Energy and Data Management in Sustainable Cities through Urban Metabolism

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ABSTRACT

The built environment accounts for two-thirds of all greenhouse gas emissions, making interventions in this area pave the way for meeting climate resilience goals. Solutions have to be thoroughly efficient in improving the environmental impact of the built environment and take into consideration the true impact of that spans time and urban space.
This is possible through an urban metabolism approach that sees urban space as a holistic system of flows, materials and processes that interact and function like a living metabolism combined with analysis spanning the whole life cycle of the subject, revealing hidden costs and effects. Building clusters of any size from block to city can be modelled through innovative software to illustrate cumulative effects such as urban heat islands and pollution on Geographical Information Systems. Intervention scenarios can be developed and analyzed for their performance throughout the life cycle of subject buildings and results projected into the same urban metabolism view. R2Cities project will be presented to elaborate this method combining the urban metabolism approach and Life Cycle Assessment over the built environment to achieve nearly zero energy cities. As a result, decisions regarding urban scale retrofitting actions can be optimized for targeted improvements regarding environmental impacts, benefits and avoided burdens.
Keywords: urban metabolism, life cycle assessment, urban sustainability, retrofitting, spatial modelling, low carbon cities

INTRODUCTION

In recent decades, additional concerns have started to arise regarding the impacts of urbanization on environment and public well-being. Present rate of urbanization is faster than ever, as 50% of the global human population living in urban areas as of today is expected to rise all the way up to 70% in 2050 (Goldstein, et al. 2013). This means sustainability issues will be even more pressing in the forthcoming decades. In order to minimize the adverse effects of built environment and urbanization, tangible steps should be taken to incorporate the concept of sustainability in design and upgrading industrial and urban systems. Furthermore, for the success of "sustainable" systems, performance of these tangible steps needs to be monitored with sound and reliable methods. Another important issue is to adopt a holistic point of view during sustainability assessment and consider how individual systems interact with each other at a network level. Complex natural and human systems need quantification methods not only for flows such as energy, water, carbon, and pollutant fluxes but also for related cost and resulting environmental impacts in an integrated approach, based on life cycle thinking to achieve sustainable decision making.

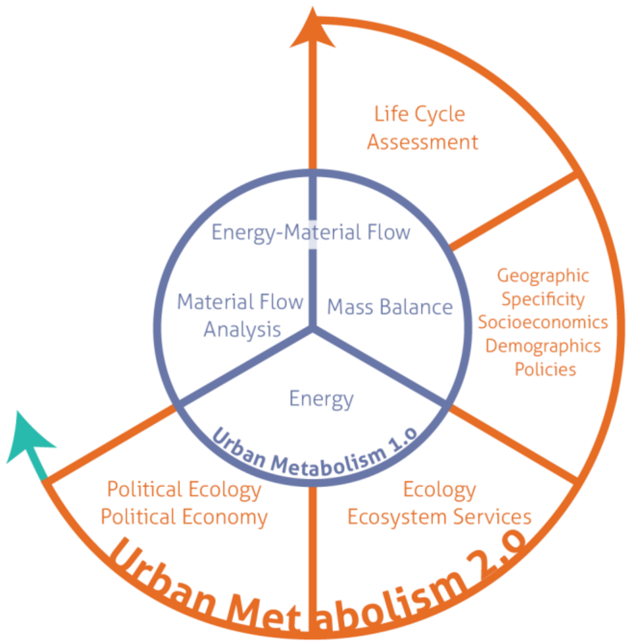

Figure 1 Future trends in application of urban metabolism [6]

