DATA QUALIFICATIONS AND DATA AVAILABILITY FOR RESOURCE FLOW ANALYSIS IN SUPPORT OF URBAN PLANNING: AMSTERDAM'S ENERGY METABOLISM

Ilse M. VOSKAMP [1, 2]
Sven STREMKE [1, 3]
Marc SPILLER [2]
Adri VAN DEN BRINK [1]
Huub H.M. RIJNAARTS [2, 3]

[1] Landscape Architecture Chair Group, Wageningen University and Research Centre, Email: ilse.voskamp@wur.nl
[2] Sub-department of Environmental Technology, Wageningen University and Research Centre
[3] Amsterdam Institute for Advanced Metropolitan Solutions (AMS)

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Abstract

Sustainable urban resource management gains importance due to ongoing urbanization. Cities increasingly show commitment to reduce their environmental pressure. Amsterdam, for instance, has the ambition to generate twenty percent more renewable energy per capita in 2020 than in 2013. To reach Amsterdam's sustainability objectives, a detailed understanding of the city's resource flows is required. At what level temporal and spatial resolution should resource flows be analysed to support urban managers in choosing planning interventions, what is the availability of data needed for such analyses and is there a gap between data needed and data available?

This research addresses abovementioned question from an Urban Metabolism (UM) and Material Flow Analysis (MFA) perspective, with particular focus on planning and design practice. A case study on the energy objectives of Amsterdam is presented, which is threefold. Firstly, the energy targets of the City of Amsterdam were translated into data needs. Secondly, the status quo of data availability was assessed. Thirdly, data gaps were identified.

Results show that two types of data needs can be distinguished: 1) data required for assessment (benchmarking) of the objectives, strategies and corresponding indicators, and 2) data required to inform the interventions that put the strategies into practice. Detailed knowledge of space-time dynamics, up to hourly data on building block level, showed to be essential to inform interventions that relate to the coupling of supply and demand and the sourcing of secondary resources. For Amsterdam, limited monitoring data is available. Especially data with a high temporal resolution is lacking.

1. Introduction

Sustainable urban resource management gains importance due to ongoing urbanization. Globally, urban areas accommodate more than half of the world's population and they are estimated to be responsible for 70% of the current pollution and resource depletion (Rees and Wackernagel, 2008). Growth of urban resource demands will not only accelerate resource depletion, but it will also add to direct and indirect environmental impacts associated to resource extraction and use (Agudelo-Vera *et al*., 2011). Many city authorities are dedicated to reduce the environmental pressure of their cities. For example the Aalborg Charter, signed by over 2700 European local authorities from more than forty countries, declares that the associated cities and towns shall move towards sustainability (European Commission, 1994). Likewise, the global C40 Cities network, to which seventy cities are affiliated, aims to collectively take measures to mitigate climate change. The network constitutes of megacities and so-called innovator cities, which are leaders in the field of taking climate change mitigation and adaptation measures and environmental sustainability (C40Cities, 2015).

One of the cities that have shown willingly to reduce its environmental pressure is Amsterdam. The city signed the Aalborg Charter, represents a C40 innovator city and has formulated ambitious objectives and related transition pathways in becoming a more sustainable city (City of Amsterdam, 2014a; City of Amsterdam, 2014b). For energy the targets are to generate twenty percent more renewable energy per capita in 2020 than in 2013, whilst decreasing energy consumption per capita by twenty percent. In terms of waste management, Amsterdam aims for an increase in municipal solid waste separation from 19% (2013) to 65% in 2020. To inform the strategies formulated to reach the city's sustainability objectives, a detailed understanding of the city's resource flows is required. This raises one main research question: At what level temporal and spatial resolution should resource flows exactly be analysed to support urban managers in choosing interventions to put the city's sustainability agenda in place, what is the availability of data needed for such analyses and is there a gap between data needed and data available? The objective of this paper is to respond to the question above, by means of a case study on the energy objectives of the City of Amsterdam from an Urban Metabolism (UM) and Material Flow Analysis (MFA) perspective, and considering planning and design practices.

