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Assessing sustainable regional energy systems: a case study of Kansai, Japan

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Abstract

Understanding and assessing sustainable energy systems at various scales are a complex proposition. The task must take into account more than just the technical realm of energy, seeking to model the dynamic interplay between environmental, social and economic systems as they influence and are influenced by the technical energy system. Energy systems are often considered at a coarse level – at the scale of a nation – or at a relatively fine scale – at the technology end. However, scales of governance, institutions and the regional territory of electricity providers (for example) can make for useful scales of analysis. The current paper describes some of the important elements for undertaking co-design and assessment of energy systems for more resilient, desirable and sustainable energy futures. Key steps are described, among which is a novel model of the technical energy system that incorporates local environmental and planetary limitations. The initial model considerations and an analysis of enablers and barriers, as well as the interactions with the scenario development are presented.

Keywords: sustainability; energy; design; participatory; model

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Nomenclature

anthropospheric	of or pertaining to the sphere of human history across the anthropocene
co-design	participatory design processes involving stakeholders
futurability	a term coined in Japan meaning as a translation of the ideographs for 'future' and 'potentiality,' expresses the wide range of possibility in future development

1. Introduction

Energy resources exploration and development have been a key feature of humanity in the Anthropocene, which accelerated human dominance in the Earth system[1]. To date, many recognized global environmental problems, such as global warming, loss of biodiversity, and mineral resources depletion, could ultimately be attributed to energy acquisition for humanity and its adverse effects, while energy depletion has long been a threat to humanity. The aftermath of the 2011 Great East Japan Earthquake appeared to promote a movement towards denuclearisation, and much effort is being currently devoted to exploration and development of alternative energy resources, to sensible use of any available energies[2], and to scenario development for transitional processes towards future-oriented energy system in the key elements of sustainable societies elaborated as: a low carbon society, a resource-circulating society, and a society in harmony with the environment.

Energy systems are one of the key focus points for reducing greenhouse gas emissions and providing quality of life in the move towards sustainable societies. Sustainable energy systems are often considered at the level of the nation or at the scale of generating technologies – in the mid-range these considerations are less common. However, in a country like Japan, with multiple, minimally-interconnected grids, it is possible to consider regions within the country (such as the Kansai area) as pseudo-independent energy systems.

Fundamentally, modern energy systems are broad, multi-layered, nested hierarchical systems with components and impacts spread across multiple spacio-temporal scales. The current design of energy systems is generally done at the component level in an uneven manner, with a highly techno-centric focus and minimal input from society at large (except by proxy through governments). (Three main exceptions: environmental impact assessment of large infrastructure; compensation or negotiation of land rights; consumer surveys on new user products). Even the modeling of "sustainable energy futures" is undertaken by academics[3], governments or industry consultants with little input from the general public.

It is noted that energy system design is currently far from co-creative – the design of current energy systems is the work of technical experts working within a set of technical and regulatory guidelines in order to plan a workable, profitable, preferably low-environmental impact energy system. Electricity generators, fuel suppliers and governments work as both adversaries and advocates in the process, but little citizen input is considered across the entire life cycle of the system. This is despite energy systems impacting significantly on the daily lives and prosperity of the community. Moreover, considering the fact that in a country such as Japan, the residential sector consumes approximately equal electricity as each of the commercial and residential sectors[4], it is surprising that the voice of this potentially powerful group of actors is given such little attention in the planning of future energy systems.

Difficulties in designing futurable energy systems stem from not only the component of stakeholders involvement, but also the fact that critical end-points for any energy system vary with spacio-temporal scales of interest. For example, the recently-emerged Planetary Boundaries framework emphasizes significant interactions among geophysical boundaries in the context of 'a safe operating space for humanity'[5], but there are no explicit descriptions on natural catastrophes such as earthquakes or on energy dimensions. Energy issues are not simply about geophysical limits, but about social justice. Thus, energy systems, we are to design, must be resilient to natural catastrophes and be harmonious with societal transformation.

To design a desirable energy system, the aspirations of citizens must be combined with practical, technical understanding of system components and interlinkaged. To enable such future energy systems to be realized, policy, economic and cultural-behavioral tools must be devised to provide an environment for transition to occur.

