outlined five key issues which in his view the chapter will need to address. The first deals with the need to address explicitly a plurality of normative concepts arising from different disciplinary perspective such as utility, happiness, or capabilities. Second, a practical way of defining living standards (see e.g. *Rao*’s contribution above) that considers geographical, cultural, and path dependency contexts will be critical for the chapter. A third challenge is the integration of different social science theories from economics, psychology, to sociology, and cultural studies. This integration is particularly germane as more restricted theoretical perspectives may lead to limited explanatory power. He mentioned as example recent findings that even quantifiable social science theories can explain actually surprisingly little (some 27%) of behavioral variations arising from attitude formation, to intention, and behavior. Fourth, he argued for the need for ex post policy analyses to identify what works (or does not work) in which context. Fifth and finally, he proposed applying the “avoid-shift-improve” concept combined with the decent living standards concept to explore transition pathways from “too little” or “too much” with a particular emphasis on product and service categories with explicit linkages to the SDGs.

***Bas van Ruijven*** reviewed current modeling efforts to study the impact of human structures (cities) and energy use on weather and climate, giving as example the efforts to represent urban areas in the Community Land Use Model. He first outlined the general structure of the model and then focused on its data needs and strategies for their collection and/or derivation from existing data sets. These data sets are then combined to describe in a spatially explicit way human settlements via a typology of ten anthropogenic Local Climate Zones, as well as six natural ones. While he emphasized that current modeling approaches remain very atmosphere-centric, there exists also potentials to integrate socio-economic and geographical information such as infrastructure availability and different usage patterns, i.e. more social science research topics, into these efforts.

***Julia Steinberger*** presented ongoing research within a project termed "Living Well within Limits" (LiLi). In the framework developed for the LiLi project, social outcomes (wellbeing and associated "need satisfiers") are conceptualized as being structured by so-called provisioning systems that include both physical (e.g. infrastructures), economic (e.g. markets), and social dimensions (e.g. culture, norms, communities, etc.). These provisioning systems in turn rely on biophysical inputs (natural resources and planetary processes). Presenting recent research, she demonstrated that traditional aggregate variables like income or aggregate (e.g. economy-wide) primary resource use have more limited explanatory power on human well-being indicators, compared to more disaggregated (e.g. household-level), service-oriented input measures. She then conceptualized the provisioning systems for human wellbeing which are characterized by a hierarchy of need satisfier systems or components. This hierarchical structure (from socio-technical systems, to institutions, to type of service, and lastly to device configurations providing that service) that co-evolve and co-depend can be used to explain persistent path dependency and lock-in effects. She used the example of automobile dependence to illustrate how particular provisioning systems evolve and create lock-in and path dependency.

## Session IV: Energy Demand, Efficiency, and Conservation: What Have we Learned?

***Skip Laitner*** opened the session with a preliminary summary of the preceding workshop deliberations. He referred to a number of points where he sees convergence in the views among the workshop participants. These include: 1) The recognition of the need to move away from many traditional concepts underlying studies of energy demand like macro-economic drivers such as GDP or the treatment of "demand" for intermediary goods in favor of services and the resource bundles needed for their provision; 2) The realization that energy efficiency/productivity potentials are much larger than frequently imagined or generally understood, and that these potentials are far from static, but evolve over time with new opportunities opened by technological, behavioral, and institutional innovations; 3) Economics (i.e. prices) matter, but there is wide recognition that next to economic variables there are many more influencing factors which require a concerted effort of bringing multiple disciplinary perspectives together. Lastly, Laitner reiterated his view that transformative changes in current systems of service provision require a large-scale "purposeful effort" and even larger "productive investments", whose mobilization again needs careful analysis and insights from relevant social science disciplines.