2. Urban Metabolism and Material Flow Analysis

The notion of urban metabolism (UM) is increasingly used to analyse resource flows in cities and to develop sustainable urban resource management concepts and practices (Kennedy et al. 2011). It fuelled the idea that urban areas should become more self-sufficient and resource demands of cities should not exceed the carrying capacity of their hinterlands. This advocates a shift from the current linear metabolism of cities - using inputs only once- to a circular metabolism that incorporates recycling of resources (Castán Broto et al. 2012). While UM is being used by a range of disciplines (Castán Broto *et al*., 2012), most research originates from urban ecology, industrial ecology and related disciplines (Barles, 2010). Urban ecologists laid the theoretical base of UM, with Wolman (1965) being the first to characterize the city as an ecosystem (Barles 2010; Castán Broto et al. 2012). Wolman used the term metabolism to describe how cities process the "materials and commodities needed to sustain the city's inhabitants" (Wolman, 1965), whereas other urban ecologists used UM as a metaphor for the city as an organism (e.g. Odum 1989) (Barles, 2010; Castán Broto *et al*., 2012). From these process analytical studies of urban metabolic processes (Zhang 2013), a quantitative approach developed primarily within the discipline of industrial ecology (Castán Broto *et al*., 2012). This discipline commonly defines UM as "the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste" (Kennedy et al. 2007). Related research encompasses mainly empirical studies that quantify resource flows to disclose how a particular city functions at a specific moment in time (Kennedy *et al*., 2011). A variety of accounting and assessment methods have been used for these studies, including Material Flow Analysis, Energy Flow Analysis, and ecological footprint assessment (Barles, 2010; Zhang, 2013). Material Flow Analysis (MFA) is extensively used for quantitative assessment of urban metabolism (Castán Broto *et al*., 2012; Zhang, 2013). MFAs allow to systematically assess the inputs and outputs of selected resources of a predetermined system as well as the flows and stocks within the boundaries of that system. Although MFA is often referred to as if it is a specific methodology for UM research, it should be considered rather a procedure for systematic assessment than a detailed method. That is, MFA theory does not prescribe how to determine system boundaries, nor what flows to and stocks to consider. Consequently, MFA studies range from analyses of particular elements (like phosphorous) to comprehensive analyses of the UM (Kennedy et al. 2011). In particular studies that provide a comprehensive analysis of the UM are of importance to inform sustainable urban resource management, planning and design practices. Only with a systematic assessment of all resource flows and stocks of an urban system, resource management practices can be developed that consider the interconnectedness between different resource flows, like the energy-water-food nexus (Villarroel Walker *et al*., 2014). The complete and integrated picture of a city's resource flows that such MFAs provide can be used to "identify environmental problems and to design more efficient urban planning policies" (Castán Broto *et al*., 2012).

2.1 Urban metabolism research for urban planning and design

Although it is increasingly argued that UM analyses can contribute to sustainable urban planning and design, few examples of application in practice are reported (Kennedy *et al*., 2011). One possible reason for this is that UM is mainly used in a technological paradigm that fails to acknowledge the interplay between society and biophysical processes influencing the actual metabolism of cities (Wachsmuth, 2012). Such a version of UM excludes socio-economic indicators (e.g. lifestyle) that are crucial for achieving sustainability (Kennedy et al. 2011). Another reason could be caused by a mismatch of the scale levels at which UM studies are performed, i.e. that of the city or regional scale, and that of urban planning and design practice (district, neighbourhood, building block) (Spiller & Agudelo-Vera, 2011). Literature on comprehensive MFAs of European cities indicates that the great majority of these studies are performed on the level of the city or metropolitan region whilst employing a method that represents the urban system as a 'black-box', not providing a thorough insight of resource flows needed by planners and designers (Barles, 2009; Browne *et al*., 2011; Hammer and Giljum, 2006; Niza *et al*., 2009; Rosado *et al*., 2014). Furthermore, MFAs do not provide information on the spatial organisation of the flows and processes they describe and the concept of time is not properly dealt with either (Moffatt & Kohler 2008). Yet, knowledge of the variability of resource provision and consumption through time and space is essential to design more self-sufficient cities. One has to consider when and where resources are available to couple supply and demand or to enable sourcing of secondary and renewable resources (Agudelo-Vera *et al*., 2012). Knowledge of space-time dynamics is also important because it provides insight in the interconnectedness of flows. Understanding the linkages between flows is essential when aiming to propose effective interventions, and not those that simply shift the burden of resource extraction and use from one flow to another (Kenway *et al*., 2011). It also supports the development of synergetic solutions that have greater potential to reduce urban environmental pressures like pollution and resource depletion (Villarroel Walker *et al*., 2014).

