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Title: Sustainability and resilience assessment of urban energy systems: Analysis from four selected Asian and European cities

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Title

Sustainability and resilience assessment of urban energy systems: Analysis from four selected Asian and European cities

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Summary

The aim of this thesis is to provide an exploratory assessment and analysis that quantifies and qualifies the level of sustainability and resilience of urban energy systems in four selected cities: Amsterdam, Hamburg, Kawasaki and Tokyo.

The assessment was conducted using a combined rather than a single approach in order to better understand local energy systems of these four cities. Combined approach is determined using integrally sustainability and resilience concepts rather than one concept only. Concepts of sustainability and resilience were developed using a Driver-Pressure-State-Impact-Response (DPSIR) framework. DPSIR framework was applied in order to select appropriate indicators, i.e. criteria against which performances of local urban energy systems were determined.

The study included a feedback on relevant theoretical knowledge which explores as a foundation, concepts of sustainability and resilience, urban energy systems, combined sustainability and resilience assessment, theoretical knowledge on development of sustainability and resilience indicators and a DPSIR model. The theoretical knowledge provided the setting for further development of conceptual framework for this thesis, defining main features as central to exploration study. As the research was developed, new findings were added and incorporated into the study i.e. theoretical knowledge.

The study proceeded with descriptive statistics to provide understanding of detailed economic, environmental, institutional performance of urban energy system in four cities, as well as resilience performance of the national energy system.

Observing the values of different indicators, it was found that sustainability performance is differently distributed among cities and strongly linked with local context, i.e. measures and technologies used in the energy sector. It was also observed that funding programmes, energy strategy and low carbon development in an urban area play a crucial role for increased sustainability performance. Expansion in the field of energy vision for the city and country is an important element for enhanced resilience performance. In the power sector of three countries, analyzed improvement of existing power generation units and switching to cleaner types of coals brings added value to sustainability and resilience. Furthermore, it was found that a profitable margin for renewable technologies is lower compared to traditional technologies.

The study concluded that integration of DPSIR framework and integrated approach to sustainability and resilience assessment may add real benefit to local energy systems` planning and functioning.

Keywords

Urban Energy System, Sustainability and Resilience Assessment, Sustainability and Resilience Indicators, Energy Policy Objectives, Energy Technologies, Amsterdam, Hamburg, Kawasaki, Tokyo.

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To Prof. Harutoshi Funabashi, Hosei University (passed away in August 2014), who believed that the only meaningful way towards energy shift was strengthening of public debate.

Abbreviations

ADM	Automated demand management
AEB	Afval Energie Bedrijf/The City of Amsterdam's Waste and Energy Company
AIM	Amsterdam Innovation Motor
AMI	Advanced metering infrastructure
ASC	Amsterdam Smart City
BEMS	Building Energy Management System
BiH	Bosnia and Herzegovina
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
C&E Office	Climate and Energy Office of Amsterdam
CCP	Cities for Climate Protection Program
cCCR	Carbon Cities Climate Registry
CHP	Combined Heat and Power
CliSAP	Integrierte Klimasystem-Analyse und Vorhersage/ Integrated Climate System Analysis and Prediction
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CUD	Connected Urban Development
DH	District heating
DPSIR	Driving Forces-Pressures-State-Impacts-Responses Model
DRO	Physical Planning Department of Amsterdam City
EE	End-use energy efficiency
3E	Environment, Economy and Energy Goals
EEG	German Federal Renewable Energies Act
EEHH	Cleantech Renewable Energy Cluster/Cluster Erneuerbare Energien Hamburg
EEWärmeG	German Federal Renewable Energies Heating Act
EIA	Energy Investment Allowance
EIA	US Energy Information Administration
EISD	Energy Indicators for Sustainable Development
EMA	Environmental Management Act
EnEV	German Federal Energy Savings Ordinance
EPBD	Energy Performance in Buildings Directive of the EU
EU	European Union
EU ETS	The EU Emissions Trading System
EV	Electrical vehicles
FP7	7th Framework Programme for Research and Technological Development
GaWC	Globalization and World Rankings Research Institute
GDP	Gross domestic product
GEA	Global Energy Assessment
GEU	General Electric Utilities
GGD	Public Health Service of Amsterdam
GRI	Global Reporting Initiative
GRIP	Greenhouse Gas Regional Inventory Project
GSI	General Sustainability Indicator
GHG	Greenhouse gas
GIS	Geographic information systems
GJ	Gigajoules
GWh	Gigawatt hour: one billion (10^9) watt hours

HEMS	Home energy management system
HHA	Hamburger Hochbahn Aktiengesellschaft
HyRaMP	European Regions and Municipalities Partnership on Hydrogen and Fuel Cells
IAEA	International Atomic Energy Agency
ICLEI	Local Governments for Sustainability
ICT	Information and communication technologies
IKEP	Integrated Climate and Energy Programme
K^2	Keio University Sinkawasaki Town Campus
kgoe	Kilograms of oil equivalent
KBIC	Kawasaki Business Incubation Centre
KERI	Kawasaki Environment Research Institute
HmbKliSchG	Hamburg`s Law to protect environment through energy savings/Hamburgisches Gesetz zum Schutz des Klimas durch Energieeinsparung
KSP	Kanagawa Science Park
KWKG	German (Federal) Combined Heat and Power Act
LEAP	Local Environment Action Plan
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MCA	Multi-criteria assessment
METREX	The Network of European Metropolitan Regions
MIA	Environmental Investment Deduction Scheme
MJ	Mega joules
MPG	Miles per gallon (fuel consumption standard)
mTOE	Million tonnes of oil equivalent
MWh	Megawatt hour: one million (10^6) watt hours
NANOBIC	Global Nanomicro Technology Business Incubation Centre
NGCC	Natural Gas Fired Combined Cycle plants
NIES	National Institute for Environmental Studies
NIMBY	`Not in my backyard` syndrome
NO_x	Mono-nitrogen oxides
NRE	Non-renewable energy
NYC	New York City
OECD	Organization for Economic Cooperation and Development
OPEC	Organisation of the Petroleum Exporting Countries
PM	Particulate matter
PPP	Public private partnership
PPS	Power Producer and Suppliers
PV	Photovoltaic systems
R&D	Research and development
RE	Renewable energy
REB	Dutch Regulatory Energy Tax/Regulerende Energie Belasting
REDA	Renewable Energy Development Bill
RES	Renewable energy sources
SEAP	Sustainable Energy Action Plan
SEW	Helio International Sustainable Energy Watch
SO_2	Sulphur dioxide
T	Tonnes
TEC	Total energy consumption
TElC	Total electricity consumption
TEPCO	Tokyo Electric Power Company

TFA	Total floor area
THINK	Techno Hub Innovation Kawasaki
TMG	Tokyo Metropolitan Government
TPES	Total primary energy supply
TRANSFORM	Transformation Agenda for Low Carbon Cities
UES	Urban energy system
UNEP-SBCI	UN Environment Programme`s Sustainable Building and Climate Initiative
VDEW	German Electricity Association/Verband der Elektrizitätswirtschaft
WEC	World Energy Council
WPR	Water Provision Resilience
Vamil	Random Deductions for Environmental Investments Plan
VAT	Value Added Tax
VOC	Volatile organic compounds

Table of Contents

List of Tables

List of Charts

List of Figures

``I feel that Japanese society should adopt an energy paradigm shift in reference to its energy policy to realize some of the following aims: active reduction in energy consumption; the vigorous introduction of a variety of renewable energies; the abolition of nuclear power generation at the earliest possible time; and the gradual reduction of the consumption of fossil fuels.

This energy paradigm shift would enable us to bring about a society with sustainability, effective countermeasures against climate change, more equitable distribution of goods between regions and countries, as well as safety and long-term prosperity.``

Harutoshi Funabashi (2012, p.73)

Chapter 1: Introduction

1.1 Urban energy system as a unit of analysis

More than half of the global population lives in urban areas. Global Energy Assessment (GEA) estimates that urban settlements are projected to absorb almost all the global population growth by 2050 whereas the contribution of megacities i.e. cities with more than 10 million inhabitants, to this growth, remains relatively small. According to GEA, 2% per year is average growth of world energy consumption, and around 80% of it originates in fossil fuels. The accounts of consumption-based energy for cities are limited for any generalizations to be made. However, estimates suggest that over 75% of energy consumption relates to cities or major city regions. GEA also assesses that under consumption-based accounting method, around 80% of energy use in the world gross domestic product (GDP) is related to the urban share. Urban energy use in more economically developed countries does not significantly differ from the national average when this approach is applied (Grubler et al., 2012). Of course, energy-use patterns involve disparateness as well.

Since urban areas are currently responsible for three-quarters of the global energy demand, this is a logical starting point for intervention to transform urban areas into resource efficient, low carbon places that use energy in optimal way (TRANSFORM, 2013).

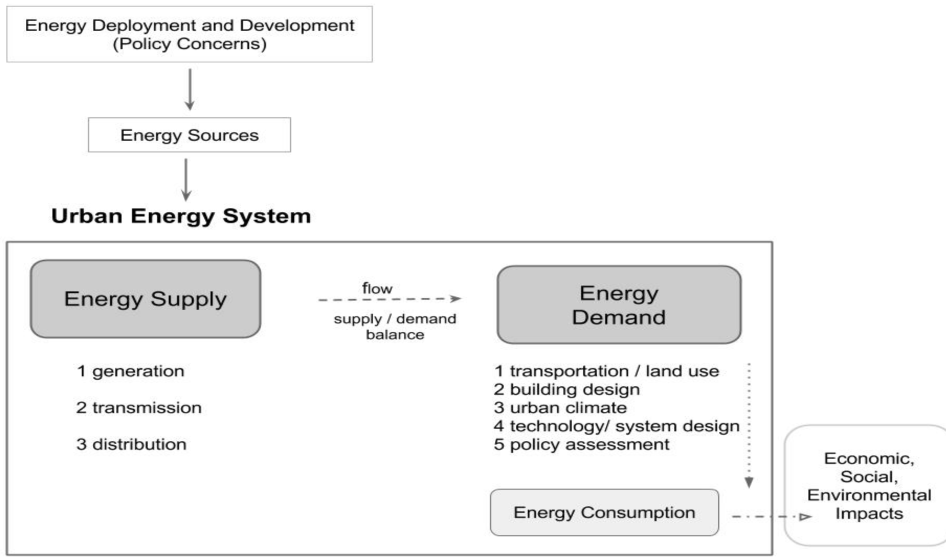
Cities are faced with the need to constantly provide energy services in situations of constrained conditions and needs to increase efficiency of operation. This impacts production and consumption in energy systems as well. Influences on energy system (therefore production and consumption) may vary from regulatory framework and policies, rising fuel prices, environmental and risks of climate change, availability of infrastructure, personal preferences etc. Every city is a complex system of economic and social factors. Flow of materials and people is everyday occurence in cities. These factors are influenced by changes occuring in the energy system as well. In the context of this research, an urban energy system (UES) refers to the system involving energy supply and demand in an urban area. Supply and demand are subject to many changes (Figure 1). Concept of UES in this research refers to flows of supply and demand within city (metropolitan) boundaries, policy concerns explained by Gross (2013) and modelling analysis conducted by Keirstead et.al. (2012).

Modelling analysis of Keirstead et.al. (2012) was conducted as a review methodology of urban energy systems in 219 published academic papers. Modelling analysis sets forth an UES in a \`geographic-plus\` definition of \`urban\` which refers to city\`s administrative boundaries and upstream flow such as electricity consumption. The analysis looked into technology, system and building design, urban climate, transport and land use modelling and policy assessment areas of practice.

Gross (2013) proposed various policy options which may affect both development and deployment of energy in urban context and wider. Deployment related policies which may overall impact an UES are those for continuously meeting demand, regulated versus non-regulated and bundled versus unbundled energy sector, centralized versus distributed generation, fuel mix used in generation process, land access and environmental or social considerations. Development related policies refer to transparency of legal system, business environment, budgetary matters and educational priorities.

Energy supply involves processes of generation, transmission and distribution towards consumers. [1] Demand is energy required by consumers and it must be made readily available.

Figure 1. Elements of urban energy system



Based on Keirstead et.al. (2012), Gross (2013) and own analysis

Energy technologies are bound to energy supply or demand side (Figure 2). Energy supply technologies may require large investments, particularly if the whole system needs to be redesigned or adapted. These are advanced gas turbines, clean coal technologies, solar cells and wind energy.[2] Demand side technologies relate to efficient vehicles and white goods, development of engines and transmissions, batteries, storage systems, lighting technologies, energy management systems in buildings (BEMS). Economic advantages (or obstacles), social attitude (primarily acceptance), and supporting infrastructure are limitation factors for penetration of new applications (Grubb et.al., 1992). Changes in supply and demand impact the energy business, and therefore sustainability and resilience of the overall system.

Furthermore, in 1980s, technological knowledge transferred very rapidly between world regions creating interdependencies of economic and energy systems. This was one of the reasons that national energy intensities between countries closely connected over time.

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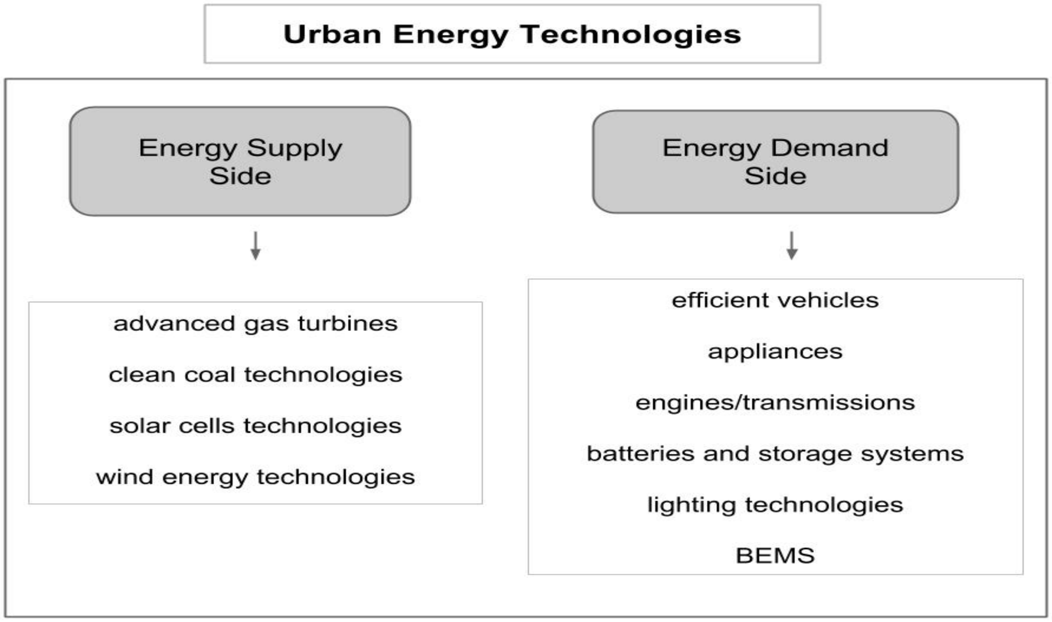
[1] For instance, where the new power plant is being included in the energetic matrix, system operator must secure transmission and distribution and, proper functioning of infrastructure which is made of various assets. For instance, capacity of generation and distribution may differ, because distribution has less impact and is linked to growth inside the urban centres. It can also be dependant on urban deployment policy, city expansion plans etc.

[2] It took more than 50 years for transition from wood to coal and coal to oil. It was proved that expansion rates of new technology were rarely above 10% a year (at most). That means that when one particular technology replaces use of another one, growth rate is limited by the rate at which existing inventory is retired (Grubb et. al., 1992)

Figure 2. Examples of urban energy technologies



According to GEA (Grubler et.al., 2012) energy, along with three other urban related services (water, sanitation infrastructure and transport) is the crucial sustainability challenge to supply expected three billion urban dwellers in following decades. More integrated and decentralized urban infrastructure offers a possibility to improve resilience and hence UES security.

Cities also, according to this logic, grew to be innovation centres in sustainability transition, and challenges of this transition are to be solved in preeminently urban systems.[3] Moreover, UES, quality of urban environment, urban form and density, including transportation, are particularly open to influences of city and policy administrators. On the urban scale, energy policy should primarily focus on demand management, meaning energy efficient buildings, public transport services of high quality (eco-friendly, non-motorized mobility), arrangement of urban form and its compactness that will lead to energy efficient housing features and integration of UES. These determinants also have the highest leverage influence. This is referred to as a `paraidgm shift` contrasted to mainstream supply-side national energy policy (p.1311). A feature belonging equally to sustainble UES and policies is that they commonly impact the overall system. For example, increased integration of various resource streams such as waste or energy will promote resource recovery (waste-heat recycling, cogeneration) and environmental performance i.e. sustainable development.

Focus of the research is on four selected cities located in highly developed, industrialized, Organization for Economic Cooperation and Development (OECD) countries (Figure 3). These cities are in the Netherlands, Germany and Japan: Amsterdam, Hamburg, Kawasaki and Tokyo. Each of them plays a vital role in the national economy and serves as important centre for production and consumption related activities. All cities have particular political, industrial, scientific, technological, social and cultural relevance.

[3] Because urban energy use dominates as a fraction of global energy use

Figure 3. Geographical coverage of cities selected in research

Design: Alexandra Tsatsou

1.2 An overview of the national energy systems as a foundation for UES

Before elaborating about UES in selected cities, it is important to reflect on historical developments and energy sources which influenced energy supply and demand of national energy systems. Their impact on UES sustainability and resilience was not negligible.

1.2.1 World energy crisis– the second oil shock

One of the most important changes which influenced energy markets and policies was the second oil shock in 1979. Organisation of the Petroleum Exporting Countries (OPEC) cartel dramatically boosted oil price in the wake of war between Iran and Iraq. Diversification away from OPEC oil stimulated shift into alternative fuels, research and exploitation activities beyond OPEC producing regions. Japan became strongly oriented towards stability and resilience of its own energy system. Western European car and motor industry was especially affected. German economy was dependent on foreign suppliers, as its petroleum sector reached maximum production in mid 1960s.

1.2.2 Growing interest in energy efficiency (EE) improvements, research and development (R&D)

There was another trend that emerged in 1980s: on one side, concerns about resource security encouraged governments to interfere in supply R&D. On the demand side of energy equation, interest for EE improvements in end-use became prominent.

After the oil crisis in the 1970s, European countries introduced appliance standards. Unlike in other OECD countries, Japanese R&D funding waxed targeting industry and government collaboration, starting `Moonlight project` in 1978. In 1998, Japan introduced Top Runner Program and subsidies for industrial energy-savings technologies (Geller et.al, 2006). Dominant efficiency improvements in automobiles occurred between 1975 and early 1980s. In 1991, European car manufacturers undertook voluntarily commitment towards 10%

reduction of carbon-dioxide (CO_2) emissions for new cars from 1993-2005 (EC, ed.1993). In developed countries, lighting accounted for around 15% of total electricity consumption (TElC), so advances were made in this sector. Schemes for energy demand reduction were developed in the Netherlands prior to 1990s.

1.2.3 Availability of gas in broader energy markets

In the 1980s, development of gas pipeline systems made it available in European and world markets. Proven gas reserves expanded dramatically. Moreover, gas has lower carbon and higher heat content than coal which made it more desirable primary fuel because of CO_2 emissions. It was expected that power generation with natural gas fired combined cycle systems (NGCC) and cogeneration would gain in significance (Kaplan, 2008).

1.2.4 Push for alternative energy sources

It was in the 1980s when renewable energy (RE) sector witnessed development. These were wind and solar energy expansion years in the Netherlands and Germany. Evolution of wind energy for grid supplies occurred with government support in Germany. SGR (2008) reports that, until 1980s, coal and nuclear energy dominated German power generation system, with agenda taking different turn after meltdown in Chernobyl Nuclear Power Station. It turned out that wind energy developments in Germany had more success than in the Netherlands, because of stimulating market incentives (Slingerland, 1990). Testing results on photovoltaic systems (PV) integration in buildings in the Netherlands and Germany were promising for their application. By 1980s, PVs could provide electricity at lower expenses than diesel especially as a remote energy source (Erickson and Chapman, 1995).

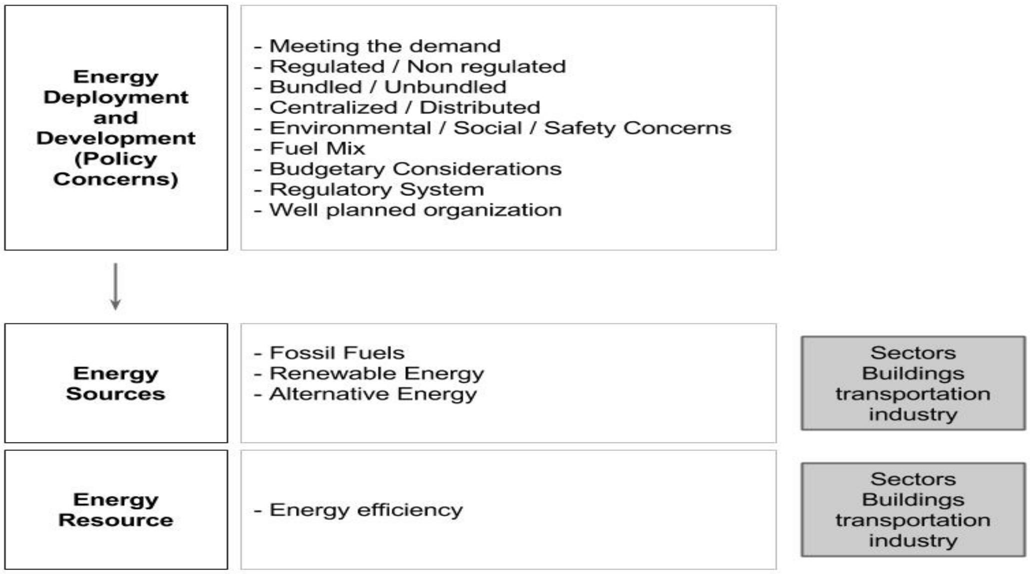
1.2.5 Strengthening the role of environmental control

The main task of the energy industry until 1980s focused on energy supply in whatever way possible. As the damage to the European lakes and forests was first discovered in 1970s, motor vehicles became recognized as crucial air pollution source. Social and environmental scale of impacts and general environmental sentiment became outspoken issues. Japan introduced rigorous standards for nitrogen-oxide (NOx) emissions. Popp (2006) found that innovations for sulphur-dioxide (SO_2) and NOx abatement technologies in the USA, Japan and Germany (1970-2000), were affected by domestic regulation and innovations from abroad. \`Not in my backyard\` syndrome (NIMBY) surfaced at that time in respect to nuclear and hydroelectric facilities. Another issue was debate about external costs of energy provision where issue of environmental impacts became crucial.

1.2.6 Major energy sources for UES and their application in the national energy systems

In the following section, a brief description of the major energy sources and resources for UES is presented (Figure 4), as they play important role from sustainability and resilience point of view (Gross, 2013): fossil fuels, alternative sources, non fossil fuels - renewable energy sources (RES), and EE as energy resources.

Figure 4. Elements with impact on an UES



1.2.6.1 Fossil fuel based energy generation

Energy generation based on fossil fuels has many advantages compared to other energy sources: cost-effectiveness, higher efficiency through combined heat and power (CHP) or tri-generation, new technologies. In 2011, Netherlands recorded the highest energy use from fossil fuels (92.3%), followed by Japan and Germany (Table 1.).