***Mithra Moezzi***, drawing on her experience with empirical household energy use and usage patterns in California, took the discussion back to a more fundamental level, raising a number of fundamental empirical dilemmas. Like for all social phenomena, variability of behaviors and patterns dominate, which are hidden when aggregated. The implication is that traditional notions of "representative agents" are inappropriate, while at the same time the question of what constitutes appropriate levels of disaggregation and of representation of heterogeneity remains open. A second consideration deals with empirical data, which are as necessary as often disappointing in terms of their availability and quality raising important challenges for research. Moezzi also argued for the need to revisit the way scientific methods are applied, considering especially much of extant statistical capabilities and sensibilities as used in many studies insufficient for the research task and the problems they try to address. The same also applies to concepts and terminology (vocabulary and metrics), often initially developed for a different research context and thus getting in the way when addressing new analytical challenges. Her main conclusion from these cautionary observations is the need to engage in a much wider and deeper discourse on methods and data when addressing the complexities of issues traditionally subsumed under the heading of “energy demand”.

***Yoshiyuki Shimoda*** presented novel research in Japan on residential/household energy use. He introduced the concept of an “energy demand science.” This approach combines detailed survey data on household characteristics, time use and occupant behavior, with housing stock and settlement characteristics, as well as environmental (climatological) data to model residential energy use over time and across different geographical settings. Model calibration is performed drawing on big data approaches such as smart meter data and reveal excellent agreement between observations and modeled parameters. Shimoda also presented recent assessments of various policy measures aimed at reducing GHG emissions in the residential sector of Japan. Absolute reductions in residential $CO_2$ emissions of up to 40% by 2030 are found to be feasible under current conditions, with larger reductions only possible with new technological and behavioral innovations. It is also worth noting that under the extreme efficiency scenarios the influence of traditional variables of residential energy demand such as demographics or settlement type no longer play a significant influencing role. Instead, distributed on-site generation (PVs) and electromobility diffusion emerge as new important policy options and influencing variables.

***Kenji Yamaji*** presented a bold new concept and vision under development in Japan and referred to as “Society 5.0”. In a nutshell, Society 5.0 aims to leverage pervasive digitalization to transfer the concept of “just in time” pioneered in the Japanese manufacturing industry to a wide range of social services and processes including *inter alia* smart food, transport, health, community services, manufacturing and material provision systems. The objective of Society 5.0 is to provide the “necessary goods and services to the people who need them at the required time and in just the right amount.” At the core of the Society 5.0 concept, a digital service platform is envisaged that allows systemic interconnections within and among materials things, humans, institutions, actors, and territorial entities (cities, regions) deepening existing, and creating new connections for improved participation as well as co-production of new knowledge and systemic solutions. The Society 5.0 concept is at the core of the envisaged transformation towards a “net zero emission society” that aligns climate mitigation with overall progress on the SDGs.

### Session V: Sectorial Perspectives (Transport, Buildings, Digitalization)

***Jari Kauppila*** opened the sectorial perspectives by considering transport and in particular urban passenger mobility. He framed the overall context that under current trends and policy options considered transport related $CO_2$ emissions are bound to increase with a large gap between projected emissions and required reduction levels under ambitious climate targets. At the same time, new social and innovation trends could revolutionize urban transport choices in the direction of significantly lower emissions. He gave examples including that only 10 percent of people of age 18 in Stockholm currently hold a driver’s license. This indicates a social trend opening up vast opportunities to a whole range of new transport options, including in particular shared mobility modes of service provision. OECD’s International Transport Forum has conducted a series of urban-scale case studies to assess the potential impacts of pervasive adoption of shared mobility, replacing individual car use as well as conventional, schedule-based public transport systems outside high-capacity mass transit corridors (light rail, metro). Simulation results for Lisbon, Auckland, and Helsinki suggest that shared urban mobility models could provide for all of passenger transport needs for current source-destination and time patterns with only 3 to 5 percent of the existing vehicle fleet. This would have significant positive impacts on congestion, urban land use (less parking space), as well as emissions ranging from a 34% to 62% reduction in Helsinki and Lisbon respectively under a scenario of 100% adoption of shared mobility (and without considering pervasive electrification). Impacts vary across cities as a function of the current model shares, public transport quality, density, trip patterns as well as preferences for modal choices. Stated preference surveys indicated preferences for shared mobility ranging between 23 percent in Dublin to 62 percent in Helsinki. Price and convenience (waiting, access and travel time, number of transfers and comfort) have also been found as important determinants of shared mobility adoption potentials.

