GUIDEBOOK

The Co-benefits Evaluation Tool for the Urban Energy System

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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 policy making 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 guidebook is to introduce a new tool to assess climate co-benefits of the urban energy system based on its systemic characteristics.

Brief description of the tool

The tool evaluates climate co-benefits of the urban energy system based on different scenarios of socioeconomic, technological and demographic developments. The tool relates systematically the climate change based on the specific energy demand in different 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.

The starting point for using the TOOL is construction of base year energy consumption patterns within the tool. This requires compiling and reconciling necessary data from different sources, deriving and calculating various input parameters and adjusting them to establish a base year energy balance. This helps to calibrate the tool to the specific situation of the urban energy system.

The next step is developing policy interventions to tackle global environmental problems, specific to a city's energy system situation and objectives.

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.

The key to plausible and useful policy interventions is the internal consistency of assumptions, especially for social, economic and technological evolution. A good understanding of the dynamic interplay among various driving forces or determining factors is necessary. The tool output is just a reflection of these assumptions. The evaluation of output and the modification of initial assumptions is the basic process by which reasonable results are derived.

The tool seeks to explore: 1) what are the proper methods to pursue the climate co-benefits approach for urban energy system and 2) what are the potentials to reduce GHG emissions and air pollution by improving energy efficiency and using low emission technologies in big cities. 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 urban energy system. 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, district heat etc.) is estimated, due to the importance of the structural changes in the urban energy system that these energy forms may introduce 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. Figure (1) shows the toolkit structure.

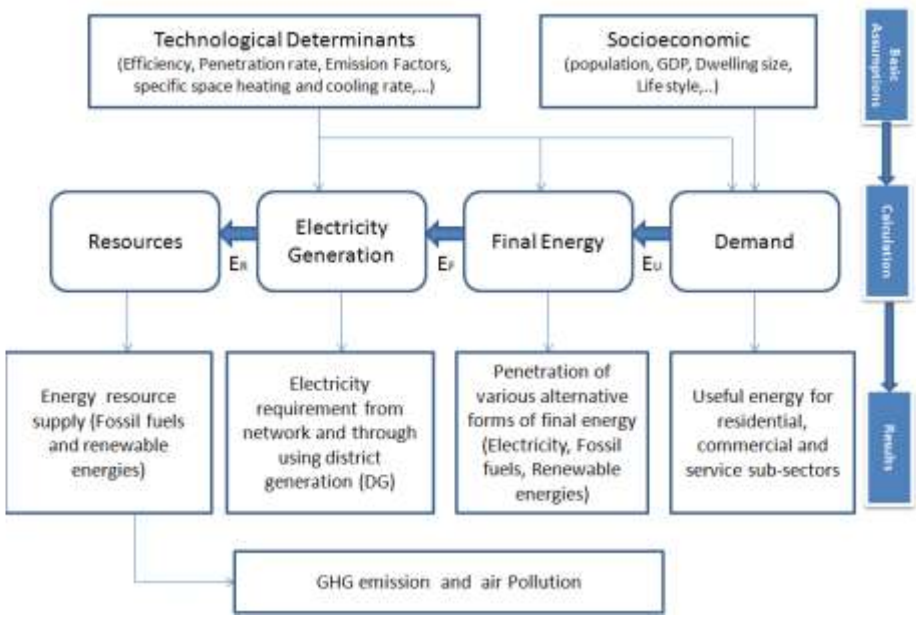


Figure 1 Toolkit structure

Organization of the tool

The software tool is provided in EXCEL Workbook. The workbook contains several worksheets devoted to various sub-sectors and end-use activities included in the tool. All worksheets have several Microsoft Visual Basic macros for performing certain functions, explained in the subsequent chapters, and executing the computations.

These worksheets also serve for inputting data and viewing results. It processes information describing the social, economic and technological behaviors of the urban energy system and also policy interventions and finally, calculates the total energy supply/demand and related GHG emission and air pollution for the desired years. The cost benefit analysis (CBA) for different policy interventions considered is also provided as part of the results of the tool.

Access to the download link

The toolkit is is freely available for download and use to the users through the UNU-IAS online website: http://tools.ias.unu.edu

The "How to Use" tab summarizes the proces required to download the toolkit. At first, the users need to register their personal information and create their own account. Then, the users must register their scenario through filling out the input data forms. These forms provide the initial data which will be required to set up the database of the toolkit. After submitting the input forms, the download link will be accessible. The toolkit can be run on the users PC be entering the username/password. After finishing use of the toolkit, the users need to upload the final results of their evaluations to the website by pushing on the "upload data " which is embedded in the tool menu.

General description of the tool

Introduction

The TOOL is a simulation model designed for evaluating the climate co-benefits of an urban energy system in the short term. The methodology which has been applied through developing the tool is based on the scenario approach. In our approach a "scenario" is viewed as a consistent description of a possible short term development pattern of a city's energy system, characterized mainly in terms of direction of local governmental policy which is named as policy intervention in this tool.

Following this approach, the planner can make assumptions about the possible evolution of the social, economic, and technological development patterns of a local energy system that can be anticipated from current trends and governmental objectives. The consistency of the scenario is a very important consideration of the methodology in order to guarantee the attainment of sound results. Such consistency is to be exercised by the planner while formulating possible scenarios of development.

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

(1) Disaggregation 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) Establishment of the energy supply-demand balance in the city

(5) Estimation of the energy related GHG emissions and air pollution from different sub-sectors

(6) Developing (consistent) scenarios (policy intervention) of social, economic and technological development for the given city's energy system;
(7) Evaluation of the climate co-benefits resulting from each scenario; and finally
(8) Selection among all possible scenarios proposed, the "most probable" patterns of development for the city through analyzing CBA and system sustainability

Objectives of the methodology

(a) The structural changes in the energy system of a city in the short term. This is done by means of a detailed analysis of the social, economic and technological characteristics of the given city's energy system. This approach takes especially into account the evolution of the social needs of the population, such as the demand for space heating, lighting, air conditioning, and this as a function of the distribution of population into different dwelling ranges; the city's policies concerning, housing etc., as well as the technological development;

(b) The evolution of the co-benefits resulting from the structural changes in the energy system.

In the calculation framework, the substitution between alternative energy forms is not calculated automatically from the evolution of the price for each energy form and its corresponding coefficient of elasticity, but from an analysis made while formulating the possible scenarios of development by using the CBA approach.

This could be considered as a drawback of the tool; however, one should bear in mind that in the actual economic context, characterized by continual changes of energy prices, the economists do not dispose of any proven technique, which would allow them to quantify the effect of changes in energy prices on energy demand. Besides, the considerable divergences between the results provided by many studies on price elasticity's of the demand have demonstrated that the traditional manner of conceiving elasticity's of the demand is no longer satisfactory.

Due to the reasons mentioned above, the TOOL does not calculate the evolution of energy demand directly from the evolution of energy prices. For example, the demand for electricity is not calculated from a hypothetical price; this price is simply taken into account implicitly while writing the scenarios of development and it serves as a reference for modulating the evolution of the parameters involved. In this case, THE TOOL simply calculates the demand for electricity as a function of the local demographic and socioeconomic parameters specified by the scenario of development: local climate change, population, dwellings by type and size etc.

Energy demand calculation

THE TOOL calculates the total energy demand for each end-use category, aggregating the urban energy system into three main "energy consumer" sectors: Residential, Commercial and Service. According to this procedure, the demand for each end-use category of energy is driven by one or several socioeconomic and technological parameters, whose values are given as part of the scenario.

Residential Sector

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). This permits a better representation of the proper needs of the individuals, of their living style, as well as a more appropriate definition of the potential markets for the alternative forms of final energy and using new technologies.

The energy consumption for secondary appliances is calculated separately for electrified dwellings, for which the use of electric appliances is assumed, and for the non-electrified dwellings, for which alternative appliances using fossil fuels are considered (kerosene lighting, refrigerators on natural gas etc.).

Tab 1. Initial input data categories distinguished in the residential sector in the tool

Item
Urban dwelling type
Fraction of urban dwellings per type
Urban dwelling average size
Required area for heating per dwelling type
Required area for cooling per dwelling type
Share of dwellings with hot water facilities
Share of dwellings with cooking system
Share of electrified dwellings
Penetration of (Traditional, fossil, biomass, electricity and renewable) forms into different technologies (Cooking, hot water, heating, cooling, lighting, etc.)

Commercial Sector

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.

The categories of energy use considered in the residential sector are: space heating, water heating, cooking, ventilation, lighting, cooking refrigeration, office equipment, computer and etc. A summary of initial input data considered for the commercial sector is given in Table 2.

Tab 2. Initial input data categories distinguished in the commercial sector in the tool

Item
Average floor area in commercial sector
Share of commercial sub-sectors in total floor area
Penetration of (Traditional, fossil, biomass, electricity and renewable) forms into different technologies (Cooking, hot water, heating, cooling, lighting, etc.)

Service Sector

The service sector consists of the "soft" parts of the economy, i.e. activities where people offer their knowledge and time to improve productivity, performance, potential, and sustainability, what is termed affective labor. The basic characteristic of this sector is the production of services instead of end products. It is sometimes hard to define whether a given company in the city is part of the commercial or service sector. For purposes of finance and market research, market-based classification systems such as the Global Industry Classification Standard and the Industry Classification Benchmark are used to classify businesses that participate in the service sector. In the TOOL, the service sector is considered as a separate sector including those parts of the city's companies and firms which have a direct effect on city's GDP progression. Therefore, the scenario parameters and related equations which characterize the energy consumption in the Service sector are related to the economic level of activity of this sector (sub-sectorial value added and labor force in the sector).

The energy consumption for space heating and air conditioning is calculated on the basis of the specific space heating and cooling requirements (kWh/sqm/yr), while that for other thermal uses, specific uses of electricity and motor fuels is calculated as a function of the value added and energy intensity at the sub-sector level within Service sector.

Tab 3. Initial input data categories distinguished in the service sector in the tool

Item
Active labor force
Share of labor force in service sector
Number of employees in service sector
Average floor area in service sector
Total Floor area in service sector
Share of Service sector in total GDP
Required area for space heating and cooling per service type
Energy Intensity (motor fuel, electricity, heat) per service type
Penetration of (Traditional, fossil, biomass, electricity and renewable) forms into different technologies (Cooking, hot water, heating, cooling, lighting, etc.)

Final energy calculation

When the demand of the given end-user can be provided by various energy forms (space heating, water heating, cooking and air conditioning and etc.), this is calculated in terms of useful energy and not in terms of final energy. The final energy demand is then calculated from the penetration into the potential market and the efficiency of each energy form (network loss, heat loss, COP) as specified in the base scenario. Table 4 shows a sample of the energy forms penetration which has been distinguished in the final energy calculation in the tool.

Tab 4. Penetration of different energy forms through calculating final energy in the tool

Energy forms	Space heating	A/C	Appliances	Other thermal uses
Traditional	X			X
Biomass	X			X
Fossil Fuels (Town gas, LPG, Kerosene,…)	X			X
Electricity	X	X	X	
Renewable (Solar, Wind,…)	X		X	X

City power supply system (energy conversion level)

This level of the urban energy system consists of the group of public and private companies, activities and installations used for the generation of electricity to meet the electricity demand in the city.

THE TOOL estimates the total electricity required to meet the energy demand for each end-use category, segregating whole urban power supply system into different electricity generation technologies through considering two connection modes: On-grid (from the network) and Off-grid (District Generation). Different power supply technologies which have been considered in the TOOL are represented as follows:

- ✓ Hydro
  - ➢ Mini hydro
- ✓ Solar
  - ➢ Thermal solar
  - ➢ PV
- ✓ Geothermal
  - ➢ Ground Power plant
- ✓ Biomass
  - ➢ Direct combustion
  - ➢ CHP
  - ➢ Co-Firing
  - ➢ Bio-gas
- ✓ Wind
  - ➢ Onshore
  - ➢ Offshore
- ✓ Waste to electricity (incinerator)
- ✓ Fossil thermal power plant
  - ➢ Coal
  - ➢ Oil
  - ➢ LNG/LPG

- ➢ HFO
- ➢ CHP
- ✓ Nuclear

Initial input data categories distinguished in the city power supply sector are represented in table 5.

Tab 5. Initial input data categories distinguished in the city power supply sector in the tool

Item
Installed capacity
Conversion efficiency
Annual operation (h/yr)
Load factor
Network loss (%)

Primary energy supply

The primary energy sources (fossil and non-fossil) must be available to city to enable the production of energy carriers. The amount of primary energy sources can be estimated on the basis of the energy demand (electricity and heat) estimated in the city.

GHG emission and Air pollutions estimation

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 AP. Quantifying the co-benefits and the incentive power of participating in a global climate change strategy 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 exposure 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

The tool estimates the amount of GHG and AP for the city based on the life-cycle analysis method considering the operation, transportation, and processing levels for each contributor technology.