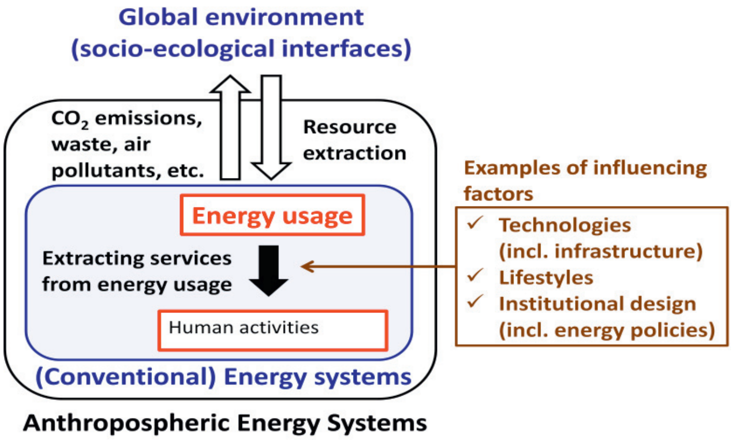

Fig. 1 Anthropospheric energy systems.

This paper describes the theoretical background, model structure and initial results of a project seeking to develop tools and procedures for co-designing and assessing anthropospheric energy systems (as described in Fig. 1). The modelling elements presented here will be used in a current study to investigate the design of sustainable future scenarios for Kansai and Japan, with a focus on the energy system[6]. The broader work is ongoing, and this paper aims to outline the underlying model and initial results, with analysis of the barriers and enablers for such a study.

The model is described in regards to its general architecture, key parameters and the usage within the broader study. Some key novelties of this model are: (a) its incorporation of calculated "sustainability limits" to determine whether the carrying capacity of a region is being approached or breached[7]; (b) incorporation of raw materials draw and industrial production capacity as limitations on the energy system; (c) the modelling of interactions between the regional, national and global systems.

2. Methodology

This ongoing research aims to review and design a series of interchangeable energy system components that can be combined into technically feasible energy systems at multiple scales. These systems will be the basis for co-design workshops with local stakeholders for tailoring to context and cultural acceptability. By demonstrating co-design of futurable energy systems in a few countries, the project will find and implement solutions to socio-ecological constraints of energy.

In this research, we examine four major realms of energy systems, seek to overcome the limitations of previous models, which remain highly technocentric:

i) **Technological** – energy extraction, generation, transmission, utilization – using current system as a baseline, but mainly looking to designs of the future;
ii) **Communities and culture** – social needs and preferences for energy generation and utilization; changing demographics and changing behavior for the future;
iii) **Governance and Institutional systems** – current regulatory environment and the policies and structures to drive a sustainable future energy system; corporate, economic and regulatory institutions and required community institutions that facilitate or promote or prevent energy system change;
iv) **Resources and environment** – the limitations of the local and global environment to provide the required ecosystem services for future energy systems;

Learnings from each of these interconnected realms must be integrated to develop futurable anthropospheric energy systems. Moreover, to develop resilient energy systems, these realms must be tested against alternative "shocks" and paradigm shifts from simulated external forces. The initial model architecture has been built around this framework, but incorporation of many of the variables is still at an early stage.

The technical model and research into the other three "realms" feed into a process outlined in Fig. 2 with the co-design "visioning workshops" at the core. To support the assessment of future envisioned scenarios, a high degree of flexibility is required, with a simplified representation of local city and prefectural economies and their connection to the broader regional (Kansai) and national (Japanese) economy. Policy decisions and cultural shifts assumed to occur in the scenario are able to be modelled by the addition of moderating parameters in a transparent manner, so as to avoid hiding any underlying assumptions.