To address these issues in urban settings, experts and academics have been conducting research under the term "*urban metabolism*" that "refers to a broad range of quantitative methods that attempt to conceptualize urban areas as organisms, requiring goods and energy to maintain functionality and support growth, while emitting waste as a by-product" (Goldstein, et al. 2013). As stated by Baynes and Wiedmann (2012), environmental sustainability assessment for urban metabolism may have two general purposes: monitoring and measuring the past or current environmental pressures, states, or impacts of urban areas. Recent studies suggest a need to improve the methods evaluating urban metabolism only through material flow analysis (MFA) and emergy (embodied energy) by integrating life cycle assessment (LCA) to these methods (Baynes ve Wiedmann 2012) (Chester, Pincetl ve Allenby 2012) (Pincetl, Bunje ve Holmes 2012)(Figure 1).Such an approach would bring standardization to urban metabolism studies, enhance communication of results with the stakeholders, enable comparison of different urban systems with each other, and support informed-decision making for planning as well as adaptation and mitigation strategies under sustainable urban development. The quest for analyzing bigger scale systems is a research topic under study to serve industrial networks, ecosystems, urban and societal communities. Though there exists no single bullet solution to answer all sustainability conundrums and quantification requirements, a holistic tool is needed to support this methodology.

Although the benefits of this strategy are acknowledged, so far, there is no holistic decision support methodology or tool which couples urban metabolism and life cycle approach in a large-scale such as city-level. The aim of this is study is to provide an overview about the urban metabolism approach for a given urban system and to go beyond the state of art with a sample study.

URBAN METABOLISM AS A HOLISTIC SOLUTION FOR SUSTAINABLE CITIES

The scale of urban issues is constantly increasing with accelerating urbanization and densification. Therefore, efforts towards tackling urban issues should go beyond present conditions and consider future trends. This necessitates temporal aspects to be considered for assessing impacts of urbanization. Only then, urban areas can reduce their footprints and cities can be ready for mitigating large scale impacts of global climate change. Furthermore, urban areas are not homogeneous in terms of population density, infrastructure, transportation or wireless networks etc., which necessitates spatial variances to be considered for understanding the true nature of such areas.

In addition, urban systems are multilayered and have many sub-systems within. These sub-systems are interconnected with each other and connected to exterior systems such as industrial zones. Finally, urban growth affects economy, humankind and the environment which in turn influence each other. In this sense, an effective approach to answer problems of urbanization should disaggregate grand urban systems but have a holistic point of view at the same time.

Therefore, there is a need of a new methodology that is capable of analyzing urban networks in terms of environmental impacts and associated external and embedded costs that will assist stakeholders and decision-makers to develop strategies to reduce urban environmental footprints, to mitigate effects of global climate change and to promote energy & resource efficiency(González, et al. 2013).

In order to cope with urbanization pitfalls, some methods are being used to understand urban systems. Urban metabolism, which is commonly traced back to Karl Marx(Pincetl, Bunje ve Holmes 2012), is one of them and roots from the analogy that associates urban systems with living organisms. Two distinct approaches used for urban metabolism include material flow accounting and Odom's emergy methods, both argued to have shortcomings (Goldstein, et al. 2013)(Pincetl, Bunje ve Holmes 2012).

In this study, it is proposed to expand the horizon of urban metabolism by incorporating LCA, geographic specificity, ecosystem services, and political economy. By this means, urban metabolism methods can be more effective in representing complex urban systems. The benefits of understanding urban metabolism are providing suitable measures of resource exploitation and waste generation as sustainability indicators and measures of resource intensity and circularity of resource streams (i.e. circular economy) that may be helpful in identifying opportunities for improvement(Ferrao ve Fernandez 2013).

As an urban metabolism tool, EPESUS, has performed as a web based platform for material and energy flow accounting at both buildings as singular facilities and at the industrial network level, capable of demonstrating life cycle impacts of production processes in addition to simple material flow analysis (MFA).

EPESUS AS AN URBAN METABOLISM PLATFORM

The relation of the urban and industrial ecosystems, especially in the field of energy and waste management has been identified as a major potential by the global policy makers in order to achieve GHG emission reduction targets.

Ekodenge has had the opportunity to develop the EPESUS software within past EU projects and field works into a platform which delivers sustainability analyses for the industrial and built environment. The platform delivers a holistic assessment capacity for the various material and energy flows of the studied systems, in relation with Life Cycle Impact and Life Cycle Cost assessments. Additionally the capacity to analyse these systems in a time series manner with hourly energy and flow data analyses has provided the capacity for the calculation of exact flows amounts among the system components.