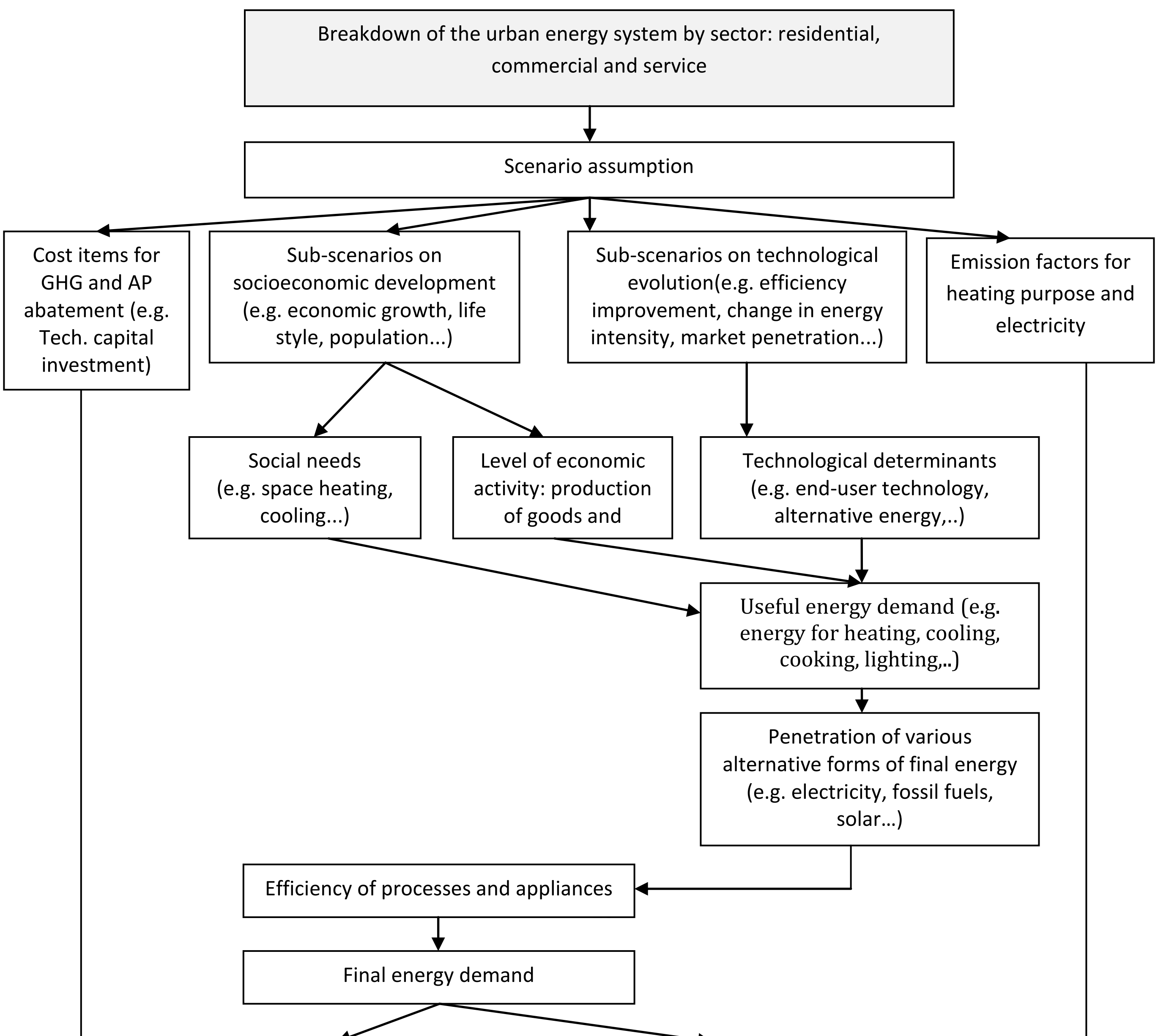
Cost Benefit Analysis (CBA)

CBA in considered in the tool as a systematic process for calculating and comparing benefits and costs of different policy interventions (scenarios) by pursuing following two purposes:

1. To determine if it is a sound investment/decision (justification/feasibility),
2. To provide a basis for comparing scenarios. It involves comparing the total expected cost of each option against the total expected benefits, to see whether the benefits outweigh the costs, and by how much.

CBA is related to cost-effectiveness analysis. In this case, benefits and costs are expressed in monetary terms, and adjust for the time value of money, so that all flows of benefits and flows of scenario costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their "net present value (NPV) ". Finally, Benefit-cost ratio (BCR) and payback period (PBP) are used in the CBA to summarize the overall value for money of each scenario.

Figure 2 shows the scheme used to project co-benefit in the tool.



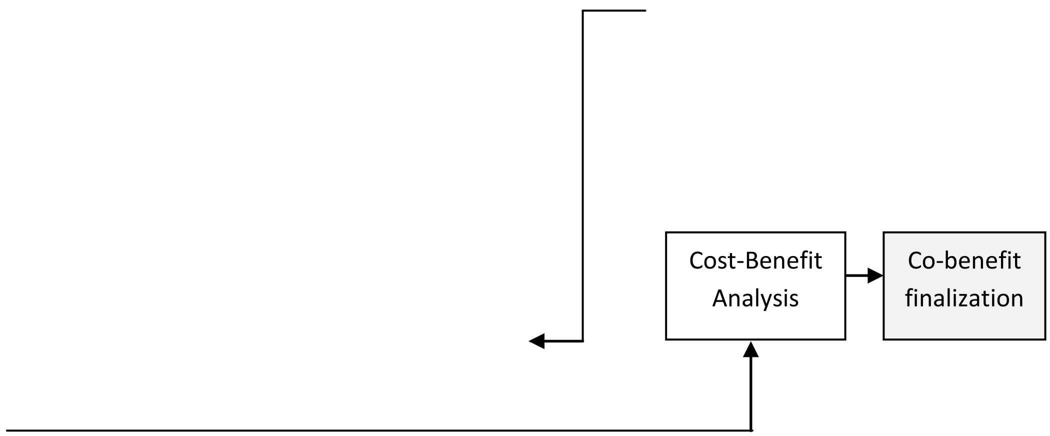


Figure2- Scheme used to project co-benefit in the tool

Maximal capabilities

Table 6 summarizes maximal capabilities of the tool.

Tab 6. Maximal capabilities of the tool

Parameter	Max. Allowance
Subsectors	3
Urban dwelling types	6
Urban dwelling end-user technologies	4
Commercial subsectors	14
Commercial end-user technologies	10
Power supply technologies	17
Alternative energy technologies	7
Energy efficiency improvement measures	6

USING THE TOOL

The toolkit operates under the Microsoft Excel software (Ver. 2007 and 2010) and can be readily installed on a PC operating in a Windows environment by downloading the file from the UNU-IAS website to any selected directory (e.g. C: /programs/ETool) on the user's computer.

This section provides an overview of the worksheets associated with the Excel workbook and describes the execution of the tool.

The excel-based tool consists of four main parts as listed in table 7.

Tab 7. List of main parts of the excel-based tool

1- Baseline scenario	Property	
Basic data	Input data	Regional demographic related data (population,…)
Residential sector	Input data	Initial input data for the residential sector
Commercial sector	Input data	Initial input data for the commercial sector
Service sector	Input data	Initial input data for the service sector
Energy supply system	Input data	Initial input data for the city power supply system
2-Policy intervention		
Lifestyle change	Action	Change in size and share of dwelling types and commercial subsectors
Alternative energy	Action	Use of different alternative energy technologies as DG heat and electricity
End-user technology	Action	Use of new technology to improve energy efficiency in each end-user group

Smart Grid	Action	Connect city to smart Grid protocol
3-Results		
Final report	Show	Final report in three categories: summary, baseline and after intervention
Energy balance	Show	Energy balances of the urban energy system in city
CBA	Show	Cost Benefit Analysis of scenarios
MAC	Show	Marginal Abatement Cost curve for different scenarios
Sustainability Analysis	Show	Sustainability indices for different scenarios
Sankey diagram	Show	Energy flow diagram of the urban energy system in city
4-Database		
Energy factors	Default data	Energy efficiency and intensity factors
Emission factors	Default data	Emission factors per fuel/technology types

Microsoft Visual Basic subroutines have been used in the Microsoft Excel environment to automatically generate the equations and tables of the tool. A brief description of various parts follows.

Some preliminaries

When the file is opened, a dialogue box will appear on the monitor screen asking the user if the Microsoft Visual Basic macros present in the workbook should be enabled. Click the “Yes” or the “Enable Macros” button as the macros provided in the worksheet are necessary for the proper operation of the program.

Figure3. *Snapshots of the dialogue box asking about the enabling of the Macros*

Toolkit menu

The tool provides an easy-access menu to navigate user path through using the tool as depicted by figure 4.

Figure4. Snapshot of tool menu

Cell "Notes"

A snapshot of the worksheet cells "Notes" is given in Figure 5. This snapshot contains information about the color code conventions used in various worksheets for making a distinction between the types of information contained in various cells, what are the data that may be entered/changed in various data worksheets and to indicate whether the cells are locked or not:

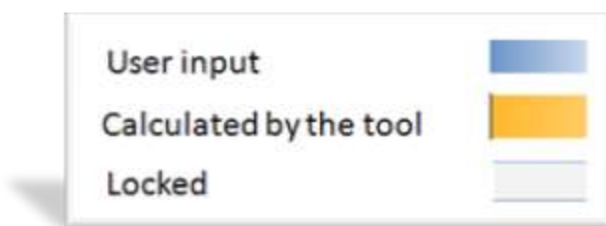


Figure 5. Snapshot of the worksheet cells "Notes"

Initialization

Before processing with a new scenario, the first step is the initialization of the tool. In this step, the user must define the corresponding project description, dwelling groups, residential sub-sectors and service sub-divisions as shown in figure 4. After that, the tool will be ready to use for analyzing climate co-benefit of the city's energy system.

Data Entry and Handling Worksheets

Basic Data

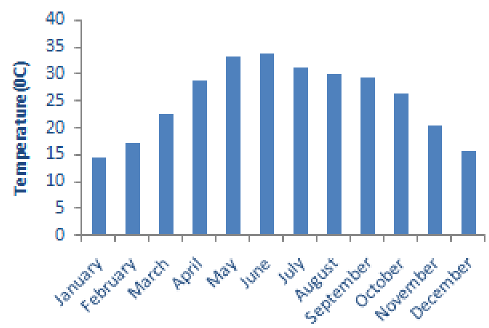
This worksheet contains the information defining the regional and demographic specifications of the city (see figure 6). These data are included: GDP, Population, mean average monthly temperature and solar radiation [5-8]. The two important parameters which are calculated from the monthly temperature are Heating degree-day (HHD) and cooling degree-day (CDD). HDD is used to estimate the potential of electricity uses during wintertime as well as CDD which is used to calculate electricity consumed for A/C during summer time.

1. Region Basic Data

Item		Base Year
GDP	Billion U$	59.76
Population	Million	16.31

2.Local Monthly Mean Temperature

	Ave. Temp (0C)
January	14.3
February	17
March	22.5
April	28.75
May	33
June	33.85
July	31.1
August	29.9
September	29.35
October	26.15
November	20.4
December	15.55
Heating Degree-Day	440
Cooling Degree-Day	4860



3.Local Monthly Mean Solar Radiation

	Solar Rad (MJ/sqm/day)
January	15.51
February	18.25
March	22.46
April	25.37
May	27.45
June	24.14
July	19.37
August	17.92
September	20.64
October	19.24
November	17.07
December	14.14
Annual Average	20.1

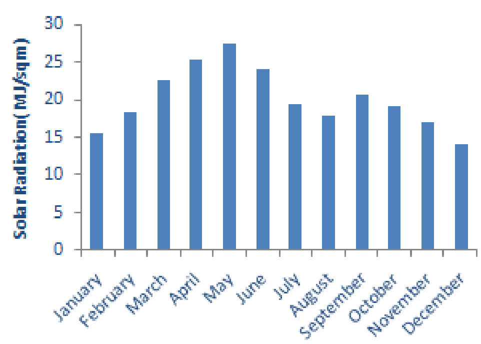


Figure 6. Snapshot of the worksheet "Basic Data"

Residential Sector

This worksheet serves as the input data form for the residential sector. It consists of seven parts as follows (see figure 7):

- Dwelling data: fraction (%) of urban dwellings by type, average size (sqm) of dwellings by type
- Share of dwelling required space heating and cooling: fraction (%) of floor area of each dwelling type which is actually heated or cooled.
- Share of dwellings with hot water facilities
- Share of dwellings with cooking facilities
- The fraction of total urban dwellings that are electrified or electrification rate of the urban households
- Penetration of energy forms into space and water heating: Share of energy forms which have been used to provide space heating and hot water in the residential sector for the base year.
- Penetration of energy forms in to cooking: Share of energy forms which have been used for cooking in the residential sector for the base year.