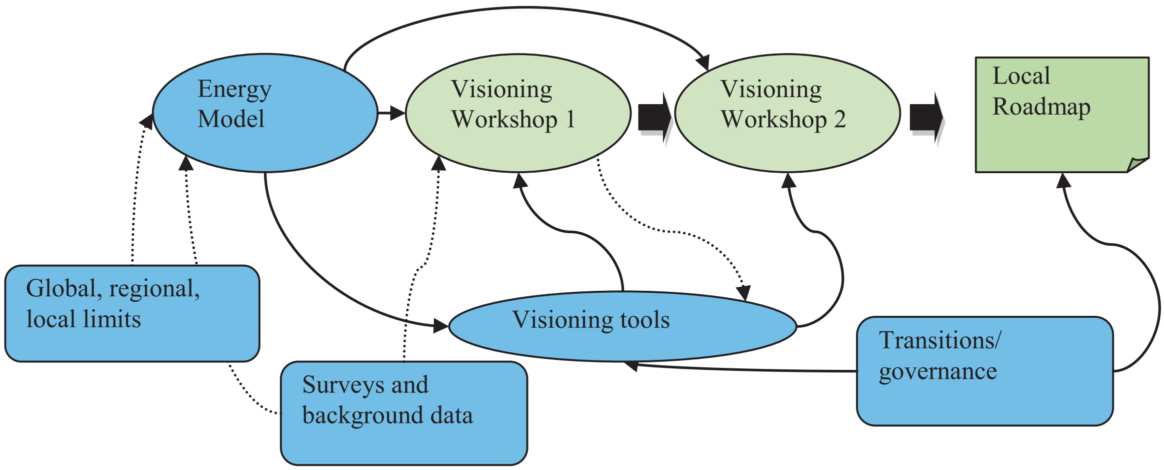

Fig. 2 Integration and scale-up of project outcomes.

The methods proposed to drive the workshops must fit the nature of the problem at hand. In order to co-design futurable anthropospheric energy systems, an interactive process is required. Various techniques could be considered for this process, but ultimately workshop techniques are one of the most valuable with regards to co-design, as they enable input from various stakeholders directly. Techniques such as participatory technology assessment[8], SUSOP® (Sustainable Operations) workshop techniques[9] or other processes could be utilized[10]. Ultimately it is important to have some degree of structure to the workshop, using established techniques and appropriate human resources. Standard participatory process challenges, such as the selection of participants to be representative and relevant, the balance between providing guiding principles or vision elements and giving free reign to participants' opinions, must be considered. Particularly in the case of energy, there is the possibility of limiting the views and opinions to sustainable options, or allowing participants' initial visions to include even elements which may be fundamentally unsustainable (e.g. large, oil-consuming vehicles in a situation of limited and high-priced oil).

The initial case study is based in Kansai, but in order to gain broader understanding, the project aims to expand to up to 30 or more domestic sites. The results of co-design workshops at each of these sites then needs to be scaled-up and fed into a national "road map" that takes into account the ideas of a broad and representative range of citizens. An outline of the process is shown in Fig. 3. In addition to local community stakeholders, a realistic vision for transition to a sustainable future will also rely on interaction with institutional and government stakeholders.

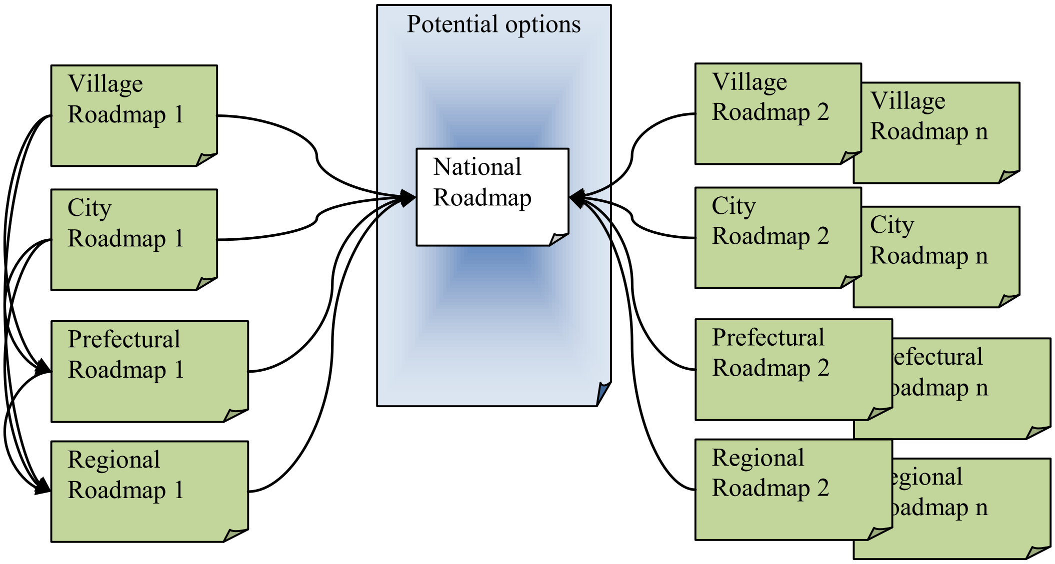

Fig. 3 Integration and scale-up of project outcomes.