3. Research Methodology

The approach taken in this case study on data qualifications for analysis of Amsterdam's energy metabolism comprised three elements. Firstly, the energy targets of the City of Amsterdam were translated into data needs. Secondly, the status quo of data availability was assessed. Thirdly, data gaps were identified.

3.1 From Energy Objectives to Data Needs

The energy objectives of the City of Amsterdam were translated into data needs using a literature review and stakeholder consultation. The stakeholders involved were the waste-to-energy company AEB Amsterdam, the City of Amsterdam (department of Urban Planning and Sustainability) and the water cycle company Waternet.

Firstly, the strategies, indicators and targets that are set to realize the city's two energy objectives were determined by a review of policy documents. Secondly, for each of the objectives the strategies were selected that require analysis of resource flows to inform implementation, as well as the planning interventions that put these strategies into practice. Because the strategies "Increase sustainability of the existing housing stock" and "Reduce energy consumption of the commercial and social sector" are rather generic and have no specified indicators or targets, one particular measure was chosen to illustrate the data needs for those strategies. Thermal energy recovery from wastewater, a measure considered by the water utility Waternet, was selected as intervention that can contribute to reduced residential energy consumption and/or to a reduction of energy consumption by commercial and public buildings. Recovery of thermal energy from wastewater and subsequent usage as source for heating of residential and office buildings seems a promising intervention for Amsterdam to reduce energy consumption. In the Netherlands, about 23% of the gas demand is used to heat water (Frijns *et al*., 2013). Due to this water heating, on a yearly basis 8 GJ per house is lost via the sewer. This implies that in theory there is a potential 2.560 TJ/year can be recovered from all 320,000 households in Amsterdam (Van Der Hoek, 2012). Thirdly, we identified at what temporal and spatial resolution energy flows have to be analysed to provide the information needed to 1) evaluate if the objectives and strategies are met (benchmarking), and 2) decide upon implementation of the selected interventions. Stakeholders were interviewed and stakeholder workshops were held to find out which analyses are necessary. Finally, the stakeholder consultations were also used to determine what spatial and temporal resolution data are required to perform these analyses. Data requirements were classified on spatial and temporal resolution, using a qualitative scale. In terms of temporal resolution, this scale ranges from decades (low resolution) to seconds (high resolution), whereas the spatial scale ranges from the Netherlands (low resolution) to exact GPS coordinates.

3.2 Assessment State of the Art Data Availability

Stakeholder commitment played a crucial role in identifying and obtaining the datasets necessary to assess data availability. The transdisciplinary research approach of the larger project this research is part of provided the commitment of relevant stakeholders that enabled us to obtain the required data. Affiliations of the stakeholders involved in this project are: AEB Amsterdam, City of Amsterdam (department of Urban Planning and Sustainability), Port of Amsterdam, Waag Society- institute for art, science and technology, Wageningen University and Research Centre (sub-department of Environmental Technology; Laboratory of Geo-information Science and Remote Sensing; Landscape Architecture Group), and Waternet. The data provided by the stakeholders were analysed on their temporal and spatial resolution. Subsequently, these data were classified in terms of spatial and temporal resolution, using the same qualitative scale that was used to classify the resolution of data required.

3.3 Identifying Data Gaps

Data available could then be compared with data required on spatial and temporal resolution because data needs and data availability were classified using the same qualitative scale. Accordingly, data gaps were identified: differences between the spatial-temporal resolution of data available and the qualifications of the data that are needed to assess and benchmark the energy targets set and data needed to perform the analyses that inform the choice for interventions to put the city's sustainability agenda in place.