1. Dwelling Data

Item		Base Year
Average household size	Person/Household	5.4
Dwelling	Million	3.34
Urban dwelling by share		
1 room	%	32.17
2 rooms	%	29.63
3 rooms	%	2
4 rooms	%	10.44
5 rooms	%	3.03
others	%	22.73
Urban dwelling by average size		
1 room	sqm	15.44
2 rooms	sqm	30.87
3 rooms	sqm	46.31
4 rooms	sqm	61.75
5 rooms	sqm	77.19
others	sqm	115.78

2. Share of dwelling required space heating & cooling

Item		Base Year
Required area for heating		
1 room	%	40
2 rooms	%	60
3 rooms	%	60
4 rooms	%	80
5 rooms	%	80
others	%	80
Required area for cooling		
1 room	%	10
2 rooms	%	10
3 rooms	%	10
4 rooms	%	15
5 rooms	%	15
others	%	15

3. Share of dwelling with hot water facilities

Item		Base Year
Dwelling with hot water facilities	%	100

Figure 7. Snapshot of the worksheet "Residential"

Commercial Sector

As shown in figure 6, this worksheet contains the required input data for the commercial sector. The most important input data is "Total floor area" in the city. The share of each sub-sector in total floor area should be provided as a ratio of the floor area covered by each sub-sector to the total floor area. Penetration of energy forms into space heating and hot water for the base year is required as the next input data in this section (see figure 8).

1. General data for commercial sector

Item		Base Year
Total floor area	Billion sqm	0.03
Share of sub-sectors in total floor area		
Manufacturing & repair services	%	18
Construction	%	0.7
Wholesale Trade	%	3.3
Retail Trade	%	49.2
Hotels & Restaurants	%	4.7
Storage & Warehousing	%	3.6
Communications	%	3.5
Financing, Insurance and Real Estate	%	7
Community & Personal Services	%	10
0	%	0
0	%	0
0	%	0
0	%	0
0	%	0

2. Penetration of energy forms into space heating & hot water

Item		Base Year
Traditional Fuels	%	0.00
Biomass	%	0.00
Fossil Fuel	%	44.10
Electricity	%	55.90
Renewable	%	0.00

Figure 8. Snapshot of the worksheet “Commercial”

Service Sector

As mentioned before, the energy consumption of the service sector is calculated on the basis of the economic level of activity in this sector. The input data required in this worksheet are listed as follows (see figure 9):

- ✓ Share (%) of Service sector in the total labor force and average floor area per employee (sqm/cap);
- ✓ Share (%) of floor area requiring space heating and what of that (%) is actually heated, specific space heating requirements (kWh/sqm/yr), share (%) of air-conditioned floor area and specific cooling requirements (kWh/sqm/yr);
- ✓ Energy intensities for motor fuels, specific uses of electricity and other thermal uses, except space heating
- ✓ Penetrations of different energy carriers into the space heating market
- ✓ Penetrations of different energy carriers into the market of other thermal uses: hot water and cooking
- ✓ Penetration of electric and non-electric equipment in the market of air conditioning

1. General data for service sector

Item		Base Year
Active labor force	Million	0.00
Share of labor force in service sec	%	0.00
Number of employees in service se	Million	0.00
Average floor area in service secto	sqm/employee	0.00
Total Floor area in service sector	million sqm	0.00
Service sector share in GDP	%	0.00
0	%	0.00
0	%	0.00
0	%	0.00
0	%	0.00

2. Space heating and cooling

Item		Base Year
Heating		
Share of area required space heati	%	0
Share of area actually heated	%	0
Total Area for heating	sqm	0.00
Cooling		
Share of area required AC	%	0

3. Motor fuels intensity

Item		Base Year
Energy Intensity		
0	kWh/U$	0
0	kWh/U$	0
0	kWh/U$	0
0	kWh/U$	0

4.Electricity intensity

Item		Base Year
Energy Intensity		
0	kWh/U$	0
0	kWh/U$	0
0	kWh/U$	0
0	kWh/U$	0

Figure 9. Snapshot of the worksheet “Service Sector”

Energy Supply System

The user in this worksheet should define corresponding specifications of the energy supply system such as: 1) City’s power supply technologies (installed capacities) and 2) Thermal energy supplied from the outside sources (from nearby factories as cogeneration/heat recovery system).

Also, a handy set of conversion factors such as efficiency, annual operation (h/yr) and electrical load factor is provided in this worksheet for calculating the maximum possible electricity generated by each technology. The electrical load factor can be set as a determinant for load profile of the specific power technology as the average load divided by the peak load in a specific time period. The contribution of different power technologies into city' electricity supply is then calculated by the tool (in the last column).

			Base Year					
			Installed Capacity	Efficiency	Annual Operation	Load Factor	Maximum Generation	Penetration rate
Connection Type		Item	MW	%	h/yr	%	GWh/yr	%
		Hydro						
Grid	100%	HydroPower	244	85	8000	100	1952.0	12.94
		Solar						
Grid	100%	Thermal solar	0	35	2000	0	0.0	0.00
Grid	100%	PV	21	20	2000	100	42.0	0.28
		Geothermal						
Grid	100%	Ground Power plant	0	25	5800	0	0.0	0.00
		Biomass						
Grid	100%	Direct combustion	0	30	5000	100	0.0	0.00
Grid	100%	CHP	0	45	5000	100	0.0	0.00
Grid	100%	Co-Firing	82	40	5000	100	410.0	2.72
Grid	100%	Bio-gas	0	30	5000	100	0.0	0.00
		Wind						
Grid	100%	Onshore	4	28.5	1600	100	6.4	0.04
Grid	100%	Offshore	0	28.5	1600	0	0.0	0.00
Grid	100%	Waste	89	45	8000	100	712.0	4.72
		Fossil thermal power plant						
Grid	100%	Coal	35	45	8000	100	280.0	1.86
Grid	100%	Oil	296	45	8000	100	2368.0	15.69
Grid	100%	LNG/LPG	713	50	8000	100	5704.0	37.80
Grid	100%	HFO	0	45	8000	100	0.0	0.00
Grid	100%	CHP	0	45	8000	100	0.0	0.00
Grid	100%	Nuclear	452	40	8000	100	3616.0	23.96
		Total	1936				15090.4	100.0

2. Network loss

Item		Base Year
Net work loss	%	20.00

3. Thermal energy supplied from outside sources(Industries,etc.)

Item		Base Year
Waste Heat (sewage+Industry)	Mtoe	0

Figure 10. Snapshot of the worksheet "Electricity Technology"

If the electricity generation is more than the required demand, the user will be asked to reset the technical parameters such as installed capacity, efficiency, annual operation or load factor again. Also, the tool will offer a reset option to the user to reset the electricity supply to its demand level automatically (Figure 11).

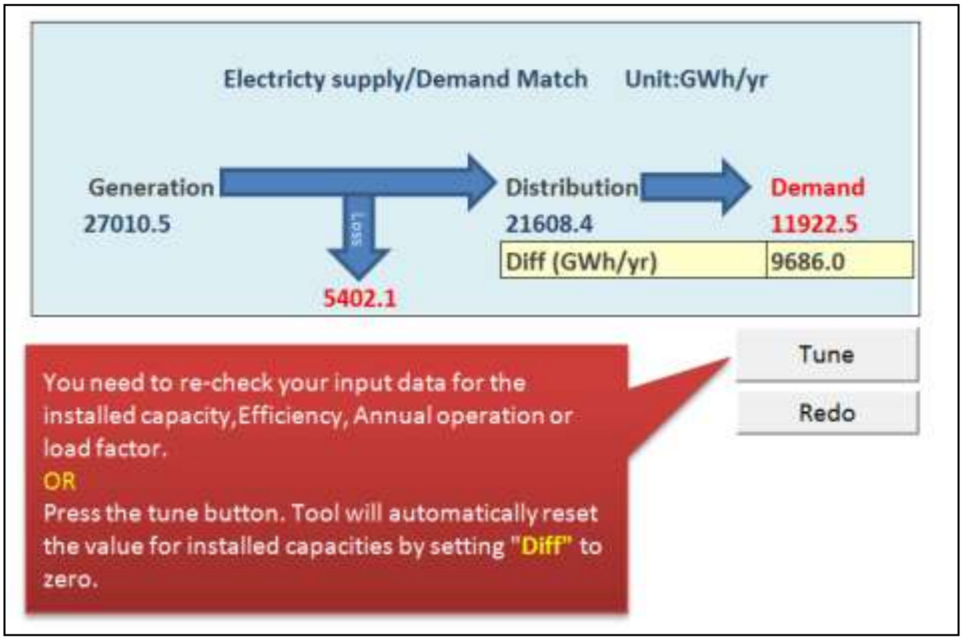


Figure 11. Mechanism to reset the electricity generation to the demand level

Policy intervention actions

The potential of GHG and AP reduction 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.

Lifestyle change

In this tool, change in urban lifestyle comprises any changes in dwelling size and share. User can use the slider bars which have been designed for this purpose to adjust new settings for the share distribution. There are also two push buttons that user can press to activate the reset mechanism. It is notable that the sum of these shares must 100%. Otherwise, an alert “Range in not allocated” will be announced which shows that the user needs to ensure increases in share of one dwelling group are reflected by decreases in other groups. A handy data entry mechanism is provided to adjust the new size for different dwellings in this worksheet. A dynamic graph automatically reflects changes in term of GHG and Air pollution reduction potential (See figure 12).

Figure 12. Snapshot of the worksheet "Lifestyle change"

A similar mechanism is provided for the commercial sector in this worksheet.

Alternative Energy

The alternative energy policy intervention provided an infrastructure which enables the large-scale introduction of renewable energy in order to reduce GHG emission and air pollution in cities.

This worksheet contains several fields, which may be changed by the user to define the specific environment of a particular intervention scenario. The fields with the blue background color are for the user to enter/modify input data. The following categories of input data are specified in this worksheet (See figures 13-14):

- New added capacity for each alternative energy category (PV, Wind, Mini Hydro, Ground Heat Pump, Waste to electricity, Biomass and solar water heater)
- Typical unit size of each technology (i.e. 2.8 kW for inclined roof PV, etc.)
- Technology distribution in the new added capacity (i.e. 50% for inclined roof PV, etc.)
- Lifetime support for each technology (i.e. 25 years for inclined roof PV, etc.)
- Conversion efficiency of each technology (i.e. 27 % for converting solar heat to electricity, etc.)
- Annual operation or utilization rate of each technology (i.e. 2000 h/yr for inclined roof PV, etc.)

Having determined the above data, the potential for GHG and AP reduction can then be estimated by the tool.

Policy Intervention (2) : Alternative Energy Measures

Photovoltaic		
Existing Installed Capacity	MW	21
New Added Capacity	MW	27

Operating Characteristics	Inclined Roof	Flat Roof	Ground	Integrated
Typical Size (kW)	2.8	2.5	2.8	2.6
Share in new capacity (%)	50	30	15	5
Lifetime (Years)	25	25	25	25
Efficiency(%)	18	14	16	12
Annual Operation (h/yr)	2000	2000	2000	2000
Electricity Generation (GWh/yr)	27	16.2	8.1	2.7
Total Area Requirement (sqm)	4891	3214	1467	529
Total CO2 reduction (t/yr)	8100.0	4860.0	2430.0	810.0

Inclined Roof Type: PV panels mounted flush on the inclined roof

Flat Roof Type: Panels mounted on a flat roof

Ground Type: When roof space is not available or if the building is not ideally oriented

	GHG	CO	NMHC	NOx	SO2	PM10	PM2.5
Baseline	7.99	3.27	3.28	15.97	39.57	1.40	0.33
After Intervention	6.22	2.38	2.39	11.65	28.83	1.02	0.24
Reduction	-1.77	-0.89	-0.89	-4.33	-10.74	-0.38	-0.09

Figure 13. Snapshot of the worksheet “Alternative Energy”

Wind Turbine		
Existing Installed Capacity	MW	4
New Added Capacity	MW	

Operating Characteristics	WTG
Typical Size (MW)	2.0
Lifetime (Years)	25
Efficiency(%)	27
Annual Operation (h/yr)	1600
Electricity Generation (GWh/yr)	0
Total CO2 reduction (t/yr)	0.0

Mini Hydro		
Existing Installed Capacity	MW	244
New Added Capacity	MW	

Operating Characteristics	MHP
Lifetime (Years)	20
Efficiency(%)	27
Annual Operation(h/yr)	8000
Electricity Generation (GWh/yr)	0
Total CO2 reduction (t/yr)	0.0