***Diana Urge-Vorsatz*** presented her assessment on new frontiers in buildings energy use research. She reminded workshop participants that there remains a significant gap in the modeling of the uptake of building efficiency options between aggregated Integrated Assessment Models and bottom-up sectorial models that project much more drastic demand responses in stringent climate mitigation scenarios. She then reviewed recent progress in demonstration projects for thermal building retrofits, often considered a constraint for drastic reduction in thermal energy loads for building, concluding that best practice available technologies yield comparable low energy benchmarks (between 50 to 100 $KWh/m^2$) as new built Passiv-Haus Standards. These low energy buildings have two major implications for modelling. First traditional variables such as climate (heating- and cooling-degree days) as well as behavioral variations become almost insignificant determinants of energy use. Second, at such low levels of energy demand increased self-sufficiency by locally harvested renewable energy flows becomes a feasibility, suggesting that the traditional segregation between demand and supply in the buildings sector may become increasingly obsolete. Even floor area might become of ever lesser importance of determining operational energy use in “net-zero” buildings. They remain however a critical determinant for the embodied energy use (materials and construction) of buildings. According to studies cited by Urge-Vorsatz new buildings construction to 2050 could consume up to one third of the remaining carbon emission budget. She suggested the utilization of carbon as building material as one technological strategy of lessening the GHG footprint of new construction.

***Charlie Wilson*** presented on disruptive consumer end-use innovations. He argued that there exists a mismatch between much of traditional modeling of required transitions in a 1.5˚C world. Most analyses focus on large-scale supply-side and carbon management options (with small or no direct consumer benefit) and with little observable innovation and market dynamics (and hence little progress in market uptake). Conversely, there are numerous trends suggesting rapid innovation and development of end-use innovations that offer direct consumer benefits via new business models (i.e. disruptive innovations). Wilson discussed altogether some 20 examples of potentially disruptive consumer innovations. He summarized them under three main commonalities: 1) move from <u>ownership</u> to <u>usership</u> (end-use service no longer provided by devices owned by consumers and used rarely); 2) emergence of a sharing economy; 3) trends away from atomized to interconnected systems. Wilson observed that a majority of the disruptive innovation examples he discussed are already commercial and are growing rapidly. He concluded by referring to the recent Low Energy Demand scenario that provides a first order quantification of many of these disruptive consumer innovations, leading to drastic reductions in final energy use (while increasing activities and human welfare) that enables the 1.5 ˚C target to be met without relying on unproven negative emissions technologies ($CO_2$ removal from the atmosphere by technological means).

***Keii Gi*** presented a new conceptual framework for linking time budgets to energy services and corresponding energy demand with an application to passenger transport in Japan. In the conceptual framing, changing time budgets lead to changes in human activities, which are provided by alternative configurations of service provisions leading to energy demand. Gi illustrated the concept through an application of passenger transport in Japan. Within the travel time budget, different trip purposes are linked to various trip purposes associated with various occupations. Also included are demographic and geographical variables (age, gender, location by settlement type). Altogether 160 representative combinations of variables that represent user heterogeneity are considered. The model is then used to explore alternative scenarios to 2050. For the time being, the model and scenario simulations do not consider yet technological and behavioral changes (such as shared mobility, or electric vehicles). Gi also identified important areas for future research in this promising field.

