ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Procedia Environmental Sciences 20 (2014) 97 – 105
Procedia
Environmental Sciences

4th International Conference on Sustainable Future for Human Security, SustaiN 2013

Developing a Tool to Analyze Climate Co-benefits of the Urban Energy System

Hooman Farzaneh[a,b,]*, Aki Suwa[a], Christopher N.H. Dolla[a] and Jose Antonio Puppim de Oliveira[a]

[a]*United Nations University, Institute of Advanced Studies, Pacifico, Yokohama, Japan*
[b]*National Institute for Environmental Studies (NIES), Tsukuba, Japan*

Abstract

The world rapidly urbanizing, and a majority of the global population will experience climate change in cities. Climate change will exacerbate the existing urban environmental management challenges in cities, in most cases making existing problems much worse. At the same time, cities are responsible for significant global greenhouse gas emissions, and given current demographic trends, this level will likely only increase over time. These challenges highlight the need for cities to rethink how assets are deployed and infrastructure investments are prioritized as well as how climate will affect long-term growth and development plans. Since responding to the complex challenges of climate change mitigation and adaptation requires a knowledge-based approach, the present research is based on providing a tool for assessing the climate co-benefits of improving performance of the energy system at the city scale. This research aims to assess the expected co-benefits arising from different sub-sectors of the city-wide energy system. It will also address in some detail the role of executive policy targets support to reduce the greenhouse gas (GHG) emission and air pollution in cities. The tool is initially tested using real data for the city of Yokohama, Japan and estimates that the city's envisioned Smart City Project could achieve GHG reduction of about 1.68Mt/yr.

Selection and peer-review under responsibility of the SustaiN conference committee and supported by Kyoto University; (RISH), (OPIR), (GCOE-ARS) and (GSS) as co-hosts

Keywords: *Climate co-benefits, energy system,eEfficiency, smart grid, renewable energy*

* Corresponding author. Tel.: +81-90-9697-1354; fax: +81-45-221-2302
E-mail address: farzaneh@ias.unu.edu.

Selection and peer-review under responsibility of the SustaiN conference committee and supported by Kyoto University; (RISH), (OPIR), (GCOE-ARS) and (GSS) as co-hosts
doi:10.1016/j.proenv.2014.03.014

1. Introduction

Over half of the global population already lives in urban settlements and urban areas are projected to absorb almost all the global population growth in the near future. Over the coming decades, the increase in urban population in many developing countries will be overshadowed by population flows to cities [1]. Energy-wise, the world is already predominantly urban. Available consumption-based energy accounts for cities are too limited to allow generalization but, it is highly likely that urban energy use (based on a consumption accounting approach) approximates the urban share in the world GDP, estimated to be some 80% [2]. Of all the major determinants of urban energy use – climate, position in the global economy, consumption patterns, quality of the built environment, urban form and density, and urban energy systems and their integration – only the final three are amenable to policymaking by city administrations, at least partially. Therefore, both in terms of leverage and potentials energy use, climate policy at the urban scale needs to focus above all on demand management with a focus on energy efficient buildings, structuring urban form and density conductive to energy efficient housing forms and to urban energy systems integration.

Systemic characteristics of urban energy use-climate are generally more important determinants of the efficiency of urban energy use than those of individual consumers or of technological artifacts. A common characteristic of sustainable urban energy system options and policies is that they are usually systemic: for example, the increasing integration of urban resource streams, including water, wastes, and energy, which can further improve both resource (e.g., heat) recovery and environmental performance. This view of a more integrated (and often also more decentralized) urban infrastructures also offers possibilities to improve the resilience of urban energy systems to climate change [3, 4].

The objective of this study is to propose a new tool to analyze climate co-benefits of the urban energy system based on its systemic characteristics. The paper seeks to explore: 1) what are the proper methods to pursue the climate co-benefits approach for city-scale energy system and 2) what are the potentials to reduce GHG emission and AP by improving integrated energy efficiency and using low emission technologies in cities. As such, the tool takes a bottom-up approach with an analysis, and aggregation of city-level data has been used as the most efficient assessment method to quantify the climate co-benefits of the city-scale energy system. The paper then takes city-level data from the city Yokohama, Japan into the tool to make an assessment of both the local and global scale emissions in the city before evaluating where savings can be made.