2.1. Model general parameters

The general parameters required by the model are defined in this section. The technical modeling methodology used here models the energy-related components of regional metabolism of Kansai as shown in Fig. 1. This model will then be used to investigate the impacts of alternative future energy scenarios on sustainability of Kansai. Some key model parameters are shown in Table 1.

In order to create a model that could support the assessment of future envisioned scenarios, a high degree of flexibility was required, with a simplified representation of the local economy and its connection to the broader regional (Kansai) and national (Japanese) economy. Policy decisions and cultural shifts assumed to occur in the scenario are able to be modelled by the addition of moderating parameters in a transparent manner, so as to avoid hiding any underlying assumptions.

Table 1. Major parameters for the model.

Category	Input	Output
Environmental	Land use (by category)	Greenhouse gas emissions (total; per capita)
	Climatic data (temperature; rainfall; insolation; wind speed)	Other emissions and solid waste
	Local resource availability	Critical material inputs
Economic	Household spending data	Energy infrastructure investment costs
	Industrial composition (local)	Fuel / operational costs
	Taxation data (potential energy and resource spend)	Change in cost of energy services
Other	Demographics	Vulnerabilities and carrying capacity breaches
	Historical electricity load curve	
	Generation fleet statistics (local and regional) (age; type; capacity;)	
	Transportation – infrastructure; demand;	

2.2. Carrying capacity, limits and vulnerabilities

One of the key questions of sustainability, and an important novelty of this model, is the identification of carrying capacity limits for economic and environmental criteria. It has been shown that it is important to attempt to quantify and measure progress against such limits in order to provide a more accurate, realistic picture of the sustainability of any human project[7]. In the current study, identified critical issues affecting the ability of the system to be self-sustaining and sustainable are tested automatically against the outputs of the model. This has rarely been attempted apart from the economic dimension – whether or not costs exceed income.

This category of outputs from the model emphasizes the importance of the physical, environmental and economic interrelationship of the local area, the region, nation and ultimately the world. For Kansai to be sustainable and resilient, it must reinforce local self-reliance as well as forging resilient interconnections with the outside[2].

Technical energy models are fairly common, but there are none that effectively incorporate planetary boundaries and local sustainability limitations[7]. Thus, it is essential to build or adapt an energy model for the purpose of this study. Furthermore, energy modelling can be used either "online" during the workshop process – as an interactive tool to help understanding – or "offline" to assess and analyze the outcomes of the workshops and feed into the subsequent workshops. The efficacy of these approaches and models needs to be assessed.

2.3. Case study site selection

The initial approach being taken to case study site selection considered that there was a benefit to select representative villages, towns, cities and prefectures within each electricity company region – for Kansai, the Kansai Electric Power Company region, in which it has a near monopoly on supply. Preferentially, it was considered that towns would be selected from a variety of past or current energy and environment-related schemes within Japan, including:

- Eco-towns
- Eco-cities
- Eco-villages
- Biomass-towns
- Future cities
- Smart cities

These schemes have been developed by the Japanese government or NGO's, aiming to improve community environmental performance. The preference for these towns was based on the assumption that background data might be more readily available and that the energy consciousness might be greater, thereby facilitating the co-design process. Other energy-specific towns of interest, such as Yubari (which went bankrupt in an effort to recover from a loss of coal mining income) or Fukushima prefecture (due to the Fukushima nuclear accident) could be included. Other approaches to site selection are also being considered using demographics, considerations of factors of "lock-in"[11] and other desirable characteristics.

Considering "lock-in", it is seen as being particularly relevant that the demand and supply ends of the energy system may move at different speeds, and react to different conditions and consumer preferences. The reconstruction of areas affected by the March 11, 2011, disaster in Japan in comparison with shifts in technology choice and decentralized energy generation elsewhere in the country, will be one significant case study in this area. This should have implications for whether the change in consumer preference (towards non-nuclear technology) is translated into structural change, and whether the elimination of all existing demand-side infrastructure (as in the disaster-affected areas) would impact the supply and demand-side technology mix in those areas more than elsewhere.