***Halina Brown*** returned to the discussion of energy demand linked to lifestyles, with a focus on the residential building sector, one of the major contributors to global greenhouse gas emissions. Drawing on the US and Scandinavian experience, she focused on the persistent trend toward ever larger homes in low density locations (suburbs and exurbs), arguing that the approaches that focus on efficiency or sufficiency concepts may be too limited to counter that trend. Instead she argues for an economic approach that explicitly recognizes residential dwellings as economic asset in addition to providing housing functions. Not only home owners benefit financially from large houses, but also municipalities dependent on tax revenues, and benefits accrue also to mortgage lenders and realtors, and construction and home furnishing industries. In order to reverse the trend toward larger and larger dwellings policies must focus on these core drivers and actors. According to Brown, that means that the prevalent model of land and home ownership by families must be subjected to scrutiny, and alternatives be considered, such a cooperatives, public land trusts and others.

## MAIN THEMES AND INSIGHTS FROM WORKSHOP

This section summarizes the main themes and insights from the presentations and discussion sessions at the workshop. Reference to presentations, statements and discussions are attributed [*with names shown in italicized brackets*].

### *1. BIG PICTURE*

X. ***There is enormous potential to transform energy services and reduce emissions***. System modelling, policy analyses, and scenario studies consistently demonstrate abundant energy-savings opportunities throughout society and the economy [*Laitner, Roy, Lutzenhiser*]. Digitalization, big data analytics, and business-model innovation are among the trends opening up new possibilities to deliver useful services with dramatically lower energy intensity [*Wilson*].

X. ***New forms of energy-service provision are commercially proven in real-world markets.*** Sectorial analyses, market studies, and 'bottom-up' case-by-case analyses show the commercial viability and attractiveness to consumers of new business models and technological innovations for delivering energy services. Examples include on-demand shared urban mobility [*Kaupilla*], smart homes and grids [*Shimoda*], and integrative design of homes and commercial buildings [*Urge-Vorsatz*].

X. ***Energy is consumed to provide services that meet human needs***. Energy demand and energy services are intermediate to the ultimate purpose of providing for human needs. The traditional focus of energy and scenario studies on energy commodities (primary and secondary energy) and products (final energy) defined at the level of commercial market transactions (producer-to-producer, producer-to-consumer) miss the most important part of the energy system (end-use transformations and energy service provision) where also the largest efficiency gains can be harvested through changing technologies and user behavior. An energy service lens of analysis is both feasible as well as needed for any analysis of larger-scale systems transformations with data availability *[in transport, industry, and buildings, cf. Kauppila, Roy, Urge-Vorsatz*] and commensurability issues *[via exergy analysis, cf. Grubler]* increasingly resolved in analysis and modelling. At the same time, it is important to recognize that energy services (like thermal comfort, mobility, communication, etc.) are in themselves also intermediaries for human welfare. Wellbeing, welfare, and decent living all provide important frameworks for linking energy demand to needs satisfaction and so broader sustainable development agendas [*Steinberger*, *Rao*]. This ethical, human-centered perspective on energy demand also allows important issues of equity, accessibility, and distributional impacts to be opened up for analysis and policy intervention.

## *2. UNDERSTANDING ENERGY DEMAND*

X. ***There is no single integrative model of energy demand***. Technical, economic and social-scientific analysis of energy demand ranges in approach, theory, analytical framework, data and methods [*Lutzenhiser*]. Different approaches pose and answer questions at varying scales and complexity and with varying degrees of uncertainty [*Moezzi*]. Hierarchical frameworks which formalize connections between scales - from individuals up to systems - are useful for organizing research on energy demand [*Creutzig*, *Steinberger*].

X. ***Energy demand is highly heterogeneous***. Variation between households, firms and other users is often extremely wide, and is one reason why analytical models have large unexplained residuals [*Moezzi, Lutzenhiser, Creutzig*]. Knowing whether heterogeneity is important depends on analytical aims and policy questions. As examples, heterogeneity at the micro-scale is important for research on distributional impacts and equity, but conversely, heterogeneity may not need representing if not yielding to bifurcations of aggregate (systems-level) effects.