2. Tool Structure

The tool is developed to evaluate climate co-benefits of the urban energy system based on different scenarios of socioeconomic, technological and demographic developments. The tool systematically relates the greenhouse gas (GHG) and air pollution emissions based on the specific energy demand in the residential, commercial and service sectors in cities to the corresponding social, economic and technological factors that affect this demand. The nature and level of the demand for energy are a function of several determining factors, including population growth, number of inhabitants per dwelling, number of electrical appliances used in households, local priorities for the development of certain economic sectors, the evolution of the efficiency of certain types of equipment, penetration of new technologies or energy forms, etc.

An understanding of these determining factors permits the evaluation of the various categories of energy demand for the urban energy system considered. The total energy demand for each end-use category is aggregated into three main "energy consumer" sectors: residential, commercial and service.

Application of the tool is subject to the identification and estimation of the performance function of the urban energy system which is possible by segregating the whole energy system into incremental elements such as end-user, final energy, energy conversion and energy resources. When various energy forms, i.e. electricity, fossil fuels, etc., are competing for a given end-use category of energy demand, this demand is calculated first in terms of useful energy and then converted into final energy, taking into account market penetration and the efficiency of each alternative energy source and using new technologies. Demand for fossil fuels is therefore broken down in terms of coal, gas or oil and the substitution of fossil fuels by alternative "new" energy forms (i.e., solar, wind, etc.) is estimated, due to the importance of the structural changes in the urban energy system that these energy forms may be introduced in the future. Since these substitutions will be essentially determined by policy decisions, they are to be taken into account at the stage of formulating and writing the scenarios of development. The scenarios can be sub-divided into two categories:

- ✓ One related to the socioeconomic system describing the fundamental characteristics of the social and economic evolution of the urban energy system such as lifestyle changes, population growth and GDP growth.
- ✓ The second related to the technological factors affecting the calculation of energy demand, for example, the efficiency and penetration potential of each alternative energy form and new technology such as smart grid.

Following this approach, the planner can make assumptions about the possible evolution of the social, economic, and technological development patterns of the local energy system that can be anticipated from current trends and governmental objectives.

In summary, the tool methodology comprises the following sequence of operations:

(1) Desegregation of the total energy demand of the city into a large number of end-use categories in a coherent manner
(2) Identification of the social, economic and technological parameters which affect each endues category of the energy demand;
(3) Establishing in mathematical terms the relationships which relate energy demand and factors affecting this demand
(4) Estimation of the energy demand related GHG emission and AP from different sub-sectors
(5) Developing (consistent) scenarios (policy interventions) of social, economic and technological development for the given city's energy system;
(6) Evaluation of the climate co-benefits resulting from each scenario; and finally
(7) Selection among all possible scenarios proposed, the "most probable" patterns of development for the city through analyzing CBA and system sustainability

Fig. 1 shows the tool structure. Quantifying co-benefits can be analyzed with tool simulations using the extended range of emission factors in its library. There are also several abstractions in this analysis:

- ✓ The focus is on emissions from fossil fuel combustion in the electricity and non-electricity sectors, and process emissions for all substances as these impact exposures to PM but are also the main source of GHG emissions, and thus the principal driver of both GHG and Local air pollution (CO, NMHC, NO_x and SO_2)
- ✓ The focus is on fine PMs with a diameter of less than 2.5 μm (referred to as PM2.5) which are responsible for deaths from particulates in the ambient air

3. Study area

The case study area is Yokohama city in Kanagawa prefecture. This city lies on partially reclaimed land with an area of 242 ha and a population of 3.7 million that makes it Japan's largest incorporated city [5]. Yokohama features a humid subtropical climate with hot and humid summers and chilly, but not very cold winters. Winter temperatures rarely drop below freezing, while summer can get quite warm due to humidity effects. The city's profile is shown in Table 1.