Table 1. Energy production, use and fossil fuel consumption in the Netherlands, Germany and Japan (1990 - 2011)

Country	Production (thousand mTOE)		Energy use: Total (000 mTOE)		Energy use: Per capita (kgoe)		Energy use: Fossil fuel % of TEC		Energy use growth (%)
	1990	**2011**	**1990**	**2011**	**1990**	**2011**	**1990**	**2011**	**1990-2011**
Netherlands	60.5	64.4	65.7	77.4	4393	4638	95.9	92.3	0.9
Germany	186.2	124.2	351.1	311.8	4421	3811	86.8	79.8	-0.3
Japan	75.2	51.7	439.3	461.5	3556	3610	84.5	89.6	0.4

Source: World Bank Group, 2014

From 1990–2011, in Germany and Netherlands percentage of fossil fuel based energy use was lowered, with exception to Japan which witnessed an increase from 84.5 to almost 90% (World Bank Group, 2014). Grubb (2006) is of opinion that emissions from fossil fuels are driven by demand in three sectors and that they result from three main systems by which energy is supplied: electricity, refined fuels, direct fuel and heat delivery. The downside of this type of energy consumption is significant environmental concern:

a. Environmental and associated economic consequences: urban air pollution (photochemical smog), acidification (acid rains) and climate change (heat waves).
b. Public health consequences: premature deaths, asthma attacks, hospitalization. By-products from emissions have high impact on population morbidity and mortality.[4]

Combustion generates by-products differing from the source. These are mostly: CO_2, carbon monoxide (CO), NOx, SO_2, particulate matter (PM), toxic heavy metals, volatile organic compounds (VOC), ozone. Natural gas has the largest content of nitrogen which leads to formation of NOx (Liu, 1993).

1.2.6.2 Alternative energy for an energy system

Alternative energy refers to consumption of finite sources, i.e. additional fossil technologies and nuclear energy. There are impacts associated with nuclear energy such as waste management from nuclear power systems. Furthermore, according to Liu (1993), alternative fuels to gasoline and diesel which are undergoing development involve:

a. Liquefied petroleum gas (LPG),
b. Compressed natural gas (CNG),
c. Methanol and Ethanol.
d. Hydrogen fuel and fuel cells which are more efficient than fuel burning (Fuel Cells 2000, 2014).
e. Superconductors which were investigated in transportation and electrical utilities.

In 2011, almost 12% of total German energy use derived from these sources, with lower figures in Japan and the Netherlands (Table 2).

Table 2. Alternative and nuclear energy in the Netherlands, Germany and Japan (1990, 2011)

	Production		Energy use	
Country	(000 mTOE)		Alternative and nuclear energy (% of TEC/TOE)	
	1990	**2011**	**1990**	**2011**
Netherlands	60.5	64.4	1.4	2.0
Germany	186.2	124.2	11.8	11.8
Japan	75.2	51.7	14.4	8.1

Source: World Bank Group, 2014

After nuclear meltdown in Fukushima-Daichi power plant in March 2011, and protests involving 90,000 people, Germany initiated a nuclear phase out plan by 2022 (Morris et.al, 2012).

1.2.6.3 Energy consumption from renewable sources

Main issues related to RES and system sustainability are access to energy source, available technology, its availability, costs, operation and ecological impacts. For Dutch government, RE is embedded in the long-term energy plan, stimulating innovation policy as this form of energy is still expensive (Government of Netherlands, 2014). German government`s goal is to achieve 50% of all electricity supply from RES by 2030. It recently reached new levels

[4] Examples are air pollution in Mexico City, New Delhi and Beijing (Graff, 2014).

generating 31% of electricity from RES (Burger, 2014). In 2011, Germany`s energy use from combustible renewables and waste accounted for 8.5% of TEC, while in the Netherlands and Japan, the figures were quite lower, as shown in Table 3:

Table 3. Production and energy use derived from combustible renewable and waste in the Netherlands, Germany and Japan (1990, 2011)

Production			Energy use	
Country	(000 mTOE)		Combustible renewable and waste (% of TEC)	
	1990	**2011**	**1990**	**2011**
Netherlands	60.5	64.4	1.5	4.6
Germany	186.2	124.2	1.4	8.5
Japan	75.2	51.7	1.1	2.3

Source: World Bank Group, 2014

1.2.6.4 Energy efficiency

Applicable from both demand and supply side and to all uses of energy, EE is recognized as immediate and most accessible energy resource (Gross, 2013). National Action Plan for Energy Efficiency views it as a low cost resource for carbon emissions (Prindle and ICF International, 2009). Janik and Lauer (2011) define it as `the other alternative fuel` in power generation process. According to the United Nation`s Environment Programme`s Sustainable Building and Climate Initiative (UNEP-SBCI), buildings consume approximately 40% of global energy and additional 40% of global resources, and emit around one third of GHG emissions. With current technologies, consumption in buildings could be reduced by 30-80% (UNEP, 2014). EE is strongly important for the building sector, and efforts to meet these challenges are many (Mohanty, 2010): developing buildings by *reducing embodied energy*, from design to utilization of advanced materials; striving for *carbon neutral buildings* (*zero-energy, energy positive buildings*); *green buildings*, less resource intensive with minimum environmental impact.

Germany was recently identified as one of the most energy-efficient world economies. Owing to its Energy Strategy, its commitment towards in industrial sphere is very strong. Its energy intensity is lowest in the world.[5] Japan ranks high for national efforts to promote EE with outstanding financial commitment and industrial EE. It has the highest efficiency rate of electricity production from thermal power plants and the best fuel economy standard for passenger vehicles (Young et.al., 2014).

1.3 Background

This research focuses on the assessment of sustainability and resilience of UES in two European and two Asian cities.

According to Hennicke et.al. (2004), the ultimate goal of a sustainable energy system is to raise a standard of living of growing population while delivering affordable energy. Sustainable energy system is the one that ultimately integrates EE with RE, an integration that reaps numerous advantages. According to the authors, the precondition for sustainable development is bringing existing share of renewable energies to the higher levels, in countries

[5] Exception is Australia

of both the North and the South. Therefore, the most encouraging way to sustainable energy system is integration of EE with RE to the largest possible extent.[6] Integration enables security of energy supply and lowers the energy bills. [7]

Academic literature offers abundance of different approaches to urban system resilience. In relation to the energy sector, McLellan et.al. (2012, p.154) define resilience as the amount of change which `one system can undergo and still retain same controls on function and structure` and at the same time `build and increase its capacity for learning and adaptation`.

In a similar fashion, Carpenter and Brock (2008) define resilience by means of three distinguishing features: amount of disturbance that the system can receive with no changes to its structure or process, the capacity of the system to self-organize proceeding a disturbance, and the ability to enhance its capacity for learning and adaptation. Other authors (Walker and Salt, 2006) define resilience as a system ability to absorb various disturbances, and as a consequence of that recover and reorganize. This definition implies that while suffering from a major perturbation (or incident) a system will maintain its resilient side only if it retains the same function and structure it had before. Folke et.al. (2002) found that in order to enable resiliency, processes in the system overlap. This is happening in an excessive way (redundancy). On a perspective for urban systems, Gunderson and Holling (2002) clarified a link where resilience was measured by `the magnitude of disturbance`. Disturbance according to them is absorbed before some critical changes happen in a system, and so the system will change the structure by means of variables or processes that are only inherent to it.

Specifically, the events of the near past (disasters that occured in Japan in 2011 for example), brought into focus importance of resilience and risk mitigation in energy infrastructure. This is why this research aims to assess impact of sustainability and resilience concepts on energy system and its components.

1.4 Brief description of four selected cities

This section provides brief introduction about four selected cities.

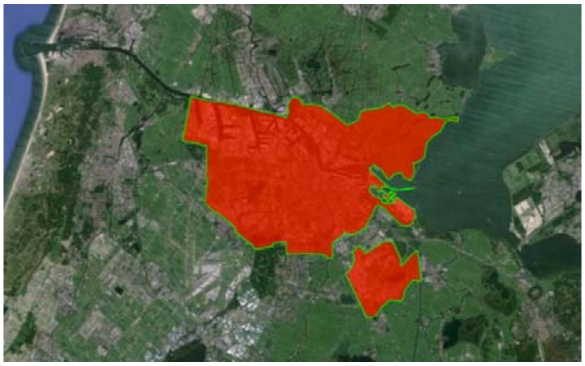
Amsterdam is a local authority divided in seven district councils. It is the capital and the most populous Dutch city. Its population within city limits ranks it the 23rd largest city in the European Union (EU).

Amsterdam metropolitan area has around 2,1 million residents. Its policies are very inventive when it comes to clean air, electrical vehicles (EV), city traffic, waste, energy and water systems (Figure 5).

[6] On a project, regional or national scale

[7] Ultimately, it is the role of the energy policy to stimulate competition between energy supply and demand side EE for provision of the same energy services.

Figure 5. Satellite image of Amsterdam and Schiphol Plaza



Note: Schiphol Plaza combines green roofing with solar energy system
Source: Google Earth and ZinCo (2014)

Amsterdam is one of the world`s top financial centres and an alpha world city according to the Globalization and World Rankings Research Institute (GaWC). In 2009, Amsterdam was the finalist competing for European Green Capital Award, and its Amsterdam Smart City (ASC) partnership won the European City Star Award in 2011. Together with company Cisco, Seoul and San Francisco, Amsterdam co-founded Connected Urban Development (CUD), a public-private partnership (PPP) to contribute CO_2 reductions by means of information and communication technologies (ICT). It uses Global Reporting Initiative (GRI) index for sustainability. Since the legislative powers of Amsterdam are limited, energy related laws are created on a national and EU-level.

Hamburg is the German 2nd largest, the EU 7th largest, and among the richest European cities. Known as the City with County Rights or City-state (Freie und Hansestadt), it has its own government, controls its own policies and aims to promote the Future city in motion model. Its credo is `more city in a city`. Hamburg combines strong industrial performance with urban renewal approach becoming the ground for the Europe´s largest urban development project – Hafen City which promotes waterfront re-urbanization (inward growth) through brownfield regeneration (Figure 6). Its metropolitan region has an estimated population of 4.3-5 million residents. It is the major European transport hub and the second largest European container port. As an economic metropolis with over 500 industrial enterprises Hamburg is the nerve centre of wind power companies in Northern Germany.

In 2011, the city received European Green Capital Award. Since 2008, Hamburg participates in European Regions and Municipalities Partnership on Hydrogen and Fuel Cells (HyRaMP).

Figure 6. Satellite image of Hamburg and Hafen City development area

Source: Google Earth and Future Megacities (2013)

Kawasaki is the 8th most populated city in Japan with more than 1.4 million residents. It has the smallest land area and the highest population growth rate among 20 government decreed cities. The city consists of seven wards, continues to expand constructing artificial islands in Tokyo Bay. It is literally located in the centre of the Tokyo Metropolitan area. Little of land expansion is used for housing purposes (Figure 7). During the period of Japanese rapid economic progress (1960s-1970s), the industry in the city became the heart of Keihin Industrial Zone, and its coastal industrial complex is a driving force of Japanese economic growth. The city is a vibrant industrial metropolis, well known for ability to foster green growth while retaining a presence of heavy industrial sector. Kawasaki is known as the city of dynamic changes, having overcome industrial pollution combining RE technologies with energy conservation measures. It established itself as an international, world class R&D city becoming home to companies and institutions known for cutting-edge technologies in environment and energy related fields. Kawasaki is forging ahead with development of life sciences, energy and environmental engineering sectors. Kawasaki successfully integrates coexistence between residential and industrial zones. Similar to Hamburg, the city is undergoing green transition, and its seafront is subject to continuous redevelopment. It is home to nine universities, and it recently marked its anniversary since being municipalized and becoming a city in 1924.

Figure 7. Satellite image of Kawasaki and view of Kawasaki-ku ward (seat of City government)

Source: Google Earth

Tokyo is the capital of Japan and the most populated metropolitan area in the world. GaWC think tank ranks it as an alpha + world city.[8] Tokyo metropolis has a population of more than 13 million people and administers 23 wards, governing each ward as an individual city (Figure 8). More than 70% of the working population is employed in tertiary sector, such as services, commerce, communication and transportation. It is a mega city with a long-term vision for RE utilization. In 2008, Tokyo Metropolitan Government (TMG) devised the first cap-and-trade program in the world to cover office buildings, and enacted it in 2010. In 2020, Tokyo will host for the Summer Olympic Games.

Figure 8. Satellite image of Tokyo and view of Sumida river from Skytree

Source: Google Earth

1.5 Problem statement

Based on the literature review, it was concluded that hardly any assessment was conducted in the realm of academic research with a focus on exploration and combined assessment of sustainability and resilience of UES. Therefore, it adds a value to explore these aspects i.e. variables in a combined context. There are however studies (Gaudreau and Gibson, 2010) in the realm of academic publications with similar aims which analyze combination of both concepts from a systems approach perspective (Fiksel, 2006).

Main problems which were identified as interconnected to research objectives, are:

1. Generally, urban growth poses a challenge for urban centres to provide adequate and sufficient level of energy service capacity (Section 1.1.). All cities require great amounts of energy for daily operations. Amsterdam, Hamburg, Kawasaki and Tokyo are all experiencing urban growth and to a bigger or lesser degree are faced with `energy transition`. These cities mostly require fossil fuels for electricity generation and distribution. Cities in general, are main polluters with CO_2 because burning of fossil fuels increases level of emissions (JPL, 2014). Additionally, air pollution which results from emissions is considered a disease of modern society. Coal or natural gas are main contributors, but some impacts strongly relate to vehicle infrastructure. In general, burning of fuel oils and coal presents problems of NOx emissions and toxic substances.

[8] Tokyo has the highest ranking and is among the world smartest cities according to IAESE Cities in Motion Index 2014 which measures 10 areas that improve living standard in cities. Amsterdam ranked 16th and Hamburg 39th out of 135 cities (Costa et.al, 2014).

2. Secondly, cities are vulnerable to climate change impacts and are main initiators and actors in climate protection programs. The energy sector, mitigation measures and the challenge to build smart energy networks for the future are set at the centre of sustainable development policy. Sustainability and resilience go hand in hand in provision of clean energy.
3. Thirdly, fossil fuels, in particular oil and gas are running out. In the context of world economies and energy markets where fuel prices are rising (Post Carbon, 2011), intensification of energy fuels is mainly used for supply. Furthermore, for Japan and Germany, which are dependant on imported fuels, most of oil and gas comes from politically unstable regions such as the Middle East or Russia.[9] There are estimates that these trends will continue until 2025. Needless to mention, there are many damaging effects of increased use of fossil fuels in city. Imports raise procurement costs on coal, oil or natural gas, leading to increase in electricity prices and having an (social) impact on domestic population. Japan for instance depends on imports for around 96% of its primary energy supply. In 2009, even when nuclear energy was included, dependency was still at 85%. Oil accounts for more than 40% of primary energy supply. 90% of oil is imported from the Middle East (Morita, 2011).
4. Fourthly, the EU put forward strict environmental regulations when it comes to energy use and generation. It is likely that it will further tighten standards for vehicles emissions which will also implicate transportation sector and energy use in cities (Lawrence, 2012).
5. Furthermore, in order to achieve a low carbon society, significant investments need to be made in existing or new infrastructure (OECD, 2012). Old systems, which are mostly carbon based systems, will have to be replaced with more sustainable ones, less resource intensive. New technologies are used at both local (distribution) and grid (transmission and distribution) levels.
6. Normally, all metropolitan areas face challenge to enlarge the physical infrastructure (Pagano, 2014). This also implies the energy system moving further into hinterlands, and expansion of transportation sector, speed, rail and energy networks. On the other side, issues related to mitigation of risk in energy infrastructure were brought in the forefront in the last years. This is emphsaized because of natural and human disasters.[10] Energy infrastructure, that every urban centre depends upon, relies on appropriate adaptation and systems upgrade to meet increasing needs of their residents.[11]
7. Finally, in all of these cities, local governments are focused on important initiatives, namely power savings (Tokyo), energy conservation (Tokyo, Kawasaki, Amsterdam), increase of energy efficiency (Kawasaki and Hamburg), reduction of CO_2 emissions (all four cities), contribution to healthy, sustainable and resilient society (all four cities).

   Ultimately, how these cities combine appraches towards local energy systems` development will determine carbon footprint and impact lives of the next generations.

[9] Germany is especially looking for ways to become more independent from Russia.
[10] Securing electrical supply at adequate levels emerged mostly after the Great East Japan Earthquake in 2011.
[11] Increasing energy sector efficiency is driven mainly by rising fuel prices and climate change impacts.

1.6 Research objective

Research aims to conduct an exploratory assessment and analysis of the level of sustainability and resilience of UES. The assessment is applied to the urban energy sectors of Amsterdam, Hamburg, Kawasaki and Tokyo.

Specific research objectives are focused on:

- Understanding of UES through integrated sustainability – resilience based approach taking into consideration specific policy, program and technology context;
- Development and application of an integrated assessment framework of indicators of sustainability and resilience of UES;
- Understanding to which extent the cities under investigation meet sustainability and resilience objectives;
- Understand what are sufficient similarities or differences between these four cities.

1.7 Research questions

The main research question (R.Q.) is:

R.Q.1: What are the main components of an integrated sustainability and resilience assessment framework of urban energy systems?

Additionally, two sub-questions are identified:

R.Q.2: How do the selected urban energy systems meet sustainability objectives?

R.Q.3: How do the selected urban energy systems meet resilience objectives?

1.8 Significance of the study

In this research, sustainability indicators are combined with resilience indicators in order to reach an integrated framework. The objective of the integrated framework of indicators is to assist in knowing of an urban energy system in terms of sustainability and resilience. Additionally, a DPSIR framework which is used to integrate these two types of indicators is a useful tool that can be combined in a decision making process among city officials, energy utilities and regulators who draft energy or climate related policies for their city.

DPSIR framework[12] (mostly used in environmental domain) has a potential as a measurement tool in both sustainability and resilience analytics, in specificity to energy context for important reason: it connects stakeholders[13] at the city or national level. In this way policy makers have a better understanding of implications of energy programs on sustainability and development in a city.

[12] In some countries (e.g. Macedonia) DPSIR is accepted as official national methodology to develop Local Environment Action Plans (LEAP) per different sectors (thematic areas).

[13] DPSIR uses a concept mapping approach.

1.9 Scope and limitations

In order to select the cities of investigation, ten following criteria were developed and applied:

1. Existing membership or application for membership in a global transnational municipal network, ICLEI Cities for Climate Protection program (CCP);
2. Location in an OECD member country;
3. Two European and two Asian cities;
4. One European and one Asian city is a state capital;
5. One European and one Asian city with services oriented economy;
6. One European and one Asian city with a track of strong industrial performance and a vision for “green transformation”;
7. All cities are port cities;
8. Clearly articulated vision for climate action future and sustainable energy;
9. Actuality of established and measurable goals and targets;
10. Promotion of climate resilient urban development.

The main limitations in the research strategy are:

1. Time resources which negatively impact depth of research and information sought.
2. Language barriers while collecting data for Japanese cities, as most statistical documents are available in Japanese language only.
3. Data availability for selected indicators may vary or be confined.
4. Limited number of cities and limited number of indicators used due to lack of availability of data.
5. Compatibility and comparability of data would also be a limitation.

Chapter 2: Literature review

This chapter reviews the existing literature on sustainability framework, sustainability and resilience assessment, sustainability and resilience energy indicators and a DPSIR framework tool. It is divided into five sections. The first section clarifies a context for sustainability and resilience concepts. The second component explains UES related concepts. The following part explains sustainability assessment and resilience assessment of an energy system. The last two sections examine sustainability and resilience indicators for energy systems and DPSIR methodology, as well as combined approaches towards assessment. In the end, the conceptual framework is explained, describing the purpose of the main concepts of the research.

The main concepts addressed in this chapter are: urban energy system, sustainability and resilience, sustainability and resilience indicators, a framework for sustainability assessment, energy policy objectives and energy technologies.

2.1 Thematic sections

2.1.1 Concepts of sustainability and resilience

Both resilience and sustainability are terms broadly used nowadays. While sustainability, gets interpretations from many different angles, especially from point of view of sustainability in cities (urban sustainability), it mostly concerns with `preserving, enhancing and balancing triple – bottom-line of environment, economy and society`. The area of energy system sustainability is particularly linked with `distributed technologies, providing diversity of generation` (McLellan et.al., 2012, p.155). Saavedra et.al (2012) state that sustainability of a system relates to system capacity to endure perturbations while continuing with provision of services. However, in order to maintain sustainability, societies also need to manage resilience.

Concept of resilience is found across various academic disciplines: engineering, ecology, economics, social sciences, psychology etc. Holling (1973) was one of the first proponents of the resilience concept. He found that a greater variety of functional groups and systems which were subjected to fluctuations demonstrated overall higher resilience levels. He identified resilience as `a measure of the persistence of systems and of their ability to absorb change and disturbances and still maintain same relationships between populations or state variables` (p.14, 1973).

According to Milman and Short (2008, p.759), definition of resilience is the one that includes more than a maintenance of a given system: resilience `...reflects system`s adaptive capacity to transform from stresses and changes`.

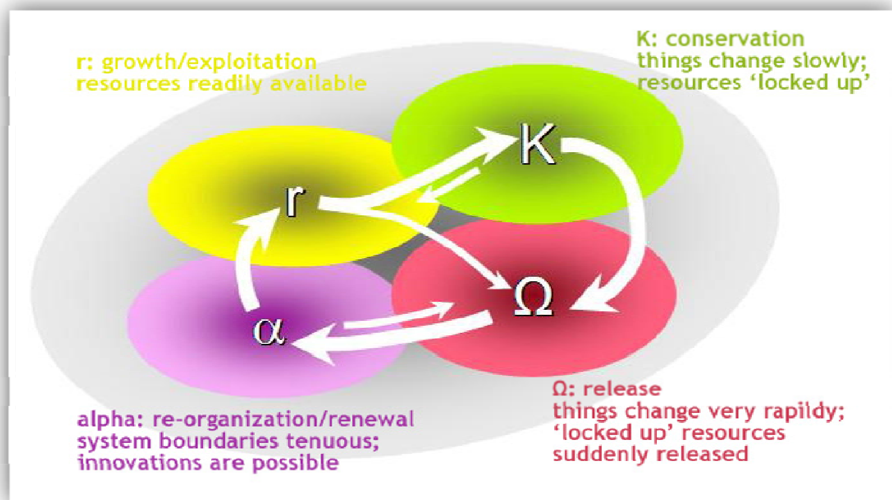
Additional work of Collier et.al. (2013), identified a lack of concrete examples to transition towards embedded urban resilience. Rather than an assessment, the authors offer a reflection about a synergistic approach that facilitates transition towards the concept of urban resilience. Fundamental research topics are proposed for a more resilient future:

1. Geospatial ICT: the foundation to develop spatial data infrastructure in support of resilience and sustainability, particularly important when addressing urban stressors.
2. Green infrastructure planning: increasingly used as a tool to enhance urban resilience and sustainability.

3. Novel design with collaborative responses: building resilient city stimulates social capital.
4. Climate planning: reduction of end-use energy demand and adoption of RE shares strengthens urban energy resilience and lowers the cost of running the system.
5. Limitation to urban sprawl
6. Shot circuit economic approaches: tools and innovation for resilience planning.