X. ***Time use is an important new analytical lens on energy demand***. Time use and the value of time helps explain patterns, schedules and plasticity of energy demand [*Shimoda*]. Time use dynamics are also useful for scenario analysis of changing patterns of work, leisure and domestic life with a direct link to various forms of service provision [*Gi*]. “Indirect” time use (an analogue to indirect or embodied energy, e.g. the working time required to pay off an individually owned vehicle) could complement traditional time budget analysis *[Grubler, Laitner].* The value of time may also serve as a useful measure of welfare relating to energy use, allowing for cross-cultural comparisons of energy demand [*Laitner*]. Further research is needed on whether activities and time might be used as proxy measures of wellbeing.

X. ***New metrics are needed to capture the multiple dimensions of energy demand***. Traditional cost and performance metrics fail to describe the potential benefits of energy services, and the decision criteria internalized by consumers [*Laitner*]. Many alternative metrics are available. As examples, different metrics describe cost considerations: upfront, lifecycle, usage-based, subscription-based. Similarly, different metrics describe hedonic wellbeing (in terms of individual utility or happiness) and eudaemonic wellbeing (in terms of social capabilities and development) [*Steinberger, Rao*]. Metrics relevant to the diverse features of energy-service transformation need to be compiled, synthesized and communicated clearly to enable like-for-like comparisons with other strategies.

X. ***Low or zero marginal cost energy services present new challenges for research***. New forms of energy service provision can significantly reduce costs on a usage basis, i.e., cost per unit of energy service delivered. This poses important challenges for analytical approaches assuming price-elastic demand and positive impacts of income growth on wellbeing. It also raises important questions about sufficiency (demand saturation) and rebound (demand expansion). Recent evidence however suggests that rebound effects in middle- to high-income countries trend to be generally smaller than frequently argued

*[Azevedo]*.

X. ***National and regional contexts shape research agendas on energy demand***. Electricity network constraints in Japan have stimulated a concerted research effort on peak demand-management, time of use pricing, negawatt trading, and distributed storage including vehicle-to-grid options. This is one example of how specific local context creates research leadership in specific fields, and emphasizes the importance of mechanisms for exchanging and transferring comparative advantages in knowledge. Countries (Japan post-Fukushima) or regions (Alaska post-Juneau blackouts) which have faced acute disruptions to energy-service infrastructure offer important insights on the plasticity of energy demand in times of crisis.

X. ***Smart, digital, connected, and coordinated systems are important elements of future energy-service provision***. Japan has articulated a vision for Society 5.0, advancing on the hunter gatherer, agricultural, industrial and digital societies seen to-date [*Yamaji*]. This sees data-rich coordination between multiple systems and infrastructures to provide accessible, efficient, and high quality “just-in-time” energy services.

X. ***Dedicated research is needed on the generalizability of insights and analyses***. Like heterogeneity, context-dependence is critical for some research questions, but less so for others. Urban-scale analysis may be generalizable between cities, or may be a function of very particular geographic, socioeconomic or infrastructural features of a single city *[Creutzig].* Understanding the conditions for generalizing between developed and emerging economics is particularly important for technology transfer, knowledge spillover, and cross-cultural learning.

X. ***Macro-level forces and trends are (re)shaping energy demand***. Important landscape-level changes affecting demand include automation, the changing nature of work, demographic transitions, urban development, and rising inequality. These are not commonly factored in to empirical and modelling analysis, but should form important considerations for longer-term scenario assessments [*Gi*].

X. ***Energy-service transformation has important implications for materials, land and other resources***. Energy services are provided by bundles of resources - operational energy, embodied energy, and also materials, land, human ingenuity, financial capital. As the energy intensity of service-provision falls, the environmental and social impacts of the wider associated resource bundle gains importance *[Laitner, Grubler].* Lifecycle assessment, energy and material flow analysis, and other systems approaches are important methods.