Table 1. Yokohama city profile

Item	
Total population (Million)	3.7
Number of households	1.2
GDP (billion US $)	11.2
Maximum ambient temp (0C)	32
Maximum solar irradiation (MJ/sqm)	15.7

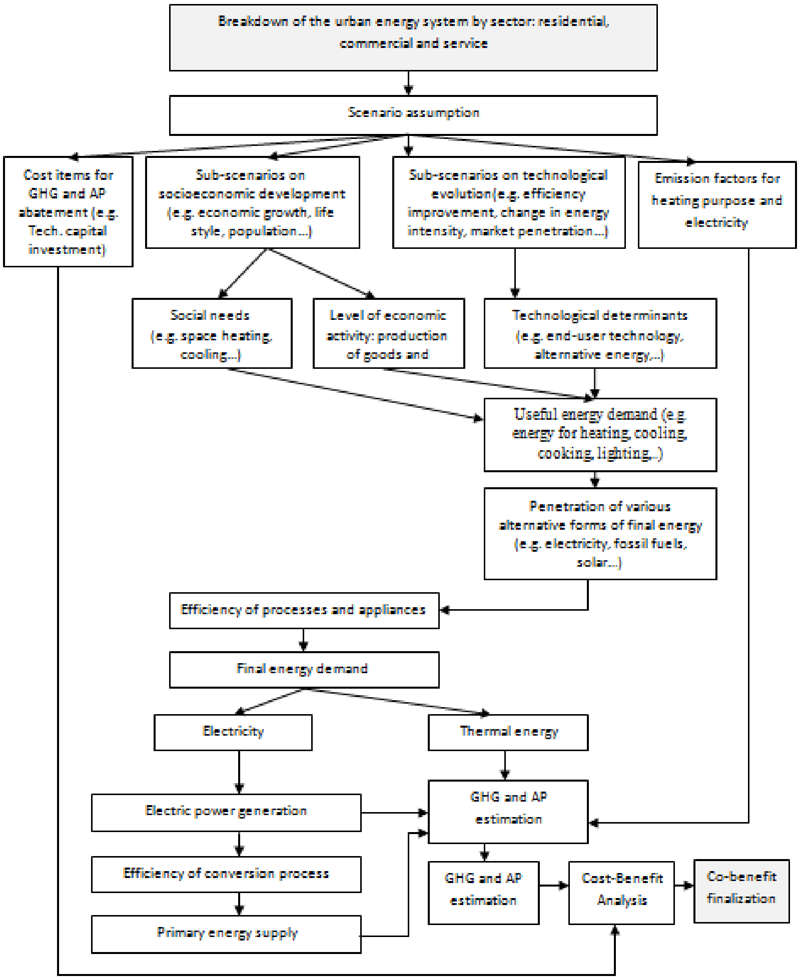

Fig1. The scheme used to project co-benefit in the tool

This city is famous for the utilization of renewable energy such as wind and solar. About 4MW wind power generator is already functioning and about 21 MW solar photovoltaic is installed to help to meet city electricity demand. Besides, about 244 MW of total electricity consumption is supplied by using the hydro power. As one of the largest cities in Japan, Yokohama aims to build the "Next Generation Energy Infrastructure and Social System" that maximizes CO2 reduction in the forefront of innovation by intensive introducing of PV and HEMS (Home Energy Management System) in the near future.

Using Yokohama city as an example, approximately 40% of total energy is consumed in the residential and commercial sectors. This energy use is associated with over 7 million tones of CO2 equivalent (CO2e) emissions in 2010 [6].

4. Scenarios

The GHG and AP reduction potential in this context is defined as the difference value between emissions in the baseline scenario and emissions in the policy intervention scenarios. The details of the scenario definition procedures are stated below.

4.1. Baseline scenario

This study takes into account demographic movements and economic activities in Yokohama city, as they are the most fundamental parameters that have an impact on GHG emission and AP. The calculations for the residential sector are performed taking into account the living conditions of the population, i.e. the place of residence (city local climate conditions), and type of residence (dwelling mode and size). Although the energy demand in commercial and residential sectors are calculated very similarly, the calculations are executed separately due to the fact that the scenario parameters and related equations which characterize their energy consumption are not the same: in the residential sector the determining factors are of demographic nature (population, number of dwellings etc.) whereas in the commercial sector they are related to the business level of activity of this sector. Table 2 shows the basic assumptions which are used to set the baseline scenario.

