ENERGY CONCEPTS FOR SMART CITIES

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Abstract

Cities will be the power plants of the future. More than 50% of the world's population lives in cities, about 65% of the resources are used in cities and 70% of the emissions are caused by cities. And more and more people move to cities. It is obvious therefore that the transition to sustainable energy systems has to start there.

So far, cities are supplied by energy from outside. Any kind of power plants and refineries is situated far from the largest consumer. This system is expensive and volatile. If one discusses the possibilities of energy transition in urban areas, the reduction of the energy demand has to be considered first. It is not mainly technologies that have to be developed, but systems. These systems require short distances, in order to minimize the energy transportation. More than this, houses have to be energy effective (with a minimum of heating and cooling).

As a second step, renewable energies have to be harvested onsite. Solar systems on roofs and facades go hand in hand with integrated small scale wind turbines. The development of smart energy grids for power and heat/cold including storage facilities will be one of the main system related challenges.

Background

The transition to sustainable energy systems has to start in cities. There is no way around and the facts are striking: cities cover about 1% of the world's surface, but they consume 75% of the energy and cause 80% of the emissions of global greenhouse gases. And the cities keep growing. Today about 50% of the world's population live in cities, and 60% are expected by 2025. At present these cities are powered by fossil energies: coal, oil and gas. While the cities contribute to climate change, also the effects will be seen mostly here. Within cities an increasing number of hot days and nights can be expected, air quality is decreasing. More than this, many cities face great problems with growing traffic, black outs and poor suburbs.

But there is also a chance: measures taken here unfold the greatest effect! Urban systems are the leverage point for solving global energy problems. There is no blueprint for such a "smart" city, but some rules are general and can be transferred into different cultures and climates.

The European Union (EU) is tackling the challenge through a policy whose target is nothing less than the transformation of the entire energy system, with far-reaching implications on how we source and produce our energy, how we transport and trade it, and how we use it. In short, it is necessary to make low-carbon technologies affordable and competitive – a market choice. This is the core idea behind the European Strategic Energy Technology Plan [1] which includes a Smart City Initiative.

The Smart Cities Initiative aims to improve energy efficiency and to step up the deployment of renewable energy in large cities going even further than the levels foreseen in the EU energy and climate change policy. This initiative supports cities and regions that take pioneering measures to progress towards a radical reduction of greenhouse gas emissions through the sustainable use and production of energy. It brings the cities involved to the forefront of the development of the low-carbon economy.

Resource Efficiency First: LOWs and HIGHs in a Smart City

We do not know, what a Smart City will look like, but there are several rules that have to be followed in order to achieve the results wanted. Table 1 shows the criteria that have been developed in a participative process in the City of Graz [2].

Table 1: LOWs and HIGHs for a Smart City

LOWs	HIGHs
SHORT DISTANCES: urban activities of everyday life are close together.	**HIGH ECONOMIC PRODUCTIVITY:** strong enterprises create meaningful jobs and fresh knowledge.
LOW GHG-EMISSIONS: energy and materials used in Graz are free of net CO2-emissions.	**HIGH INTERACTION:** Graz cooperates and interacts permanently with its international partnership and its surroundings.
LOW WASTES: waste air, waste water and waste have no negative influence on the environment, neighbourhood or nature.	**HIGH (Bio-) DIVERSITY:** all kind of inhabitants and users meet a very attractive urban living space including nature.
SMALL FOOTPRINT: the inhabitants´ demand in Graz is in line with the bio-capacity of earth.	**HIGH PERSONAL FREEDOM:** Graz encourages its inhabitants to take their own way of smart living.
LOW EXTRA COSTS: all (investment) decisions are taken on the basis of lowest life-cycle costs.	**HIGH EVOLUTIONARY CAPABILITY:** Graz will transform itself and has the capability for changes and evolutions.
LOW THREATS OF HEALTH: There are no emissions that jeopardize the health of people living inside or around the area.	**HIGH RESOURCE EFFICIENCY:** Resources are used as effectively[1] as possible. People's demands are covered by services and not by products as far as possible.

As we discuss urban energy systems, we have to concentrate on the energy services needed. These are:

- Low temperature heat (house heating, sanitary applications, low temperature industrial processes)
- High temperature heat (mainly industrial)
- Cooling and air condition (storage, offices, living rooms, …)
- Refrigeration (freezing, cold storage)
- Light and information
- Mobility of people and goods
- Stationary drives (pumps, elevators, …)

Smart Cities Live on Renewable Energy

Transformation from the current fossil based energy system to a renewable regime is both possible and necessary. The reasons are well known and need not be discussed here: climate change, peak oil, nuclear disasters, political dependency from few regimes, rising energy prices, and more. The European Commission has demanded a reduction of CO2-emissions by 20% till 2020 compared to 1990. Scientific research findings on climate change and, more than this, political statements of leading politicians and EU bodies demand a further reduction of greenhouse gas emissions beyond the 2020 target. In July 2009, the leaders of the European Union and the G8 announced an objective to reduce greenhouse gas emissions by at

[1] Effective use means (in contradiction to efficient) to achieve a desired effect by means of a low energy and material input (efficiency describes the relation of useful output / input)

least 80% below 1990 levels by 2050 in the industrialized countries. In October 2009 the European Council set the appropriate abatement objective for Europe and other developed economies at 80-95% below 1990 levels by 2050 [3, 4].