## *3. DATA*

X. ***Many new data sources can help understand energy demand***. New data sources with high temporal resolution are becoming available from smart meters (electricity, gas), smart phones (location, speed), online services (financial transactions, search, social media preferences). These can be harnessed to better understand and model user behavior and resulting energy demand [*Shimoda*]. Geospecific data can also be generated and validated by users through wikis or open-source platforms [*van Ruijven*]. Accessing and using new data sources poses significant challenges for privacy, protection, and consumer rights. These important debates are playing out differently across the world.

X. ***Systematic data collection is needed for non-observables affecting energy demand***. Behavioral, psychological and sociological variables influencing energy demand are often not directly observable. Longitudinal, standardized, cross-national surveys would significantly support efforts to understand energy demand [*Steg*], serving as a social-science analogue to the global satellite monitoring which has transformed understanding of climate science. Anonymized links between survey responses and revealed preference data from energy bills, smart meters, or other sources should be made wherever possible and subject to data protection [*Shimoda*].

X. ***A global data observatory can help share information on market diffusion and best practice***. New forms of energy service-provision are being tried and tested by firms all over the world. Data on market shares, diffusion activity, user acceptance, and supportive regulatory frameworks is very patchy. A global observatory designed to collect and share market intelligence and best practices can help transfer knowledge among innovators and regulators *[Wilson].*

## *4. METHODS & ANALYSIS*

X. ***Demand-side change can be formally analyzed and modelled***. Techno-economic modelling has shied away from endogenous representations of energy demand as user behavior is framed as too complex, unpredictable or unquantifiable [*Moezzi*]. However, systematic and generalizable explanations of user behavior, supported by a growing evidence base, are available to support formal analysis and modelling efforts [*Steg*].

X. ***City-scale analysis of energy-service provision helps address implementation challenges***. Urban or regional (subnational) analysis matches the scale at which new energy services and associated infrastructures are implemented and managed. Municipal authorities are increasingly important innovation actors, often linked to ambitious emission-reduction goals in response to weak national policy frameworks *[Creutzig]*.

X. ***Micro-level analysis can be integrated up to the urban scale for policy analysis***. Data and modelling tools specify individual or household-level drivers of energy demand. New simulation techniques including agent-based modelling are opening up possibilities to nest micro-level analysis within urban-scale assessment frameworks [*Shimoda*, *Kaupilla*]. This ensures policy-relevant insight for city managers and planners. City-scale data on traffic, transit, infrastructure usage, electricity distribution networks, and building stock characteristics provide constraints and validation opportunities for scaling up micro-level analysis.

X. ***Storytelling is an important method for both communicating and acknowledging variation in energy service-provision***. Stories are embedded within daily lives. Narrative is an important lens through which people see and interpret their own patterns of energy service *consumption [Steg, Wilson].* Telling compelling stories helps makes energy-demand research salient and impactful. Different stories can be told from the same research to acknowledge variation in the targeted audience.

X. ***Methodological pluralism in energy-demand research invites synthesis and comparative evaluation***. There are a very wide range of methods used to analyze energy demand, from quantitative systems models to longitudinal ethnographic studies *[Lutzenhiser]*. This reflects the wide range of disciplines involved. Methodological advancements should emphasize integration, hard and soft linking, triangulation, and comparative analysis of insights from contrasting methods.

### *5. MODELLING*

X. ***Greater interaction on energy-demand analysis is needed between sectorial and system modelers***. Integrated systems modelling is influential in global climate change and sustainable development debates, but lacks detailed resolution of energy demand. Sectorial models and analysis resolve energy demand and user behavior in greater detail and can be more readily tested against observations *[Urge-Vorsatz].* However, sectorial modelers are different communities of researchers, with the exception of transport in which there is greater interaction and cross-validation of within sectorial models and between sectorial models and global systems models *[Kauppila].* This should be deepened and extended to other end-use sectors, building on the extensive knowledge base and expertise of sectorial analysis and models.