Table 2. Baseline data for Yokohama city used to construct the baseline [7]

Dwelling groups	Share in total sector (%)	Average area (sqm)
Under 29 sqm	3	28
Between 30 to 49 sqm	8	40
Between 50 to 69 sqm	17	60
Between 70 to 99 sqm	32	85
Between 100 to 149 sqm	30	125
Over 150 sqm	10	200
Commercial Subsectors	Share in total sector (%)	
Hotel (Western style)	2	
Hotel (Japanese style)	3	
Office and Bank	2	
Shop	19	
Theatre and Film	2	
Hospital	2	
Office	17	
Mall	20	
Department Store	10	
Bank	4	
Theatre and Entertainment	2	
Others	2	
Primary School	8	
Junior High School	7	

4.2. Policy intervention scenarios

Climate change intervention, control, or mitigation scenarios are defined to capture measures and policies for reducing GHG emissions and AP with respect to the baseline (or reference) scenario. They contain emission profiles, as well as costs associated with the emissions reduction to quantify the benefits of reduced impacts from climate change. In this study, the policy intervention scenarios are defined by considering two important issues through developing the tool: the identification of overall cost levels of mitigation and the role of technological development in the future.

4.2.1. Scenario I) Alternative energy

According to Yokohama Smart City Project (YSCP), next-generation energy infrastructure which enables the large-scale introduction of renewable energy is planned to establish in order to reduce CO_2 emissions in this city. The target for the end of FY2014 is the introduction of renewable energy with a total capacity of about 27 MW of medium- and large-sized PV systems [8]. This should make the percentage of power generated by residential PV systems out of the final energy consumption by the households in the demonstration area more than 5%. Besides, introducing ground-source heat pump (GSHP) technology in the residential sector can be considered to accelerate the increase in renewable energy equipment in the area. GSHP systems can achieve a higher coefficient of performance than conventional air source heat pump (ASHP) systems because the ground, which functions as the heat source or sink, is at a higher temperature in winter and lower in summer than the air temperature. The other promising opportunity includes solar water heater technology to supply hot water demand through detecting upper-atmospheric weather conditions and the potential of solar irradiation in this city.

4.2.2. Scenario II) Energy efficiency

Accelerating progress to make energy use in the residential and commercial sectors more efficient is indispensable. There is significant scope for adopting more efficient technologies in these sectors. The energy efficiency scenario can be defined as the introduction of end-user technologies which are effective in CO_2 emissions reduction through the provision of following techniques:

- Wall-Mounted-Occupancy-Sensor for lighting (WMOSL) which is detecting movements of people and automatically turn lights on and off
- With LED lighting
- Compact Fluorescent Lighting (CFL)
- High performance windows with low emissivity glazing factor

4.2.3. Scenario III) Scenarios I & II coupled to the Smart Grid

This scenario demonstrates the mechanisms by which the smart grid can contribute to energy efficiency and the integration of renewable generation to provide climate co-benefits to the Yokohama city. These mechanisms can be introduced as follows:

(1) Data monitoring, AIM (Advanced Impedance Monitoring) and system performance diagnostics at the end-user level: The focus of this mechanism is to determine the potential benefits of leveraging the smart grid assets to provide detailed and timely energy feedback and a variety of usage information. The studies reviewed provide convincing evidence that consumers will change their energy consumption behaviour in response to feedback, and that the conditions surrounding feedback, such as frequency and specificity, are influential variables [9]. This implies that a smart grid/metering system may yield considerable savings in terms of end-use conservation, with a basic goal of time-of-use load shifting. In this study, the energy-use reductions achieved is estimated from a range of 5% to 20%, with a median of approximately 6% [10].

(2) Conservation voltage reduction and load management though the electricity transmission sector: This mechanism describes a viable method to reduce the peak load on a distribution feeder as well as being an effective form of conservation. The most comprehensive field study show that a 1% change in distribution line voltages provided a 0.25% to 1.3% change in energy consumption, and those voltages could be reduced from 1% to 3.5% [11].

To conduct a preliminary quantitative estimate of the level of investment needed for this scenario, the core technologies are separated into three broad areas: transmission, distribution and the customer interface. The total capital investment needed to implement smart grid in Yokohama city is represented in table 4.

5. Results and Discussions

5.1. The result of emission reduction effect

There are strong linkages between global climate change and energy consumption in cities and emissions from the combustion of fossil fuels contribute significantly to GHG emission and air pollution. Table 3 shows calculated co-benefits potential by each scenario that had been considered in this case study. The results demonstrate that, emissions mitigation through implementation of scenario III accounted for 21% of GHG emission and 25.4% of total air pollutions by promoting the city's energy performance in both electricity supply system and end-user level.