Figure 14. Snapshot of the worksheet “Alternative Energy”-continued

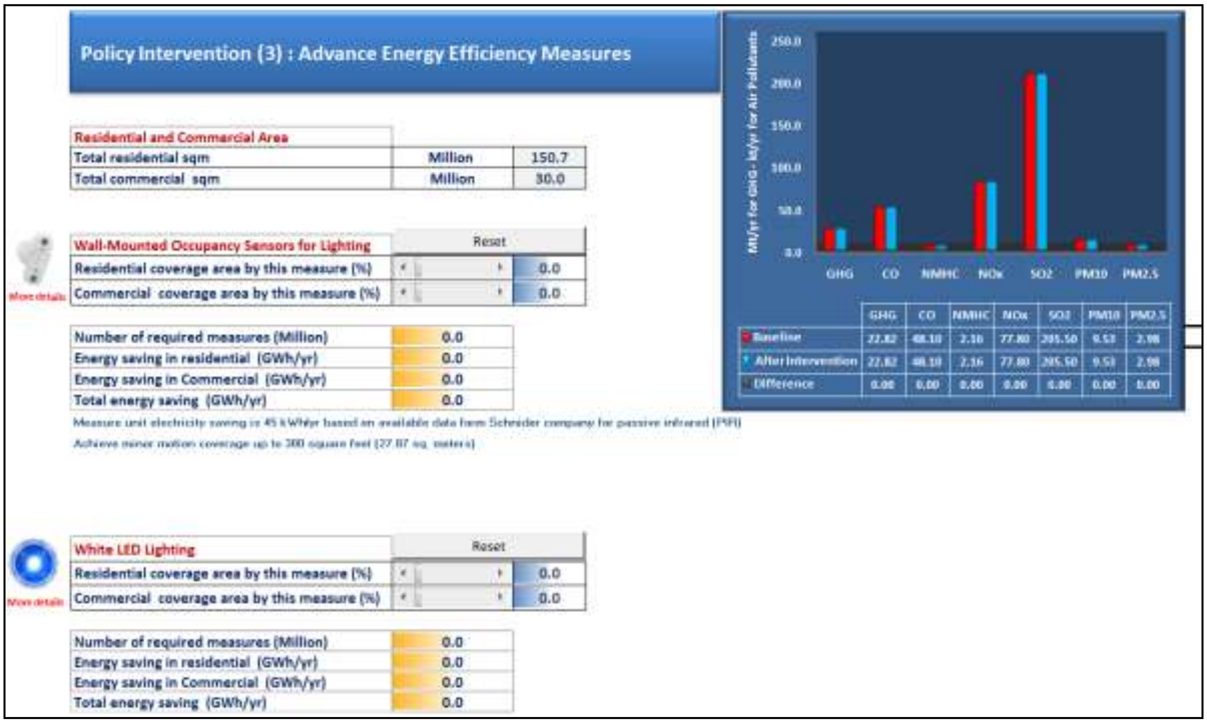
End-user Technology

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

1) **Wall-Mounted Occupancy Sensors for Lighting**: Occupancy sensors detect movements of people and automatically turn lights on and off. Measure unit electricity saving is estimated about 45 kWh/yr based on available data from Schnider company for passive infrared (PIR) [9].
2) **White LED**: Light Emitting Diode (LED) technology for producing white lamps which consumes 25% less energy than fluorescent light bulbs (which are already efficient) and they last ten times as long as fluorescents.
3) **Compact Fluorescent Lighting**

4) **High Performance Windows:** a U- value of less than 0.25 which reduces gas space heating costs by roughly 0.8 MMBtu per window [10].

5) **COP improvement In the air conditioning**



Air Conditioning Efficiency	
Current COP	2.5
New COP	2.7
Energy saving in residential (GWh/yr)	353.8
Energy saving in Commercial (GWh/yr)	384.6
Total energy saving (GWh/yr)	738.3

Figure 15. Snapshot of part of the worksheet “End-user Technology”

The co-benefits resulting from this scenario is based on the total sqm which is covered by the measures. The user needs to adjust the value for this parameter through using the slider bars as shown in figure 15. Having determined total area covered by different measures, savings from improving efficiency at the end-user level can be calculated by the tool. The COP improvement could also be obtained through direct inserting a new value for New COP.
(For more details please refer to the Principle Equations section).

Smart Grid

A **smart grid** is a modernized electrical grid that uses information and communications technology to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.

This worksheet is intended for handling this innovation in the urban energy system. First of all, the user should have sufficient understanding about the Smart Grid technologies. Generally, the smart grid can contribute to energy efficiency and the integration of renewable generation to provide climate co-benefits to the city. Principally, the benefits of the Smart Grid are numerous and stem from a variety of functional elements which include cost reduction, enhanced reliability, improved power quality, increased national productivity and enhanced electricity service, among others. In this tool, the Smart Grid technologies comprise following applicable mechanisms in both customer and supplier sides:

- ✓ Customers (End-user level)
  - o Data monitoring, AIM (Advanced Impedance Monitoring) and system performance diagnostics
- ✓ Supplier (City's power supply system)
  - o Load management
  - o Voltage reduction and advanced voltage control
  - o Support penetration of renewable energy generation

The reductions in electric utility electricity and CO_2 emissions attributable to the above mentioned mechanisms by direct and indirect effect are shown in table 8 which has been addressed by the Department of Energy [11].

Evaluation of the co-benefits of Smart Grid is possible through having enough detail data about the city's energy system. These required data are available from the energy balance worksheet which will be discussed later. The only data that user needs to enter in the Smart Grid worksheet contains:

1- City's monthly average electricity consumption profile for the base year.

Or

2- Average yearly electrical load factor.

Having above data, the user can check the check box of "Smart Grid is connected" to see the results. Details of the calculation are explained in the Principle Equations section.

Tab 8. Potential Reductions in Electricity and CO_2 Emissions Attributable to Smart Grid technologies

Mechanism	Reductions in Electricity Sector Energy and CO_2 Emissions[(a)]	
	Direct (%)	Indirect (%)
Conservation Effect of Consumer Information and Feedback Systems	3	-
Joint Marketing of Energy Efficiency and Demand Response Programs	-	0
Deployment of Diagnostics in Residential and Small/Medium Commercial Buildings	3	-
Measurement & Verification (M&V) for Energy Efficiency Programs	1	0.5
Shifting Load to More Efficient Generation	<0.1	-
Support Additional Electric Vehicles and Plug-In Hybrid Electric Vehicles	3	-
Conservation Voltage Reduction and Advanced Voltage Control	2	-
Support Penetration of Renewable Wind and Solar Generation (25% renewable portfolio standard [RPS])	<0.1	5
Total Reduction	**12**	**6**

(a) Assumes 100% penetration of the smart grid technologies.

Results

Final Report

There are three forms of final report: Summary report, Baseline report and after intervention report. The summary collates the results of the base between baseline and intervention scenarios in the following sections:

A) Primary energy supply to the city

Primary energy is directly calculated from converting secondary energy carries such as electricity and heat into primary energy carries. It includes traditional fuels, fossil fuels, nuclear, solar, wind, biomass, geothermal, hydro, waste material and heat recovery for outside of the city.

B) Electricity demand/supply match

In some case, cities may be faced with the increasing deficit in power supply, both in meeting its normal electricity requirements as well as its peak load demand. It means that the total installed power capacity is not sufficient to meet the city's electricity demand over the certain time period.

C) Electricity generation mix

The generation mix shows the contribution of different power generation technologies in the city's total electricity supply.

D) Total useful and final energy demand in different end-users

E) Urban energy system total emissions (GHG and AP)

F) Urban energy system efficiency

The overall functionality of the urban energy system can be evaluated through introducing different indicators. In this tool, fossil fuel intensity and Heat island index are considered to represent the efficiency of the city's energy system (see the sustainability analysis section).

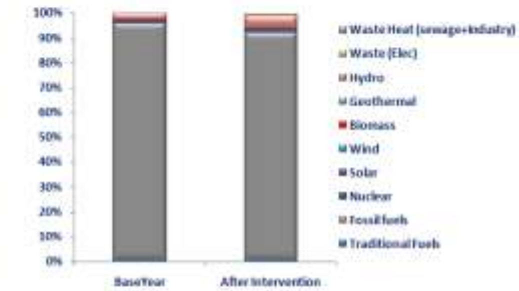
The Baseline and after intervention reports contain more detailed data on the energy demand and GHG emission based on the different technologies (Heating, cooling, air conditioning, cooking, etc.) and sub-sectors (dwelling groups, commercial and service sub-divisions).

Summary Report

BaseYear Report | Policy Intervention Report

1. Primary energy supply

Item		BaseYear	After Intervention	Diff
Traditional Fuels	Mtoe	0.088	0.088	0.000
Fossil fuels	Mtoe	8.238	7.660	-0.577
Nuclear	Mtoe	0.112	0.103	-0.009
Solar	Mtoe	0.003	0.031	0.028
Wind	Mtoe	0.000	0.000	0.000
Biomass	Mtoe	0.001	0.001	0.000
Geothermal	Mtoe	0.000	0.000	0.000
Hydro	Mtoe	0.235	0.448	0.212
Waste (Elec)	Mtoe	0.013	0.087	0.074
Waste Heat (sewage+Industry)	Mtoe	0.000	0.000	0.000
Total	Mtoe	8.690	8.417	-0.272



2. Electricity demand/supply match

Item		BaseYear	After Intervention	Diff
Residential	GWa	1.361	1.269	-0.092
Commercial	GWa	1.285	1.241	-0.044
Service	GWa	0.000	0.000	0.000
Electricity demand	GWa	2.646	2.511	-0.135
Elctricity Supply*	GWa	2.467	2.511	0.044
Supply/demand gap	GWa	-0.179	0.000	-0.179

* Network loss included

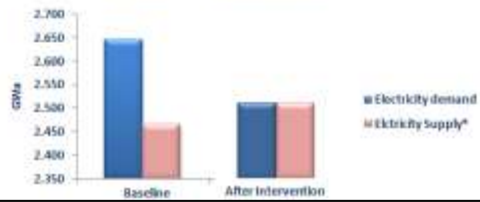


Figure 16. Snapshot of part of the worksheet "Summary Report"

8.Residential useful energy

Item		Base Year				
		Heating	Cooling	Hot Water	Cooking	Elec for Appliance
Under 29	GWa	0.0034	0.0001	0.0044	0.0037	0.0022
30-49	GWa	0.0175	0.0005	0.0118	0.0098	0.0058
50-69	GWa	0.0673	0.0011	0.0251	0.0208	0.0124
70-99	GWa	0.2002	0.0028	0.0472	0.0392	0.0234
100-149	GWa	0.3085	0.0090	0.0442	0.0367	0.0219
Over 150	GWa	0.2470	0.0034	0.0133	0.0000	0.0061
Total	GWa	0.8439	0.0170	0.1460	0.1102	0.0719

9. Commercial useful energy

		Base Year			
Item		Space Heating	Cooling	Other heat demand	Light & Appliance
Hotel(Western style)	GWa	0.001	0.005	0.011	0.007
Hotel(Japanese style)	GWa	0.001	0.003	0.018	0.007
Office and Bank	GWa	0.000	0.002	0.000	0.005
Shop	GWa	-0.005	0.042	0.016	0.106
Theatre and Film	GWa	0.001	0.005	0.011	0.007
Hospital	GWa	0.001	0.005	0.011	0.007
Office	GWa	0.008	0.042	0.096	0.061
Mall	GWa	0.010	0.050	0.111	0.072
Department Store	GWa	0.005	0.025	0.056	0.036
Bank	GWa	0.002	0.010	0.023	0.014
Theatre and Entertainment	GWa	0.001	0.005	0.011	0.007
Others	GWa	0.001	0.005	0.011	0.007
Primary School	GWa	0.004	0.020	0.045	0.029
Junior High School	GWa	0.003	0.017	0.039	0.025
Total	GWa	0.0331	0.2348	0.4625	0.392

Figure 17. After intervention report: detailed data for different technology

Energy Balance

The first law of thermodynamics is a statement of material balance—a mass or energy can neither be created nor destroyed—it can only be transformed. This indicates the overall balance of energy at all times. The energy balance is then designed to illustrate the general energy flow (production to end-user) of the urban energy system.

The energy balance table has four main building blocks: the supply-side information (resources), conversion details, final distribution and the demand side information. The supply-side information captures domestic supply of energy products (Electricity and Heat) through production. Energy production provides the quantities of energy domestically produced in a city. The conversion section of the energy accounting captures the conversion of primary energies into secondary energies either through physical or chemical changes. Normally the inputs used in the transformation process are given a negative sign while the outputs are given a positive sign (See figure 18). Commonly used conversion process for an urban energy system is electricity generation. However, as with supply information, conversion is also a city specific section of the energy account and would normally vary across cities. The conversion section also captures information on energy used by the end-users and transmission and distribution losses. Both these elements carry a negative sign as they represent the reduction in energy flows for use by consumers.