At the urban level, the system components could be individual buildings, building groups or a district of a city. The buildings are assessed both with their whole life cycle flows and processes as well as their hourly breakdowns of energy demand. As shown in the below infographic, this approach enables the system to be addressed both in the 60 year life cycle span of a building and also with the hourly analyses of electricity, fuel and other relevant flows.

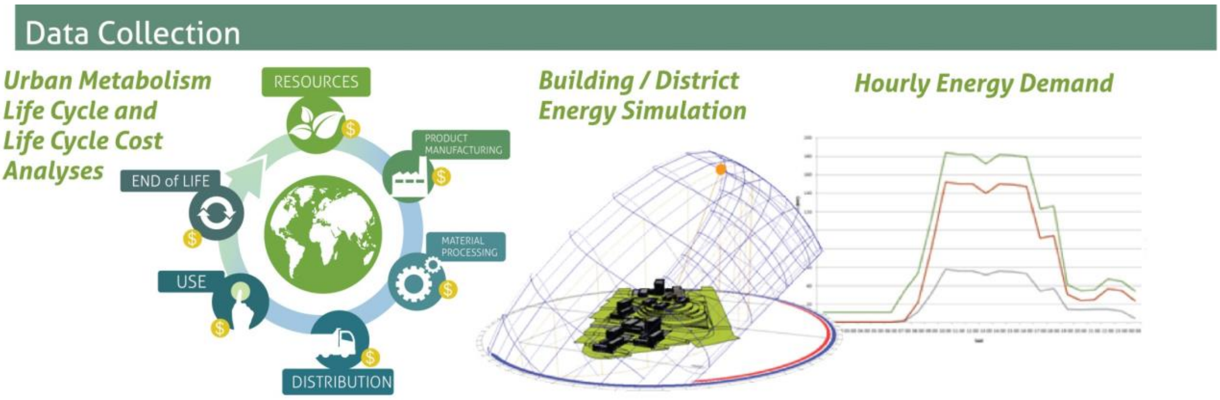

Figure 2 Levels of analyses performed by EPESUS

The ability to integrate temporal and spatial aspects into the analysis of multiple flows in urban space is the basis of EPESUS's urban metabolism capability. By altering parameters one can calculate and visualize changes in these flows and their impact on the overall Life Cycle Impact of the defined spatial zone.

R2CITIES PROJECT AS A CASE STUDY

Funded under European Union's Seventh Framework Programme for research, technological development and demonstration, the objectives of Renovation of Residential and Urban spaces towards: nearly zero energy CITIES (R2CITIES) project are to develop and to demonstrate replicable strategies for designing, constructing and managing large scale district renovations for achieving nearly zero energy cities. This covers a very ambitious renovation plan of three residential districts in Valladolid, Genoa and Kartal, which will involve more than 57.000 m2, 850 dwellings and 1500 users, with a potential of energy consumption reduction close to 60%.

In the design phases of the refurbishment projects of demonstration districts, a holistic methodology is applied with selected district sustainability indicators (consisting of energy, economic, comfort, social, environmental and urban indicators) which provide a similar approach to urban metabolism with a life cycle point of view. Different building retrofitting scenarios have been evaluated through these indicators and the best scenario for the district is selected by Kartal Municipality and other relevant stakeholders.

Retrofitting scenarios of Kartal district have been analyzed and evaluated with EPESUS platform by means of economic (LCC), environmental (LCA) and energy performances at district level.

Firstly, the information in building level which consists of floor area, building type, building height, occupant density, building age, has been defined in GIS-based EPESUS platform according to their locations. From the previously defined system model database of EPESUS, the most suitable model is selected according to the energy performance type of the building. This system models includes hourly energy demands, CO_2 emissions, environmental impact categories and life cycle costs per floor area for a year.

By defining all of the R2cities demonstration buildings in Kartal neighbourhood, one can have a district-level model which can display hourly energy demand density and CO_2 emissions of Kartal District. By extrapolating this information with the integrated databases of EPESUS platform to the city-level, energy consumptions, CO_2 emissions and retrofitting scenarios of the buildings in a city can be analyzed and monitored.