Resilience Alliance defines resilience as ability to absorb disturbances, be changed and reorganise, while retaining the same basic structure and way of functioning. The concept implies a learning process from disturbances, whereas attention is transitioned from growth and efficiency to recovery and flexibility. Resilience management aims to prevent system from moving into undesirable state or regime from which it has no possibilities for recovery (Resilience Alliance, 2014). Fundamental concepts of resilience are: non-linearity, thresholds and alternate regimes, adaptive cycle and adaptability, cross-scale and multiple scale effects (`panarchy`), transformability, general versus specified resilience (Figure 9). Conceptually, adaptive capacity as a resilience component is viewed as a general model of systematic change involving rapid growth, conservation, collapse and re-organization.

Figure 9. Adaptive capacity as a central feature in a resilient system

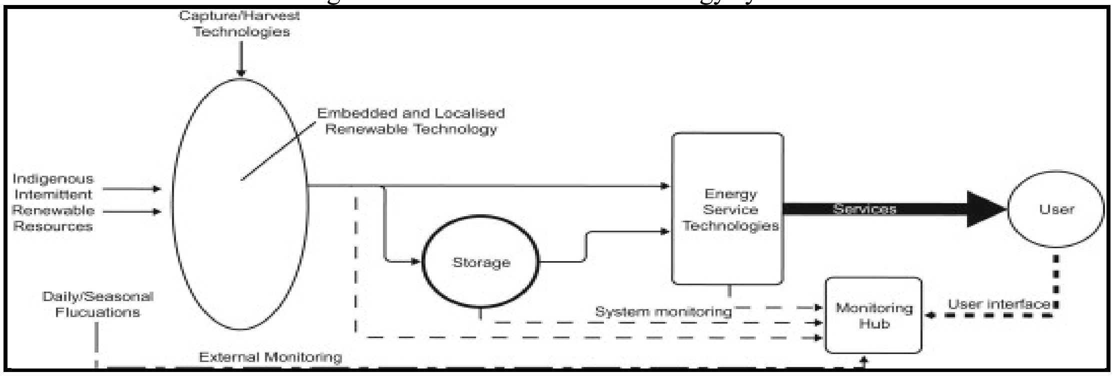


Source: Resilience Alliance, 2014

Newman et al.(2009) tried to answer what makes an ideal conception of a resilient city. They examined a relationship between high performance on climate change issues and the enhancement of urban resilience. In their book, they argue that a resilient city is more in coherence with its bio-sphere and bioregions. Most importantly, according to them, RE and carbon neutrality are the main ideas of a revitalized and resilient city as opposed to `collapse`, `ruralised` or `divided` city outcome.

O`Brien and Hope (2010) conducted a study on how to embed resilience into an energy system. They conceptualised a working definition of a resilient energy system. A system is resilient if it is capable to respond to disruptions and innovations and develop new trajectories, involving one key aspect: learning from and learning how.

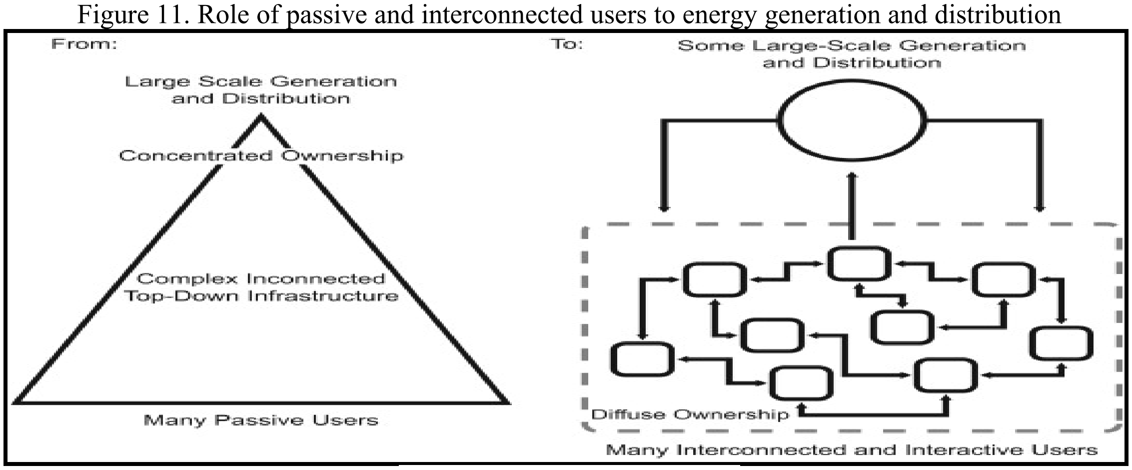
Figure 10. A resilient localised energy system



Source: O`Brien and Hope (2010)

Vulnerability is an essential element of a conventional energy system whereas a low carbon path is an opportunity to foster resilience. Three signals calling for a new approach of an energy system development are: energy security, climate change related concerns and diminishing resources. If the users are capable of capturing energy and managing resources to meet the energy demand, the energy system is considered a resilient one. As shown in Figure 10, this is the case of localised and embedded systems, autonomous off-grid utilization or renewable projects owned by communities. It means that the household level is the starting point for analysis. In a resilient system, human adaptive capacity employs indigenous resources to meet the energy needs (Figure 11).

Figure 11. Role of passive and interconnected users to energy generation and distribution



Source: O`Brien and Hope (2010)

2.1.2 Urban energy systems

Keirstead et.al. (2012) define an UES model as a `combined process of acquiring and using energy in a given society or economy` (p.3848, 3849) referring to acquisition and usage of energy, and overall energy system as a part of society and economy. Based on definitions of Jaccard and Ramaswami et.al., they referred to urban energy system as `a system within the administrative boundaries plus easily traceable upstream flows, like electricity consumption`.

According to the authors, UES has several distinct features related to acquiring and using energy as well as its geographical boundaries:

1. Combined process - different steps stand in need to provide energy service delivery, namely extraction of resources, refinement, transportation, storage and conversion to end service delivery;
2. Acquisition and usage - UES is inclusive of both energy supply and demand;
3. Social and economic aspect - institutions, consumer behaviour, markets and other social, economic or technical elements affect operation of technical infrastructures;
4. Pure geographic boundaries (a) - within the city`s administrative boundaries;
5. Geographic-plus - technologies of (a) with traceable upstream flows;
6. Pure consumption - energy related activities of city`s inhabitants irrespective of their location.

They collated analysis identifying five practicing areas to interpret UES model: technology, building and systems design, urban climate and policy assessment.

Rutter and Keirstead (2012) looked into historical development of UES addressing how UES came into existence. Development of energy services was examined covering a path from the basic needs to supply food and fuel in early settlements, to a diverse range of energy services in modern cities, such as heating and cooling of buildings, lighting, communication, mobility services etc.[14] The main aspect of the future UES is interacation between concentrated local demand and diffuse energy supplies which can be summarised in Table 4. Pattern of `increasing efficiency under constraints` is evident in the urban environment (Rutter and Keirstead, 2012, p. 4).

Table 4. Main constraints and drivers in energy transition trends

	Main transition trends and their aspects	Elaboration	Constraints
			Drivers
1.	Fuel transition *Intensification of energy use*	Increase of per capita energy use in spite of technological innovations, in heating or lighting (e.g. commuting in London, which increased the demand for transport energy)	Growing scarcity of fossil fuels, aging infrastructures, climate change, rapid urbanization in developing economies, barriers towards adoption and use of proven technologies, institutional and market changes.
2.	Complexity of UES *Organizational and technological complexity*	Early systems required small lines of supply, local area and biomass crop management. Transition to coal and different approaches, (England versus continetal Europe) requires expansion to the hinterlands and better coordinated energy supply chain. Need for modern electricity and gas networks.	
3.	Benefits from innovation policies *Strategy and long-term aims*	Engagement of governments and privates sector. Mitigation of downsides in current systems.	Optimization of UES, smart-grids, improved EE, new supply side technologies, changes in cost structures, proliferation of energy service companies, ICT, integrated mobility services, online consumer access.
4.	Increased rapidity *Transition to coal, modern grids and oil based economic development*	Overall innovation needs to advance. Each system will exhaust available resources and capacity of infrastructure, lead to market or price signals. Record of higher energy intensity of every new system.	

Source: Rutter and Keirstead (p.78,79, 2012)

[14] This is important as to understand the future transition of UES in Western Europe.

2.1.3 Sustainability assessment and resilience assessment of an energy system

Del Rio and Burguillo (2008) contributed to sustainability assessment with their own integrated theoretical framework: a comprehensive analysis of socio-economic impacts of RE systems on local sustainability. The framework was developed as a response to a scarcity of empirical studies on this subject. Two conceptual frameworks were outlined (p.1328):

1. A substantive framework which focuses on a triangular and a top-down approach,
2. A procedural, bottom-up approach, sustainability conceptual framework.

Del Rio and Burguillo applied this framework in a context of developed countries. According to them, main impact of RE investments was on the standard of living. RE projects mostly use local resources and contribute towards so called endogenous development. This methodology is relevant for policy makers and urban residents in order to understand:

1. Implications of a selected range of energy technologies employed on the city scale,
2. The programs dealing with urban energy sustainability.

Shen et.al. (2010) proposed a multi framework based on policy goals, criteria and RES. They examined the innovation state Taiwan where carbon emissions were adressed by the means of RES.[15] The main purpose of the assessment model presented in the article was to select suitable RE technology while meeting environmental, economic and energy goals (3E goals), whereas the environmental goal appeared to be the most important. According to the authors the government should always manifest ability for only one particular technology.

The research of Shen et.al. reckons the RES assessment framework proposed by Komor and Bazilian (2005). [16] The framework assessed relationship of the following concepts: energy policy objectives, policy instruments and sustainable technologies. According to them, policy goals lead to specific RES and technologies. In other words, one or each individual energy policy aim would be best accomplished by distinct mechanisms and technologies.[17]

A framework Shen et.al. proposed is significant as it can be used by authorities or decision makers to examine programs and technologies for any specific goal.

On the other hand, Kanada et.al. (2013) investigated implementation of policies designed for pollution control and explored impacts on industrial activities in Kawasaki City. They found that policy development was strongly correlated with global warming process, impact on industrial energy intensity and consumption. The argument made was that policy tool or instrument reinforced compliance. A relatively strong effect of preventive actions was found: the policy which nurtures a technological development requires a smart mix of measures and a broad recognition in society.[18]

Molyneaux et.al (2012) performed a resilience analysis of electricity system using a measure of composite Resilience Index which calculates resilience of the national power system. The sample used in the paper consisted of countries with considerable deposits of mineral resources. Japan was the only country exceptional to this case: with no deposits of metal ores,

[15] Similar to Japan, Taiwan is a densely populated sub-tropical country in the Pacific with limited natural resources and high imports to secure energy supply.
[16] Authors analyzed the case of RES deployment in Ireland when the country considered policy change of its own energy system.
[17] They argued that many drivers and instigators in Irish renewable energy policy could be categorized into energy, environmental and economic or industrial goals.
[18] Particular industrial and locally specific changes in energy consumption, as well as sharp decline of energy intensity in the manufacturing was found during 1970s and 1980s in Kawasaki.

yet the world´s third largest copper and steel refiner. However, its own electricity system resilience provides an insight into the country´s ability to attract electricity intensive industry. A robust power system is an essential component of a country´s functioning economic system including a network of financial transactions.

Economic losses occur due to power fluctuations and blackouts. Key resilience attributes are redundancy, efficiency and diversity. A resilient system should be efficient, conserve resources and minimise the costs, strengthen diversity, reduce the risks associated with fuel supply, spare capacity or redundancy to allow unplanned surges in demand or the loss of electricity, and secure if it relies on foreign sources. The following aspects are taken into consideration for the composite Index Molyneaux et.al developed:

Non-renewable fuel used in generation ① Generation efficiency ②
Distribution efficiency ③ Carbon intensity of generation ④
Diversity of generation ⑤ Redundant power for use in GDP ⑥
Reliance on imports ⑦

2.1.4 Sustainability and resilience indicators for energy system

In a review paper, Liu (2014) constructed a framework for a general sustainability indicator (GSI). GSI measurement includes 11 basic indicators for RE systems. He combined discussion on sustainability, reviewed different scales and assessment criteria. The framework can be used as a future guidance for assessment of various energy systems.

By the same token, Milman and Short (2008) argue that indicators measuring urban sustainability have narrow focus and solely describe the current state of the urban system. Existing sustainability indicators will not provide sufficient information nor will they offer information about the likelihood of system improvements over time. They argue that indicators incorporating a measure of system resilience provide a missing but credible information. For the particular case reference in the water sector, they developed Water Provision Resilience (WPR) Index.

In 2005, the International Atomic Energy Agency (IAEA) developed guideline framework known as Energy Indicators for Sustainable Development (EISD). National level EISDs improve statistical analytics of any particular country. They are useful in coordinating statistical services and national priorities and benefit policy makers, energy analyists and statisticians. They are in the format that aids decision making at the national level in order to help countries assess effective energy policies for action related to sustainable development (IAEA, 2005). There are 30 EISDs divided in 3 main groups (economic, environmental and social). Indicators are framed in accordance with Agenda 21, and present a clear picture of the whole system i.e. context of economic background that influences sustainability, resources availability, long-term implications of current policy decisions, major inter-linkages or trade-offs.

The work of Keirstead (2007) deals with his view of relevant urban energy indicators for the City of London. Accordingly, no single indicators are appropriate for all applications and need to be readily available. Traditional indicators (Table 5) for London are based on: drivers (demographics, economic structure etc.), activities (transport, domestic, commercial, industrial use), stocks and flows (total energy production, total energy imports, total energy exports, total primary demand, land, water), impacts (social, economic and environmental).

Table 5. Overview of urban energy system indicator themes for London

SYSTEM LEVEL			
↓	↓	↓	↓
Drivers + headline metrics	Activities + headline metrics	Stocks & flows + headline metrics	Impacts + headline metrics

Source: Keirstead, 2007, p.7. (based on Ravetz, 2000)

Analytical validity is more relevant as criterion than measurability itself and the number of indicators according to this line of reasoning will depend on the needs of stakeholders, temporal and spatial frontiers. System-based approach in the energy sector is relevant from adaptability, resilience and robustness point of view.

Spalding-Fecher (2003) turned attention to analysis of sustainability of South African energy sector using Helio International Sustainable Energy Watch (SEW) based indicators. SEW indicators are seen as a package meaning they offer a comprehensive picture only if they are analysed as a full unit of indicators (Table 6). They counterbalance between how accurately a certain sustainability dimension is targeted and the ease with which data can be prepared and interpreted on an annual basis. Vectors assigned to indicators correspond to:

1. `1` - indicating a measure of `status quo', as a global average,
2. `0` - being the sustainability goal.

Table 6. Sustainable Energy Watch indicators and vector values

Sustainability dimension	SEW Indicator	Sustainability target (vector = 0)	Reference for unsustainability (vector = 1)
Environmental	Global impacts: energy sector carbon emissions per capita	70 % reduction from 1990: 339 kgC/capita	1990 global average: 1,130 kgC/capita
	Local impacts: level of most significant local energy pollutant	10 % of 1990 value	1990 level of pollutant
Social	Households with access to electricity: share of households with access	100%	0%
	Investment in clean energy, as a proxy for job creation: RE and EE investment as share of total energy sector investment	95%	1990 level
Economic	Resilience to external trade impacts		
	Exports: NRE (non-RE) exports as share of total export value	Exports: 0 %	Exports: 100%
	Imports: NRE imports as share of total primary energy supply (TPES)	Imports: 0 %	Imports: 100%
	6. Burden of energy investments on the public sector: public investment in NRE sector as share of GDP	0%	10%
Technological	7. Energy intensity: primary energy consumption per unit of GDP	10 % of 1990 value: 1.06 MJ/US$1990	1990 global average: 10.64 MJ/US$1990
	Use of renewable energy: RE supply as a share of TPES	95%	1990 average: 8.64 %

Source: Spalding-Fecher (2003), based on Helio International (2000)

In a consistent study about the application of sustainability assessment tool to rehabilitate national electric power system of Bosnia and Herzegovina (BiH), Begić and Afgan (2007) proposed four sets of indicators to perform energy technologies assessment: resource, environmental, social and economic indicators with 14 subcategories expressed in the form of sub-indicators. A multi-criteria sustainability assessment (MCA) was combined to select new power capacities that would provide additional electricity generation for BiH. The combination of these four selective types of indicators contributes to the General Sustainability Index and assessment of effective energy choice for sustainable development.

Suggesting a package of indicators for energy sector with regard to EU requirements for Baltic States, Streimikiene et.al. (2007) promoted methodology based on EISD tool to assess trends, goals, progress monitoring and overall development for transitioning economies. Twelve priority area indicators were outlined, all of which address strategic priorities for Baltic States: energy use, energy intensities, end-use energy intensity of economic sector, energy security,environmental energy impacts. According to the authors, energy productivity indicators are essential for the framework because the correlation with measurement of progress towards sustainable energy system is very close. By means of indicators, the authors addressed energy consumption decrease and increase vs. GDP decrease and increase.

Arup, RPA and Siemens conducted a research related to vulnerabilities of the New York City (NYC) electricity grid and steps that could mitigate the risks. It was analyzed how resilience of urban infrastructure systems can prepare cities to cope with vulnerabilities and hazards more effectively (Cook et.al, 2013). According to the authors, it is essential to make equipment more robust, develop smart grids and widen demand reduction programs to decrease peak demand and network congestions. Installation of robust technology and equipment is essential. Five major characteristics for a resilience framework of urban infrastructural systems are: robustness, redundancy, diversity and flexibility, responsiveness, coordination. According to this rationale, 15 resilience performance indicators help designers and managers of the city infrastructure system. Examples of potential investments to advance resilience are presented in the following Table 7.

Table 7. Potential investment options to advance electricity grid resilience using resilience performance indicators

ROBUSTNESS	Gas insulated switchgear /Flood and water proofing/ Undergrounding/ Voltage/VAR controls/ Fuse saving technologies/ Hydrophobic coatings
REDUNDANCY	Demand reduction/Energy efficiency/ Vehicle-to grid/ Battery storage
DIVERSITY AND FLEXIBILITY	Battery storage/Vehicle-to grid/Distributed generation/Automated switches/Intelligent feeders and relays
RESPONSIVENESS	Intelligent feeders and relays/Automated switches/ Advanced Metering Infrastructure (AMI)/Smart metering/ Automated Demand Management (ADM)
COORDINATION	AMI/Geographic Information Systems (GIS)

Source: (Cook et.al, 2013, p.50)

Siemens developed Green City Indices, a unique research project comparing cities in Asia, Europe, Germany, Africa, Latin America, US and Canada, across eight different categories (The Green City Index. 2012). The Green City Index is a measure of one city´s environmental record and its commitment to reduce environmental impact in the future. Following aspects are taken into consideration: CO_2 emissions, energy, buildings, transport, water, waste and land use, air quality, environmental governance.

The assessment based on the data publicly available presents these eight categories in 30 individual indicators:

1. 16 quantitative indicators measuring current city´s performance,
2. 14 qualitative indicators, assessing future commitment towards urban environmental sustainability.

Yee et.al (2011) found a DPSIR scheme to be a very flexible tool in relating anthropogenic stresses on water management and ecosystem services within Coral Reefs Project in Tampa Bay. They found particularly important *uphill and downhill* processes related to local concerns regardless which of the single five DPSIR concepts was used (drivers, pressures, state, impacts or responses). According to them, it was demonstrated that unique characteristic of the DPSIR framework which is a concept mapping approach, encourages scientists and decision makers to move beyond their separate and isolated scale of the research domain, economic or financial affects or management focused areas, and analyze problems from the point of view of their complex interactions. DPSIR framework uses broad definitions for five concept areas and analyzes interdependences between them. When these five different concepts are placed in five distinct categories, DPSIR perceptibly simplifies complex connections between humans and environment.

Huang et.al. (2011) developed a DPSIR model to assess greenhouse effect in Taiwan mostly concerned to consumption of energy, impacts on environment and government policies, and expenditures or responses. The authors initially categorized GHG-related indicators to develop a cause and effect pattern of GHG emissions, and assessed greenhouse effect by means of the DPSIR tool. According to these authors, composition of DPSIR scheme can be readily adapted in different countries dependant on availability of economic, societal, and ecological data.

Further, Yee et.al. (2012) identified DPSIR framework to be a main tool for sustainability research opportunities. This was done by integrating social, cultural and economic aspects of human (asthma disparities) and environmental health into its five framework categories. Yen et.al. broadened traditional environmental locus of DPSIR by adding supplemental categories which easily relate to consideration of human communities and individuals.

2.1.5 Combined sustainability and resilience assessment

Saavedra et.al (2012) analyzed two groups of cities which prominently differed in planning approach towards climate change related actions. Dealing with disturbances as a result of climate change, depends upon the capacity of communities to foster transformations. They found that capacity of urban areas to accommodate resilient urban conditions could be characterized as combination of following attributes: `level of social capital, openness to change, cultural diversity, sharing information and resources` (p. 9). These could all be identified as social resilience aspects. Most often, adaptive measures in support of resilience are confronted with social rather than technical barriers

Common features could be drawn up between the papers of Saavedra et.al (2012) and Collier et.al. (2013). Both papers identified social, cultural structures and relationships as vital elements in urban commitment and planning process.

In a similar fashion, Gaudreau and Gibson (2010), conducted a sustainability-resilience criteria assessment of a small-scale biodiesel project. The project incorporated energy, transportation, waste management, security, public health and community aspects. They integrated and applied both sustainability and resilience objectives having identified the main benefit of the project being social learning and not only energy security. Through sustainability assessment they address requirements and multiple interrelations. Impact assessment and a project appraisal were based on a methodology (p.235, 236) identified as a combination of:

1. An established set of eight generic sustainability assessment criteria, and
2. Nine resilience analysis criteria (Table 8).

Table 8. Sustainability and assessment criteria according to Gaudreau and Gibson

Assessment criteria	
Sustainability criteria	*Resilience criteria*
Socio-ecological system integrity	Diversity
Intra-generational equity	Ecological variability
Intergenerational equity	Modularity
Livelihood sufficiency and opportunity	Acknowledge slow variables
Resource maintenance and efficiency	Tight feedbacks
Precaution and adaptation	Social capital
Socio-ecological civility and democratic governance	Innovation
Immediate and long-term integration	Overlap in governance
	Ecosystem services

Source: Gaudreau and Gibson, 2010

Based on the review of academic literature the following could be concluded:

1. Analysis and assessments of urban energy sector exploring integration and combined application of sustainability and resilience opens the new door for research and analysis of many components in urban energy. It is becoming increasingly a field of interest for urban and energy professionals alike.
2. Monitoring of development, maintenance, or city energy and electricity sector redesign could become more meaningful with a twofold assessment approach.
3. Combined sustainability-resilience assessment approach is a paradigm shift as opposed to currently existing theoretical view that sustainability and resilience are two quintessentially separate domains.
4. For the purpose of research in Japan, Germany and the Netherlands, observing the changes in indicator values over time helps quantify progress or lack thereof. It also helps to understand inherent differences betweeen these countries and cities.

