How to Assess the Energy Performance of Cities?

Setting targets for urban energy efficiency is problematic

Cities are open systems and heavily rely on trade for their energy (and food) supply. This makes any analysis of urban energy metabolism extremely complex. Setting general and uniform targets, like a 40% reduction of emissions by 2030 as proposed in the Covenant of Mayors, generates more problems than solutions if we do not first discuss context, scale, and definitions. General targets set at city level do not consider potential implications for the many specialized functions (residential sector, economic sectors, transport, etc.) carried out in the city, nor for cities' dependence on trade (primary resources, industrial production). On the other hand, targets set for specific processes (e.g., efficiency of buildings, transport efficiency) do not link (potential) energy savings at the local (sectoral) scale to possible impacts on performance at city-level.

A city's metabolic pattern of energy involves two sets of conversions that are qualitatively different and demand distinct analyses and indicators. First, primary energy sources (e.g., coal, oil, solar radiation, wind) are transformed into energy carriers (fuel, electricity), then energy carriers are consumed to perform the many functions that characterize the city (conversion of energy carriers to end-uses). In addition, the overall analysis of the metabolic pattern must include dimensions beyond energy: local and global emissions, economic costs, employment, citizens' quality of life, etc. Without considering all these dimensions it is easy to fall into a trap of flawed monitoring, where an unplanned fall in economic activity may be interpreted as successful environmental policy.

A meaningful analysis of urban energy metabolism must necessarily be based on a *complex information space*, linking diverse aspects of urban metabolism at different scales and levels. Use of indicators and targets that ignore the dependence of urban energy consumption and emissions on trade (imports from outside the city boundaries) risk incentivizing cost-shifting strategies (externalization). Also, the use of common per-capita indicators for extremely open systems like cities, where workers, consumers and tourists continuously move in and out, can be outright misleading. For example, in Barcelona tourists account for 22% of the total hours of human activity spent in consumption in services, comprising leisure, entertainment, culture, hotels and catering. Our analysis also indicates that 50% of the hours of paid work performed inside Barcelona concern non-resident workers. Would these workers live in Barcelona, an extra 19,5km^2 of apartments and an extra 38% of electricity and heat would be required in the residential sector (not taking into account their families). Instead, these workers use public transport or infrastructure for private mobility.

Key message

Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) is a novel methodology for characterizing and monitoring the energetic performance of cities. It is based on complex systems theory and generates quantitative indicators for informing policy-making.

The end-use matrix is MuSIASEM's main tool for understanding how, where, when, and why different forms of energy carriers are used to perform the city's multiple tasks and functions. It integrates heterogeneous data, uses multiple scales of analysis, addresses the openness of the urban system (fluidity of population), and allows a meaningful comparison among cities at (sub) sectoral level.

The end-use matrix has been validated for the city of Barcelona.

Tools for moving from energy efficiency to energy performance

The energy end-use matrix is a novel tool that provides organized information related to different scales, levels and dimensions of analysis to inform energy policy. It identifies key aspects such as: Which types of energy carriers are used and how much? Who is using them, when, where and why? The end-use matrix overcomes the limits of conventional quantitative analysis by moving away: (i) from mono-scale, mono-dimensional analysis of efficiency toward multi-scale, multi-dimensional analysis of energy performance; (ii) from predicative toward impredicative representations (and from deterministic to contingent results); (iii) from models providing representations chosen by analysts toward co-production of information with the users of the analyses.

An example of an energy end-use matrix developed for the city of Barcelona is shown in Figure 1. It illustrates information for three levels of analysis: the city as a whole, economic sectors and subsectors. For example, we see that Services and Government play a dominant role in Barcelona's paid work sector in terms of total human activity, value added and electricity and fuel consumption. However, in order to make meaningful comparisons among (sub-)sectors, we need to look at the metabolic rates (EMR per hour) and densities (EMD per km^2) (Figs. 1 and 2). For example, Barcelona's port has a higher metabolic rate (EMR) for all energy carriers than the other economic sectors (except energy sector).

This analysis can be further extended, bridging with even lower levels up till individual structural elements characterized by technical aspects, and upper hierarchical levels (metropolitan area, province, country).