This has been an application of the urban metabolism approach to district and building level analyses within the scope of the project goals of R2cities. Integrating other types of energy and material flows such as transportation, industrial activities and public space management to this platform can elaborate the urban metabolism approach within EPESUS' capabilities further to support different types of decision making processes of authorities.

RESULTS

Hourly energy consumption of the selected district or city can be analyzed by the GIS module of EPESUS. Hourly energy consumptions (according to fuel types and end-uses such as heating, cooling, lighting etc.) of the buildings can be defined by the integrated building energy simulation tool (Energy+) or the monitored real-time data (obtained from the energy meters of energy management systems of buildings) in the background of this module. Therefore, one can visualize the energy consumptions in the user-defined district or districts for the selected time interval (hourly, daily and annual). The energy demand in Kartal, Yakacık District is illustrated in Figure 3.

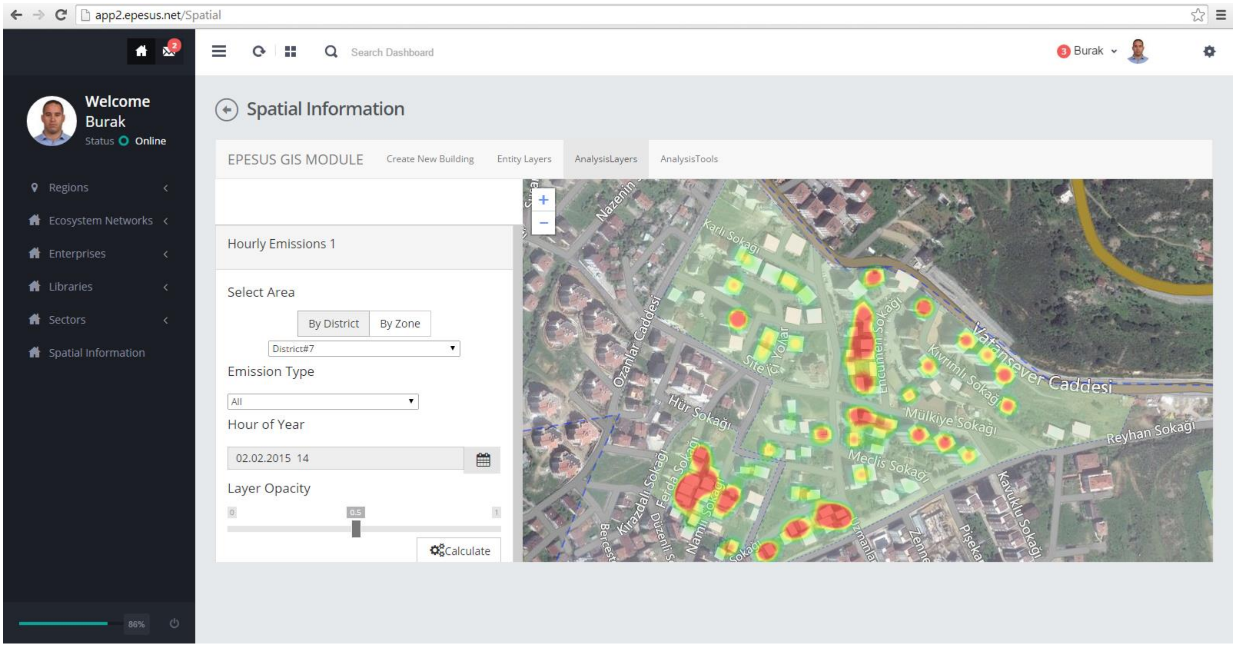

Figure 3 Hourly Energy Consumption Analysis

Previously defined energy efficient retrofitting scenarios of a building or district can be analyzed and one can compare different scenarios such as building envelope insulation, HVAC equipment replacements and renewable energy systems integration. The comparison figures of existing scenario, envelope retrofitting scenario and HVAC retrofitting scenario of two different building in Kartal district are illustrated in Figure 4.