The final distribution captures the energy flows available as final energy forms such as electricity and heat. This section comprises four main sub-levels: Heat in (from primary energy sources), Heat recovery (from nearby factories), Electricity In (form conversion level) and finally, electricity transmission which includes the amount of electricity which inflows to the final end-users.

The final level is the demand side. In terms of accounting balance, this is the residual amount available for domestic consumption from primary supplies after accounting for conversion and other transmission losses. Generally, net supply is calculated from the supply side while the net demand is calculated from the demand side and these two figures should match, thus ensuring correctness of the accounting. However, it is quite rare that the two items are exactly same. The statistical difference term is used as the balancing item. Its sign would indicate whether the supply-side total is higher (thus requiring a deduction of any balancing amount) or lower (thus requiring some balancing amount) than the demand side total.

As the energy balance is organized in four sections (supply, conversion, final distribution and use), it is possible to gain insight in these areas, depending on the need and purpose of the analysis. For example, the primary energy requirement indicates the total energy requirement of the city to meet final demand. The trend of the primary energy requirement of a city shows how the internal aggregate demand has changed over time. Similarly, the conversion section of the energy balance provides information on energy conversion efficiency and how the technical efficiency of aggregate conversion has changed over the study period could be easily analyzed from energy balance tables. Final consumption data can be used to analyze the evolution of useful energy demand of the city by fuel type and by sector of use. Such analyses provide better understanding of the demand pattern of each sector and energy source. As a simple example, figure 19 shows that how the fossil fuel has been distributed in the urban energy system. It can be observed, approximately 1.125 Mtoe (Blue box) of the 2.624 Mtoe (Red Box) provided has been consumed in the final energy level to provide the major part of the city's thermal energy demand. The details of electricity generated from fossil fuel is demonstrated by the green box where the amount of waste energy from this process is estimated to be about 0.755 Mtoe (See the total column)

Urban Energy System Balance (Baseline)

Unit : Mtoe

Levels	Traditional Fuels	Fossil fuels	Nuclear	Solar	Wind	Biomass	Geothermal	Hydro	Waste	Electricity	Heat	Total
Resources	0.000	2.624	0.783	0.018	0.002	0.089	0.000	0.199	0.147	0.000	0.000	3.862
Import	0.000	2.624	0.783	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.407
Production	0.000	0.000	0.000	0.018	0.002	0.089	0.000	0.199	0.147	0.000	0.000	0.455
Conversion	0.000	-1.499	-0.783	-0.018	-0.002	-0.089	0.000	-0.199	-0.137	1.308	0.000	-1.419
Hydro	-	-	-	-	-	-	-	-0.199	-	0.169	-	-0.030
Wind	-	-	-	-	-0.002	-	-	-	-	0.001	-	-0.001
Geothermal	-	-	-	-	-	-	0.000	-	-	0.000	0.000	0.000
Biomass	-	-	-	-	-	-0.089	-	-	-	0.036	0.000	-0.053
Solar	-	-	-	-0.018	-	-	-	-	-	0.004	-	-0.015
Waste	-	-	-	-	-	-	-	-	-0.137	0.062	-	-0.075
Fossil	-	-1.499	-	-	-	-	-	-	-	0.724	-	-0.775
Fossil-CHP	-	0.000	-	-	-	-	-	-	-	0.000	0.000	0.000
Nuclear	-	-	-0.783	-	-	-	-	-	-	0.313	-	-0.470
Final Energy	0.000	-1.125	0.000	0.000	0.000	0.000	0.000	0.000	-0.010	-0.065	1.135	-0.065
Heat in	0.000	-1.125	-	0.000	-	0.000	0.000	-	-0.010	-	1.135	0.000
Heat Recovery											0.000	0.000
Electricity in	-	-	-	-	-	-	-	-	-	-1.308	-	-1.308
Transmission	-	-	-	-	-	-				1.242		1.242
Demand	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-1.037	-0.932	-1.968
Residential	-	-	-	-	-	-	-	-	-	-0.486	-0.551	-1.037
Commercial	-	-	-	-	-	-	-	-	-	-0.551	-0.381	-0.931
Service	-	0.000	-	-	-	-	-	-	-	0.000	0.000	0.000
Sum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.206	0.203	0.409

Figure 18. Snapshot of the worksheet “Energy Balance”

Urban Energy System Balance (Baseline)

Unit : Mtoe

Levels	Traditional Fuels	Fossil fuels	Nuclear	Solar	Wind	Biomass	Geothermal	Hydro	Waste	Electricity	Heat	Total
Resources	0.000	2.624	0.783	0.018	0.002	0.089	0.000	0.199	0.147	0.000	0.000	3.862
Import	0.000	2.624	0.783	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.407
Production	0.000	0.000	0.000	0.018	0.002	0.089	0.000	0.199	0.147	0.000	0.000	0.455
Conversion	0.000	-1.499	-0.783	-0.018	-0.002	-0.089	0.000	-0.199	-0.137	1.308	0.000	-1.419
Hydro	-	-	-	-	-	-	-	-0.199	-	0.169	-	-0.030
Wind	-	-	-	-	-0.002	-	-	-	-	0.001	-	-0.001
Geothermal	-	-	-	-	-	-	0.000	-	-	0.000	0.000	0.000
Biomass	-	-	-	-	-	-0.089	-	-	-	0.036	0.000	-0.053
Solar	-	-	-	-0.018	-	-	-	-	-	0.004	-	-0.015
Waste	-	-	-	-	-	-	-	-	-0.137	0.062	-	-0.075
Fossil	-	-1.499	-	-	-	-	-	-	-	0.724	-	-0.775
Fossil-CHP	-	0.000	-	-	-	-	-	-	-	0.000	0.000	0.000
Nuclear	-	-	-0.783	-	-	-	-	-	-	0.313	-	-0.470
Final Energy	0.000	-1.125	0.000	0.000	0.000	0.000	0.000	0.000	-0.010	-0.065	1.135	-0.065
Heat in	0.000	-1.125	-	0.000	-	0.000	0.000	-	-0.010	-	1.135	0.000

Figure 19. Understanding the results of energy balance (an example)

The above representation is considered through developing the Energy Balance tables for both baseline and after intervention scenarios. Comparing theses two tables shows how the implementation of new policy interventions enables the co-benefits of the energy system in cities.

Cost Benefit Analysis

This worksheet gives CBA of the policy intervention scenarios. The input data required in this worksheet are the followings:

1- Average electricity price ($/kWh)

2- Average yearly discount rate (%)

3- Cost items for each investment such as: capital cost, installation cost, maintenance cost and fuel cost

The tool-calculated data are:

1- Total fixed capital investment
2- Total running/operation cost
3- Total benefit from electricity generation/ saving
4- Total benefit from thermal energy generation/saving
5- Payback period or the length of time required to recover the cost of each investment
6- Profitability index (BCR) at end of the period for each investment

To provide a better understanding of the CBA, the tool also calculates the Net Present Value (NPV) and BCR of the total investment for the short term period (up to 2030). Figure 20 shows the snapshot of part of this worksheet (details of the calculation are provided in the Principle Equations section).

Figure 20. Snapshot of part of the worksheet "Cost Benefit Analysis"

Besides economic issue, the lead-time for the erection of new technologies especially 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. But, the evaluation of worldwide smart grid projects shows that the operation of this technology will be accompanied with more expected lead time which in this tool, it has been considered to be about 8 years from the reference year. This issue has been considered through developing the CBA in the tool.

MAC Analysis

Based on the method of the marginal abatement cost (MAC) curve advocated by McKinsey, the amount of GHG discharge reduction and the relation of that measure cost are analyzed by the tool [12]. A marginal abatement cost curve is defined as a graph that indicates the cost, associated with the last unit (the marginal cost) of emission abatement for varying amounts of emission reduction (in general in million/billion tons of CO_2). Each box on the curve represents a different opportunity to reduce greenhouse gas emissions. The width of each box represents the emissions reduction potential that opportunity (measure) can deliver over its life period. And the height of each box represents the average net cost of abating with one tonne of CO_{2e} (carbon dioxide equivalent) through that activity.

The graph is ordered left to right from the lowest cost to the highest cost opportunities. Those opportunities that appear below the horizontal axis offer the potential for financial savings even after the upfront costs of capturing them have been factored in. Opportunities that appear above the horizontal axis are expected to come at a net cost. The average abatement costs can be calculated by dividing the total abatement cost by the amount of abated emissions (see figure 21).

Figure 21. Snapshot of the worksheet “MAC Analysis”

There is also one push button “Update” in this worksheet that the user can press to refresh the curve for a new set of data entry.

Sustainability Analysis

There are many scientific publications proposing approaches to measuring sustainability of the urban energy system with different goals, assumptions, definitions and indicators. Each indicator reveals a certain aspect of the system performance, which is important. In this tool, the following indicators are considered to express the sustainability performance of the city's energy system:

- ✓ Fossil fuel intensity indicator

The fossil fuel intensity reflecting the technical behavior of the energy system which can be defined as the total amount of respective primary fossil resources used divided by the total number of dwellings in the city.

- ✓ Diversification indicator

Several purely statistical indices have been proposed to measure the diversity of fuel supply the urban energy system context. In this tool, HHI, the Herfindahl Hirschman Index has been selected to represent the renewable energy diversification (details of the calculation are provided in the Principle Equations section).

- ✓ Urban Heat Island indicator

An urban heat island (UHI) is a metropolitan area that is significantly warmer than its surrounding rural areas due to human activities. The main cause of the urban heat island is the modification of the land surface by urban development which uses materials which effectively retain heat. The waste heat generated by the urban energy system is a secondary contributor.
This index is calculated as the ratio of waste heat generated by the urban energy system (calculated in worksheet "Energy Balance) to ambient reference temperature (298 K).

- ✓ GHG emission indicator

This indicator is composed of GHG emission in term of CO2eq per each year.

Because indicators may be expressed in different units, the normalization process has been considered in this worksheet. Quantification of the sustainability analysis is represented by the help of"amoeba" plot. To this aim, the indicators have been calculated on the basis of obtaining results from the energy balance worksheet. Finally, estimated sustainability indices for the urban energy system are represented in a table as shown in figure 22.

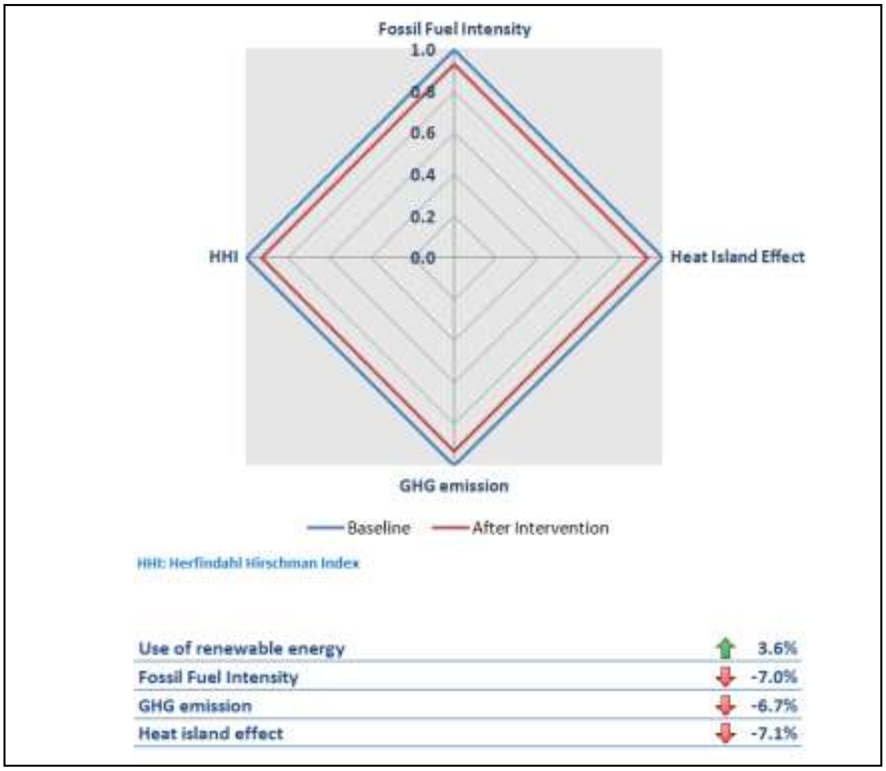


Figure 22. Snapshot of the worksheet “Sustaiability Analysis”

Sankey Diagram

Sankey diagram is a specific type of the energy flow diagram, in which the width of the arrows is shown proportionally to the flow quantity. It is also commonly used to visualize the energy balance of the urban energy system (See figure 23). It has been provided for both baseline and after intervention scenarios.