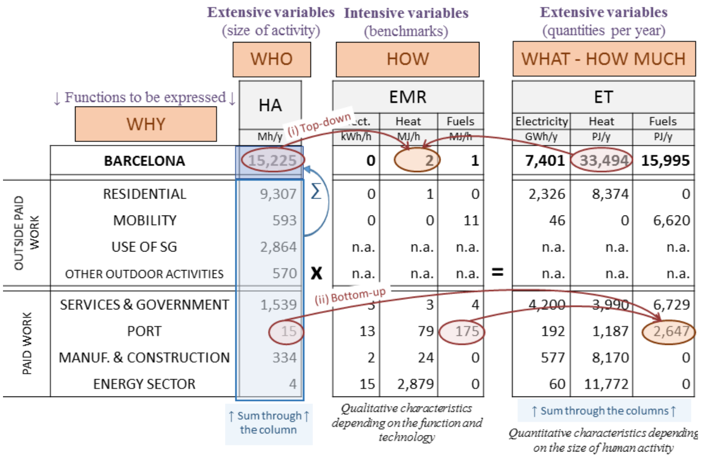

Figure 1. Simplified end-use matrix characterizing the city's functions by energy throughput (ET), hours of human activity (HA) and their metabolic ratios (EMR).

Relevance of this tool for urban energy policy

The energy end-use matrix improves transparency and provides relevant information on individual economic (sub) sectors and activities so as to better inform sustainability pacts among cities. Its design accommodates the integration of data related to other relevant factors, such as food, water, time and space use, demographic aspects, inequalities among urban districts, and waste generation. However, at the same time the end-use matrix standardizes the characterization of the urban metabolic pattern among cities. In this way, it improves the transparency of the information for participatory processes and auditing of

Policy recommendations

To handle the problem of urban (in)sustainability we must abandon business as usual and embrace the philosophy of complexity by developing and using tools that can identify and characterize policy relevant issues. In this context, it is important to:

(i) Characterize simultaneously different scales, levels and dimensions of analysis;
(ii) Generate information that is transparent and co-produced in participatory processes;
(iii) Generate contextualized and comparable information, such as metabolic rates and densities for economic (sub)sectors and activities, in order to identify best practices among cities.

MuSIASEM's energy end-use matrix for cities is a promising step into this direction.

public policies as well as for comparative studies (among cities) of urban policies.

Following the same logic as Wikipedia, and similarly to what already done in the Covenant of Mayors, a reference website where the end-use matrixes of different cities can be consulted is recommendable. Only then a meaningful comparison among cities can be carried out by comparing the performances of specific economic sectors and sub-sectors and not only the overall efficiency at city level.

Further reading:

Deliverable 4.3: *The metabolism of Barcelona: characterizing energy performance across levels and dimensions of analysis at the city level.*

Table 1. Example of an end-use matrix: Services and Government Sector of Barcelona

	HA	US	EMR			EJP	EMD			EUSP	ET			VA
			Elect.	Heat	Fuel		Elect.	Heat	Fuel		Elect.	Heat	Fuel	
	Mh	km^2	kWh/h	MJ/h	MJ/h	€/h	kWh/m^2	MJ/m^2	MJ/m^2	€/m^2	GWh	PJ	PJ	M€
SERVICES & GOV.	**1,539**	**31.8**	**2.7**	**2.6**	**4**	**39**	**132**	**125**	**211**	**1,884**	**4,200**	**3,990**	**6,729**	**59,956**
Education	101	3.6	1.3	6.3	0	35	38	177	0	986	135	637	0	3,542
Healthcare	157	1.9	1.4	1.3	0	22	116	104	0	1,805	223	201	0	3,477
Offices	641	7.0	1.9	1.2	0	45	177	112	0	4,075	1,246	792	0	28,697
Commerce	321	8.3	4.1	5.4	0	35	156	208	0	1,337	1,300	1,730	0	11,114
Hotels, bars & rest.	135	2.0	2.2	2.0	0	37	149	133	0	2,467	304	270	0	5,031
Other	119	3.7	5.9	3.0	0	33	190	99	0	1,063	696	360	0	3,881
Transport	65	5.3	4.6	0.0	104	65	56	0	1,278	800	296	0	6,729	4,212

HA (Human Activity): *time invested in end-use per year*
US (Useful Surfaces): *quantity of area devoted to end-use*
ET (Exosomatic Throughput): *Amount of energy carrier i (electricity, heat or fuel) metabolized by end-use.*
VA (Value Added): *Value of goods & services produced by end-use*

EMR (Exosomatic Metabolic Rate): *ET_i/HA: amount of energy carrier metabolized per hour of work allocated to end-use*
EJP (Economic Job Productivity): *GVA/HA: value added per hour invested in end-uses*
EMD (Exosomatic Metabolic Density): *ET_i/US: amount of energy carrier metabolized per quantity of area devoted to end-uses*
EUSP (Economic Useful Surfaces Productivity): *GVA/US: value added per area of end-use*

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 649342.

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