2.2 Explanation of conceptual model

A concept of analysis elements is presented in a conceptual framework (Figure 12). As it can be observed the main concepts are sustainability and resilience assessment of an UES. The performance is monitored and measured by means of indicators. There are two types of indicators relating to two different variables of an UES: sustainability and resilience indicators. As a basis for categorization and distinction of indicators, a DPSIR reporting framework was used to distinguish between different sets of indicators. Sustainability indicators correspond to all five boxes (concepts) of the DPSIR framework, while the resilience indicators correspond only to state and response boxes.

For sustainability indicators, a selection process starts with categorization of economic, environmental, social and institutional aspects, meaning that their values reflect on the state of corresponding sustainability features in a given energy system. *Driving forces* in urban or metropolitan area are those whose activities directly impact state of environment i.e. an ecosystem (Giupponi, 2007). These are essentially social or economic sectors that fulfil human needs or infrastructure. Drivers can be trends in energy, transportation, buildings and home construction, services or industry and engineering (ports), families and individuals, health, security etc. Both economic and social sustainability indicators fall into this category (for example average household electricity consumption, energy use per capita or per unit of GDP etc.).

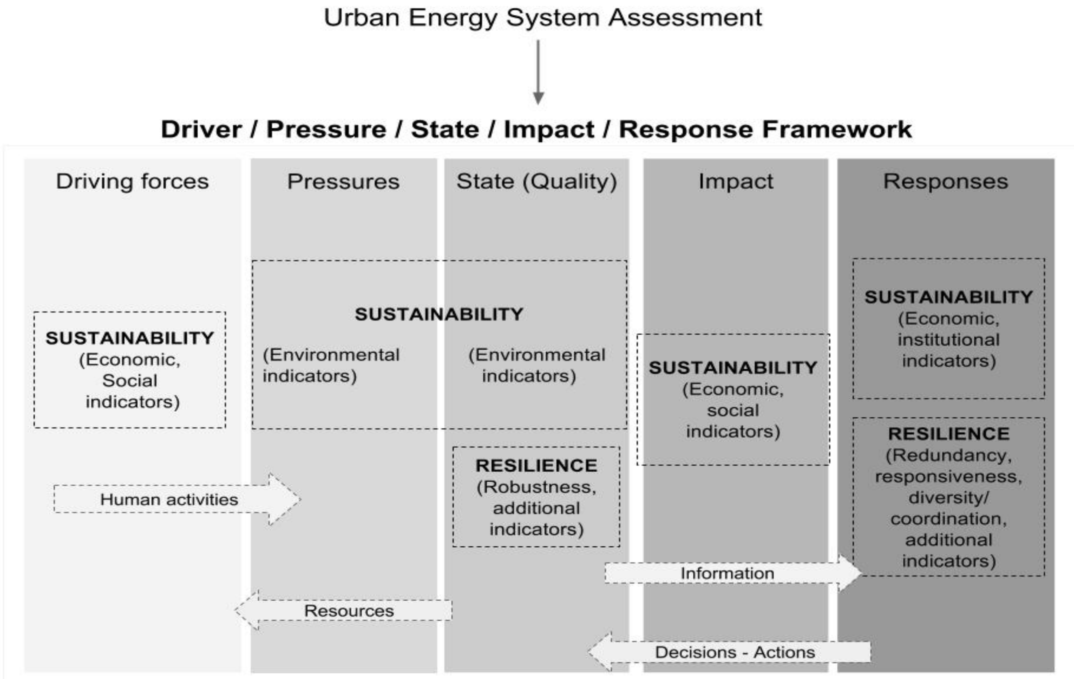
Pressures (GHG emissions) are exerted by a human factor or activity with a positive or negative impact (Giupponi, 2007). In other words human factors affect the state of environment, climate, climate change etc. Environmental sustainability indicators, such as level of CO_2 equivalent emissions, are used to measure them.

Furthermore, environmental indicators relate to the *state* (quality) of environmental media (air, soil, water etc.) in an urban area (Giupponi, 2007) measuring concentrations of air pollutants that occur as a result of different pressures (levels of SOx, NOx, PM, ozone or other). Essentially, state refers to the physical and chemical (environmental) and ecological status of ecosystems. Also, resilience indicators (robustness and additional) can reflect on the current state of the electrical infrastructure, efficiency in generation and transmission etc.

These changes have an *impact* on human health, welfare, ecosystem, financial value and expenditures (Giupponi, 2007) which is why economic and social sustainability indicators are used to describe them (changes in EE or energy intensity of different sectors, average electricity price, share of household income spent on fuel or electricity).

Finally, based on the information received about the state and impact on a system the policy makers and society engage in efforts to make *response* to these various challenges in an UES (Giupponi, 2007). Category of sustainability (economic and institutional) and resilience (redundancy, diversity and coordination, responsiveness, additional) indicators correspond to response box of the framework, reflecting the objectives of local, national or international policy making.

Figure 12. Conceptual framework



For example, the national or local government may decide to impose regulation or ordinance to increase the percentage of RE share in electricity, promote clean energy policy or mechanisms to improve sustainable energy and environmental measures, adopt low development framework. The energy utility can decide to invest financial resources that will improve functioning of the energy system over the certain time period (redundancy), increase the number of departments that would handle different inquiries from citizens or various entities. The utility or the country may decide to increase the diversity of energy resources in the electricity sector, introduce new technologies in the energy portfolio to improve generation diversity or respond to various system related concerns. Measures as such can increase stability of the electricity grid system which is a sort of a feature of adaptive measures of local energy system.

Chapter 3: Research Design and Methods

3.1. Research approach and techniques

The research is a combination of exploratory, desk and field study approach. The primary purpose of this research is to integrally examine urban energy sustainability and resilience concepts. A research technique consists of quantitative data collection. Indicators are used in as the main tool to evaluate level of sustainability and resilience, obtain information about past and current developments and. Indicators are basis for assessment. Given the primary aim of the research which is to assess the level of sustainability and resilience in UES using a set of sustainability and resilience indicators, descriptive statistics was used to perform the assessment for two sets of indicators in four selected cities. It is shown in the research matrix below (Table 9).

Table 9. Research matrix

OBJECTIVES	APPROACH	TECHNIQUES	DATA COLLECTION	INSTRUMENTS	SOFTWARE
Exploration: How do cities´ UESs perform in sustainability/resilience?	Quantitative	Descriptive statistics	Desktop research	Analysis of available data and documents	Excel SPSS
Urban Energy System (UES) as a Unit of analysis	Quantitative	Descriptive statistics	Secondary data collection	Existing data sets	Excel SPSS

3.2 Operationalization: variables and indicators

There are three main variables in this study: urban energy system, sustainability and resilience of energy system. The indicators associated to them are shown in Table 10. Combination of indicators is derived from the following academic literature:

1. IAEA Methodology for energy indicators for sustainable development (IAEA, 2005);
2. Economist Intelligence Unit (The Green City Index, 2012).
3. Toolkit for resilient cities developed by Siemens (Cook et.al., 2013).
4. Resilience indicators developed by Molyneaux (2012).

Indicators are divided in two different categories, according to the UES variables:

1. Sustainability
2. Resilience

Sustainability category is further divided in four sub-categories, and resilience category is divided in five sub-categories:

Category: Sustainability (Total: 13 indicators)

1a. Economic sub-category
1b. Environmental sub-category
1c. Social sub-category
1d. Institutional sub-category

Category: Resilience (Total: 13 indicators)

2a. Robustness sub-category
2b. Redundancy sub-category
2c. Responsiveness sub-category
2d. Diversity and coordination sub-category
2e. Additional resilience indicators sub-category

Table 10. List of indicators used in UES assessment

Variable	**Urban energy system**				
Variable	**Indicator and sub-category**				
Category	Sub-category	Code	Description	Unit of measurement	Corresponding DPSIR component
SUSTAINABILITY	Economic	S_Econ_1	Energy use	Gigajoules (GJ)	Driver
		S_Econ_2	Energy intensity (buildings, transport, industry)	koe/$05p	Driver
		S_Econ_3	Fuel share in energy/electricity	%	Driver
		S_Econ_4	Share of RE	%	Driver
		S_Econ_5	Average electricity price, including value added tax (VAT)	ct€/kWh	Impact
	Environmental	S_Env_1	CO_2 emissions from energy consumption (1990, 2000, 2005, 2010, 2011)	T per capita	Pressures
		S_Env_2	Concentrations of air pollutants in urban areas, NO_2, SO_2, PM_{10} (1990, 2000, 2005, 2010, 2011)	µg/m^3	State
	Social	S_Soc_1	Share of household income spent on fuel/electricity	%	Impact
		S_Soc_2	Average electricity consumption of household per capita	kWh/cap	Driver
	Institutional	S_Inst_1	Sustainable energy action plan (SEAP)	Number of plans	Response
		S_Inst_2	Climate change action plan/Low carbon development plan	Number of plans	Response
		S_Inst_3	Clean energy policy/energy measures for environment	Number of policies/measures	Response

Variable	Urban energy system				
Variable	**Indicator and sub-category**				
Category	Sub-category	Code	Description	Unit of measurement	Corresponding DPSIR component
RESILIENCE	Robustness	R_Rob_1	Average age of infrastructure	Years	State
		R_Rob_2	Material damage to infrastructure due to environmental effects	Euro/Yen	Impact
	Redundancy	R_Red_1	Total improvements made in city wide energy system in last 5 years	Euro/Yen	Response
	Responsiveness	R_Res_1	Speed of emergency response	Days	Response
		R_Res_2	Inquiries handled	Number (monthly,yearly)	Response
	Diversity and coordination	R_DC_1	Residential/commercial/institutional buildings served by own energy generation	%	Response
		R_DC_2	Policies jointly coordinated by two or more institutions	Number	Response
		R_DC_3	Supporting initiatives from citizens and businesses	Number	Response
	Additional indicators	R_AR_1	Non-renewable fuels in generation	%	Driver
		R_AR_2	Generation efficiency	% of output	State
		R_AR_3	Distribution efficiency	% of output	State
		R_AR_4	Carbon intensity	gC/kWh	Pressure
		R_AR_5	Diversity of generation	HHI	Driver

3.3 Validity and reliability

In order to ensure validity and reliability, the research methodology involved consistent approach and use of energy indicators from national, governmental and international energy organizations`databases, which all provide credible and relevant secondary sources of data.

World Energy Council (WEC) is the global energy body accredited by the UN. It provides objective, dynamic and unbiased data sets about energy sector worldwide (indices, indicators, policies, measures, energy issues monitor etc.). *The US Energy Information Administration (EIA)* is the foremost agency of the US Federal Statistical System, the part of the US Department of Energy. It covers full spectrum of energy sources worldwide in a comprehensive data collection program. *Eurostat* is the leading EU Statistical office. *National Institute for Environmental Studies (NIES)* is an independent administrative and central environmental pollution research institution in Japan and includes extensive GIS monthly and annual updated database on urban air quality accessible online. *Kawasaki Environment Research Institute (KERI), Hamburg ambient air pollution network, GGD Amsterdam (Municipal Health Services)* provide validated data on environmental and air quality measured at various city locations. Outmost, data provided by these institutions cover historical and actual data which is a precondition in this case to ensure reliability.

3.4 Methods for data collection

Main data collection method is a desktop research, based on secondary sources of information obtained from previous scientific studies, policy, monitoring and evaluation reports from city or metropolitan governments, government databases, websites, local, regional, national or metropolitan strategies. In this research descriptive statistics is the optimum approach to assess the significance of variables, and the primary reason why it is employed as a research strategy. The objective of this research however, is not to determine of predictive encounters based on existing time series, although the prognostic analysis can be conducted as a future research endeavour.

Secondary data sources used in the research process are the following:

1. Statistical reports and databases, government data-sets,
2. Academic journals and published papers, public library journals,
3. Doctoral dissertations, academic books,
4. City (government, metropolitan) reports,
5. Various annual reports, research reports,
6. Review studies,
7. Policy documents and memoranda,
8. Archives,
9. Blogs and newsletters,
10. University databases or academic records on energy statistics.

Chapter 4: Research Findings

From the original set of 26 indicators in the context of sustainability and resilience assessment, the following ten indicator values were gathered:

Sustainability indicators	Resilience indicators:
Economic indicators:	Other resilience indicators:
RE share in energy consumption (%) Average electricity price in 2010, including VAT, (ct€/kWh)	Rate of electricity transmission/distribution losses (%) for 1990, 2000, 2010 and 2011.
Environmental indicators:	Total electricity generation efficiency (%) for 1990, 2000, 2010, 2011.
CO_2 emissions from energy consumption (tCO_2/year) Concentrations of three air pollutants in urban areas, NO_2, SO_2 and PM_{10}, 2008-2013 ($\mu g/m^3$)	Carbon intensity of generation (gC/kWh) for 2007, 2009 and 2011.
Institutional indicators:	
Sustainable energy action plan (SEAP) Climate Change Action Plan (CCAP)/Low carbon development plan Clean energy policy/Promotion of energy measures for environment.	

The following section (4.1) with sub-sections presents the findings about urban energy system in each examined city in general. It is followed with the data findings about sustainability and resilience indicators for energy system. Annex 1 provides more information about Section 4.1.

4.1 Urban energy system of cities

4.1.1 Energy system of Amsterdam

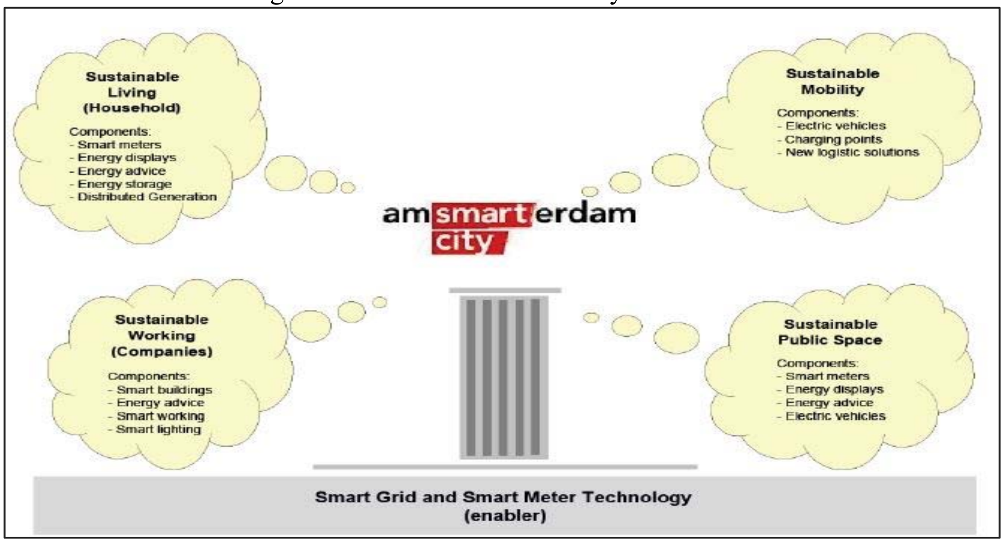
Climate and energy related policies in Amsterdam are coordinated from the Climate and Energy Office (C&E Office) in the Physical Planning Department (DRO). C&E Office initiated the Amsterdam Smart City (ASC), with Liander [19] and Amsterdam Innovation Motor (AIM), to apply innovative technologies and stimulate residents` behavioural change (Figure 13). C&E office is active in networking, engaging citizens with energy stakeholders through Energy Cafés (City of Amsterdam, 2014).

Amsterdam invests heavily in efficient electric transport and car sharing schemes. Its goal is to expand electric transport to 40,000 EVs, including 10,000 plug-in hybrids between 2015-2025. In spite the fact that city has been expanding, demand for gas and heat is in decline,

[19] local, and the largest Dutch grid network operator

because of stronger insulation requirements. The footprint per household is in decline. Electricity demand is increasing due to stronger economic performance (Zanten, 2012). Amsterdam's energy consumption per head per year is less than the Dutch average of 81 GJ (22,500 kWh).

Figure 13. Amsterdam Smart City focus areas



Source: IDC Energy Insights (2009)

For electricity, Amsterdam is part of the national grid. Five power plants are located near the city: three of them run on gas (2 are CHP), one on coal and one on waste. Households and enterprises can freely choose their supplier. Provider Nuon dominates in Amsterdam region, and has acquired 50% market share, and since 2009, it is a part of Swedish company Vatenfall.

The Dutch heat market however is not liberalized, and residents cannot freely choose their provider. Two main heat providers are: Nuon and Westpoort Warmte (WPW), a 50-50% joint venture between Nuon and the City (Zanten, 2012). Energy-efficient district heating (DH) network stands for one of the best in Europe. Residual heat which Amsterdam has in abundance is produced in two Nuon gas-burning power plants and AEB. Surplus heat is considered underutilized.

Process industry in the city is limited because services sector is significant. Electricity for enterprises dominates in energy consumption landscape (it accounts for two thirds of total demand). Approximately 6% of CO_2 emissions come from the ICT, data centres and offices, which are heavy users (City of Amsterdam, 2010).

Approximately 50,000 households are connected to the heating network (Table 11). The plan is to expand the grid together with Nuon to a heating ring, and add additional 200,000 houses by 2040. In area where technical conditions do not allow this expansion, heat and cold storage, the gas will be used to provide heating (City of Amsterdam, 2010).

Table 11. Energy consumption in Amsterdam in 2010

Energy consumption	
Natural gas consumption	850 million m^3
Electricity	Approx. 4100 GWh
Heat	555.5 GWh (2 million GJ)
Energy network	
Gas infrastructure	
DH distribution network	cca 45,000-60,000 units

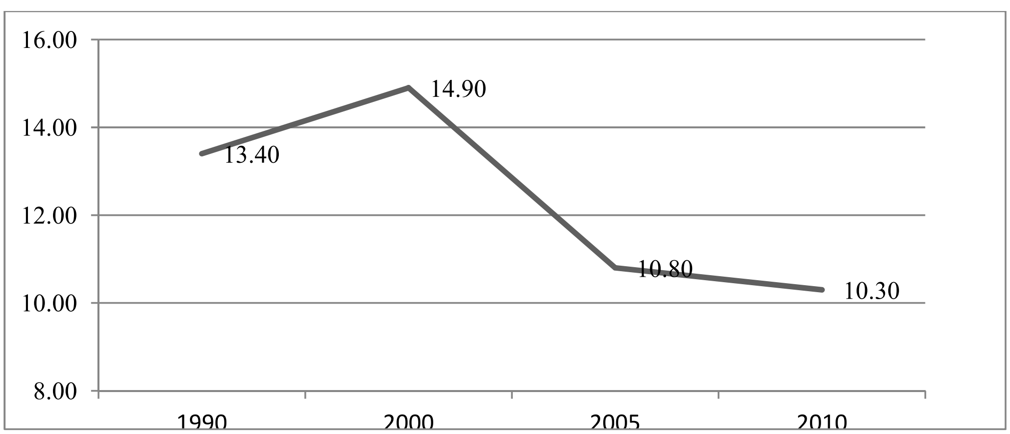
Source: Zanten (2012)

4.1.2 Energy system of Hamburg

In terms of energy supply, similar to Amsterdam, Hamburg`s energy system is undergoing major transition. City of Hamburg plans to gradually create electricity, gas and long distance heating enterprises that will be active in energy supply. The Advisory Energy Council and Energy Forum are also responsible for the city`s energy concept. About 80% of electricity is imported from the national grid. Main energy providers for the city are Vattenfall, E.ON and Hamburg Energie. Hamburg Energie was established in 2009, by the Senate of Hamburg. As a municipal energy utility, it secures stable supply for citizens and businesses in the metropolitan area with real environmental benefit. Hamburg aims to strengthen economic position of the city with the enterprise committed to produce at least 50% of annual consumption by themselves. Currently it produces 40,000 MWh of electricity and has 90,000 customers (Hamburg Energie, 2012).

Hamburg made strong investments in wind energy over last decades. This is why emissions per kWh and per inhabitant show steady decline since the end of 1990 (Chart 1). Transport, residential, services and industry were the largest contributors of CO_2 emissions sector wise.

Chart 1. Trend of CO_2 related emissions in Hamburg from 1990-2010 (T/per capita, per year)



In relation to climate protection the city developed major actions and numerous sub-actions which are identified in Table 12. Hamburg is involved in achieving energy intelligent cooperation in different urban districts through Smart Power project or integration of smart grids (Smart Power Hamburg, 2012).

Through National Innovation Programme for Hydrogen and Fuel Cell Technology which is part of agreement between the city and Vattenfall utility, public hydrogen filling station was opened to provide fuel for Hochbahn hydrogen buses and hydrogen powered cars. Hydrogen is produced only using renewable electricity (CEP, 2014).

Table 12. Major actions related to energy system and climate change in Hamburg

ENERGY SUPPLY Low carbon heat supply CHP Smart grid Waste heat Load management Doubling wind power capacity Current storage Innovative gas/steam power station	BUILDINGS Modernization of insulation CHP Central DH Heat demand reduction Decentralized heating grids	TRAFFIC/ TRANSPORTATION Mobility management plans Smart public transportation Car sharing
TRADE AND INDUSTRY Enterprises for Resource Protection EE Waste heat from industry Industrial enterprises` commitment	URBAN DEVELOPMENT Smart-city Integrated action fields Whole city integrated concept City of short distances Initiative Arbeit und Klimaschutz	CONSUMPTION Ecological footprint and agriculture Personal CO_2 balance Eco lifestyle Regional eco-products
WASTE MANAGEMENT Recycling management and source segregated recycling Waste separation Circular economy Integrated product design	RESEARCH, SCIENCE, EDUCATION Research for renewables Integrated Climate System Analysis and Prediction (CliSAP) Cluster of Excellence Interdisciplinary Klima Kampus RE cluster (EEHH) Intelligent urban infrastructures	CLIMATE ADAPTATION Climate change management Modeling hotspots Dynamic risk management: heat periods/floods

Source: TRANSFORM (2013)

Hamburg is known as the district heating capital of Germany. Around 45,000 households (19%) are connected to its vast DH network. Table 13. provides basic information about energy consumption and network for Hamburg city:

Table 13. Energy consumption and energy network data in Hamburg

Energy consumption	
Annual power consumption	Approx. 13,000 GWh
Natural gas consumption	Approx. 21,000 GWh
Energy consumption for DH	5,000 GWh
Energy network	
Energy network	27,000 km power lines/1.1 mil. supply points
Highly developed gas infrastructure	7,300 km/over 150,000 connections
District heating distribution network	800 km/ cca 500,000 residential units

Source: Gabányi (2013)

4.1.3 Energy system of Kawasaki

Kawasaki is important city for energy resources in wider Tokyo metropolitan region. It has strong manufacturing and technological roots. It is currently undergoing industrial regeneration. Kawasaki supports power demands and production in Greater Tokyo region, and is continuously evolving as a hub to supply clean energy. Municipal division in charge of climate change measures for the City is Global Environment and Sustainability Office in the Environmental Protection Bureau. The Bureau initiated various actions integrated with energy related policies (Table 14).