X. ***Agent-based modelling is useful for specific types of research question***. Agent-based approaches explicitly represent end-user heterogeneity in preferences, choices, behavior, and social interactions, but with a trade-off in their increased computational complexity, data uncertainties (in parameterizing discrete agents), and structural uncertainties (in defining agent-interaction rules). Agent-based modelling is therefore useful in specific conditions when heterogeneity is not meaningfully aggregated at the systems level into mean or representative behavior and above all, in all those cases where agent interactions strongly influence systems outcomes *[Grubler].*

X. ***There is enormous scope for global system models to improve their resolution of energy demand***. Exogenous or highly-simplified (mean representative agent) representations of energy demand characterize global systems modelling of climate policy *[van Ruijven].* Developing more behaviorally-realistic representations of consumer preferences and heterogeneity is an active research field. Efforts should be redoubled, and effective innovations should be diffused more rapidly through the model stock.

X. ***Global scenarios and modelling analysis should explore energy-service transformations***. A slew of model inter-comparison projects (MIPs) involving more than a dozen global models and generating more than a hundred scenarios were synthesized in the IPCC's most recent assessment report. Few, if any, systematically explored energy demand. A comprehensive scenario framework on energy-service transformation should be implemented to guide global modelling efforts and ensure comparability of results *[Akimoto, Riahi]*.

## NEXT STEPS & COLLABORATIVE OPPORTUNITIES

The discussion at the workshop contributed to the emergence of a new, highly interdisciplinary research community. All participants found the discussions most fruitful with numerous novel perspectives opened up. There was a wide consensus on the desirability of joining forces to create a more lasting community effort centered specifically around the energy demand perspective as the most critical intersection for climate policy and SDG analyses. The following thematic areas and specific activities were suggested as a follow up to the most successful Nara Workshop:

- Use the 'rethinking energy demand' platform to build a collaborative network of demand-side scientists, analysts, and modelers (at both sectorial and systems level).

- Develop proposals for regional or city-scale hubs for collaboration on specific implementation challenges in particular in the domains of transport and buildings energy use (including policy and planning-defined problems).

- Develop collaborative relationships between research communities and service-providers from tech, utility, infrastructure, building, and financial sectors (e.g., to access data from smartphones, bank purchases, smart meters).

- Develop incremental research agendas, rather than grand visions, to ensure proposals stay aligned with funding agency conservatism.

The workshop participants, as well as IIASA and RITE plan to follow up these most useful suggestions with the objective of forging a ‘rethinking demand’ forum in which regular exchanges involving different science communities, policy makers, industry as well as agents of civil society can take place to move from improved scientific understanding to actions that leverage the demand-side options for meeting multiple sustainable development objectives.

## Appendix I. List of Participants of Nara Workshop

| | | | | |
|---|---|---|---|---|
| Keigo | Akimoto | RITE | Japan | |
| Ines | Azevedo | Carnegie Mellon Univ. | USA | * |
| Halina | Brown | Clark Univ, | USA | * |
| Felix | Creutzig | Mercator Inst. | Germany | * |
| Keii | Gi | RITE | Japan | |
| Arnulf | Grubler | IIASA | Austria | |
| Ayami | Hayashi | RITE | Japan | |
| Jari | Kauppila | ITF/OECD | France/Finland | |
| Skip | Laitner | AEES | USA | |
| Loren | Lutzenhiser | Portland State | USA | * |
| Sebinia | Matthew | Global Climate Capital | USA/Myanmar | |
| Mithra | Moezzi | Purdue Univ | USA | |
| Takahiro | Nagata | RITE | Japan | |
| Yuko | Nakano | RITE | Japan | |
| Sumie | Nakayama | J Power | Japan | |
| Narasimha | Rao | IIASA | Austria/USA | |
| Keywan | Riahi | IIASA | Austria | |
| Joyashree | Roy | Jadavpur Univ | India | |
| Fuminori | Sano | RITE | Japan | |
| Yoshiyuki | Shimoda | Osaka Univ. | Japan | |
| Linda | Steg | Delft Univ/ | Netherlands | |
| Julia | Steinberger | Leeds | UK | * |
| Taishi | Sugiyama | Canon Institute | Japan | |
| Diana | Urge-Vorsatz | Univ. Budapest/IPCC WGIII Vice-Chair | Hungary | |
| Bas(tien) | van Ruijven | IIASA | Austria/Netherlands | |
| Charlie | Wilson | UEA | UK | |
| Kenji | Yamaji | RITE | Japan | |
| Kiyomi | Yamamoto | RITE | Japan | |