2.4. Scenarios and co-design

The scenarios to be tested with this model are derived from an interactive back-casting workshop that is undertaken with key stakeholders and the project team. The workshop is held over two days, using a structured process of back-casting from long term visions of a sustainable or unsustainable city, region or nation, in order to trace back potential pathways to the current time. Technical feasibility is a key factor; therefore the underlying energy model is of vital importance to this process. Policy or technology initiatives can then be implemented to mitigate or enhance steps in the causal chain, so as to avoid the unsustainable futures.

The co-design process is reliant on a structured-facilitation process, guided by the input of experts but without driving a single set outcome. The balance of participants in the workshops must be determined in order to give sufficient coverage of alternative perspectives and the facilitators must be able to direct the process towards consensus whilst enabling the silent participants to have equal say to the more vocal stakeholders. Moreover, the balance of power relationships, hierarchies and cultural deference to the position in society of a stakeholder rather than their opinion, must be negated where possible.

Items which also need to be considered, but will not necessarily fall within either general technical scenarios or, perhaps, the realm of general stakeholders, include:

- Radical behavioral change – e.g. daylight operation
- Industrial and commercial sector – including industrial sector restructure
- Demographic shifts – urbanization, ageing population
- Smart grids / smart cities
- Resource circulation and industrial ecology – linked material-energy cycles
- National / International policy
- Game-changing technologies or resources: critical minerals, methane hydrates, hydrogen, electric vehicles
- Radical supra-national energy collaboration: HVDC connection to Korea, sub-sea oil and gas developments Japan-China-Korea in the zone of “contested” islands

These additional scenarios should be tested by the model, and ideally have stakeholder involvement in identifying the most desirable options among them.

3. Results

At the time of publishing, the results of the technical modeling are still incomplete, however there are still a number of important learnings from the research so far that will be described here.

3.1. Barriers

In order to effectively integrate the four realms of energy systems into a model and a process for co-designing futurable energy systems, a number of key theoretical-practical elements must be bridged. Firstly, the level of uniqueness in a local energy scenario is somewhat restricted by national/state policies, institutions, and the interconnectedness of the multi-scale energy system. Recognizing and appropriately incorporating the bi-directional interactions between national scenarios and local roadmaps are therefore important. Secondly, grasping the uniqueness of a single workshop and site (both physical, temporal and social) in contrast with the relative conformity of technological systems is vital. Extracting unique energy systems futures given the physical and community characteristics of a region is challenging, and must be based on well-guided use of a relatively minimal set of “building block” energy system elements. Scale-up, on the other hand, is also a large challenge, as typically within even the technological system the whole is more than the sum of the individual parts. Thus, scale-up across multiple scales and realms will pose an even greater challenge, but one that should produce very useful contributions to knowledge.

3.2. Enablers

One of the most important enabling factors in examining such multi-disciplinary energy system design, is the focus that energy has been given post-Fukushima – both with regards to the preferences for energy generation and the importance of energy savings measures[12]. Moreover, as mentioned earlier, the availability of numerous sites which are currently or have previously been involved in initiatives on energy and environment will assist the project.

4. Conclusions

This paper has broadly described a model for the co-design and assessment of sustainable energy systems (or futurable anthropospheric energy systems). Fundamentally, modern energy systems are broad, multi-layered, nested hierarchical systems with components and impacts spread across multiple spacio-temporal scales. The current design of energy systems is generally done in with highly techno-centric focus and minimal input from society.

However, to design a desirable energy system, the aspirations of citizens must be combined with practical, technical understanding of system components and interlinkaged. To enable such future energy systems to be realized, policy, economic and cultural-behavioral tools must be devised to provide an environment for transition to occur. The project and model described in this paper are being developed specifically to enable participatory design of energy systems with community and institutional stakeholders.

The model described in this paper is currently being applied to future scenarios envisioned for the Kansai region, Japan. The model itself will be unique in its scope, including local environmental limitations and resource constraints otherwise are not widely considered.

Many barriers exist to the development of such a project and model, with the key ones being the limitations of scale-up and integration across various scales – exacerbated by the multi-realm modelling that is being attempted. Nonetheless, the results of the project will provide significant knowledge on energy system design theory and the “ambient” energy awareness is a key factor that will enable its success more broadly.

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