4. Findings and Discussion

4.1 From Energy Objectives to Data Needs

To reach the two energy objectives that the City of Amsterdam has formulated to make the more sustainable, three strategies per objective are formulated. Both objectives and four out of the six strategies have indicators and corresponding targets. These are the following (City of Amsterdam 2014b):

1. Objective: Generate per capita in 2020 twenty percent more renewable energy than in 2013
   Indicator: Yearly amount of renewable energy generation per capita (GJ/ca)
   Targets: 3.3 GJ/ca in 2013, 3.5 GJ in 2016, 3.7 GJ/ca in 2018 and 4.0 GJ in 2020

   1.1. Strategy: Increase the amount of electricity generated from solar energy (PV)
   Indicator: Installed capacity PV (MW)
   Targets: From 9MW in 2013, towards 25 MW in 2016, 75 MW in 2018 and 160 MW in 2020

   1.2. Strategy: Increase the amount of electricity generated from wind energy
   Indicator: Installed capacity wind turbines (MW)
   Targets: From 67 MW in 2013, towards 76 MW in 2018 and 85 MW in 2020

   1.3. Strategy: Increase the usage of district heating
   Indicator: Number of house equivalents connected to the district heating network
   Targets: From 62.000 in 2013, towards 70.500 in 2016, 81.000 in 2018 and 102.000 in 2020

2. Objective: Energy consumption per capita in 2020 is twenty percent less than in 2013
   Indicator: Yearly energy consumption per capita (GJ/ca)
   Targets: 68 GJ/ca in 2013, 61.9 GJ/ca in 2016, 57.8 GJ/ca in 2018 and 54.4 GJ/ca in 2020.

   2.1. Strategy: Increase sustainability of the existing housing stock
   2.2. Strategy: Reduce energy consumption of the commercial and social sector
   2.3. Strategy: Stimulate energy-neutral building
   Indicator: Number of net-zero energy buildings
   Targets: From 0 in 2013 towards 1000 in 2018

4.1.1 Required analyses and data to benchmark objectives and strategies

In order to assess all indicators (both these related to objectives and strategies), yearly analyses have to be performed. The relevant spatial scale for benchmarking the objectives and strategies is the municipal scale level, because the indicators and corresponding targets are formulated at municipal level. Yet, to inform these yearly, municipal numbers, analyses at the building level are required. This is the level at which PVs and wind turbines are installed, connections to the district heating network are made and energy-neutral buildings are realized. As such, these analyses provide the information needed to determine the total numbers for Amsterdam as a whole.

4.1.2 Required analyses and data to inform strategies

To inform the strategies 1.1, 1.2 and 2.3 (i.e. where to implement PV panels, wind turbines and energy-neutral buildings) primarily data on city and climate characteristics is required, like data on land use, building protection status, roof top orientation and angle, building restrictions and distance to dwellings at building level. Conversely, assessing the options to realize strategy 1.3, 2.1 and 2.2 clearly also requires analyses of resource flows.

For strategy 1.3 different assessments are required. On the one hand, an analysis of building characteristics is required to assess which houses are suitable for connection to district heating, including ownership of the building, building typology (low-rise or high rise buildings), function (residential, industrial, commercial, etc.), existing or newly built houses. Likewise an analysis on neighbourhood characteristics is needed to know if implementation of new infrastructure (i.e. the district heating network itself) is possible. Moreover, the heat demand and potential supply have to be assessed. In Amsterdam the main elements on the supply side of the district heating system are two centralized combined heat and power (CHP) plants, which are Amsterdam's waste-to-energy plant and a gas-fired CHP-plant in Diemen, a smaller biogas turbine, several small fossil fuel based cogeneration turbines and heat storage facilities. When aiming to extend the district heating network, one needs to know whether these suppliers are able to meet the future demand. High time-space resolution data is required to get a good impression of the heat demand, considering that heat demand is seasonal and variable during the day, but also dependent on a building's function. This means that data on hourly demand at building block level is desirable for optimal system layout. Because heat can be stored up to several days, supply data of lower temporal resolution suffices (about 72-hourly). Supplier-specific data is required because each supplier feeds the heating network within a particular geographic area of the city.

