# Dynamic Energy Mapping Project Outline

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## Contents

**Abstract**

This document provides an approach of adding the "time" dimension to an Energy Map. The approach is demonstrated with a model of a conceptual urban setting created in CityEngine based on the extracted topological and density pattern from an existing urban design project. The buildings in the conceptual model is then assigned an energy profile of certain DOE Commercial Benchmark Building Reference model based on its building type. Hourly energy demand profile of heating and cooling end use is then obtained from the EnergyPlus Reference models. The energy consumption data is classified into groups with consideration of building energy design context and the data distribution properties. A corresponding color coded energy profile is then generated and imported to CityEngine. 8760 color coded 3D map images was then extracted from CityEngine with Python script. A data reading, ploting, color-coding calculation and a user interface for visualizing the images and dynamic data plot with sliders is implemented using Python and related packages. The tool is anticipated to provide decision support for community energy management and planning, demand-side strategy design and district system sizing.

The document will also briefly discuss one of the testbed for data classification and visualization.

# 1 General Introduction

## 1.1 Definition of Energy Map

### 1.1.1 Energy Thematic Map

In a restricted sense, Energy Map is an instance of a thematic map that depicts energy information. It is an abstract representation of some energy feature in an urban environment. It is useful in providing energy related qualitative or quantitative insight.

The energy topics depicted in an Energy Map can be classified into four major categories: energy supply, energy demand, energy related building design / urban planning, and energy related environmental impact. One common sub-category of the supply side topics concerns the locations and evolving process of energy infrastructures such as power plants, energy transmission pipelines, energy refining facilities and market hubs. EIA state energy profile map [14], U.S. natural gas pipeline map [11], and U.S. wind farm development dynamic map [9] are under this sub-category. Other supply side topics include total energy production [7]; total energy source production like global coal production map [12]; sustainable energy potential map of wind, solar, biomass, geothermal energy potential [18] and hidropower potential [8]. Common demand side topics include: energy demand for one or more enduses [19], energy source demand like coal demand [13] and energy cost [3]. The design side topics concerns building physical conditions like Calgory Heat Map [16], design policy information like climate zone map [5] and energy code adoption map [6]. The energy behavior environmental impact map include both the impact of building or energy infrastructure to environment and the environment change to buildings or infrastructures. The carbon emission map as [1] is an instance of the former and the "Energy Sector's Vulnerabilities to Climatic Conditions" Map is an example of the latter [4].

It is necessary to mention some unfortunate terminology overloading involved in the topic of Energy Map. The term "Heat Map" used in this discussion refers to the Energy Map with building heating energy as its theme, not to be mis-interpreted as the color-coded representation of matrix values as in this definition [20].

The history of thematic map dates back to early 17th century, and from then map can present spatial changes of some feature in addition to merely recording locations of geographic features [21]. Over a century later, spatial analysis emerges and map starts to assisting geo-data analysis. Finally after the born of modern computer and the development of database, map becomes a more powerful information system that undertakes more complecated tasks including data aggregation, managing, querying and presenting. This gives Energy Map a much broader meaning.

### 1.1.2 Geo-database of Building Energy

In a broader sense, Energy Map is a hibernation of two types of databases: building energy database, a subset of the BIM (Building Information Model), and Geographical Information System (GIS). The basic functions of an Energy Map includes 1) storing energy data in an organized fashion, that facilitate easy analysis and query of energy data and 2) provide reports in the form of graphs, tables, animations etc that conveys numerical information in a way that best support pattern recognition and decision support.

## 1.2 Why "time" dimension is important for an Energy Map

### 1.2.1 Strong Temporal Variance Energy Demand

Building energy demand is strongly dependent on weather conditions, building types, size, building physical design, building mechanical system and appliance selection and operation schedules. The factors of building design, mechanical system and appliance selection remain relatively constant over time. Weather conditions have strong seasonal pattern and day-night pattern. This type of variation takes the form of a global influence on building heating or cooling load. The building operation schedule vary greatly from building to building as a result of difference in building types, sizes, design, appliance etc. Different operation scheduce indicates a non-coherent arrival of peak demand within a mixed-use urban environment. Difference in building type suggests a different indoor environment requirement such as ventilation rate, lighting intencity etc., indicating a dramatic variance in data distribution of energy consumption over time. Building envolope and mechanical system quality indicate a great variance in the range and extreme value of energy consumption. All of these suggests a simple annual or monthly average cannot effectly represent the real energy consumption behavior of an urban environment. In order to present this complecated behavior of energy demand, the time dimension is

In order to match the supply side to the demand side, understanding the spatial-temporal pattern of the energy demand is crutial.

### 1.2.2 Temporal variation of the Supply Side

The commonly used renewable energy source includes: solar, wind, geothermal, hydropower and biomass. Among these sources, solar energy have strong temporal fluctuation as a result of the temporal variation of solar radiation between different hours of a year and the time of year [15]. There is also a cost variation involved in the energy supply.

### 1.2.3 Close Match of Supply Side to Demand Side Improves Community Scale Energy Performance

As the result of the finiteness of fossil fuels, the using of renewable energy begins to come into play. In 2013, renewable energy account for 9% of the residential and commercial primary energy source [10]. Electricity generated from sustainable sources normally do not have much storage capacity, hence in order to meet the energy demand with renewable electricity, a better understanding of the spatial-temporal pattern of energy demand is important [17].