Table 3. Energy demand/supply and related GHG and AP in different scenarios in Yokohama

Useful energy demand (PJ)	Baseline	S1	S2	S3
Residential	43.61	43.61	41.05	37.92
Commercial	39.16	39.16	38.26	35.49
Final Energy demand (PJ)				
Residential	53.77	53.77	50.62	44.10
Commercial	49.95	49.95	47.83	40.75
Primary energy supply (PJ)				
Fossil fuels	110.33	107.53	100.98	81.66
Nuclear	32.95	32.49	30.70	23.77
Solar	0.77	2.30	0.77	2.30
Wind	0.08	0.08	0.08	0.08
Biomass	3.47	3.47	3.47	3.47
Geothermal	-	1.08	-	1.08
Hydro	8.37	8.37	8.37	8.37
Waste-to-electricity	5.77	5.77	5.77	5.77
GHG and Air pollution (kt/yr)				
GHG (CO_2+CH4)	7991.62	7802.88	7663.20	6301.80
CO	3.27	3.22	3.14	2.40
NMHC	3.28	3.24	3.16	2.42
NOx	15.97	15.78	15.35	11.78
SO_2	39.6	39.1	38.0	29.14
PM10	1.40	1.38	1.34	1.03
PM2.5	0.33	0.32	0.29	0.24

5.2. Cost-benefit analysis

Besides economic issues, the lead-time for the implementation of new technologies especially a smart grid is an important factor in the assessment of cost-benefit. In this case, the expected lead time for renewable energy and efficient technologies at the end-user level is considered to be about 2 years. However, the evaluation of worldwide smart grid projects and the outline of YSCP show that the operation of this technology will be accompanied with more expected lead time which in this study, it has been considered to be about 8 years from 2012 as the base year.
Table 4 presents a summary of the cost-effectiveness indicators for the different scenarios. In all cases, the net benefits of the alternative energy measures are less than the net costs in the short time (up to 2030). The results show that, the scenario III stands out as the most cost-effective scenarios considered here with net benefit-cost ratio

(BCR)[†] about 0.8, assuming that sufficient smart grid technology is available to develop in Yokohama city before 2020.

Table 4. Cost-benefit analysis of different scenarios

	S1	S2	S3
Total capital investment (M$)	934.9	759.8	7734.9
Solar PV	116.4		116.4
GSHP[1]	742.5		742.5
Solar heater[2]	76		76
Lighting improvement[3, 4]		85.8	85.8
High performance window[4]		674	674
Smart Grid technologies			6040
Benefit from electricity saving (M$/yr)	19.6	16.6	739
Benefit from thermal energy saving (M$/yr)	38.4	53.6	92
Net Present Value (M$) @ 2030	79.3	476.6	6800
Net Benefit-Cost Ratio (BCR) @ 2030	0.08	0.62	0.8

[1] Planed in 20,000 households (2 ton cooling load/household)

[2] Planed in 100,000 households (4 sqm surface area/household)

[3] Including: WMOSL, CLF and LED

[4] Area covered: for residential sector (5.7 Million sqm) and for the commercial sector (2.1 Million sqm)

Electricity price is considered to be 0.21 $/kWh as well as the thermal energy saving is estimated on 100 $ per barrel crude oil

5.3. Marginal abatement cost of emissions reduction

Based on the method of the marginal abatement cost (MAC) curve advocated by McKinsey [12], the amount of GHG emission reduction and its relationship to cost are analyzed. Figure 2 shows the calculated MAC for scenario III as the most cost-effective scenario.