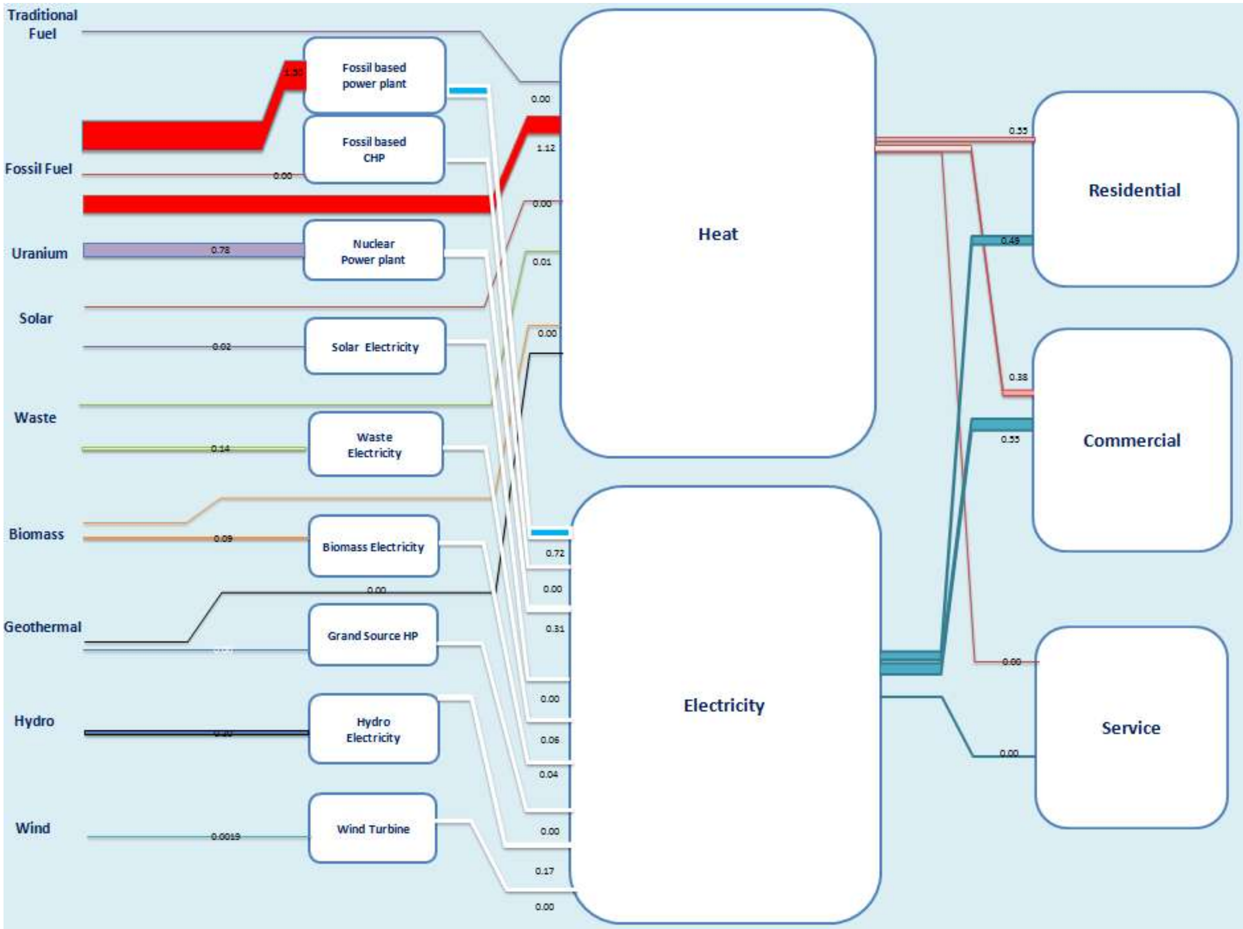


Figure 23. Snapshot of the worksheet “Sankey Diagram”

Database

In order to be able to estimate climate co-benefits of the urban energy system in a city, a list of energy conversion coefficients and emission factors are provided in following worksheets.

Energy Factors

This worksheet provides information about the coefficients such as specific energy consumptions for all dwellings or commercial sub-sectors while for different categories of energy use such as space heating, air conditioning, etc. The energy demand is calculated based on these factors. For example, the energy demand for space heating and air conditioning is calculated based on specific space heating and cooling requirements (kWh/sqm/yr) [13-14].

Emission Factors

The coefficients in worksheet are arranged in 2 different groups of emission factors: emissions from electricity and emissions from heat technology at end-user level. Electricity-based emission factors have been split into generation, transport and raw material and also processing and conversion subgroups in order to facilitate the tool in estimating life-cycle emission from electricity generation. The emission factor for different pollutants such as CO_2, CO, CH_4, NMC, SO_2, NOx, PM10 and PM2.5 are collected from official references [15-16].

Principle Equations used in the tool

This section provides a logical sequence of the calculations performed by the tool. Some of these equations are trivial but they may help to clarify how the various scenario parameters affect the results as well as in understanding the tool calculation algorithm. In order to keep this description as compact as possible, the definitions of various variables given in the last section of the manual are generally not repeated after the related equations.

As the energy intensities of the various energy uses in residential, commercial and Service sectors are expressed in kWh/MU, the specific energy consumption in the residential sector is expressed in kWh/dw/yr or kWh/cap/yr and in the service sector in kWh/sqm/yr, the straightforward internal energy unit of the tool is **Gigawatt-year** (1 GWa = 8760 GWh = 8.76 TWh = 31.536 PJ = (29.89) 30 trillion (10 12) Btu).

Useful energy demand calculations

Residential sector

Space heating

(1)

$$U_{RSHi}(\mathrm{GWa}) = [\mathrm{ND\ (Million)} \times \mathrm{DDW_i}(\%) \times \mathrm{DSH_i}(\%) \times \mathrm{DSZ_i}(\frac{\mathrm{sqm}}{\mathrm{dw}}) \times \mathrm{DSHEF_i}(\frac{\mathrm{Wh}}{\mathrm{sqm.C.h}}) \times \mathrm{HDD(C.Day)} \times 24(\frac{\mathrm{h}}{\mathrm{Day}})]/(1000 \times 8760)$$

Where, i refers to the dwelling type

Hot water

(2)

$$U_{RHWi}(\mathrm{GWa}) = [\mathrm{DDW_i}(\%) \times \mathrm{DHW_i}(\%) \times \mathrm{POP(Million)} \times \mathrm{DHWEF_i}(\frac{\mathrm{kWh}}{\mathrm{cap}})]/(8760)$$

Cooling

(3)

$$U_{RCOOLi}(\mathrm{GWa}) = [\mathrm{ND\ (Million)} \times \mathrm{DDW_i}(\%) \times \mathrm{DCC_i}(\%) \times \mathrm{DSZ_i}(\frac{\mathrm{sqm}}{\mathrm{dw}}) \times \mathrm{DCOOLEF_i}(\frac{\mathrm{Wh}}{\mathrm{sqm.C.h}}) \times \mathrm{CDD(C.Day)} \times 24(\frac{\mathrm{h}}{\mathrm{Day}})]/(1000 \times 8760)$$

Cooking

(4)

$$U_{RCOOKi}(\mathrm{GWa}) = [\mathrm{ND\ (Million)} \times \mathrm{DDW_i(\%)} \times \mathrm{DCO_i(\%)} \times \mathrm{DCOOKEF}\ \ (\frac{\mathrm{kWh}}{\mathrm{dw}})/(8760)$$

Electricity uses

(5)

$$U_{RELECi}(\mathrm{GWa}) = [\mathrm{ND\ (Million)} \times \mathrm{DDW_i(\%)} \times \mathrm{DSE_i(\%)} \times \mathrm{DELECEF}\ \ (\frac{\mathrm{kWh}}{\mathrm{dw}})/(8760)$$

Total useful energy demand in residential sector

(6)

$$U_{RT}(\mathrm{GWa}) = \sum_{\mathrm{i}} U_{RSHi} + \sum_{\mathrm{i}} U_{RHWi} + \sum_{\mathrm{i}} U_{RCOOLi} \ + \sum_{\mathrm{i}} U_{RCOOKi} + \sum_{\mathrm{i}} U_{RELECi}$$

Commercial sector

Space heating

(7)

$$U_{CSHi}(\mathrm{GWa}) = \mathrm{CA\ (Billion\ sqm)} \times \mathrm{CSZ_i(\%)} \times \mathrm{DCSH_i}(\frac{\mathrm{kWh}}{\mathrm{sqm}}) \times 1000/8760$$

Where, i refers to commercial sub-sector.

Cooling

(8)

$$U_{CCOOLi}(\mathrm{GWa}) = \mathrm{CA\ (Billion\ sqm)} \times \mathrm{CSZ_i(\%)} \times \mathrm{DCCOOL_i}(\frac{\mathrm{kWh}}{\mathrm{sqm}}) \times 1000/8760$$

Lighting and appliances

(6)

$$U_{CELECi}(\mathrm{GWa}) = \mathrm{CA\ (Billion\ sqm)} \times \mathrm{CSZ_i(\%)} \times \mathrm{DCELEC_i}(\frac{\mathrm{kWh}}{\mathrm{sqm}}) \times 1000/8760$$

Other heat uses

$$U_{COHi}(\text{GWa}) = \text{CA (Billion sqm)} \times \text{CSZ}_\text{i}(\%) \times \text{DCOH}_\text{i}(\frac{\text{kWh}}{\text{sqm}}) \times 1000/8760 \tag{9}$$

Total useful energy demand in commercial sector

$$U_{CT}(\text{GWa}) = \sum_\text{i} U_{CSHi} + \sum_\text{i} U_{CELECi} + \sum_\text{i} U_{CCOOLi} + \sum_\text{i} U_{COHi} \tag{10}$$

Service sector

Space heating

$$U_{SSHi}(\text{GWa}) = \text{SHA (Million sqm)} \times \text{DSSH}_\text{i}(\frac{\text{kWh}}{\text{sqm}})/8760 \tag{11}$$

Where, i refers to the service sub-sector

Cooling

$$U_{SCOOLi}(\text{GWa}) = \text{SHA (Million sqm)} \times \text{DSCOOL}_\text{i}(\frac{\text{kWh}}{\text{sqm}})/8760 \tag{12}$$

Motor fuels

$$U_{SMOTFi}(\text{GWa}) = [\text{GDP(Million \$)} \times \text{SGDP}(\%) \times \text{SGDP}_{\text{i}(\%)} \times \text{MOTFINT}_\text{i}\left(\frac{\text{kWh}}{\$}\right)]/8760 \tag{13}$$

Electricity

(14)

$$U_{SELECi}(\mathrm{GWa}) = [\mathrm{GDP(Million\ \$)} \times \mathrm{SGDP(\%)} \times \mathrm{SGDP_{i(\%)}} \times \mathrm{ELECINT_i}\left(\frac{\mathrm{kWh}}{\$}\right)]/8760$$

Other Heat uses

(15)

$$U_{SOHi}(\mathrm{GWa}) = [\mathrm{GDP(Million\ \$)} \times \mathrm{SGDP(\%)} \times \mathrm{SGDP_i(\%)} \times \mathrm{OHINT_i}\left(\frac{\mathrm{kWh}}{\$}\right)]/8760$$

Total useful energy demand in service sector

(16)

$$U_{ST}(\mathrm{GWa}) = \sum_{\mathrm{i}} U_{SSHi} + \sum_{\mathrm{i}} U_{SOHi} + \sum_{\mathrm{i}} U_{SCOOL_i} + \sum_{\mathrm{i}} U_{SMOTFi} + \sum_{\mathrm{i}} U_{SELECi}$$

Final energy calculations

Method for calculation of final energy in all end-users (residential, commercial and service sectors) is similar. Equation 17 represents how the final energy can be calculated in the residential sector.

(17)

$$F_{Rij\tau}(\mathrm{GWa}) = [U_{Rij\tau}(\mathrm{GWa}) \times \mathrm{PF_{Rij\tau}(\%)}]/\mathrm{EF_{Rij\tau}(\%)}$$

Where, τ refers to the technology type (heating, cooling, cooking, lighting, etc.) and j refers to fuel type.