In order to identify favourable locations to install heat exchangers that collect heat from the sewer network and transfer the heat from the sewer into the heating network (intervention for strategy 2.1 and 2.2), data with a high spatial and temporal resolution is of crucial importance. In particular because options to store the recovered thermal energy are limited. To enable the balancing of heat supply and demand, hourly data at neighbourhood level on quantity and temperature of the wastewater in the sewer as well as on heating demand are required.

4.2 Data Availability

4.2.1 Data to assess objectives and strategies

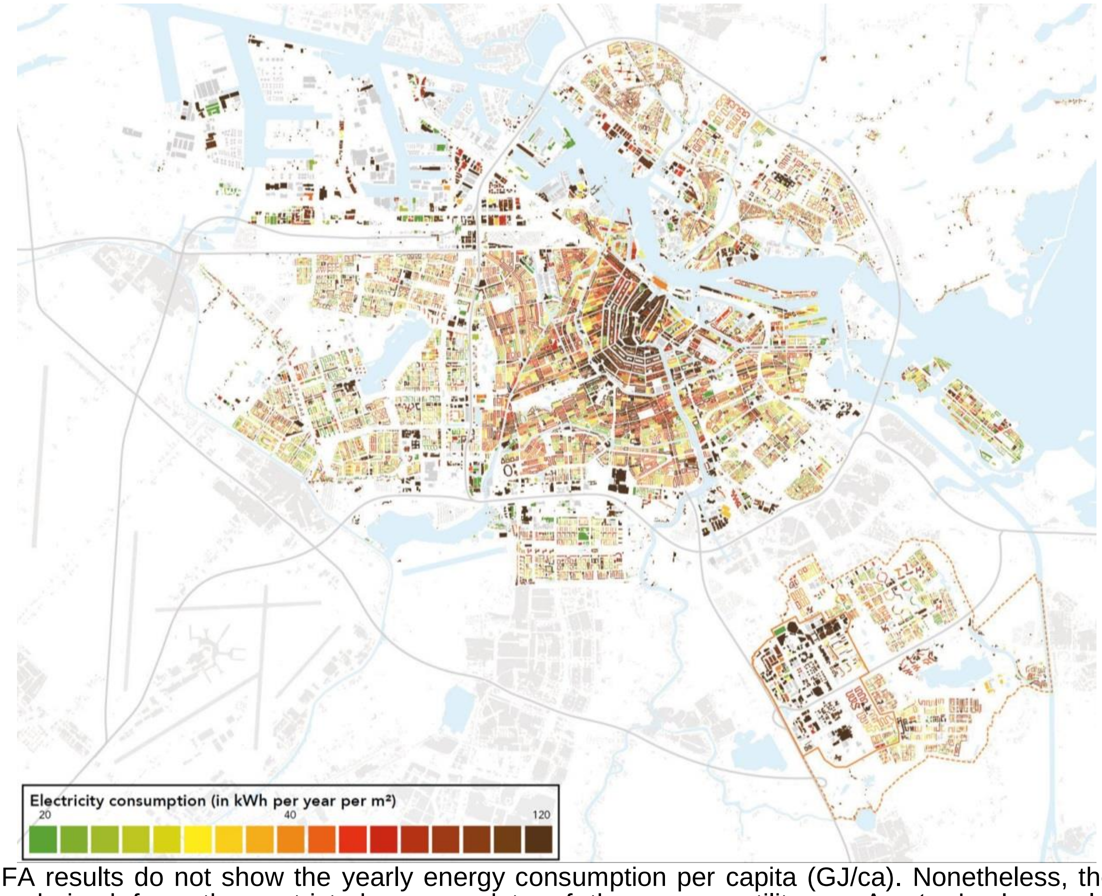
Table 1 Locally generated energy in Amsterdam Municipality in 2012, in total and per capita