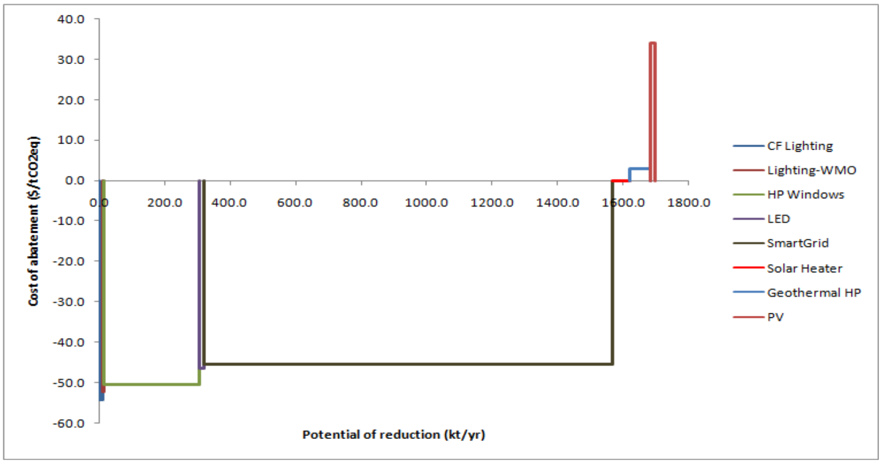

Fig2. Long-term Marginal Cost Abatement curve for scenario III

[†] The ratio of net present value to the total capital investment

The average MAC of all measures in this scenario is -26.48 [USD/t-CO2] per year which shows there is a considerable potential to implement this scenario in Yokohama. It can further be observed from this figure that, lighting improvement, high performance windows and smart grid technology which are hang below the horizontal axis on the left hand side of the graph meaning they have a negative cost and will therefore save money over their life period. The rapid and cost-effective decrease in emissions originates in the city's energy system through introducing the smart grid and the high performance window technologies.

6. Conclusion

In order to estimate the climate co-benefits of the urban energy system, an analytical tool has been developed based on the integrated assessment approach, which provides a quantitative base for effective urban energy planning and management as well as alternative scenarios for the development of a low-carbon city. The implementation of the tool in Yokohama city showed that the measures, which promote low-carbon communities, have a GHG emissions reduction potential of 21% (1.68 Mt/yr). The cost-effective policy intervention scenario that would allow an integrated perspective on deploying renewable energy, energy efficiency measures and smart grid technology was introduced in the third scenario enables the large-scale of co-benefits of the energy system in this city. Based on the outcomes of this study, in order to achieve overall co-benefits of the urban energy system, all aspects related to the energy use, carbon emissions and pollution in a city's lifecycle should be addressed. A comprehensive life cycle assessment method is necessary in addition to find suitable case studies with sufficient data for testing the method in the future research. Work is on going to test how the tool can perform with respect to data availability in other cities.

Acknowledgements

The authors would like to thank to the Institute of Advances Studies of the United Nations University Great Support and helpful comments.

References

1. Biello D. Eco-cities of the future. *Scientific American* , 2008 (Earth 3.0):6
2. Bocquier P. World Urbanization Prospects: an alternative to the UN model of projection compatible with the mobility transition theory. *Demographic Research* , 2005,**12** (9):197–236.
3. James K, Nouri S, Nilay S. SYNCITY: An Integrated Tool kit for urban energy systems modeling, *Fifth Urban Research Symposium, France*, 2009.
4. Canadian Urban Institute, *ICES Municipal Policy Toolkit*, 2010.
5. City of Yokohama website, http://www.city.yokohama.lg.jp/lang/en(in English)
6. Satoshi Y, Satoru S, Yuichi I, Ryota K. Case study on the effects of smart energy community construction at Kanazawa seaside district in Yokohama, *World Renewable Energy Congress* 2011, Sweden.
7. Kurabayashi, T. Characteristics of energy consumption of residential and commercial sector in Yokohama City, *Yokohama-City Environmental Science Research Institute, Bulletin* No 2009.
8. Master plan of Yokohama Smart City Project (YSCP), *Climate Change Policy Headquarters Ward (or Bureau)*, City of Yokohama, 2010
9. Faruqui A, Sergici S, and Sharif A.. The Impact of Informational Feedback on Energy Consumption – A Survey of the Experimental Evidence. *Energy* (in press). 2013
10. Fischer C. Feedback on Household Electricity Consumption: A Tool for Saving Energy? *Energy Efficiency*.2008. **1**(1):79-104.
11. Beck RW. Distribution Efficiency Initiative. *Technical Report prepared for the Northwest Energy Efficiency Alliance*, Portland, Oregon. 2007.
12. McKinsey & Company. *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*, January 2009.