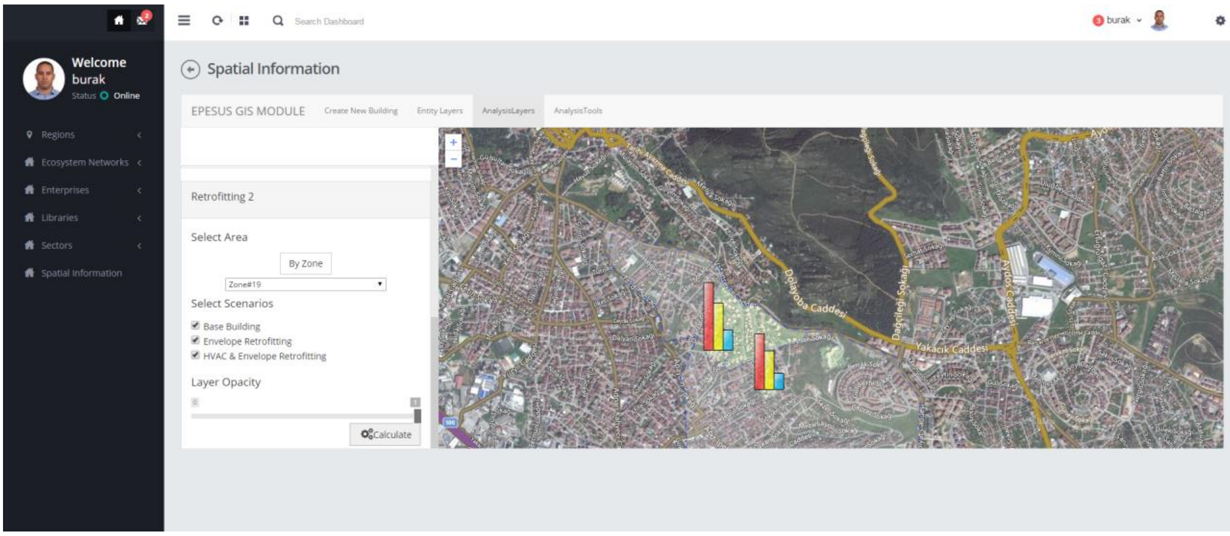

Figure 4 Retrofitting Scenarios Comparison

Flue gas emissions (NOx, SOx) from solid fuels (natural gas, coal, fuel oil etc.) can be shown with respect to the plume dispersion model, which takes into account wind direction and speed, at building or district level as shown in Figure 4..