	(TJ)	(GJ/ca)
Locally generated energy	**21.040**	**26,6**
Renewable energy	**19.199**	**24,3**
Electricity	**2.501**	**3,1**
Wind energy	560	0,7
Solar energy: PV	12	0,0
Incineration of green waste	1846	2,3
Biogas combustion	83	0,1
Heat and cold	**16.698**	**21,2**
Solar heat	Unknown	Unknown
(Geo)thermal	288	0,4
Incineration of green waste	231	0,3
Biogas combustion	214	0,3
Biomass fuelled stoves and boilers	15.815	20,0

Cold extracted from surface water	150	0,2
Energy recovered from waste	**1.842**	**2,3**
Electricity from waste incineration	1.637	2,1
Heat from waste incineration	205	0,3

The recently performed comprehensive MFA of Amsterdam provides insight in data availability for evaluation of Amsterdam's yearly renewable energy generation and consumption per capita (GJ/ca). The comprehensive analysis revealed the amount of locally generated renewable energy in Amsterdam Municipality in the year 2012 and it identified the amount of energy recovered from waste as other major category of local energy extraction within Amsterdam (shown in table 1). Note that not all categories included in the MFA are also considered in the calculation of Amsterdam's energy targets.

Although these numbers provide insight in the Amsterdam's renewable energy generation per capita (GJ/ca), only few are based on actual measurements of energy provision. A look at the data sources behind the figures on renewable energy generation shows that only the amount of cold extracted from surface water and the amount of electricity and heat produced from biogas combustion rely on actual measurements (AEB, 2015;Nuon, 2015). Wind and solar energy figures are based on installed capacity (City of Amsterdam, 2015; Windstats, 2015), whereas numbers for geothermal energy are estimates based on licensed ATES (Aquifer Thermal Energy Storage) capacity (City of Amsterdam, 2014c). Although electricity and heat production from waste incineration is measured (AEB, 2015), the biogenic waste fraction of the incineration waste in Amsterdam is unknown. Therefore the Dutch average percentage of the biogenic fraction in incinerated waste (Agentschap NL, 2013) was taken as a value for calculations. For the heat generation by biomass fuelled stoves and boilers, no Amsterdam-specific data were available. Therefore, top-down extrapolations from national data were used, provided by the Dutch Ministry of Infrastructure and the Environment (Klimaatmonitor, 2015). Data on the sourcing of solar thermal energy by solar heat collectors are lacking entirely. So, for evaluation of Amsterdam's yearly renewable energy generation per capita (GJ/ca) data are generally available. Yet, these data rely on calculations and estimations rather than on monitoring data of actual energy generation.



The MFA results do not show the yearly energy consumption per capita (GJ/ca). Nonetheless, these data can be derived from the restricted access data of the energy utility on Amsterdam's yearly energy consumption (EnergieInBeeld, 2015).

4.2.2 Data to inform strategies

Concerning data availability for the extension of the district heating network and the implementation of thermal energy recovery from wastewater, a distinction can be made between demand-specific and supply-specific data. In terms of demand specific data, data on energy (electricity and gas) consumption are available with a high spatial resolution, namely on building block level. Figure 1 shows these data for electricity consumption. Data with a higher temporal resolution than yearly are not available. Regarding the potential future demand for district heating in Amsterdam, a study on prospective additional connections has been performed (AEB and Nuon, 2012). Based on an analysis of building and neighbourhood characteristics, it has been determined for which buildings connection to the district heating network is feasible. For supply-specific data, data qualifications of the information available are diverse. As regards to district heating, the heat flow and its temperature is monitored at different places in the district heating network, including at the heat source, at boosters and transfer stations and at (particular) consumers. Depending on the location, data is recorded every minute up to every month (Nuon, 2015). Supplier-specific, validated monthly totals of the amount of heat supplied are reported (AEB, 2015). For the implementation of thermal energy recovery from waste water, essential data on sewer characteristics are available. For the entire municipality the drains and sewers with a diameter of at least one meter, which is the minimum required width for heat recovery from wastewater to be cost-effective, are known and mapped out (City of Amsterdam, 2014c). However, measurements on quantity and composition of the wastewater flow only occurs at the wastewater treatment plant. These influent characteristics are reported on yearly basis, but wastewater temperature is not recorded (Waternet, 2014).