Table 14. Major actions related to energy system in Kawasaki

ENERGY SUPPLY Energy Park Lithium-ion batteries Fuel cells Construction waste Mega solar/biomass facilities	BUILDINGS BEMS CASBEE	TRAFFIC/TRANSPORTATION Environmentally friendly transport Convenient public transport E-vehicles
TRADE AND INDUSTRY Commitments from industry (partially successful) Voluntary CO_2 emission reductions	URBAN DEVELOPMENT Smart City/Eco City Industrial symbiosis Zero emission industrial complex Eco-industrial complex	ENERGY CONSUMPTION Visualization CO_2 offsetting Industrial consumption decrease Eco lifestyle Kawasaki Brand Mechanism
WASTE MANAGEMENT 3R society Eco-Town Sustainable City Subsidized waste management Construction waste	RESEARCH, SCIENCE, EDUCATION \`Experience rather than lecture\` approach Institute for Comprehensive Policy Research Kawasaki Environment Research Institute (KERI) International Exchange Centre Centre for Climate Change Actions Kanagawa Science Park (KSP) Keio University Sinkawasaki Town Campus (K^2) Kawasaki Business Incubation Centre (KBIC) Global Nano-micro Technology BIC (NANOBIC) Techno Hub Innovation Kawasaki (THINK)	

Source: Own analysis

Five power generating facilities in and around Kawasaki area: a thermal power plant (2GW output) and natural gas power generation plant (850 MW), biomass power generation plant (33MW), mega solar power plants (20,000 kW) in Ukishima and Ogishima, and a large wind power generation plant (3GW), have all combined approximate power capacity of 6,3GW. This is almost equivalent to consumption of households in four greater Tokyo metropolitan prefectures: Tokyo, Kanagawa,Chiba and Saitama.[20]

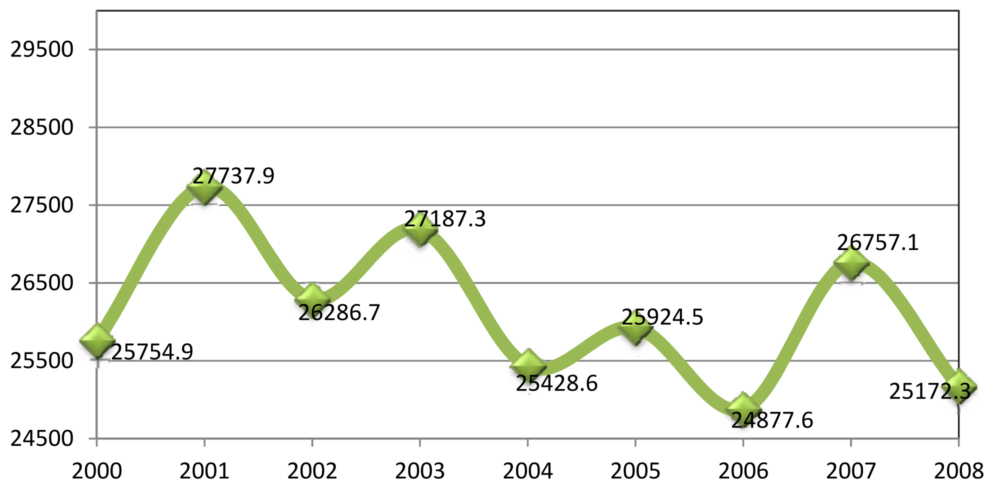
In the aftermath of the Fukushima nuclear accident, Kawasaki decided to become energy independent city. Tokyo Electric Power Company Incorporated (TEPCO) is the largest power utility in Japan, servicing Kantō region and Yamanashi Prefecture, area covering cities of Kawasaki and Tokyo. The largest power investment projects in extension of the energy system are Mega Solar Power Generation[21] and Energy Cycle and Effective Energy Use Initiative in collaboration with companies. The later one supplies steam from thermal electric power plant to factories in the surrounding areas (TEPCO, 2014).

[20] Thermal power plant in Kawasaki uses top-notch technologies and maintains very high efficiency. It is considered a top power plant in the world.
[21] It started in 2011 together with TEPCO.

Japan is a prominent example of cooperative R&D where industry, steered by the central government, improves energy services. Japan maintained extremely high investment spending in R&D since 1970s, the trend which considerably increased its EE rates. Japanese government policy emphasized conservation and efficiency with lower oil imports dependency. Compared to other developed world economies, Japan`s EE in area of industry is the highest in the world. Since 2000, oil demand in Japan declined overall by nearly 15% (EIA, 2013). Kawasaki is no difference to this.

Today, more than half of the GHG emissions in the city relate to the industrial sector. As the Chart 2 below presents, the city had slightly different levels of CO_2 equivalent emissions in 2000, 2004, 2006 and 2008. CO_2 emissions had steady fluctuations over the years.

Chart 2. A trend of emissions in Kawasaki city, 2000-2008, (CO2 eq., 000 ton)



Source: Kawasaki City Office

Kawasaki City registers more than 870,000 electricity and more than 560,000 gas connections (Table 15):

Table 15. Consumption and energy network data for Kawasaki

Energy consumption	
Annual power consumption (2012)[22]	3113.301 GWh
Natural gas consumption	950430000 m^3
Energy network	
Energy supply	877,440 electricity connections[23]
Gas infrastructure	564,221 gas connections

Source: Kawasaki City Office

[22] including consumption from industry
[23] number of contracts

4.1.4 Energy system of Tokyo

City department that handles and develops climate related policies, including energy measures is Division of Global Urban Environment, Bureau of Environment, TMG. As a metropolitan area, and the largest metropolis in the world, Tokyo provides electricity for around 10% of the population of Japan. It is faced with high stresses and constraints in peak hours. Its energy system is heavily dependant on imported fuels. Significant portion of electricity generation for Tokyo is from natural gas (45%), and nuclear power (28%). TEPCO is the electrical utility responsible for energy related services (Table 16). Another one is Tokyo Gas.

Table 16. Energy network data in Tokyo

Energy network	
Number of customers covered by TEPCO (million), FY 2012	9.12
Electricity sales (TWh)	74.7
Area (km^2)	2,264
Generation capacity (GW)	
Thermal energy (GW)	2450
New energy from facilities with expected supply capacity	0.004

Since 2005, the sale of electric power in Japan was partially liberalized and electricity suppliers were diversified. Companies that operate extra high voltage and high voltage power may purchase electricity from Power Producer and Suppliers (PPS) in addition to General Electric Utilities (GEU).

In the Asian Green City Index, Tokyo ranked well above average with excellent performances in energy and CO_2 categories. It is the only city in the report to have ranks of such high levels due to highly efficient energy consumption and strong government policies on energy and climate change. Performance of Tokyo UES is outstanding and it is serving as desirable example of rapidly growing compact mega city when it comes to urban energy use (Siemens, 2012). According to ICLEI Japan, most GHG emissions in the city relate to commercial sector, while the lowest discharge comes from the waste sector (cCCR, 2014).

Tokyo is the major commuting city. Trains and subways are the primary mode of transportation.[24] Its public transport system is rightfully regarded as among the most efficient and fastest in the world. In its metropolitan area, railway has the largest share of passenger transportation and is more important than in any other large Japanese city. Major problem of Tokyo urban railways is congestion during rush hours.

Main energy related documents which were formulated by the TMG are Smart Energy Saving Toward a Smart Energy City and District Energy Planning system for Effective Utilization. In 2011, TMG formulated Tokyo Initiative, Emergency Power-Saving Program, encouraging residents and companies on energy saving by taking advantage of climate change countermeasures. The Program was initiatied because power shortages were expected in TEPCO service area. TMG also developed facility standards to bring change to public facilities in Tokyo. In 2010, TMG introduced Cap-and-Trade Program covering 1400 public

[24] Tokyo has the most extensive urban rail network in the world.

facilities, in order to reduce CO_2 emissions in urban area by 10%. Tokyo is currently considering own tax system to promote energy saving measures (Table 17.) (ISEP, 2009a).

Table 17. Major actions related to energy system in Tokyo

ENERGY SUPPLY	BUILDINGS	TRAFFIC/TRANSPORTATION
Carbon-Minus Tokyo Smart Energy City Promotion of solar energy Replacement of old thermal with efficient natural gas plants RE investments Electricity system reform Energy supply revision Reduction of peak energy demand Co-generation system and dispersion type power source Private power generation at government owned facilities Energy storage	Installation of solar power EE hot-water heaters and ACs Replacement of incandescent with fluorescent lamps Environmentally friendly architecture /Green buildings Improvements in insulation Energy saving schemes for new buildings	Low fuel consumption vehicles Eco-driving Clean fuel program Road improvements to alleviate congestion Hybrid buses
TRADE AND INDUSTRY	URBAN DEVELOPMENT	CONSUMPTION
ETS Low interest loans for energy saving technologies Advancement of an independent power producer	Smart and compact city Green spaces Introduction of new reduction target for large scale urban development	HEMS Cap and trade for large users Energy Savings Program
WASTE MANAGEMENT	RESEARCH, SCIENCE, EDUCATION	CLIMATE ADAPTATION
Recycling systems Waste reduction Promotion of reuse	Environmental education Environmental courses for adults	Centre for Climate Change Actions

Source: Own analysis

4.2 Sustainability energy indicators

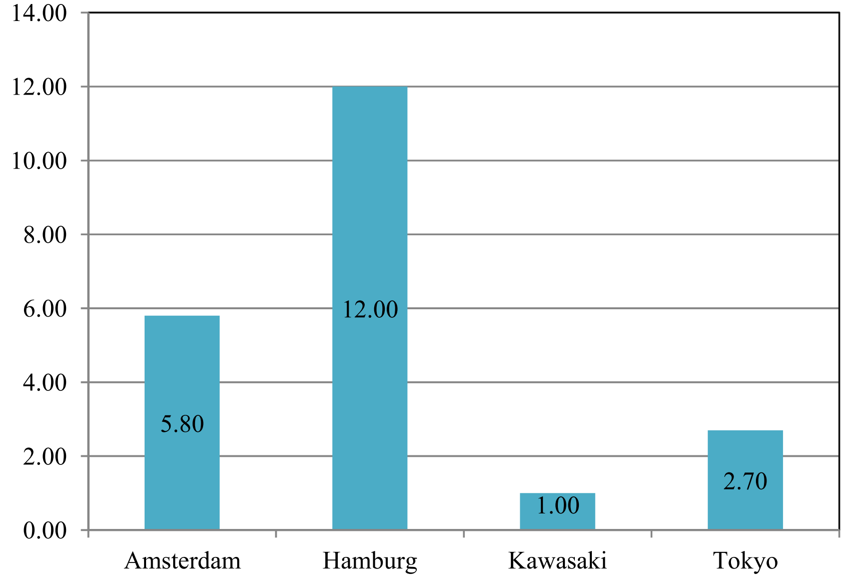
In order to provide answer for the second, sub-research question the following indicators were obtained: economic indicators (RE share and average electricity price), environmental indicators (CO_2 emissions from energy consumption and concentrations of urban air pollutants), institutional indicators (SEAP, CCAP/Low carbon development plan, Clean energy policy/Promotion of energy measures for environment).

4.2.1 Economic indicator: RE share (%)

In terms of RE share, Hamburg is the best performing of all four cities: 12.8% of its electricity is generated from RES. It also has the highest targets in this category. It is followed by Amsterdam, where almost 6% of the energy consumed in the city originates from RES (either waste, biomass or wind turbines). Amsterdam is followed by Tokyo that generates around 2.7% of RE. The lowest ranking city with contribution of RE to its UES is Kawasaki (almost less than 1%) (Chart 3).

Strong performance in this sector in Amsterdam and Hamburg ows to commitment of local government and utilities (AEB and Hamburg Energie) involved in production of RE with strong figures and recent years` growing trends. The goal of Amsterdam is 20% renewable in the city energy mix by 2025. Currently, public transport, trams and trains run on green electricity which is generated in the Amsterdam`s Waste to Energy facility (AEB). AEB is the world`s leader in green energy generation and the largest single location waste processor in the world (AEB, 2014).[i]

Chart 3. RE share (%) in four selected cities



Source: Own analysis

Hamburg Energie totally abandons production from coal or nuclear power plants. It has investment program in its own renewable production.[25]. From 2014, transport company Hamburger Hochbahn AG (HHA) which operates the underground transit system (U-Bahn) and large part of the bus system, obtains green power for subways. From 2020, HHA will purchase only zero-emission buses.

Tokyo ranks quite lower compared to Amsterdam and Hamburg. However, it has an ambitious goal to increase RE share to 20% of total consumption by 2020. It recently introduced new, 20 year subsidy program which pays high prices to either homeowners or companies for generating and selling solar energy.

RE policies in Tokyo started with implementation of the wind power pilot project Tokyo Kazaguruma. In `New Strategic Program for Sustainable Tokyo` 2006, energy conservation and RE promotion are identified as the vital pillars for global warming measures. In 2006, TMG published Global Warming Policy. When it comes to RE deployment, it declared plans to match the pace of development with other energy advanced countries and regions, such as EU and California. Tokyo Renewable Energy Strategy consists of three areas with the main goal being extension of renewables market (TMG, 2006):

1. Creating demand for RE or advancing market-driven `pull` approach.

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[25] In 2013, it generated 11.8MW from PV, 7.4 MW from wind energy and 1.35 MWel from CHP (Hamburg Energie, 2012).

2. Making better use of natural energy - proactively using solar heat (natural energy sources) to meet demand for low temperature heat.
3. Enabling individuals and regions to choose the type of energy - enabling independent production while redeveloping town blocks and apartment complexes.

After nuclear disaster in Fukushima Prefecture in March 2011, the government adopted Renewable Energy Development Bill (REDA) with introduction of feed-in tariff system. Japan also raised feed-in tariffs for solar power to encourage non-residential use of solar energy (24-40 yen/kWh). However, power generated from solar panels is still relatively expensive in Japan (ISEP, 2009). It is being argued that the government should provide further regulatory incentives in Renewable Energy Bill which was adopted after Fukushima nuclear disaster.

RE share in Kawasaki is currently at quite low level (less than 1%). Renewable energies are not a core part in energy mix of Kawasaki city, although the city is a home to pioneer Mega Solar Generation Plant.[26] In 2005, Kawasaki City established a RE target of 8066TJ (2240,50 GWh) of energy generated from RES by 2010 (ISEP, 2009). This was presented in its New Energy Vision for the City. Its Climate Change Strategy promotes power generation from PVs by subsidizing 70,000 yen/kw to install PV system in houses.[27] Therefore, Kawasaki ranks the lowest in comparison to three other cities concerning this economic sustainability indicator. One of the reasons this indicator is lower for both Japanese cities compared to European cities might be the fact there are significant transmission and grid constraints for introduction of new energy applications (such as RE) according to the Japanese Strategic Energy Plan. Bureaucratic and authorization procedures are quite lengthier than in other two countries.

4.2.2 Economic indicator: Average electricity price in 2010 (ct€/kWh)

Average electricity price for 2010 was obtained for Amsterdam and Hamburg. Data were compiled from average electricity prices (ct€/kWh) of two major utility providers in both cities` metropolitan areas (Frontier Economics, 2011). Two main suppliers in Amsterdam, Nuon and Essent were both sold to foreign energy companies. In Hamburg, main suppliers are EON Hanse Vertrieb (EONHV) and Vattenfall Europe (VE).

For average electricity price in Hamburg, two different tariffs were considered (Chart 4):

1. General tariff of the local incumbent (EONHV Regiostrom, VE Berlin Basis Privatstrom);
2. The best offer by the incumbent (EONHV Klassikstrom, VE Berlin Easy Privatstrom).

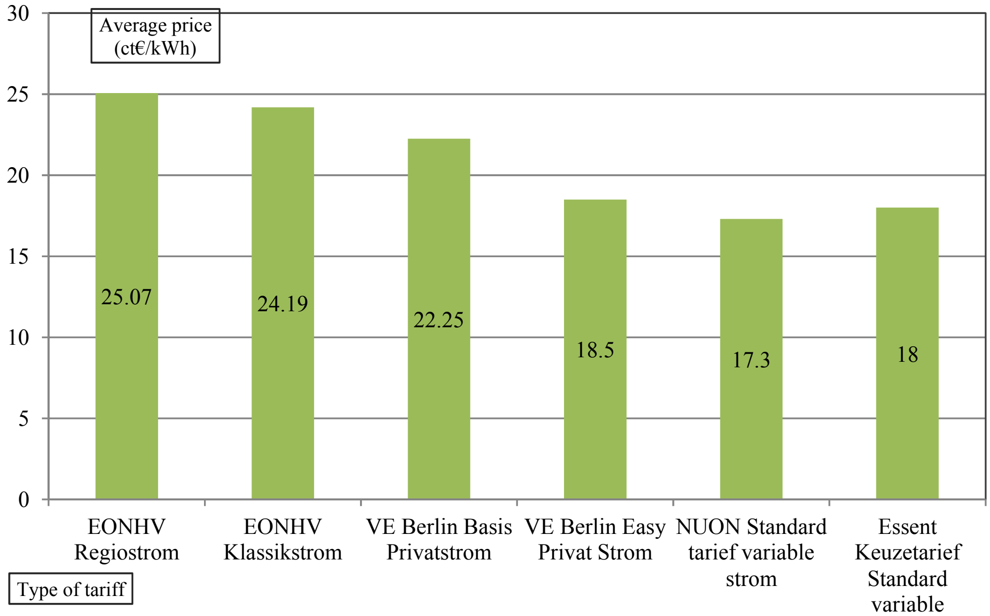
Only standard and not the cheapest tariffs were considered for average electricity price in Amsterdam.

Citizens of Hamburg pay higher electricity bills compared to residents in Amsterdam. EON Hamburg utility has the highest average price per household per kWh for both types of tariffs (Regiostrom and Klassikstrom), followed by Vattenfall Europe. The lowest average price was of Dutch Nuon standard tariff. This means that for electricity bill, citizens of Hamburg will

[26] Solar Power Plant has 100,000 panels and output 20MW.
[27] Up to 240,000 yen in total which is equivalent to 1,747 Euro.

pay on average 640-880 Euro per year, while citizens of Amsterdam will pay on average 600-630 Euro per year.

Chart 4. Average electricity price (including VAT) for household consumers in Hamburg and Amsterdam, 2010



Source: Frontier Economics (2011)

Dutch energy market was liberalised many years ago. Same provider supplies gas and electricity. Besides Nuon and Essent there are other energy suppliers: Eneco Energie, Oxxio, EnergieDirect, EON and Nederlandse Energie Maatschappij. Dutch energy networks are fully regulated and publicly owned. Since the market was enlarged and liberalised it reduced the influence by Amsterdam local authority. In the Netherlands in general, energy cost in the tariff applies to all Dutch cities, while only the network costs will be different between cities or areas (Frontier Economics, 2011).

The residents of Hamburg recently voted in a referendum forcing local government to purchase back the energy grid. The grid was sold to utilities Vattenfall Europe AG and EON SE in the beginning of 1990s, when the energy market was deregulated (Brautlecht, 2013). Hamburg privatized its municipal utilities Hamburgische Electricitaetswerke AG (HEW) and Hein Gas in late 1990s. It prepares to spend 2 billion Euro on the buyback. `Re-municipalisation` trend is underway in other German cities, under the arguments that consumer power prices went 68% higher than in 1998.

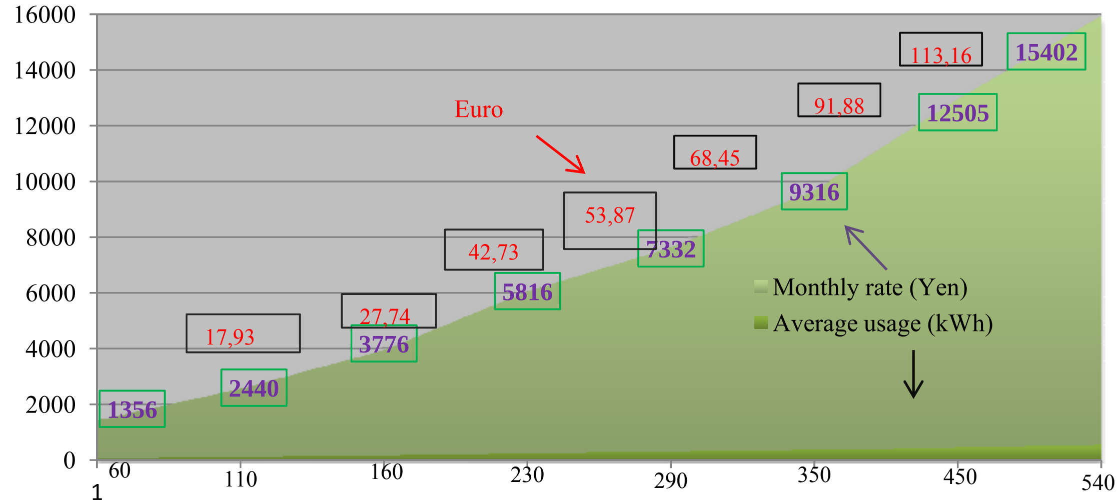
In general, Germans pay more for power than any other EU country except Cyprus and Denmark. Therefore, in terms of the value for this economic sustainability energy indicator it is evident that Amsterdam is better performing compared to Hamburg since electricity is more affordable.

TEPCO increased electricity prices in summer of 2012, due to higher fuel costs and loss of its nuclear power generation capacity.[28] Their request was approved by the government of Japan.

[28] The data for electricity prices in 2010 were not obtained.

Rates for electricity differ based on the major contract type and usage. The breakdown of average (increased prices) in both currencies Yen and Euro are shown in Chart 5. For an average usage of 230 kWh of electricity, a household in Tokyo or Kawasaki will pay between 40-45 Euro, for 350 kWh of electricity use, the monthly rate will be around 70 Euro, and for the average usage of 540 kWh or more, monthly price is more than 110 Euro.

Chart 5. Electricity rate (Yen and Euro) by major contract type and usage



Source: TEPCO, 2012

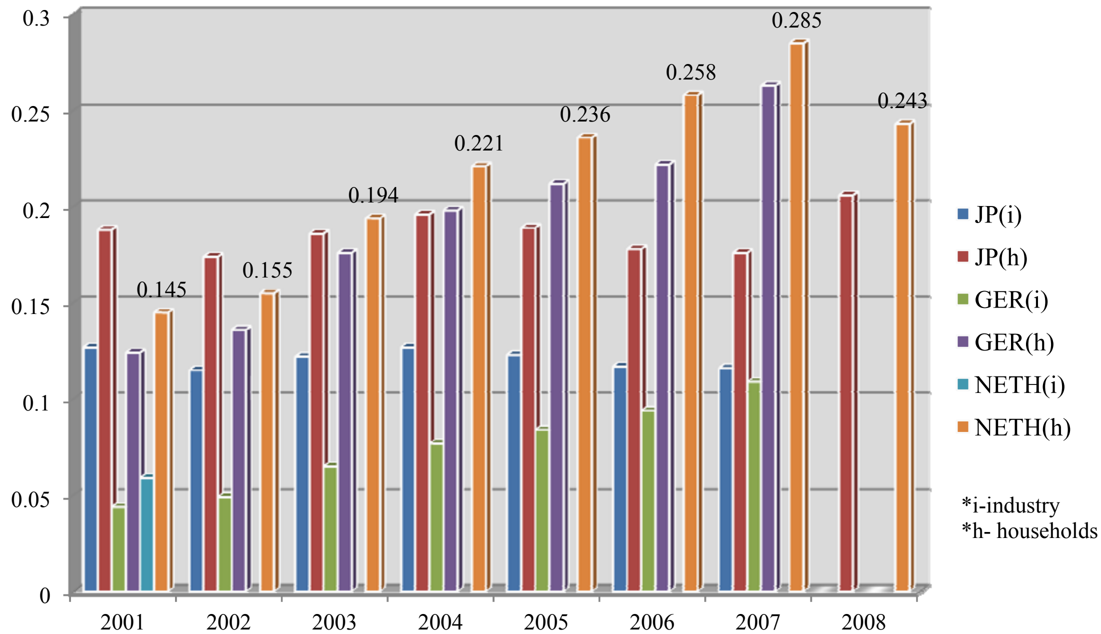
However, comparison of average national electricity prices for household and industry (average end-use price including applicable taxes) in EIA database in these three selected countries (US$/kWh), clearly points out that from 2003 onwards, Netherlands had the highest average electricity price for households in 2007, followed by Germany and Japan (Table 18).