* participation via teleconference/Skype

## Appendix II. Agenda of Nara Workshop

### Tuesday, 25 September

Note: * denotes remote presentation via Skype

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|---|---|
| 09:30-10.00 | **Session I: Opening and Welcome**<br>*Arnulf Grubler and Keigo Akimoto*<br><br>Reframing Energy for the 21st Century:<br>Understanding the Imperative of Energy Efficiency<br>*Skip Laitner* |
| 10.00-12:00 | **Session II: Multiple Science Perspectives on Demand**<br>**Moderator**: *Arnulf Grubler*<br><br>Kick-off statements (10 minutes each):<br>• *Loren Lutzenhiser* (sociology of energy demand) *<br>• *Ines Azevedo* (insights from economics) *<br>• *Narasimha Rao* (decent living standards)<br>• *Linda Steg* (lessons from psychology)<br><br>General discussion |
| 12:00-13:00 | *Lunch Break* |
| 13:00-16:00 | **Session III: Multiple scales, Perspectives from the South and the Urban Scale**<br>**Moderator**: *Keywan Riahi*<br><br>Kick-off statements (10 minutes each):<br>• *Joyashree Roy* (framing and introduction, IPCC AR6 and industry)<br>• *Felix Creutzig* (demand concepts in IPCC AR6 and for urban settings) *<br>• *Bas van Ruijven* (demand modeling at urban scales)<br>• *Julia Steinberger* (linkages to welfare) *<br><br>General discussion |
| 16:00-17:30 | **Reflections on Sessions II & III**<br>**Moderator**: *Skip Laitner*<br><br>General discussion |

## Wednesday, 26 September

| | |
|---|---|
| 09:30-12:00 | **Session IV: Energy Demand, Efficiency, and Conservation: What have we learned?**<br>**Moderator**: *Narasimha Rao*<br><br>Kick-off statements (10 minutes each):<br>• *Skip Laitner* (intro and summary of issues/findings)<br>• *Mithra Moezzi* (empirics: AREBA surveys)<br>• *Yoshiyuki Shimoda* (urban buildings)<br>• *Kenji Yamaji* (Japan Society 5.0 concept)<br><br>General discussion |
| 12:00-14:00 | *Lunch Break and tour of Todai-ji Temple* |
| 14:00-16:30 | **Plenary Session V: Sectorial Perspectives (Transport, Buildings, Digitalization)**<br>**Moderator**: *Taishi Sugiyama*<br><br>Kick-off statements (10 minutes each):<br>• *Jari Kauppila* (transport)<br>• *Diana Urge-Vorsatz* (buildings)<br>• *Charlie Wilson* (end-use transformations)<br>• *Keii Gi* (time budgets and transport)<br>• *Halina Brown* (residential floorspace demand) *<br><br>General discussion |
| 16:30-17:30 | **Reflections on Sessions IV & V**<br>**Moderator:** *Joyashree Roy*<br><br>General discussion |

## Thursday, 27 September

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|---|---|
| 09:00-12:00 | Informal discussions and exploration of research and collaboration possibilities (IPCC Plenary participants depart to South Korea)<br><br>**Moderators**: *Arnulf Grubler and Charlie Wilson*<br>General discussion |
| 12:00-13:00 | *Lunch Break followed by Excursion to Horyuji Temple* |

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