4.3 Data Gaps

The analysis on data gaps uncovers that only for the assessment of (the indicators of) all strategies the data available meets the data qualifications (Figure 2). The data available for assessment of the objectives as well as for informing the planning interventions of strategies 1.3, 2.1 and 2.2 is of insufficient temporal resolution, except for some data on heat supply by the district heating network. The data available to assess the objectives partially lacks the required spatial resolution (such as data on heat from biomass fuelled stoves and boilers), whereas data on heat supply by the wastewater network (for 2.1 and 2.2) is lacking entirely.

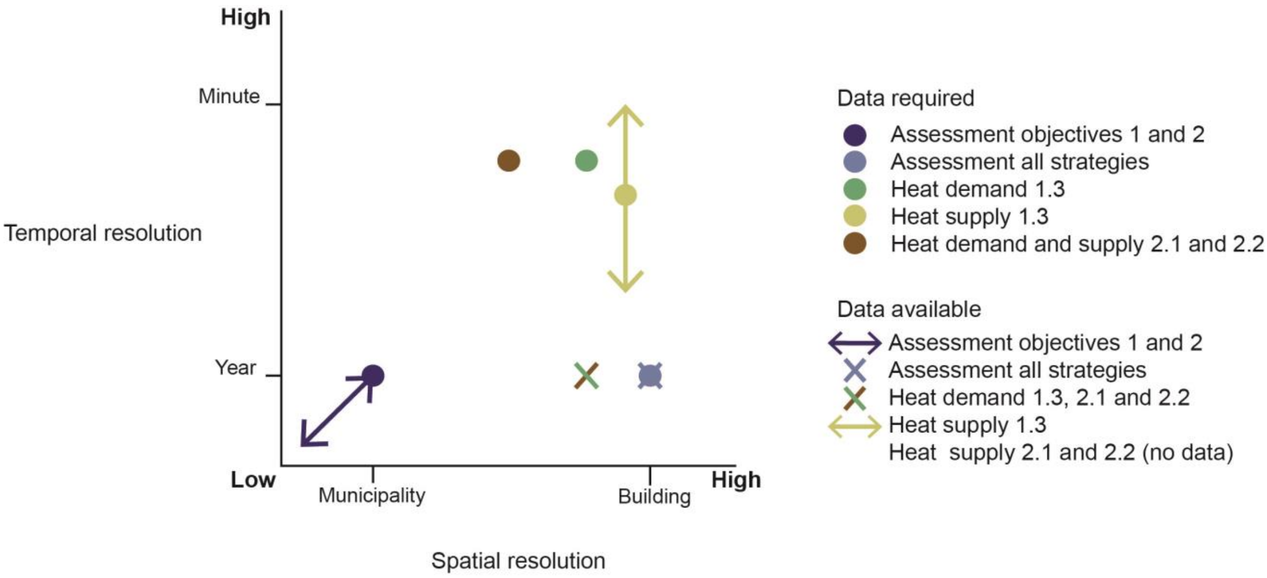


Figure 2 Comparison of data qualifications and availability for Amsterdam's energy objectives

5. Conclusion and Further Research

The case study of the energy metabolism of Amsterdam shows that we can distinguish between two types of data needs to inform the city's sustainability objectives: 1) data required for assessment of the actual, yearly renewable energy generation and consumption (status quo) and 2) data required to inform the interventions that put the strategies into practice (potentials). A comprehensive MFA study on the scale level of Amsterdam Municipality can provide the data needed to assess yearly renewable energy generation, whereas data on yearly energy consumption is available at the energy utility. Nonetheless, limited monitoring data is available that relies on measurements of actual yearly renewable energy production. Data qualifications to inform the strategies are highly dependent on the planning interventions envisioned. Detailed knowledge of space-time dynamics up to hourly data on building block level showed to be essential to inform interventions that relate to the coupling of supply and demand and the sourcing of secondary resources. For Amsterdam especially data with a high temporal resolution are hardly available. Accordingly much additional data of a high temporal and spatial resolution has to be obtained to perform the UM analyses that are needed to inform sustainable management, planning and design. Further research is needed that identifies and weighs different means to close the identified data gaps.

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