Table 18. Maximum and minimum values of average national electricity prices from 2001-2008

	2001	2002	2003	2004	2005	2006	2007	2008	Min	Max
JP(h)	0,188	0,174	0,186	0,196	0,189	0,178	0,176	0,206	0,174	0,206
GER(h)	0,124	0,136	0,176	0,198	0,212	0,222	0,263		0,124	0,263
NETH(h)	0,145	0,155	0,194	0,221	0,236	0,258	0,285	0,243	0,145	0,285

Japan had the highest average electricity price for households until 2003. It also had the highest average electricity price in industrial sector, followed by Germany. Data for Dutch industrial sector were available until 2002 (Chart 6).

Chart 6. Average yearly electricity prices for selected countries (US$/kWh)



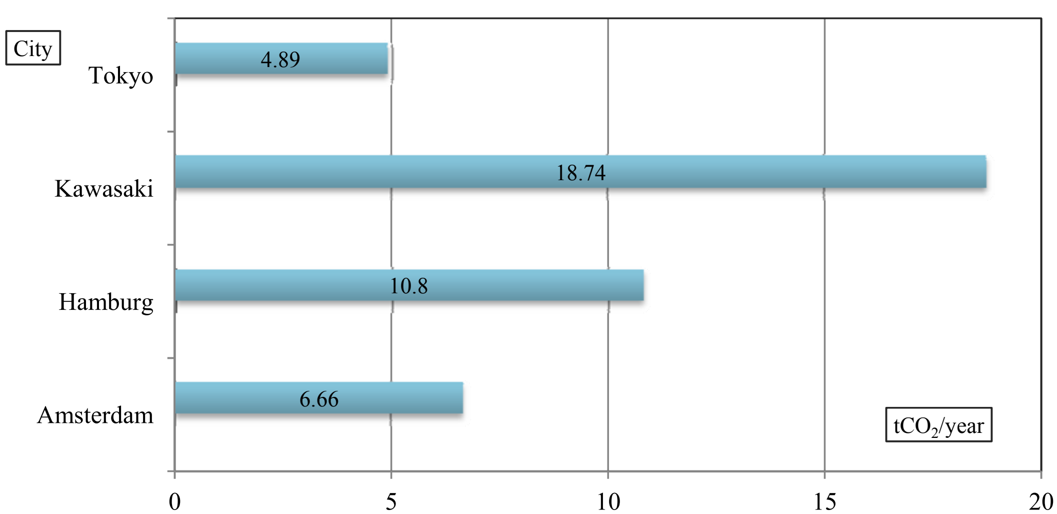
Source: EIA, 2013

4.2.3 Environmental indicator: CO_2 emissions from energy consumption

4.2.3.1 CO_2 emissions in selected cities (2006)

In order to provide an answer to the second i.e. sub-research question from the point of view of UES meeting sustainability objectives (sustainability and environmental performance), environmental indicator related to CO_2 emissions was analyzed. Data for environmental indicator CO_2 emissions from energy consumption (T/per capita per year) were obtained for 2006. As shown in Chart 7, Kawasaki city had the highest emissions of CO_2 per inhabitant (18.74T). It was followed by Hamburg (10.8T) and Amsterdam (6.66T). The lowest CO_2 emissions were in Tokyo (4.89T).

Chart 7. CO_2 related emissions per inhabitant, 2006 (tCO_2/year)



Source: Own analysis

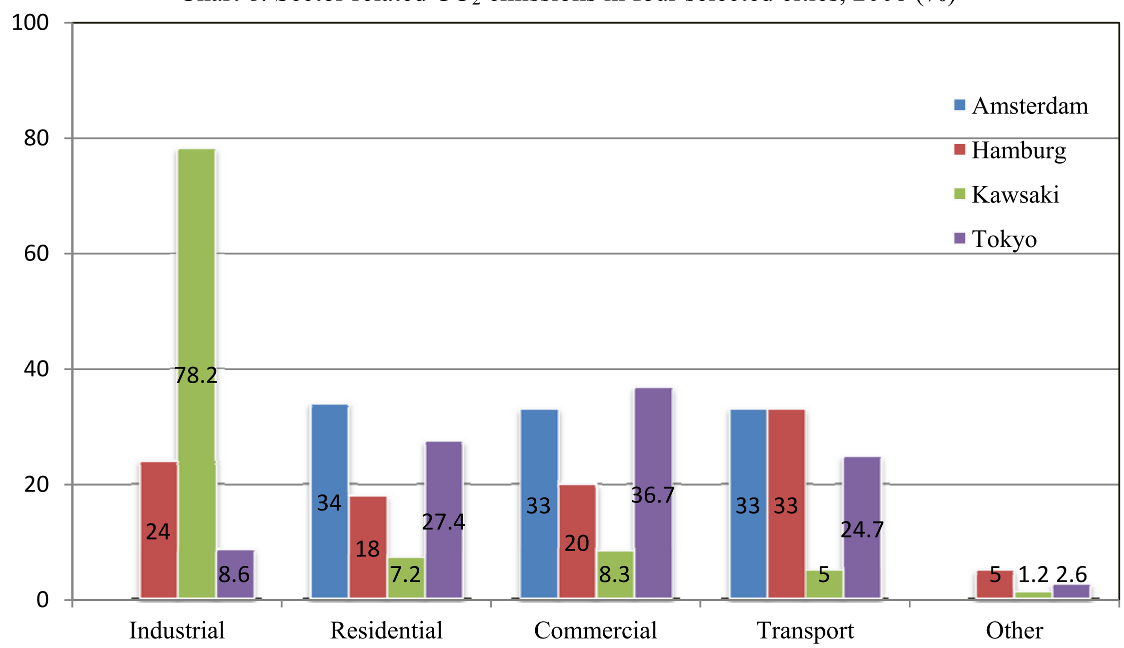
Kawasaki has strongly developed industrial sector which is mostly responsible for the highest level of CO_2 emissions among four analyzed cities. In recent year, the sector accounted for almost 80% of CO_2 emissions. The average CO_2 emissions (tCO_2e/capita) in Japan in 2007 were 10.76.

4.2.3.2 Breakdown of CO_2 related emissions in selected cities per sector (2008)

Breakdown by the sector related CO_2 emissions (Chart 8) clearly points out to the contribution of industry to total emissions of CO_2 in Kawasaki. In spite of the highest level of emissions, this does not mean that Kawasaki as a city wastes energy. On the contrary, Kawasaki is a city of energy innovation, distinguished for endeavours in sustainable energy investment projects in recent years. Its government was proactive with efforts to address the issues of climate change countermeasures. The picture for all four cities is quite versatile. Composition ratio for Kawasaki is indicative of disproportionately high percentage from industry related emissions as compared to the national average: 72.5% in Kawasaki vs. 33.8% nationwide in FY2011 (KERI, 2014). In Amsterdam, sector related CO_2 emissions were the highest for residential and commercial buildings. Hamburg had the highest levels of emissions from transportation sector and the industry.

In Tokyo, commercial sector emits the highest level of CO_2, and is followed by residential and transportation sectors. This is why TMG decided to address large CO_2 emitting facilities and subject them to Cap and Trade Program which is a component of Tokyo Climate Change Strategy. Cap-and-Trade covers 1400 facilities, mostly commercial and industrial buildings, which annually consume 1500 kilolitres or more energy (crude oil eq.). The first compliance period covers 2010-2014 FYs, and the second period covers 2015-2019 FYs.

Chart 8. Sector related CO_2 emissions in four selected cities, 2008 (%)



Source: Own analysis

For Kawasaki city and Tokyo, the industrial sector as per the data presented, includes industrial process sector and energy conversion sector. It has to be noted however, that annual

GHG related emissions for Tokyo are comparable to emissions in Scandinavian countries (Denmark and Sweden). Its annual emissions were quite stable since the 1990s.

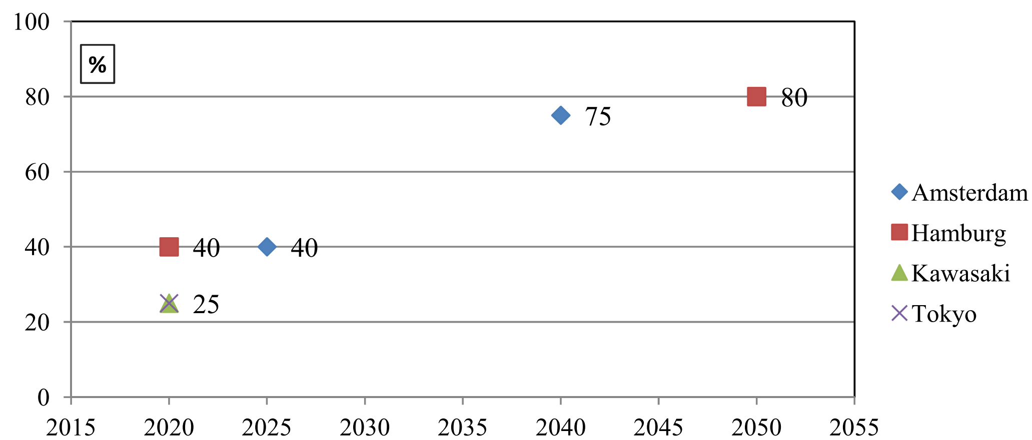
4.2.3.3 CO_2 emission reduction targets in selected cities (%)

Chart 9 shows Amsterdam and Hamburg have very ambitious targets to reach reduction of CO_2 in the next five to ten years among all four cities compared. Baseline year for Amsterdam, Hamburg and Kawasaki is 1990, and for Tokyo is 2000 (Annex 1).

Amsterdam`s target to reduce its CO_2 emissions is 40% by 2020, and 75% by 2040 (according to SEAP). Hamburg has the same target in terms of percentage reduction, 40% by 2020 and at least 80% by 2050 (according to SEAP). Hamburg had accelerated rate of CO_2 reduction of 14% between 1990 – 2007 and 8% accomplishment in only four years, from 2003 – 2007 (City of Hamburg, 2013) at around 1.6 % reduction per annum, a significant achievement for one large city.

The target for Tokyo and Kawasaki is 25% until 2020, taking into account different baseline years. In both of these cities, Climate Change strategy requires very active participation of all social sectors.

Chart 9. CO_2 emission reduction targets for four selected cities (%)



4.2.4 Environmental indicator: Concentrations of air pollutants in urban areas (mean annual values, µg/m^3)

Average annual concentrations of urban air pollutants (NO_2, SO_2 and PM_{10}) were analyzed for the four selected cities. The average annual values of PM_{10} (µg/m^3) were gathered for Tokyo, Amsterdam and Hamburg. Data for Kawasaki presented in Charts 13 and 14 include combined values of major pollutants and show trend of emission in tons on annual basis of NOx, SOx and PM transition from 1973 – 2011. Data were obtained from the following measuring locations relating to period 2008-2013:

a) NO_2:

1. Amsterdam: the highest average annual value, traffic location Haarlemmerweg
2. Hamburg: the highest average annual value, urban area Veddel
3. Tokyo: average annual value for the whole city

4. Kawasaki: average annual value for the whole city

b) SO_2:

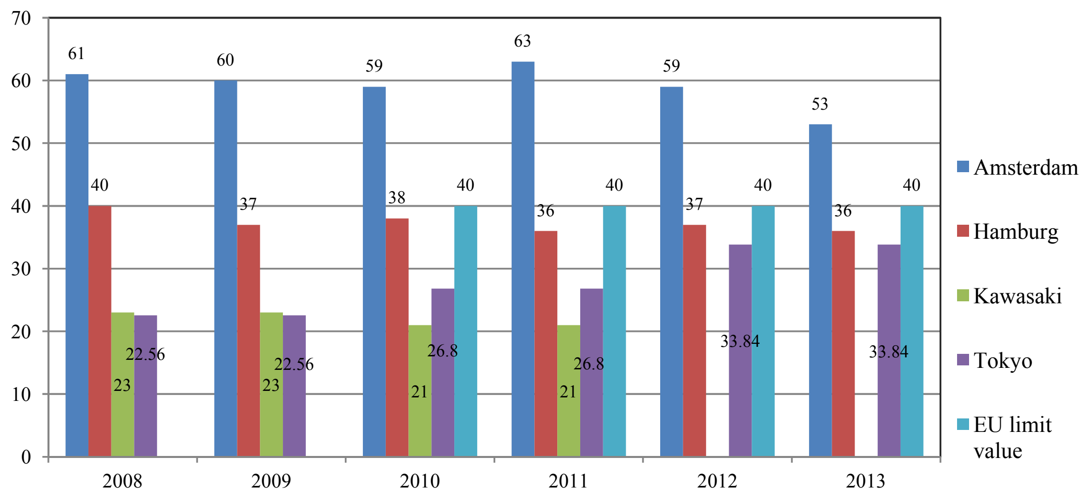
1. Amsterdam: the highest average annual value, urban background site Westerpark [29]
2. Hamburg: the highest average annual values, urban background station Veddel
3. Tokyo: average annual values for the whole city
4. Kawasaki: average annual value for the whole city

c) PM_{10}:

1. Amsterdam: the highest average annual values, traffic affected point Einsteinweg
2. Hamburg: the highest average annual values, urban location Veddel
3. In Tokyo: average annual value for the whole city

Chart 10. indicates concentrations of NO_2 were the highest in Amsterdam at the measured location, from 2008-2013. The values (53 to 61) exceed the EU limit value of 40 μg/m^3 which entered into force in 2010. Kawasaki and Tokyo ranked the best of all four cities. Kawasaki had the lowest annual means. This may be partly explained by the fact that the city was involved in widespread measures of introducing low-emission and more fuel-efficient vehicles. In late 1970s, when road traffic increased tremendously, Kawasaki joined efforts with nine other cities to improve air quality. Wide restrictions were imposed on diesel vehicles.

Chart 10. Average annual concentrations of urban air pollutant NO_2, 2008-2013 (μg/m^3)

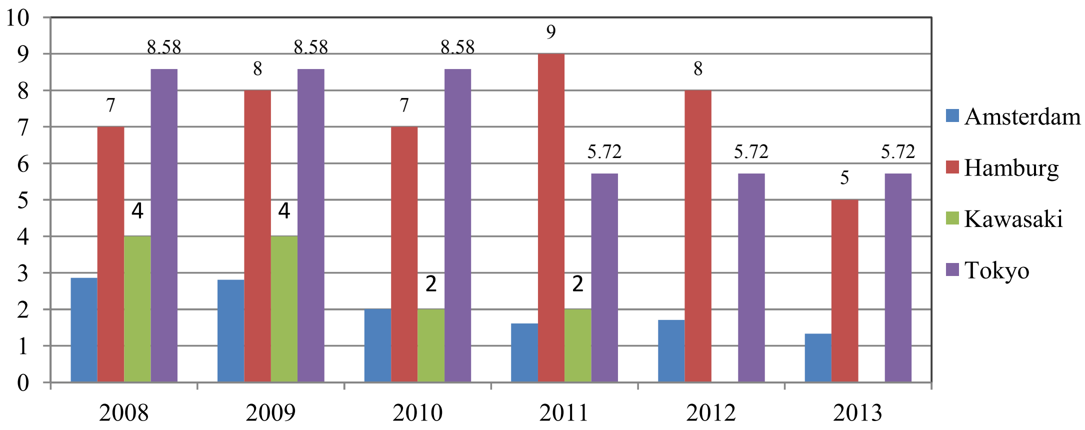


Source: HaLm (2014), KERI (2012), NIES (2014), GGD (2014)

Levels of SO_2 in these four cities are at acceptable low levels. However, comparisons of SO_2 annual mean concentrations show that Tokyo and Hamburg had the highest levels of measured SO_2 in urban air, and Amsterdam had the lowest (Chart 11).

[29] Amsterdam has only one station measuring SO_2.

Chart 11. Average annual concentrations of urban air pollutant SO_2, 2008-2013, ($\mu g/m^3$)

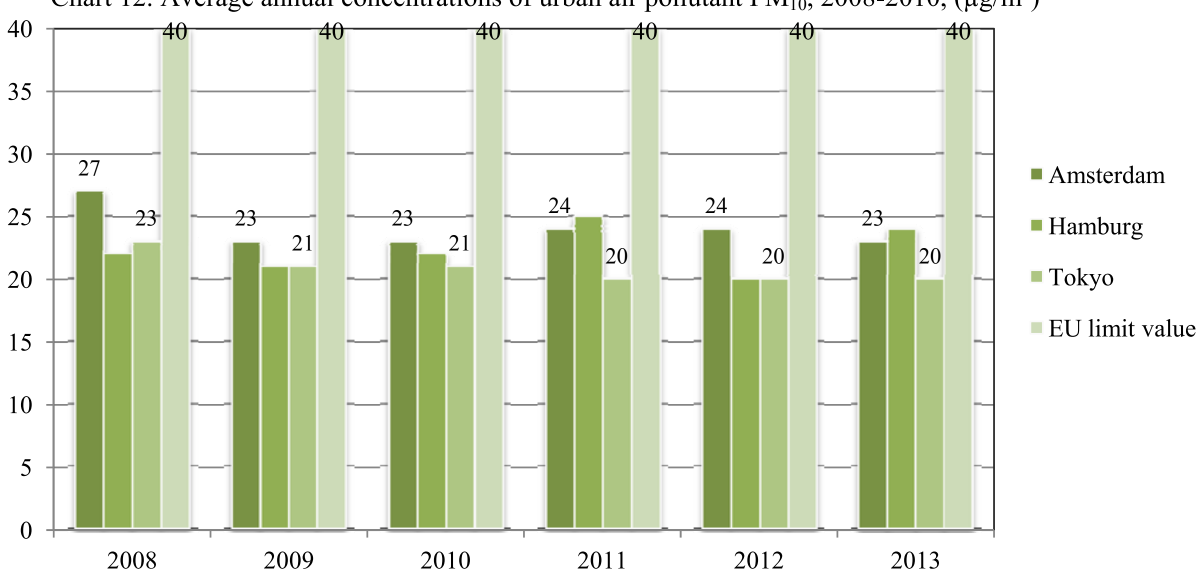


Source: HaLm (2014), KERI (2012), NIES (2014), GGD (2014)

The main sources of SO_2 are industrial activities which process materials or electricity generation from fossil fuels which contain sulphur. Hamburg and Kawasaki are both industrially oriented cities, while Amsterdam and Tokyo are service oriented cities. In spite of that, the figures are higher for Tokyo, and much lower in Kawasaki than in Hamburg (in 2011: 2 versus 9 $\mu g/m^3$).

For the observed period, annual mean values of fine particular matter PM_{10} were all below EU established limit values of 40 $\mu g/m^3$. PM_{10} are especially dangerous form of air pollution. The largest concentration recorded was in Amsterdam in 2008, 27 $\mu g/m^3$, and the lowest in Tokyo, 20 $\mu g/m^3$, 2011-2013. PM are mainly emitted from diesel vehicles. In recent years, PM_{10} environmental concentration in cities has mostly shown a downward trend, which resulted from various regulations on all facilities that generate smoke, or regulations on vehicles` exhaust emissions.

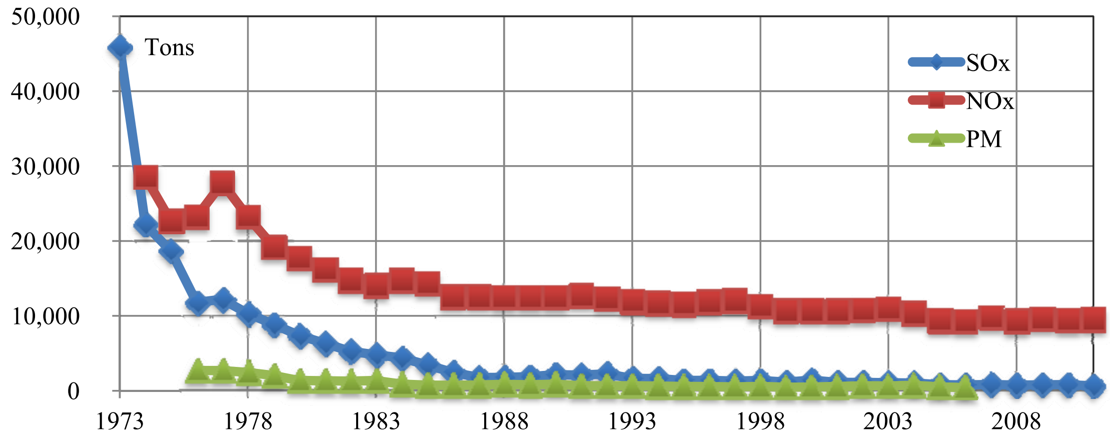
Chart 12. Average annual concentrations of urban air pollutant PM_{10}, 2008-2010, ($\mu g/m^3$)



Source: HaLm (2014), NIES (2014), GGD (2014)

Charts 13 and 14 show changes in values for yearly concentrations of urban air pollutants, SOx, NOx and PM from 1973 to 2011 (tons).

Chart 13.Trend of atmospheric pollutant emissions from operations in factories and business establishments, Kawasaki City (1973 – 2011)

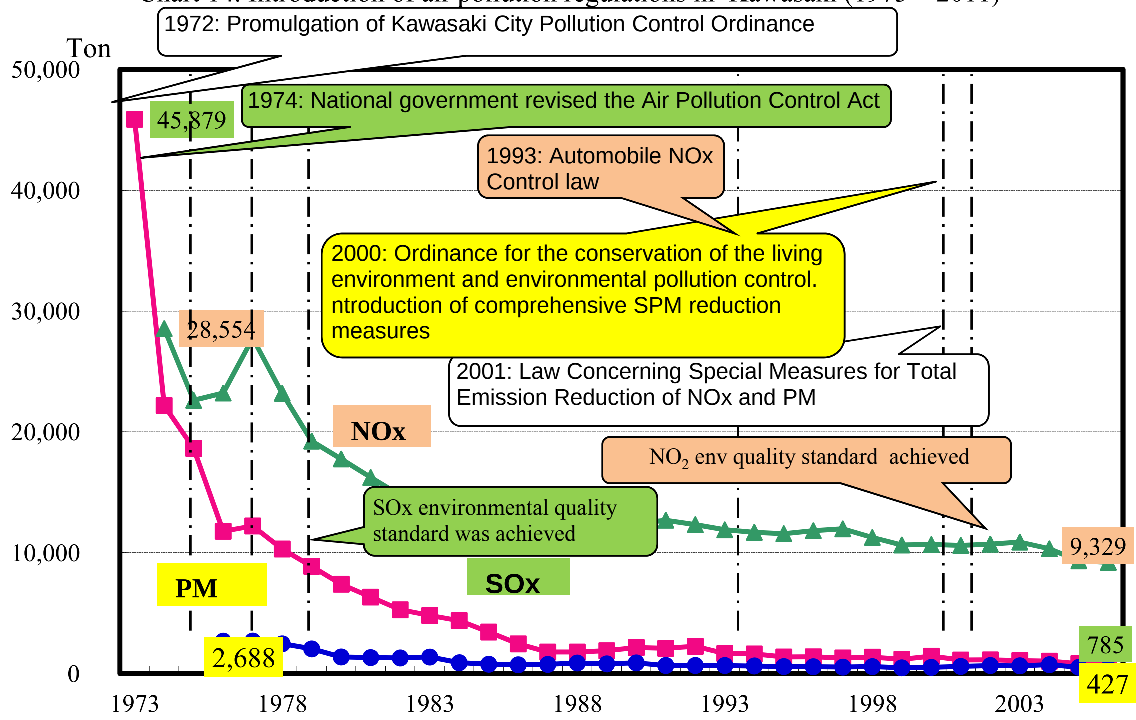


Source: KERI (2014)

In 1979, environmental target for daily average of 0.04 ppm or less was set independently by the city, achieved in all city areas and continuously maintained since then. In the end of 1960s, air pollutants caused severe illnesses for its population. Environmental Agency of Japan was established in 1971.