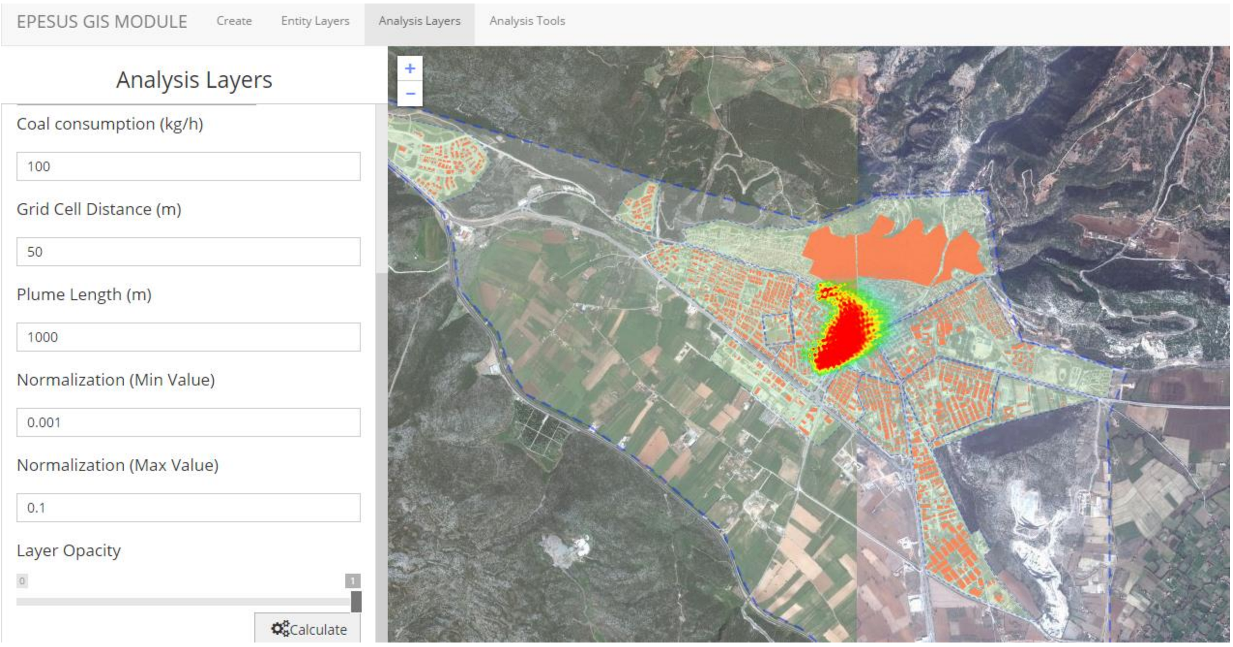

Figure 5 Air Emissions Analysis

Many experts from different fields including municipalities, industrial facilities or zones, buildings and building groups, can benefit from these analyses which can be accomplished with an integrated urban metabolism platform.

As one of the main beneficiaries of an urban metabolism platform, municipalities can find many solutions for their responsibilities in energy management, waste management, water footprint, urban sustainable energy action plans, urban air pollution monitoring and forecasting. For energy management tasks of municipalities, main actions which can be accomplished by the platform can be listed as:

- Retrofitting decisions by analysis and monitoring of fuel and electricity consumptions of municipality facilities
- Improvements in user behaviours and decision making processes by comparing historical and expected energy consumption data
- Energy savings by reactive power compensation method
- Optimization of renewable energy systems integration for maximum usage
- Energy demand management with forecasting byreal-time data or simulations

In the scope of waste management activities, main benefits of municipalities can be listed as:

- Integrated waste management by forecasting of the amount of waste and energy saving potentials
- Logistics improvement scenarios modeling and supports for their applications
- System design with waste seperation potential forecasting (waste collection and usage modelings)

For water management and footprint activities:

- Water consumption monitoring of public parks and gardens
- Water savings in irrigation with integrated weather forecasting
- Reusing of waste water in irrigation systems

For urban sustainable energy action plans:

- Energy consumption identification of buildings and industries
- Scenario comparisons and feasiblity analysis of urban renewal and retrofitting
- Urban performance criteria definitions and monitoring system

For urban air pollution monitoring and forecasting:

- Forecasting of PM1, SOx and NOx emission concentrations of urban resources
- Air pollution forecasting according to weather data
- Decision support and analysis of air pollution reduction and cost scenarios

Other than municipalities, organized industrial zones can use this platform for active /reactive power management, waste management and waste heat valorisation within or between industries. For industrial facilities, the platform can be treated as process data management and can perform decision support for automation systems, measurements of energy improvement potential scenarios, environmental performance monitoring, environmental product declarations.

If has been seen and proven that multiple decision support actions to the urban actors can be provided which include;

- Performance analyses of various scenarios
- Analyses of consumption and flow metrics, delivery of warnings and improvement recommendations
- Analyses on demand forecasts and effects of various external parameters for these scenarios such as weather changes in the short terms and climate change related effects in the mid and long term

Additionally, future research and development topics are provided with the presented platform and methodology. These include;

- Dynamic optimisation of the flows with multiple objectives
- Connectivity to external data and sensor networks
- Involvement of the citizens as agents of the ecosystem and modelling their behaviours, vulnerability and well being with respect to the changes in the urban ecosystem

As a result, an urban metabolism platform tool is a promising technology for many applications in different fields and provides solutions for the problems of dealing with complex urban systems in compliance with recently developed technologies and regulations around the world.

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