For j=electricity, the calculation method of efficiency is represented by the following equation:

(18)

$$\mathrm{E}F_{\mathrm{Rij\tau}}(\%) = \mathrm{Y_{elec}} \times [1 - \left(\frac{1}{\mathrm{E_{loss}(\%)}}\right)]$$

Total final energy

(19)

$$F_T(\mathrm{GWa}) = F_{T_{\mathrm{non-elec}}}(\mathrm{GWa}) + F_{T_{\mathrm{elec}}}(\mathrm{GWa})$$

(20)

$$F_{T_{\mathrm{non-elec}}}(\mathrm{GWa}) = \sum_{\mathrm{i}}\sum_{\mathrm{j}}\sum_{\tau} F_{R_{\mathrm{ij}\tau}}(\mathrm{GWa}) + \sum_{\mathrm{i}}\sum_{\mathrm{j}}\sum_{\tau} F_{C_{\mathrm{ij}\tau}}(\mathrm{GWa}) + \sum_{\mathrm{i}}\sum_{\mathrm{j}}\sum_{\tau} F_{S_{\mathrm{ij}\tau}}(\mathrm{GWa})$$

j= Traditional, Fossil fuel, biomass and solar

(21)

$$F_{T_{\mathrm{elec}}}(\mathrm{GWa}) = \sum_{\mathrm{i}}\sum_{\mathrm{j}}\sum_{\tau} F_{R_{\mathrm{ij}\tau}}(\mathrm{GWa}) + \sum_{\mathrm{i}}\sum_{\mathrm{j}}\sum_{\tau} F_{C_{\mathrm{ij}\tau}}(\mathrm{GWa}) + \sum_{\mathrm{i}}\sum_{\mathrm{j}}\sum_{\tau} F_{S_{\mathrm{ij}\tau}}(\mathrm{GWa})$$

j= Electricity

Electricity supply /Demand at conversion level

Electricity supply

(22)

$$\mathrm{ELEC_k}(\mathrm{GWa}) = \left[\mathrm{Cap_k}(\mathrm{GW}) \times \mathrm{OF_k}\left(\frac{\mathrm{h}}{\mathrm{yr}}\right) \times \mathrm{LF_k}(\%)\right]/8760$$

Where, k refers to the electricity generation technology type (Fossil, solar, wind, nuclear, etc.)

Total electricity generated by the city's power supply system can be calculated through using the following formula:

(23)

$$\mathrm{ELEC_T}(\mathrm{GWa}) = \sum_{\mathrm{k}} \mathrm{ELEC_k}$$

Electricity supply –demand match

Managing the electric load is all about matching supply and demand. Since electricity is the only commodity that is simultaneously produced and consumed, matching supply and demand must happen every second of every hour of every year in perpetuity (or as long as society wants electricity). To ensure supply can meet expected demand at a given moment in time t, the city's power supply system must plan and procure generation in staggered amounts over the course

of time leading up to time *t*. The level of demand for electricity in a city varies hourly, daily and seasonally as well as regionally. In this case, renewable energy resources can be able to concurrently match or exceed that portion of demand for electricity at each moment in time.
The tool provides a simple approach to formulate matching electricity supply with demand in the context of the capacity constrained electricity system by introducing the build-up new capacity variable as follow:

$$F_{T_{\mathrm{elec}}} = \mathrm{ELEC_T} + \Delta\mathrm{ELEC_T} \tag{24}$$

$$\begin{cases} \Delta\mathrm{ELEC_T} > 0 & if \quad F_{T_{\mathrm{elec}}} > \mathrm{ELEC_T} \\ \Delta\mathrm{ELEC_T} = 0 & \mathrm{if} \quad F_{T_{\mathrm{elec}}} = \mathrm{ELEC_T} \\ \Delta\mathrm{ELEC_T} < 0 & if \quad F_{T_{\mathrm{elec}}} < \mathrm{ELEC_T} \end{cases}$$

And

$$\Delta\mathrm{ELEC_T} = \sum_{\mathrm{k}} \Delta\mathrm{ELEC_K} = \mathrm{NewAddCap_{PV}} + \mathrm{NewAddCap_{Wind}} + \mathrm{NewAddCap_{Waste}} + \mathrm{NewAddCap_{Biomass}} + \mathrm{NewAddCap_{Hydro}} \tag{25}$$

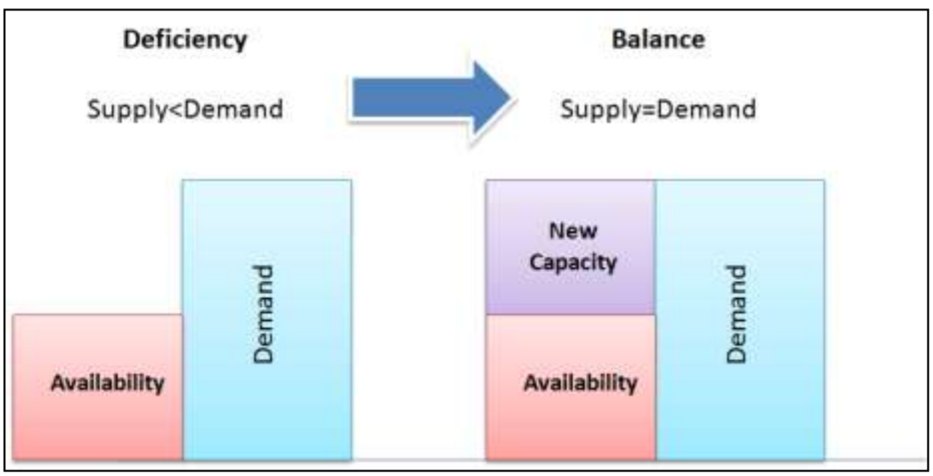


Figure 24. Role of Build-up new capacity variable to match supply and demand

The amount of $\Delta\mathrm{ELEC_T}$ can be defined by the user through introducing new intervention policy based on using alternative energy source which is described in following section.

Primary energy supply

$$\text{Res(Mtoe)} = [\sum_{k} \frac{\text{ELEC}_T}{Y_k} + F_{T_{\text{non-elec}}}] \times \text{CF} \qquad (26)$$

Where, k refers to the electricity generation technology type (Fossil, solar, wind, nuclear, etc.). CF is the conversion factor (1 GWa= 0.752 Mtoe)

Co-benefits evaluation

Energy saving

Lifestyle changes

$$\text{ElecSave}_{\text{LFS}}(\text{GWh}) = F_{T_{\text{elec}_\delta}} - F_{T_{\text{elec}_{\delta_{\text{New}LFS}}}} \qquad (27)$$

$$\text{HeatSave}_{\text{LFS}}(\text{GWh}) = F_{T_{\text{non-elec}_\delta}} - F_{T_{\text{non-elec}_{\delta_{\text{New}LFS}}}} \qquad (28)$$

Where, δ refers to the end-users; R for Residential, C for Commercial and S for Service.

Alternative energy

Photovoltaic

$$NewEelecGen_{\text{PV}}(\text{GWh}) = \sum_{\mu} \text{NewAddCap}_{\text{PV}\mu}(\text{GW}) \times \text{OF}_{\text{PV}\mu}\left(\frac{\text{h}}{\text{yr}}\right) \qquad (29)$$

Where, μ refers to the PV technology (inclined roof, flat roof and integrated type)

Wind energy

$$NewEelecGen_{\text{Wind}}(\text{GWh}) = \text{NewAddCap}_{\text{Wind}}(\text{GW}) \times \text{OF}_{\text{Wind}}\left(\frac{\text{h}}{\text{yr}}\right) \qquad (30)$$

Hydro electricity

(31)

$$NewEelecGen_{\mathrm{Hydro}}(\mathrm{GWh}) = \mathrm{NewAddCap}_{\mathrm{Hydro}}(\mathrm{GW}) \times \mathrm{OF}_{\mathrm{Hydro}}\left(\frac{\mathrm{h}}{\mathrm{yr}}\right)$$

Grand Heat Pump (Geothermal)

(32)

$$\mathrm{TotalAreaCoverage(Million\ sqm)} = [\mathrm{NewAddCap}_{\mathrm{GHP}}(\mathrm{GW}) \times \frac{\alpha}{\beta}\ ]/1000000$$

Where:

β= 3.51 (Conversion factor for converting 10^6 cooling ton to 1 GW)

α= 45 sqm/cooling ton (cooling index) [17]

(33)

$$ElecSave_{GHP}(GWh) = TotalAreaCoverage(Million\ sqm) \times \theta$$

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. This phenomenon is represented in the above formula by considering θ. The reasonable value for θ is reported by EPA standard that should be set to be about 65.2 kWh/sqm/yr.

(34)

$$HeatGen_{GHP}(GWh) = [\mathrm{NewAddCap}_{\mathrm{GHP}}(\mathrm{GW}) \times \mathrm{OF}_{\mathrm{GHP}_{\mathrm{winter}}}\left(\frac{\mathrm{h}}{\mathrm{yr}}\right)\ ]$$

Biomass electricity

(35)

$$NewEelecGen_{\mathrm{Bio}}(\mathrm{GWh}) = \sum_{\rho} \mathrm{NewAddCap}_{\mathrm{Bio}\rho}(\mathrm{GW}) \times \mathrm{OF}_{\mathrm{Bio}\rho}\left(\frac{\mathrm{h}}{\mathrm{yr}}\right)$$

Where, ρ refers to the Biomass technology (Direct combustion, CHP, Co-firing and Bio-gas)

Waste-to-Electricity

(36)

$$NewEelecGen_{\mathrm{Waste}}(\mathrm{GWh}) = \mathrm{NewAddCap}_{\mathrm{Waste}}(\mathrm{GW}) \times \mathrm{OF}_{\mathrm{Waste}}\left(\frac{\mathrm{h}}{\mathrm{yr}}\right)$$

Solar Water Heater

(37)

$$HeatGen_{\mathrm{SWH}}(\mathrm{GWh}) = \left[\mathrm{RAD}\left(\frac{\mathrm{MJ}}{\mathrm{sqm.\,day}}\right) \times \mathrm{NDW}_{\mathrm{SWH}}(\mathrm{Million}) \times \mathrm{B}_0\left(\frac{\mathrm{sqm}}{\mathrm{Dwelling}}\right) \times \mathrm{OF}_{\mathrm{SWH}}\left(\frac{\mathrm{day}}{\mathrm{yr}}\right) \times \mathrm{Y}_{\mathrm{SWH}}(\%)\right]/3.6$$

Where:
B_0= 4 (Average collector surface area to provide hot water for each household)

End-User Technology

Wall-Mounted Occupancy Sensors for Lighting (WMOSL)

(38)

$$\mathrm{TotalAreaCoverage}(\mathrm{Million\ sqm}) = [WRR\% \times \textstyle\sum_i(\mathrm{ND} \times \mathrm{DSH_i} \times \mathrm{DSZ_i})\ ] + [\mathrm{W}RC\% \times \mathrm{CA}]+[\mathrm{WRS}\% \times SHA]$$

(39)

$$ElecSave_{WMOSL} = \mathrm{TotalAreaCoverage}(\mathrm{Million\ sqm}) \times \frac{\mathrm{WF(kWh/y)}}{\mathrm{WA\ (sqm)}}$$

Where:
WF= 45 kWh/y (electricity saving per each measure per year) [18]
WA= 30 sqm (achieve minor motion coverage area) [18]

White LED Lighting

$$\text{TotalAreaCoverage(Million sqm)} = [LRR\% \times \textstyle\sum_i(\text{ND} \times \text{DSH}_\text{i} \times \text{DSZ}_\text{i})\ ] + [\text{L}RC\% \times \text{CA}]+[\text{LRS}\% \times SHA] \tag{40}$$

$$ElecSave_{LED}(GWh) = \text{TotalAreaCoverage(Million sqm)} \times \frac{\text{LEF(kWh/y)}}{\text{LEA (sqm)}} \tag{41}$$

Where:
LEF= 50 kWh/y (electricity saving per each measure per year) [19]
LEA= 10 sqm (achieve minor lighting coverage area) [19]

Compact Fluorescent Lighting

$$\text{TotalAreaCoverage(Million sqm)} = [FRR\% \times \textstyle\sum_i(\text{ND} \times \text{DSH}_\text{i} \times \text{DSZ}_\text{i})\ ] + [\text{F}RC\% \times \text{CA}]+[\text{FRS}\% \times SHA] \tag{42}$$

$$ElecSave_{CFL}(GWh) = \text{TotalAreaCoverage(Million sqm)} \times \frac{\text{FEF(kWh/y)}}{\text{FEA (sqm)}} \tag{43}$$

Where:
FEF= 37 kWh/y (electricity saving per each measure per year) [19]
FEA= 10 sqm (achieve minor lighting coverage area) [19]

High Performance Window

$$\text{TotalAreaCoverage(Million sqm)} = [HRR\% \times \textstyle\sum_i(\text{ND} \times \text{DSH}_\text{i} \times \text{DSZ}_\text{i})\ ] + [\text{H}RC\% \times \text{CA}]+[\text{HRS}\% \times SHA] \tag{44}$$

$$HeatSave_{HPW}(GWh) = \text{TotalAreaCoverage(Million sqm)} \times \text{HPF(kWh/sqm)} \times \text{WWR(\%)} \times \text{BH(m/m)} \tag{45}$$

Where:
HPF= 146 kWh/sqm (electricity saving per each sqm per each measure) [20]
WRW= 12% (Window-wall ratio)
BH= 2.5 (Building height ratio)

COP improvement

(46)

$$\text{ElecSave}_{\text{COP}}(\text{GWh}) = F_{T_{\text{elec}_{\text{Current-COP}}}} - F_{T_{\text{elec}_{\text{New-COP}}}}$$

And

$$F_{T_{\text{elec}_{\text{New-COP}}}} < F_{T_{\text{elec}_{\text{Old-COP}}}}$$

Smart Grid

For 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 behavior in response to feedback, and that the conditions surrounding feedback, such as frequency and specificity, are influential variables. 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% (See table 8).