In 1972, Kawasaki started regulating emissions by enacting its own ordinance on total emissions much ahead of the national government. The city had to take various measures to cope with serious levels of air pollution and restore air quality. Kawasaki automatically checks emissions from all major factories at the release source (KERI, 2014).

Chart 14. Introduction of air pollution regulations in Kawasaki (1973 – 2011)



Source: KERI (2014)

4.2.5 Institutional indicators

In order to answer the second i.e. sub-research question, from the point of view of sustainability and institutional performance and governance related to energy policies in four selected cities, three indicators were developed and assessed as described previously. Additionally, a brief analysis of network membership performance was conducted. A simple coding analysis was performed.

Table 19. Institutional indicators for sustainability assessment

Indicators ↓		Code	AMSTERDAM	HAMBURG	KAWASAKI	TOKYO
Institutional	SEAP	S_Inst_1	X	X	O	O
	CCAP/ Low carbon development plan	S_Inst_2	X	X	X	X
	Clean energy policy/ Promotion of energy measures for environment	S_Inst_3	X	X	X	X

X- stands for `yes`, O - stands for `no`

All four cities have excellent performance of institutional indicators.

4.2.5.1 Sustainable Energy Action Plan

As it can be observed, membership in EU Covenant of Majors is an important involvement of the local government towards local energy system development. Amsterdam and Hamburg have both committed themselves to goals of this European movement. Both cities developed Sustainable Energy Action Plans. The plans are a mandatory requirement for membership. Hamburg became a signatory party and approved the Plan in 2009, while Amsterdam City Council joined and submitted a Plan in 2010. Covenant signatories aim to reach a 20% reduction of CO_2 emissions by 2020, according to the EU Climate and Energy Package adopted in 2008 (Covenant of Mayors, 2014). Membership in Covenant is terminated upon a failure on behalf of the city to comply with the agreements or fail to submit the Plan within the deadline. Both cities are taking leads and are committed to achieve significant CO_2 reductions by 2020 and 2025 (Annex 1). These are voluntarily commitments; however in both of these cities they are twice as higher than what the EU aims for. Hamburg has more ambitious target than Amsterdam (see 4.2.3.1). Ever since its adoption, Hamburg allocated significant financial resources to its implementation, approximately 25 million Euro funding for all measures identified in SEAP. The city distributes 25 million Euro annually since submission of the plan in 2009.

In 2013, Amsterdam launched Revolving Energy Investment Fund worth 45 million Euro directed towards large-scale sustainable energy projects that contribute to SEAP i.e. Energy Strategy 2040 (INNAX Group, 2013). According to SEAP, building sector in Amsterdam consumes 70% of energy for heating and electricity needs. Amsterdam ranked the fifth overall in the European Green City Index, and had the highest rank for water, waste and land use. Its worst performance was in the category of CO_2 emissions, since most emissions are caused by transport, industry and heating systems. Therefore, as a result, the city showed responsibility and committed itself to very ambitious targets. It targets to have neutral climate-impact of all municipal institutions by 2015.

This indicator can be percieved as building foundation for all urban energy related policies and for building its institutional capacity. Evidently, there is a positive correlation between this indicator of institutional performance and financial commitments towards urban energy sustainability.

Kawasaki and Tokyo do not have such a plan. At the moment there is no movement with similar objectives in Asia. However, targets for GHG emission reduction for Tokyo were announced in 2006 by TMG with aim of 25% reduction by 2020 compared to 2000 levels. Kawasaki City established the same target compared to the level of emissions in 1990.

4.2.5.2 Climate Change Action Plan or Low Carbon Development Plan

All cities have a positive score for indicator Climate Change Action Plan.

Related to its 40% GHG emissions reduction by $2025_{1990,}$ Amsterdam developed New Amsterdam Climate Program (Bigliani and Gallotti, 2009).

Hamburg developed Master Plan Climate Protection, with initial period from 2007-2012. Its climate protection goals focus on three main areas, primarily in energy sector (City of Hamburg, 2013):

1. Vision 2050, options and alternative to achieve a low carbon city;

2. Action plan 2020, supports national goals with the highest impact for CO_2 reduction;
3. Participation, dialogue with stakeholders.

New developments in Hamburg, according to this Plan are carried out at low emission standards. They are supported through Work and Climate Protection Programme (Program Arbeit und Klimaschutz). As a result of the Plan, the city established Co-ordination Centre for Climate Issues, an institutional body which approves climate protection endeavours within and outside the city administration (Free and Hanseatic City of Hamburg, 2011). Its climate protection strategy is outstandingly comprehensive because it involves very innovative measures for its implementation. In 2009, Hamburg coordinated EUCO2 80/50 project and developed a metropolitan CO2 inventory. Hamburg is also the only city among four selected cities that has passed its own Municipal Climate Protection Act (Hamburgisches Klimaschutzgesetz, HmbKliSchG). The Act was approved by the Senate early in 1997. The effect of this law was on land-use planning and energy supply, with the aim to protect the environment through efficient, healthy, resource-saving, low-risk production, distribution and use of energy. The law sets out numerous aims in particular for energy related developments in the city (HmbKliSchG, 1997):[ii]

1. Useful energy, with a very low specific consumption of NRE or higher RE while largely avoiding emissions;
2. Converting and using energy with the highest possible efficiency;
3. Heat supply primarily from CHP, using waste heat or renewable energies.

Important steps for establishing measures against climate change in Tokyo was The Climate Change Strategy for Tokyo approved in 2007, under the name `10-Year Project for a Carbon-Minus Tokyo` and Tokyo Metropolitan Environmental Master Plan.

The Strategy includes a number of different measures. The most important ones are mandatory CO_2 emission reduction system which targets large emitters, an independent Cap and Trade Program. It is the first world`s program of this kind at urban scale. The Program applies to large emitters such as commercial facilities, office and public buildings, factories and other facilities. Their total emissions represent 40% of all CO_2 emissions from commercial and industrial sectors in Tokyo area (TMG, 2012a). Tokyo established a Fund to Promote Measures against Climate Change with a budget of 50 billion Yen (408,1 mil. Euro) for ten year period. Tokyo also established Green Building Program covering newly planned large buildings whose total floor area (TFA) is more than 5000 m^2, assessing and rating performance in categories of energy, resources, natural environment and heat island effect.

Climate change policy in Kawasaki was established in 2008. It is implemented as Carbon Challenge Kawasaki Eco-strategy (CC Kawasaki). Its policies are characterized by strong focus on environmental measures using advantages of core city`s strengths, contributing on international scale by means of promoting environmental technologies that were developed in Kawasaki, and accelerating trends of CO_2 reduction engaging all stakeholders. The city has two important regulations: Global Warming Countermeasure Area Promotion Plan, established in 2005, and Local Ordinance for Countermeasures against Global Warming. Another initiative for addressing global warming is the Climate Change Kawasaki Energy Park, certified in 2011. Kawasaki was the first local government in Japan which developed `Kawasaki Mechanism` that evaluates external contribution and direct emission volumes of GHG by business operators. It provides certification for companies inside the city based on their reduction of GHGs (KERI, 2014).

4.2.5.3 Clean energy policy or Promotion of energy measures for environment

All four cities are committed towards green vision and promotion of clean energy policies, by incorporating energy measures for environment. However, the way these actions are conducted are meaningful and very different from city to city.

Amsterdam has a vision to become a green and environmentally balanced city by 2030. It is among the leading European cities when it comes to promotion of clean and efficient energy use policies. Amsterdam follows the principle of Trias Energetica, focusing on three core pillars (Zanten, 2012):

1. permanent increase in EE and energy savings
2. sustainable energy production (augmented use of RES)
3. clean and efficient use of remaining fossil fuels

Amsterdam has a long tradition of pursuing progressive energy policy. It introduced numerous \`clean\` or \`green\` pilot schemes such as a city centre climate street, smart metering, energy feedback displays, smart plugs and shore power units. All of them are intended to reduce energy consumption and promote clean energy. It established a subsidy programme to encourage residents on construction of green roofs and walls. Energy-saving systems were recently initiated for over 1,000 households. From 2015, the city plans to build climate-neutral buildings only, important from energy and environmental standpoint, since average house energy label in Amsterdam is \`D\`.

Hamburg has well defined targets and strong monitoring performance of clean energy policy and climate change. It reduced CO_2 emissions per capita by approximately $15\%_{1990}$, and accomplished energy savings of 46,000 MWh annually. This is unique for one large world\`s city (EC, 2011). Sustainable energy policy in Hamburg rests on 3 pillars (Gabányi, 2013):

1. Increased production from renewable energies
2. EE: cogeneration, efficiency in public companies, new construction standards
3. Extension of smart grids (conversion), heat supply, virtual plants, storage integration and network administered by the city.

Its clean energy policy focuses on abandonment of fossil energies, nuclear power and EE at increased levels. Solar, wind, biomass and solar thermal plants play important role in its energy and environmental policy.[30] In 2003, the Senate and the business world established Environmental Partnership Programme (Umwelt-Partnerschaft) which promotes investments in resource saving and climate protection activities of enterprise sector (heat use, light energy, machinery whose impacts are environmentally related) (Climate Alliance, 2014).

Kawasaki implemented antipollution related measures much ahead of the Japanese government by enacting the ordinance (which included regulation of total emissions), signing agreements with 39 factories, and installing Pollution Monitoring Centre and Pollution Research Laboratory System. Main involvement of the city in last years is NOx emissions control (KERI, 2014). Its environmental measures strongly emphasize energy component. Kawasaki is well-known in Japan for its strong R&D base. When the country was impacted

[30] German national plan is to spend 550 billion Euro to expand solar and wind power

by the oil crisis in 1970s, the city started investing heavily in energy and resource saving technologies. Steel manufacturing plants located in Kawasaki developed state-of-the art steel plants and expanded casting facilities, contributing to environmental protection through reduced air pollutants and emissions (SO_2 in particular) (KERI, 2014). Kawasaki area is the next generation Energy Park whose aim is to interconnect between RE related facilities inside the city. The city itself assists with introduction of energy creation and accumulation devices such as household solar, fuel cells and home energy management systems (HEMS).

Kawasaki established `Low $CO_2$ Kawasaki Brand`, and in 1997 by approval from the Japanese government, it set up Kawasaki Eco-Town Plan to create a model city of environment and industrial harmonious co-existence (KERI, 2014). Low CO_2 Kawasaki Brand and Kawasaki Mechanism Certification System contribute to the city`s overall energy and environmental sustainability in two ways:

1. Supporting (low carbon) whole life-cycle approach for procured, produced, sold, utilized and recycled related products and technologies in the city,
2. `Visualize` companies that contribute to reductions of GHGs and receive favourable evaluation (initiated in 2013).

In 2002, TMG established Environmental Master Plan and took measures in addition to the ones spearheaded by the national government, to enhance energy conservation such as green energy efficient building program, automobiles and transportation reduction of CO2. In its Environmental Ordinance to Ensure Tokyo Citizens' Health and Safety, (released in 2000), TMG for the first time included the words `global warming` in its official documents. The aim of that document was to control automobile exhaust gases under the `No Diesel Vehicle Campaign.` Tokyo's environmental policies are mainly aimed at energy conservation, and represented by the global warming control program and EE labelling system. In 2005, TMG introduced Environmental Energy Reporting Program. This Program stipulates electricity suppliers operating in Tokyo metropolitan area to report CO_2 emission factors and corresponding targets for reduction of emission factors, as well as their RE volumes. Since results get published, citizens are in position to freely choose for `more environmentally conscious suppliers`.

It can be concluded, that all four cities have outstanding performance in the field of institutional capacity to provide sustainable energy for long-term future.

4.2.5.4 Membership in networks

In order to provide answer to the second (sub-research) question, an additional analysis was conducted in regards to membership in various regional or international energy and climate related networks. Networks play important role in performance of each city`s institutional indicator. Below is a brief analysis of their performance.

Since 2007, Hamburg and Amsterdam are active members of The Network of European Metropolitan Regions (METREX) and signatories of the European Covenant of Mayors (Table 6). From 2008-2010, Hamburg coordinated EUCO_2 80/50, an advanced climate mitigation METREX project to apply the energy scenario tool GRIP (Carney and Shackley, 2009) (Greenhouse Gas Regional Inventory Project) methodology [31]

[31] Focusing on 14 regions to identify ways of reaching 80% CO_2 reduction by 2050 and inventory CO_2 emissions.

Via METREX, with four other European cities they are developing platform for Smart Urban Labs participating in TRANSFORM (Transformation Agenda for Low Carbon Cities), (2012-2015)[32] an FP7 funded project. Hamburg is a member of Climate Alliance of European Cities (Klimabundnis).[33]

Table 20. Membership in civic, regional or transnational networks

Organisation / Geographic area covered	METREX	Covenant of Majors	Climate Alliance of European Cities	C40 Climate Leadership Group	ICLEI CCP	Connected Urban Development	POLIS
Europe							
Amsterdam	x	x		x	x	x	x
Hamburg	x	x	x		x	x	x
Asia							
Kawasaki					x		
Tokyo				x	x		

Source: Own analysis

Amsterdam, as an innovator city, and Tokyo, as a megacity, are members of the C40 Cities Climate Leadership Group, the network of largest world cities dedicated to sustainable climate policies. All four cities have membership in ICLEI (Local Governments for Sustainability) Cities for Climate Protection Program (CPP).

Tokyo and Kawasaki report their performance in carbonn Cities Climate Registry (cCCR) prepared by ICLEI, a platform for local climate action. Amsterdam and Hamburg are members of Connected Urban Development (CUD) or Smart 2020 Initiative of the Climate Group and POLIS network. CUD connects smart solutions with cutting-edge technologies for sustainable future. Within CUD, Hamburg engages in intelligent traffic management and Amsterdam for sustainable work and living solutions.

POLIS focuses on sustainable mobility by introducing innovative transport solutions in European cities and regions. Amsterdam and Hamburg are also members of the Eurocities Working Group on metropolitan areas.

4.3 Resilience energy indicators

In order to provide answers for the third (sub-research) question, resilience indicators and numerical data which represent robustness and redundancy of electricity system either in local area, or in four specified cities were not obtained. Therefore, other resilience indicators were taken into consideration:

1. Rate of electricity transmission and distribution losses (%),
2. Total electricity generation efficiency, and

[32] Consortium of 19 cities, energy/grid companies, commercial and knowledge institutions to develop methodology for implementation of smart energy plans.
[33] Hamburg partners in: Sustainable Energy Europe Campaign (European Green-Light Programme), European Motor Challenge Award and European Mobility Week.

3. Carbon intensity of generation (gC/kWh).

All indicators were obtained through the World Energy Council Database.

4.3.1 Rate of electricity transmission and distribution losses (%)

This resilience indicator refers to losses in energy supply chain, i.e. electric transmission and distribution losses between sources of supply and points of distribution and in the distribution to the final consumers. The smallest and the largest values for the rate of transmission and distribution losses were (Table 21):

1. Maximum: in Germany (2000), 6.37 %,
2. Minimum: in the Netherlands (2011), 3.58%

Critical year for German power sector was 2000, when the country suffered the highest rate of network losses (6.37%), compared to other two countries. After that year, there was a steady tendency in decline of system losses (Chart 15).

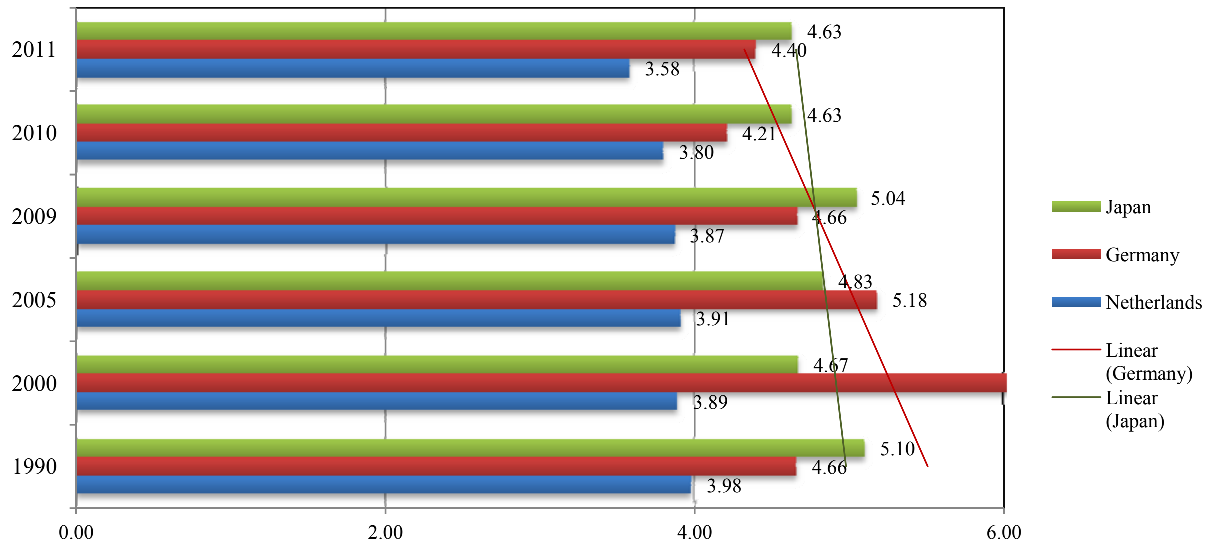
For the Dutch national power sector the highest rate of distribution and transmission losses was in 1990 (3.98%). The rate was proportionally decreasing ever since, reaching the level of 3.58% in 2011. This could be partially explained by the trends before and after the Dutch energy market became deregulated. In the period after electricity market liberalization, the rate of losses improved.

Table 21. Maximum and minimum values of electricity transmission and distribution losses

Value	Netherlands	Germany	Japan	Year
Maximum	3,98	6,37	5,1	2000
Minimum	3,58	4,21	4,63	2011

In 1990, Japan had the highest of network losses (5.10%), and the rate is higher than compared to the energy system of two other countries until 2011 (with exception to 2000). Natural disasters to which Japan is vulnerable (earthquakes) may impact power losses and cause system failures. This also means that operating costs for main Japanese utility, TEPCO, were higher than for energy utilities in two other countries.

Chart 15. Rate of electricity distribution and transmission losses (%) in years 1990-2011



Source: World Energy Efficiency Indicators

4.3.2 Total electricity generation efficiency (%)

Japan had the highest electricity generation efficiency (Chart 16) in the observed period (increase from 42 to 46.4%), with exception to years 2009 and 2010 when efficiency rate was lower than in the Netherlands. It is followed by the Netherlands (40.6-45%) and Germany (33.3-39.8%). The smallest and the largest values for the efficiency rate of electricity generation were:

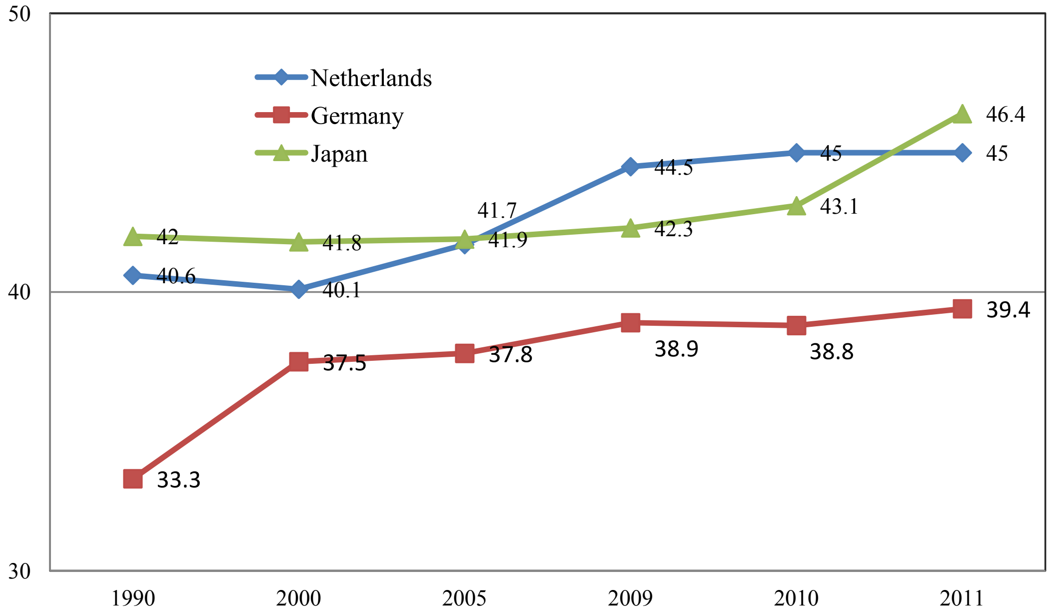
1. Maximum: in Japan (2011), 46.4 %,
2. Minimum: in Germany (1990), 33.3%

Table 22. Maximum and minimum values of electricity generation efficiency

Value	Netherlands	Germany	Japan	Year
Maximum	45	39.4	46.4	2011
Minimum	40.1	33.3	41.8	1990

Japan is a resource poor country. It diversified energy sources after two oil crisis, through increased use of natural gas, nuclear energy as a stable supply source, coal and EE improvements (See 1.2). In general, TEPCO invests tremendous resources to preserve its high thermal efficiency levels which are currently the highest in the world. According to the company, 1% increase in the thermal efficiency of its power plants reduces 1.9 million tons of CO_2 emissions per year (TEPCO, 2014a).