### 1.2.4 Development of Supply Side Requires Better Understanding of Supply Side

### 1.2.5 Community energy planning and district system design requires a more detailed picture of the energy temporal behavior on community level

## 1.3 General Description of Dynamic Energy Map

Within the current context, "dynamic" refers to changing over time, hence Dynamic Energy Map is an Energy Map equipped with temporal information. As a result of the "dynamic" property, one assumption about Dynamic Energy Map is that at least one of the energy related variables depicted in the map should change over time. Due to the fact that there are two versions of definitions for Energy Map, there are also two versions of corresponding Dynamic Energy Map.

In a restricted sense, where an Energy Map is defined as a thematic map focusing on energy topics, Dynamic Energy Map is just a series of maps, each of which is a thematic Energy Map representing the status of energy information happened at a certain time spot. Also with the convention that thematic maps are ordered in increasing time order. The purpose of such a Dynamic Energy Map is to facilitate the comparison of thematic maps at different time steps. Baring this in mind, it makes more sence to apply a universal map symbol and breakpoints to the sequence of thematic maps in this version of Dynamic Energy Map.

In a broader sence, where Energy Map is defined as a energy-geo-database, Dynamic Energy Map is an energy-geo-database with "time" being one of its data entries. One major purpose of Dynamic Energy Map under this definition is to enable search, filter and query of the energy data by "time" field, thus presumably, time should act as one of the indexes in the database that facilitates faster search and query of the time data. The second task of Dynamic Energy Map is to provide more powerful reporting tools than normal Energy Maps that accounts for the difficulty and complexity of spatial-temporal data visualization aiming that better conveying the dynamic spatial pattern.

In this study we explored the realization and application of Dynamic Energy Map with a restricted use case senario of supporting district energy system design and community energy management.

A district energy system consists of a power plant, a series of buildings as ternimal energy users and a network of pipelines that transmit energy from the power plant to end-users. Commonly used media for energy transmission include steam, hot water or chilled water [2].

For this scenario, we identify "demand side",

with heating and cooling demand as two major variables.

- Dynamic Energy Map holds 8760-hour meta data of energy demand and supply [2].
- Dynamic Energy Map has multi-dimensional graphical display of the meta data in conveying spatial-temporal pattern
  - 1D: data plot for providing quantitative information
  - 2D/3D: graphical display of spatial relationship of energy data
  - 1D + 2D/3D: interactive graphical display of spatial-temporal pattern of energy data

## 2 Objective

1. Discuss the specifications / definitions of dynamic Energy Map
2. Evaluating some possible approaches to implement dynamic energy map
3. Presenting one major implementation approach

# 3 Related Works

## 3.1 Energy Map (without temporal dimension) (grouped with field of application)

1. Supply side: Assessing renewable energy potential
   1.1. "Evaluation of Renewable Energy potential using a GIS decision support system", Voivontas et al., 1998
   1.2. "Spatial mapping of renewable energy potential", Ramachandra and Shruthi, 2007
   1.3. "Energy Potential Mapping: Visualizing Energy Characteristics", Dobbelsteen et al. , 2013
   1.4. "NYC City Solar Map": present solar energy potential for buildings across the city. Information presented include: solar energy generation curve, estimated solar system installation area, finantial incentive and payback etc`http://www.nycsolarmap.com/`.
2. Supply and Demand Side: Analysis or design support of existing energy infrastructures
   2.1. "Developments to an existing city-wide district energy network Part I: Identification of potential expansions using heat mapping", Finney et al. , 2012
   2.2. National Heat Map, `http://tools.decc.gov.uk/nationalheatmap/`
3. Demand Side: Energy consumption prediction model
   3.1. "A large-scale study on predicting and contextualizing building energy usage", Kolter, J. Zico; Ferreira Jr, Joseph.
4. Smart Management of Urban Energy System
   4.1. "Smart Urban Services for Higher Energy Efficiency" (SUNSHINE) project (2013): energy consumption map, automatic alerts, remote control of public building lighting system.

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[10] EIA. Monthly energy review. web, May 2014. http://www.eia.gov/energyexplained/index.cfm?page=us_energy_homes.

[11] EIA. About u.s. natural gas pipelines. web, July 2015. http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/ngpipeline_maps.html.

[12] EIA. Asia leads growth in global coal production since 1980. web, July 2015. http://www.eia.gov/todayinenergy/detail.cfm?id=4210.

[13] EIA. Rising asian demand drives global coal consumption growth. web, July 2015. http://www.eia.gov/todayinenergy/detail.cfm?id=4390.

[14] EIA. State profile and energy estimates. web, July 2015. http://www.eia.gov/state/?sid=PA.

[15] EIA. What is renewable energy. web, July 2015. http://www.eia.gov/energyexplained/index.cfm?page=renewable_home.

[16] Geoffrey Hay, Christopher Kyle, Bharanidharan Hemachandran, Gang Chen, Mir Mustafizur Rahman, Tak Fung, and Joseph Arvai. Geospatial technologies to improve urban energy efficiency. *Remote Sensing*, 3:1380–1405, July 2011.

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