For the 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% (See table 8).

A smart grid facilitates shifting load from peak load to shoulder or off-peak-load periods using demand response and distributed generation and storage. Doing so with demand response or storage and can save energy and carbon emissions, depending upon the mix of base, intermediate, and peak load generating resources being used at any given time to serve customers for a given utility. (See table 8).

(47)

$$\text{ElecSave}_{\text{Smart}}(\text{GWh}) = Saving_{\text{End-user}} + Saving_{\text{Load}} + Saving_{\text{Volt}}$$

(48)

$$Saving_{\text{End-user}} = F_{T_{\text{elec}}} \times \varphi_1$$

(49)

$$Saving_{\text{Load}} = \frac{SYS_{Eloss}}{\text{LLF}} \times \varphi_2$$

(50)

$$\text{LLF} = 0.3\text{LF} + 0.7\text{LF}^2$$

(51)

$$LF = \frac{AverageLoad}{MaximumLoad}$$

(52)

$$Saving_{\mathrm{Volt}} = \mathrm{SYS}_{\mathrm{Eloss}} \times \varphi_3$$

Where

φ_1= Percentage of electricity saving through using data monitoring, AIM and system diagnostics

φ_2= Percentage of electricity saving through the load management (Peak saving)

φ_3= Percentage of electricity saving through reducing voltage loss

Total co-benefit from energy

(53)

$$TotalEnergyCobenefit\ (GWa) = [\mathrm{ElecSave}_{\mathrm{LFS}} + \mathrm{HeatcSave}_{\mathrm{LFS}} + NewEelecGen_{\mathrm{PV}} + NewEelecGen_{\mathrm{Wind}} + NewEelecGen_{\mathrm{Hydro}} + ElecSave_{GHP} + HeatGen_{GHP} + NewEelecGen_{\mathrm{Bio}} + NewEelecGen_{\mathrm{Waste}} + HeatGen_{\mathrm{SWH}} + ElecSave_{WMOSL} + ElecSave_{LED} + ElecSave_{CFL} + HeatSave_{HPW} + \mathrm{ElecSave}_{\mathrm{COP}} + \mathrm{ElecSave}_{\mathrm{Smart}}]/8760$$

Total co-benefit from emission reduction

Co-benefit form air pollution (AP) reduction

(54)

$$TotalAPCobenefit(ton) = \sum_{\tau}\sum_{\theta}(EnergyCobenefit_{\tau}\ (GWa) \times EF_{\theta}(ton/GWa)$$

Where θ refers to pollutant type (i.e. CO, Nox, etc.) and τ refers to measure in equation 54.

(55)

Co-benefit form GHG reduction

$$TotalGHGCobenfit(ton) = \sum_{\tau}\sum_{\theta}[EnergyCobenefit_{\tau}\ (GWa) \times (EF_{CO2} + 21EF_{CH4})\ (ton/GWa)]$$

(56)

$$TotalEmissioncobenfit(ton) = TotalAPCobenefit + TotalGHGCobenfit$$

Cost Benefit Analysis (CBA)

Total capital investment

$$C_{Total}\,(Million\ \$) = \sum_{\tau} Capex_{\tau} \tag{57}$$

Where τ reefers to measure (i.e. solar PV, LED, etc.)

Total Benefit

$$B_{Total}\,(Million\ \$) = \sum_{\tau} (B_E + B_H)_{\tau} \tag{58}$$

Total cash flow

$$CF(Million\ \$) = B_{Total} - \sum_{\tau} Opex_{\tau} \tag{59}$$

Net Present Value

$$NPV(Million\ \$) = \sum_{n=1}^{T} \frac{CF_n}{(1+r)^n} - C_{Total} \tag{60}$$

Benefit-Cost Ratio

$$BCR = \frac{NPV}{C_T} \tag{61}$$

$BCR > 1$ $\quad$ $Profitable$

$BCR < 1$ $\quad$ $Non-profitable$

Marginal Abatement Cost (MAC)

(62)

$$MAC\ (\frac{\$}{tCO2}) = \frac{C_{total} - \frac{CF_n}{(1+r)^n}}{TotalGHGCobenfit}$$

n=T

Sustainability Indices

HHI, the Herfindahl Hirschman Index, defined as

(63)

$$HHI = \sum_i W_i^2$$

Where W_i refers to the share of primary energy source i in total primary energy supply

Urban Heat Island Index

(64)

$$UHI(\frac{PJ}{K}) = \frac{Q_{loss}(PJ)}{AT(K)}$$

(65)

$$Q_{loss}(PJ) = \sum_k Qloss_k + SYS_{Eloos}$$

Nomenclature

POP: Population

ND: Number of Dwelling (Million)

DDW_i : Fraction of urban dwellings per type

DHW_i: Share of urban dwellings with hot water facilities

DSH_i : Fraction of floor area that is actually heated in urban areas, by dwelling type

DCC_i : Fraction of floor area that is actually cooled in urban areas, by dwelling type

DCO_i : Share of urban dwellings with indoor cooking facilities (kitchen)

DSE_i : Fraction of total urban dwellings that are electrified

DSZ_i : Dwelling average size

$DSHEF_i$: Specific heating load rate by urban dwelling type.

$DCOOEF_i$: Specific cooling load rate by urban dwelling type.

DCOOKEF : Specific energy consumption for cooking in urban dwellings.

DELECEF : Specific electricity consumption in urban dwellings

$DHWEF_i$: Specific energy consumption for water heating per person

CDD: Cooling Degree Day

HDD: Heating Degree Day

CA: Coverage area by the commercial sector

CSZ_i : Fraction of commercial sub-sectors per type

$DCSH_i$: Specific heating load rate by commercial sub-sector.

$DCCOOL_i$: Specific cooling load rate by commercial sub-sector.

$DCELEC_i$: Specific electricity consumption by commercial sub-sector

$DCOH_i$: Specific heat consumption for other heating purpose by commercial sub-sector

SHA: Coverage area by the service sector

$DSSH_i$: Specific heating load rate by the service sector.

$DSCOOL_i$: Specific cooling load rate by the service sector.

GDP : Gross Domestic Production

SGDP: Share of service sector in total GDP

$SGPD_i$: Share of service sub-sector in GDP generated by the service sector

$\mathrm{MOTFINT}$: Motor fuel consumption intensity in service sub-sector

$\mathrm{ELECINT_i}$: Electricity consumption intensity in service sub-sector

OHINT : Other thermal energy intensity in service sub-sector

$\mathrm{PF_{Rij\tau}}$: Penetration of fuel type j into technology τ in dwelling type i

$\mathrm{EF_{Rij\tau}}$: Efficiency of fuel type j used in technology τ in dwelling type i

$F_{R_{\mathrm{ij\tau}}}$: Final energy provided for the residential sector

$F_{C_{\mathrm{ij\tau}}}$: Final energy provided for the commercial sector

$F_{S_{\mathrm{ij\tau}}}$: Final energy provided for the service sector

$\mathrm{E_{loss}}$: Network loss

Y_{elec} : efficiency of electricity consumption in cooking, lighting, etc.

COP: Coefficient of performance for air conditioning

$\mathrm{Cap_k}$: Installed capacity of each electricity generation technology

$\mathrm{OF_k}$: Operating factor of each electricity generation technology

$\mathrm{LF_k}$: Electrical load factor based on the nominal capacity of each electricity generation technology

$U_{Rij\tau}$: Useful energy demand in residential sector by dwelling type i through using fuel type j and technology τ
$\mathrm{Y_P}$: Conversion efficiency or thermal efficiency of each power generation technology

$\mathrm{ELEC_T}$: Total electricity generated by the existing installed capacity

$\Delta\mathrm{ELEC_T}$: Build-up new capacity

$\mathrm{ElecSave_{LFS}}$: Total useful energy saving through implementing new changes in lifestyle in each end-user

$F_{T_{\mathrm{elec}_{\delta_{\mathrm{New}LFS}}}}$: Total electricity saving after implementing new changes in lifestyle in end-user δ (Residential, Commercial or Service)

$F_{T_{\mathrm{non-elec}_{\delta_{\mathrm{New}LFS}}}}$: Total thermal energy saving after implementing new changes in lifestyle in end-user δ (Residential, Commercial or Service)

$NewEelecGen_{\mathrm{PV}}$: Electricity generated based on the new installed capacity for PV

$\mathrm{NewAddCap}_{\mathrm{PV}_{\mu}}$: New added capacity for PV per each technology μ

$NewEelecGen_{\mathrm{Wind}}$: Electricity generated based on the new installed capacity for wind energy

$\mathrm{NewAddCap}_{\mathrm{Wind}}$: New added capacity for wind energy

$NewEelecGen_{\mathrm{Hydro}}$: Electricity generated based on the new installed capacity for hydro

$\mathrm{NewAddCap}_{\mathrm{Hydro}}$: New added capacity for hydro

$\mathrm{TotalAreaCoverage}$: Total residential area covered by GHP

$\mathrm{NewAddCap}_{\mathrm{GHP}}$: New added capacity for GHP

$ElecSave_{GHP}$: Total electricity saving through using GHP

$HeatGen_{GHP}$: Total heat generated through using GHP

$NewEelecGen_{\mathrm{Bio}}$: Electricity generated based on the new installed capacity for biomass

$\mathrm{NewAddCap}_{\mathrm{Bio}\rho}$: New added capacity for Biomass

$NewEelecGen_{\mathrm{Waste}}$: Electricity generated based on the new installed capacity for Waste-to-Electricity

$\mathrm{NewAddCap}_{\mathrm{Waste}}$: New added capacity for Waste-to-Electricity

$HeatGen_{\mathrm{SWH}}$: Thermal energy generated through using solar water heater

$\mathrm{NDW}_{\mathrm{SWH}}$: Number of households/dwellings which are planned to use solar water heater

$\mathrm{OF}_{\mathrm{SWH}}$: operating factor of solar water heater which indicates total sunny days per year

$\mathrm{Y}_{\mathrm{SWH}}$: Collector efficiency which can be considered by 80%

$WRR\%$: Percentage of coverage area by WMOSL in residential sector

$WRC\%$: Percentage of coverage area by WMOSL in commercial sector

$WRS\%$: Percentage of coverage area by WMOSL in service sector

$LRR\%$: Percentage of coverage area by Light LED in residential sector

$LRC\%$: Percentage of coverage area by Light LED in commercial sector

$LRS\%$: Percentage of coverage area by Light LED in service sector

$FRR\%$: Percentage of coverage area by compact Fluorescent Lighting in residential sector

$FRC\%$: Percentage of coverage area by compact Fluorescent Lighting in commercial sector

$FRS\%$: Percentage of coverage area by compact Fluorescent Lighting in service sector

$HRR\%$: Percentage of coverage area by high performance window technology in residential sector

$HRC\%$: Percentage of coverage area by high performance window technology in commercial sector

$HRS\%$: Percentage of coverage area by high performance window technology in service sector

$Saving_{\mathrm{End-user}}$: Electricity saving through data monitoring, AIM and system diagnosis

$Saving_{\mathrm{Load}}$: Electricity saving through managing the electrical load

$Saving_{\mathrm{Volt}}$: Electricity saving through reducing the voltage loss

$Saving_{\mathrm{RE}}$: Electricity saving through supporting renewable energy generation

$\mathrm{SYS}_{\mathrm{Eloss}}$: Total energy loss through electricity distribution and uses

EF_{θ} : Emission factors per each pollutant (t/GWh)

EF_{CO2} : Emission factor for CO_2

$(EF_{CH4}$: Emission factor for CH_4

$Capext_{\tau}$: Capital investment requirement for each measure

B_E : Total benefit from electricity generation or saving for each measure

B_H : Total benefit from heat generation or saving for each measure

$Opex_\tau$: Operation cost (i.e. fuel cost, labor cost and maintenance cost) for each measure

r: Discount rate

n: period (year)

T: Time
CRF: Capital Recovery Factor

Q_{loss} : System total heat loss

$Qloss_k$: Heat loss from each power generation technology (calculate from last column of the energy balance sheet)

AT : Ambient temperature (K)

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