Chart 16. Total electricity generation efficiency (%) in years 1990 - 2011

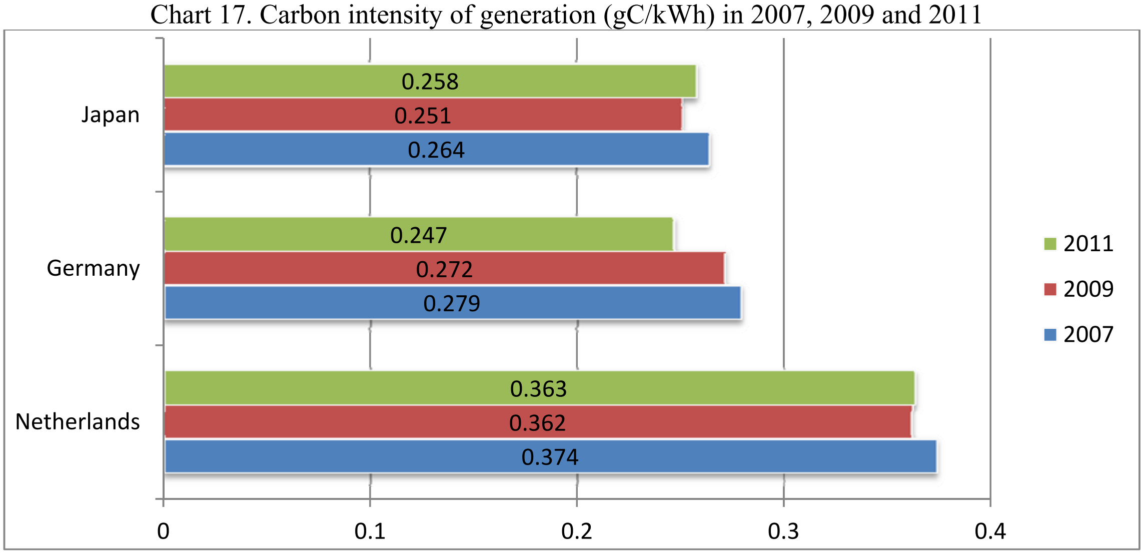


Source: World Energy Efficiency Indicators

4.3.3 Carbon intensity of generation (gC/kWh)

This resilience indicator is one of the measures of CO_2 emissions in a power system and is also associated with climate change. Chart 17 illustrates carbon intensity in the energy generation for these three countries. Interpretation has a lower value when the carbon intensity of power system is higher (Chart 17).

Chart 17. Carbon intensity of generation (gC/kWh) in 2007, 2009 and 2011



Source: World Energy Efficiency Indicators

Chart 17 illustrates that the Dutch energy system has the highest rate of carbon intensity, and subsequently the lowest resilience in this respect. It also means that the country relies less on non-fossil fuel sources for its energy generation. In 2007 and 2009, Japan had the lowest carbon intensity (0.264 compared to 0.374 and 0.279; 0.251 compared to 0.362 and 0.272), while in 2011, carbon intensity was the lowest in Germany (0.247 compared to 0.363 and 0.258). Gas dominates for heating and hot water in general, and almost every Dutch house has a gas connection. It is widely known that the Netherlands has ambition of becoming a gas rotunda in Northwest Europe.

Chapter 5: Conclusions and recommendations

The assessment of four municipal urban energy systems was conducted using a combined rather than a single approach in order to better understand functioning and performance of the energy systems and identify similarities and differences between them. Concepts of sustainability and resilience were further developed using a DPSIR framework. DPSIR framework was applied while properly selecting and allocating indicators, which reflect sustainability and resilience criteria against which performances of local urban energy systems were determined. Rather than assessing only one feature of a system (sustainability or resilience individually), combined approach refers to integrally assessed and both concepts were analyzed.[34] When it comes to measurements of resilience, the study had to be adapted accordingly related to national indicators for the reason of data constraints.

5.1. Research questions

5.1.1 R.Q.1: What are the main components of an integrated sustainability and resilience assessment framework of urban energy systems?

In order to answer the first research question, operationalisation was the guidance for assessment, focusing on main variables: urban energy system, sustainability and resilience, and corresponding set of 26 indicators in total. The study proceeded with descriptive statistics to provide in detail understanding of economic, environmental, institutional performance of urban energy system in four cities, as well as resilience performance[35] from the point of view of five different aspects. Integrated framework in this case refers to the point that knowledge and expertise are combined from two different domains in a single structure. Under the presumption, that DPSIR is *the* comprehensive framework that links these two domains of assessment in optimum way, as derived from theory, main components of an integrated assessment framework of UES are:

1. A conceptual model characterized by interlinkages between socio-economic drivers, human activities that generate pressures and changes in environment, with governmental and societal actions to counter or ameliorate changes;
2. A review and grouping of DPSIR related indicators;
3. Process of data collection to assign quantitative and qualitative values;
4. Analysis and application of the data to the local urban energy context.

[34] Taking into consideration timely, technical and financial limitations of the study.
[35] Of the national energy system, due to data limitation.

5.1.2 R.Q.2: How do the selected urban energy systems meet sustainability objectives?, R.Q.3: How do the selected urban energy systems meet resilience objectives?

In order to provide answers to sub-research questions R.Q.2 and R.Q.3, two phases were conducted. In the first and preliminary stage, it was necessary to collect relevant information about main features of local urban energy systems:

1. Local institution(s) responsible for energy policy and its implementation on urban (metropolitan) scale,
2. Energy utilities, providers and characteristics of the energy market,
3. Energy and electricity infrastructure,
4. Resources and local energy technologies in use,
5. Energy network and energy consumption data.

Major activities related to energy system and climate change were collected and identified per each sector where it was possible. Energy and climate change related policy documents, supporting mechanisms and measures were analyzed (Annex 1). It was found that institutional indicator added a bonus to sustainability performance. Therefore, it needs to be considered as a theoretical component in assessment.

Furthermore, in order to provide answer to R.Q.2, comparison of established GHG (CO_2) reduction targets was made, both on city and national scale (Annex 1). In this stage, literature sources for sustainability and resilience indicators were identified based on which the actual data were searched. In the second stage, collected data were screened, synthesized and analyzed.

5.2 Discussion about results of analysis

5.2.1 Sustainability performance of energy systems

This study was influenced by theoretical knowledge on sustainability and resilience concepts, starting first with the focus on sustainability defined by McLellan et.al. (2012), as crux of the triple fundamentals: economic, environmental and social aspects. In the context of this study, sustainability was approached by balancing these three aspects related to the urban energy system, supplemented with an additional one, namely, institutional aspect. Economic aspects were analyzed by examining the share of RE in the local urban energy mix and the average electricity price of the energy utility. Furthermore, maximization of a resource base, i.e. a transition from a concentrated generation and distribution towards a multi-stakeholder model is essential for energy system resilience (O`Brien and Hope, 2010). As Hennicke et.al. (2004) argue, it is the sustainable energy system that delivers affordable energy, where such a system integrates energy efficiency with RE. Thus, these two aspects had to be analyzed.

Sustainability indicator for RE in Hamburg is the highest (Table 23). Hamburg Metropolitan Region is experiencing a development boom of RE sector. The city is considered to be a laboratory for entire Europe as recognized pioneer for commitment to integrate renewable energies in land-use plans. The city installed 60 wind turbines generating 53MW, and continually identifies new areas for installation to double the current performance level. Future goal is to have output increased to 100MW of electrical power by replacing older systems with more efficient ones (Gabányi, 2013).

Table 23. Ranking of cities (countries) per sustainability and resilience indicator

City/Country ➔ Indicator ▼	**Amsterdam** **The Netherlands**	**Hamburg** **Germany**	**Kawasaki** **Japan**	**Tokyo** **Japan**
Economic indicators				
RE share in energy consumption	2	1	4	3
Average electricity price, 2010	1	2	3	3
Environmental indicators				
CO_2 emissions from energy consumption	2	3	4	1
Concentrations of air pollutants in urban areas				
NO_2, 2011	4	3	1	2
SO_2, 2011	1	4	2	3
PM_{10}, 2011	2	3		1
Institutional indicator				
SEAP				
CCAP				
Clean energy policy/Energy-environment measures				
Resilience indicators				
Rate of electricity transmission and distribution losses	1	2	3	3
Total electricity generation efficiency, 2011	2	3	1	1
Carbon intensity of generation, 2011	3	1	2	2

Note: For sustainability indicators, cities are ranked on the scale 1-4 or 1-3 (electricity price, PM_{10}). 1 denotes the best performance, 4 or 3 denotes the worst performance. For resilience indicators, countries are ranked on the scale 1-4.
Blue colour denotes the highest ranking, orange colour denotes the lowest ranking.

Furthermore, the case of cities Hamburg and Amsterdam prove the theoretical statement that the area of energy system sustainability is strongly linked with diversity of generation (Meclellan et.al., 2012) and energy system that combines RE with energy efficiency. The Municipal Climate Protection Law in Hamburg strongly stipulates efficiency benchmarks for energy, special saving measures and measures for economical use of energy. Utility Hamburg Energie provides green electricity from regenerative sources such as wind and solar energy systems, and it built solar atlas which is freely accessible to Hamburg`s residents. Energy office in Amsterdam also released an information tool, Energy Atlas, making high level detail energy related data to consumption available to the public. In AEB plant in Amsterdam, biomass and biogas from waste and sewage are converted into heat and electricity which production is enough to cover the 75% of the households` needs in Amsterdam. Around 50% of its electricity and power is sustainable.

In Hamburg, the largest waste management service provider (Stadtreinigung Hamburg) gains heat and electricity from organic waste (Behörde für Stadtentwicklung und Umwelt, 2013). Furthermore, Hamburg aims to reach 100% renewable electricity by 2025, and 100% use of renewables for heating and cooling by 2050 for its two major urban locations: Elbe Islands and Renewable Wilhelmsburg (Annex 1).

It was found, based on the data gathered about the municipal energy system network, that Hamburg has the highest power consumption: 18,000 GWh (13,000 GWh of electricity and 5,000 GWh of heat), compared to Amsterdam and Kawasaki (Table 24). [36]

Table 24. Comparison of power, gas consumption and energy network in selected cities

	Power consumption		
Amsterdam	4,655 GWh		
Hamburg	18,000 GWh		
Kawasaki	3,113 GWh		
Tokyo			
	Natural gas		
Amsterdam	850,000,000 m^3		
Hamburg	21,000 GWh		
Kawasaki	950,430,000 m^3		
Tokyo			
	Electricity connections	Gas connections	DH connections
Amsterdam			
Hamburg		150,000	45,000
Kawasaki	877,440	564,221	
Tokyo			45,000

If it is assumed that Japanese households consume between 270 and 450kWh (monthly), on average, or between 3,324 and 5,400 kWh annually (Chart 5), and that the average annual Dutch family electricity consumption is around 3,340 kWh (2 person household), conclusion can be based on the average tariff rate/kWh and prices dependant on the type of contract. Amsterdam, in this sub-category, has the best economic sustainability performance compared to other three cities. Tokyo and Kawasaki may have lower average consumption, but the average price is higher compared to other two European cities.

Environmental indicator, CO_2 related emissions, shows clearly that Tokyo has the highest and Kawasaki the lowest performance in this sub-category (Table 24). The trend of CO_2 emissions reductions, is likely to continue in the case of Tokyo, since introduction of the Cap-and-Trade Program. In the first compliance period emission cap is 6% below base year emission, and in the second period is approximately 17% below base year emissions (which still has to be decided). In 2002, Tokyo first introduced Carbon Reduction Reporting Program, a forerunner of Tokyo Cap-and-Trade (and revised it in 2005).

All cities perform continuous monitoring and measurement of urban air pollutants to ensure compliance with EU directives and regulations, national and local Japanese air quality standards. Monitoring is one of the countermeasures against air pollution. Tokyo has installed 47 constant air quality measurement locations, Hamburg 17, Kawasaki 18 and Amsterdam

[36] Data for Tokyo power consumption were not obtained.

12. The results are quite versatile depending on the type of pollutant. For NO_2 pollutant, Kawasaki has the best sustainability performance, Amsterdam for SO_2, and Tokyo for PM_{10} (Table 24).

In 1968, as a very polluted city, Kawasaki established continuous monitoring system for SO_2 through centralized air pollution monitoring (KERI, 2014). It implements measures jointly with the industrial sector, the so called `end-of-pipe technologies` during the final processing stage. It introduced flue gas treatment systems, overall improvements in manufacturing processes and improvement in fuel quality. Kawasaki manufacturing sector uses heavy oil with reduced sulphur content. It increased desulphurization capacities and enabled fuel conversion to LNG. Thermal power plants in Kawasaki area use heavy oil converted to LNG that is free of sulphur (KERI, 2014). After the local government introduced Pollution Control Ordinance in 1972, urban air pollutants significantly dropped in subsequent years (Chart 14).

Based on performance of institutional indicators, all four cities are strongly oriented to provision of clean, sustainable energy. The cities are turning to implementation of innovative measures as part of environmental and energy policies: SEAP and Climate and Energy Fund in Amsterdam, SEAP and Master Plan Climate Protection in Hamburg, `Low $CO_2$ Kawasaki Brand` and `Kawasaki Mechanism` in Kawasaki, Cap-and-Trade in Tokyo, Top Runner Program in Japan. In fact, ***transition*** from `traditional` to sustainable energy system is a feature of all four cities.

5.2.2 Resilience performance of energy systems

According to the theory, as explained by Molyneaux et.al (2012), countries that use a mix of coal, gas and nuclear energies like Japan and OECD Europe, have higher resilience of their national energy system.

As all three countries are OECD member states, resilience assessment shows that Dutch energy sector has the lowest rate of transmission and generation losses. In 2011, Japan had the highest rate of network losses. As the rate of losses in the Netherlands was at the quite similar level over the years, trend lines for Japan and Germany (Chart 15) can be interpreted as a decline in losses in transmission of electricity. Trend lines with an approximate mean square error explain an average decrease of energy losses in both countries. In other words, the angle represents an average decrease of losses in certain years. As the trend line is more upright, as in the case of Japan, decrease is more stable, while in Germany the angle is greater, i.e. has lesser stability. In other words, the trend in Japan is better although the rate of losses is the highest.

Resilience assessment in this study indicates the highest electricity generation efficiency is achieved in the Japanese energy sector (2011). One of the main characteristics of its resilience is so called `best mix of power sources`, i.e. different types of power sources, but also very strong economic and industrial energy efficiency (See 1.2). In the 1970s, after the first oil shock, Japanese power system became extremely susceptible to increased prices and was very expensive. It had a quite low resilience index. However, high technological improvement which is a backbone of Japanese economy contributes to greater resilience and efficiency of its power system.

Dutch energy system has the highest rate of carbon intensity (Table 24). The Netherlands is one of the largest world importers and exporters of oil and oil based products. For energy sources, Dutch government selected the best value for money which is a mix of grey and green energy (Government of Netherlands, 2014). Primary energy sources in the Netherlands are mostly fossil fuels: natural gas, coal and oil. In power supply, gas and coal dominate. Most of the Dutch electricity is produced from gas, coal and small portion of nuclear energy which explains why the indicator is higher than in other two countries.

5.3 Recommendations for future research

This study came to conclusion, that the relatively small size of selected cities in research, number and availability of indicators may play a limiting role for an integrated combined assessment. Additionally, it was found in the theory, that DPSIR framework was mostly applied in environmental and public health, water resources and biodiversity related sectors, ecological security and assessment of GHG affect, but rarely if ever in the context of local urban and national energy system. Therefore, for the future research directions it is a recommendation to integrate first two missing components:

1. DPSIR framework from the phase of municipal energy planning onwards,
2. Integrated sustainability and resilience assessment of urban energy system during investment stages and continual monitoring and reporting process.
3. Explore, from technical point of view, measures conducted by each city to integrate new technologies (such as gasification) to take advantage of that portion of urban waste that is currently not considered to obtain energy.

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Annex 1 Main characteristics of four selected cities

Based on different local, national government acts or industry documents, ( ) denotes target year, subscript denotes baseline year

City/Country → Description ↓	AMSTERDAM (THE NETHERLANDS)	HAMBURG (GERMANY)	KAWASAKI (JAPAN)	TOKYO (JAPAN)
Area (km^2)	165.76 km^2	755 km^2	144.35 km^2	2,187 km^2 13,281.35 km^2 Greater Tokyo Area
Density (persons/km^2)	4892.2/ km^2 (+1,31%/year)	2300/ km^2 (+0,98%/year)	10104/ km^2 (+1.26%/year)	5946.9 km^2 (+0.66%/year)
Population	799,442	1,734,272	1,458,542	13,290,000
Average GDP per capita(€,¥) Average GDP economy (€,¥)	41,443 31.81 bn €	52,400 € 94.4 bn €	5162260000000 ¥ (2011)	54,685 €
Average CO_2 emissions (T/capita, 2006)	6.66	10.8	18.74	4.89
Average energy consumption per head	74.51 GJ (16.9GJ, Liander)			
Percentage of RE consumed by city	5.8%	(3% in primary energy production) RES generate 12% of electricity	1%	2.7%
Climate Change Policy Document	New Amsterdam Climate Programme `Amsterdam, Smart City`	Climate Action Plan 2007-2012 Master Plan Climate Protection – Strategic development plan for energy, environment and urban planning. Action Plan 2020	2010 Basic Plan on Measures against Global Warming and 2009 Ordinance. Kawasaki Mechanism. Authorization System Low CO_2 Kawasaki Brand	2006 Renewable Energy Strategy 2008 Environmental Master Plan Tokyo Cap-and-Trade Program (Mandatory emission reductions and ETS, 2008) Action program 2011 for "Tokyo's 10 year plan" 2006 Tokyo's Big Change – the 10 year Plan
Energy Policy Document	2040 Energy Strategy Amsterdam/Sustainable Energy Action Plan (SEAP)	Sustainable Energy Action Plan (SEAP)	Kanagawa Pref New Energy Plan Kawasaki Eco-Strategy Revised Energy Conservation Act (2008)	Renewable Energy Strategy Revised Energy Conservation Act (2008)

City/Country → / ↓ Description	AMSTERDAM (THE NETHERLANDS)	HAMBURG (GERMANY)	KAWASAKI (JAPAN)	TOKYO (JAPAN)
Established Targets for CO_2 reduction	Climate neutral (2015) 40% (2025)$_{1990}$, 75% (2040)	40% (2020)$_{1990}$ At least 80% (2050)	25% (2020)$_{1990}$	25% (2020)$_{2000}$
National targets for CO_2 reduction	20% (2020)$_{1990}$ 40% (2030) 80-95% (2050)	VDEW, 25% (2015)$_{1987}$ 21% (2008-2012)(achieved 26,5%) ,40% (2020) GHG emissions: 35-37% (2020)$_{1990}$ (IKEP/with activities in RE sector) 55%, 70%, 80-95% (2030, 2040, 2050) ($_{1990}$)	25% (2020)$_{1990}$ 30% (2030)$_{1990}$	
Agenda for other energy related targets focused on cities	Clean & Efficient programme: Energy conservation rate of 2% annually (2015), EE improvements annually 30% in GHGs (2020)$_{1990}$ 20% RE in city energy mix (2025) 25% of electricity needs generated sustainably (2025), 50% (2040) Liander: Minimize risks related to smart grid development investments (2020) 10,000 EVs (2015), 200,000 (2040) 100% green heating network supply in the future. Wind capacity enlargement: additional 117MW (2016) Connect 100,000 REU (2025), 200,000 (2040).	100% renewable electricity (2025) 100% renewable for heating and cooling (2050) for Elbe Islands/Renewable Wilhelmsburg 35% (2020), at least 80% (2050) (in stages) of renewable energy generation 50,000 households connected to DH (2020) Increased blending requirement for bio fuels to 6.25% (2010 onwards)		Increase RE share of total consumption to 20% (2020)

Agenda for other national energy related targets	20% energy savings (2020) (all new buildings must be energy neutral) 6000 MW installed power capacity onshore wind turbines (2020) 1 million EVs (2025) 14% RE in the energy mix (2020) 10% bio-fuel in petrol (2020) Gradually increase percentage of bio fuels at pumps: 0,5% (2013-2014)	Increase renewable share to 30% (2020). CHP to 25% (2020) (forthcoming legislation) 50% energy intensity reduction (2050) 20% reduction in primary energy use (2020) 50% reduction (2050)$_{2008}$ Long-term target, annual additions 2.5-3.5 GW range of solar panels installations Cut electricity consumption 10% (2020), 25% (2050)$_{2008}$ Sectoral EE targets: 9% EE improvements (2007-2016) Doubling building renovation rate from 1% to 2% Reduction of heating requirements (2020) Reduction of final consumption in transport by 10% (2020), 40% (2050)$_{2005}$ Electrical mobility strategy: 1 million EVs (2020), 6 million (2030). Increase share of RE in heat generation from 6% to 14% (2020)	Mandatory energy savings goal Electricity savings Plan: reduce electricity use in summer months by 15% 30% energy intensity reduction by (2030)$_{2003}$ Fuel economy standard passenger vehicles:55mpg (2025) 12% fuel economy improvement (trucks/busses) (2002-2015) 100 hydrogen refuelling stations (2015) Japan insists on 80% reduction (2050) (Post Kyoto), while EU insists on 20-30% reduction (2020)$_{1990}$ Increase self-sufficiency of energy supply (+independent development) from 38% to 70% (2030). Increase share of RE in total electrical power to 20% (2020) (National). Introduction of renewable energies to 2.4 times current levels (15 times excluding hydropower) (2030)
Supporting mechanisms or measures	EU ETS scheme /Ecodesign Directive Incentive Scheme for Sustainable Energy Production. Energy Investment Allowance (EIA). Environmental Investment Deduction Scheme (MIA). Random Deductions for Environmental Investments Plan (Vamil). Environmental Management Act (EMA). Green Deals Initiative /Innovation Contracts. Regulatory Energy Tax (REB).	EU ETS scheme and Voluntary agreements Feed-in tariff, tax rebates, partnership with climate protection and energy companies	Voluntary experimental Cap and Trade: 1,400 installations and 1% of the country`s emissions Tax Scheme for Promoting Investment in Reform of the Energy Demand-Supply Structure (30% of acquisition costs) Feed-In Tariff

*Based on different local, national government acts or industry documents, ( ) denotes target year, subscript denotes baseline year.

Annex 2 List of Endnotes

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[i] `Sustainable` refers to processing around 1.4 million tonnes of waste annually. Biomass accounts for almost 50% of that waste. It qualifies for CO_2 neutral certification. Incinerator that AEB owns is one of the most efficient in the world. Its electrical efficiency is 30%, much higher compared to the average of 8%. It also produces renewable electricity for approximately 320,000 households (AEB, 2014):

AEB or households	Produced per year, GJ or GWh*	Consumption per year, GJ or MWh*
District heating	300,000 (83,33*)	
Average household in Amsterdam		36 (10*)
Electricity	1000*	

[ii] Major legal obligations from the Municipal Climate Protection Law (HmbKliSchG, 1997) are:

1. Savings in public buildings
2. Requirements for existing buildings, heating and ventilation, domestic hot water/hot water plants, heating and air conditioning systems
3. Thermal protection requirements for future constructions
4. Restrictions on mechanical space cooling and reconnection of electrical heating etc.

Germany has a federal framework - Integrated Climate and Energy Programme (IKEP). It has role in Hamburg`s energy policy, through following documents (Hamburg Parliament, 2008):

1. Renewable Energies Heating Act (EEWärmeG). From 2009, new buildings are required to use a certain percentage of renewable energies for space heating. Hamburg can achieve enormous CO_2 savings in existing building stock. Savings potential in new buildings is cca 1% of total requirements for the building sector. With other states, Hamburg proposed mandatory inclusion of existing buildings in the EEWärmeG Act.
2. Energy Savings Ordinance (EnEV) regarding more climate-friendly standards.
3. Combined Heat and Power Act (KWKG): CHP generated electricity double to 25% by 2020.
4. Act for New Regulation of Renewable Energies in the Electricity Sector (EEG). Tariffs for grid feed-in of electricity generated from RE, main contribution from offshore wind energy.
5. Bio fuels. Legally stipulated blending percentage in existing vehicle fleet.
6. Planning law and amendments to the Building Code (BauGB), establishing urban modernisation measures in urban planning, development and urban conversion activities.