The technical feasibility of such a transition has been proven in numerous studies on national levels as e.g. for Austria in 2011 [5] and for agricultural regions. There are few designs of 100% RE-based densely populated cities in mild or cold climates. The report for Munich can be accounted as a blueprint for such concepts, but it concentrates on living and mobility and ignores all commercial activities [6]. An example for a planning in a smaller city, one can cite Sonderborg in Denmark [7], the vision for turning Sonderborg into a vibrant ZEROcarbon city by 2029, creating sustainable growth and many new jobs in Cleantech.

It has also to mentioned that there are remarkable projects going on in Asia, mainly in China [e.g. 8], Japan [e.g. 9] and Saudi Arabia. A collection of international urban agenda can be found in [10].

These ambitious targets need to be translated into a low carbon society with all its social and technological implications.

Renewable Energy Resources for Urban Systems

Nearly zero-energy buildings:

Buildings account for 45% of total energy consumption in the EU, mainly for heating, lighting, appliances and equipment. Increasing living space per capita and higher levels of comfort and equipment for homes and offices lead to rising energy consumption. The impact of energy use in buildings is pervasive, since it is estimated that Europeans spend 90% of their time indoors [11].

The European Union has published a directive that says that all Member States shall ensure that [12]:

(a) by 31 December 2020, all new buildings are nearly zero- energy buildings; and

(b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings,

where: "*'nearly zero-energy building' means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby".*

There are many ways to achieve this goal. This includes a good thermal insulation, but also the selection of suited building surfaces including planted walls and roofs, if cooling is an issue. Different surfaces have different albedo (reflection) values by virtue of their specific grain, texture and color. The utilization of daylight for lighting is an important way to reduce the electricity consumption during day-time. In many houses lights have to be on, even if there is bright sunshine outside. In a smart city, every worker should have the right for a naturally lighted working place.

Thermal solar collectors

Low temperature heat for space heating, sanitary purposes and many of the industrial applications can be supplied by solar thermal collectors. Different types of collectors suited for different temperature levels up to 200°C and various climates are available. Studies show that also most of the industrial processes are running at temperatures lower than 250°C. Food industry, textiles, metal treatment and most of the chemical industry can therefore be supplied by solar thermal collectors at least partially. The worldwide market development of glazed water collectors is characterized by a steady growth over the past decade. Between 2000 and 2010 the average growth rate worldwide was about 21% [13]. Between 2000 and 2010 the annual installed glazed water collector area worldwide increased 6-fold, and compared to the year 2009 the worldwide market grew by 13.8%. Regardless of this development, it should be noted that the growth 2009/2010 rate was the lowest since the period 2004/2005 (see Figure 1).

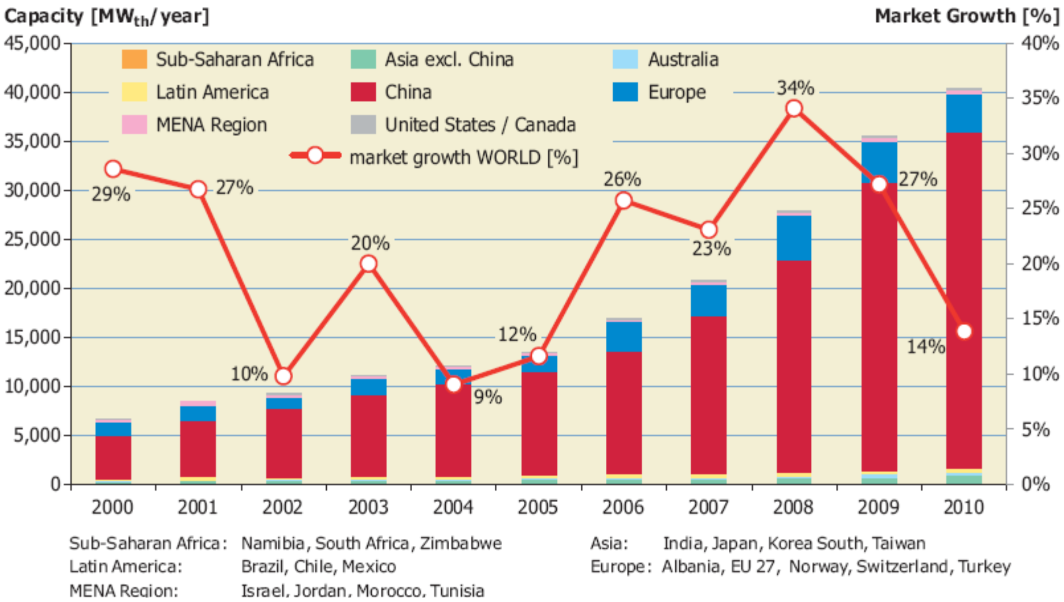

***Figure 1**. Annual installed capacity of flat plate and evacuated tube collectors from 2000 to 2010*

PV

Photovoltaics are the perfect technology to convert solar radiation into the most useful form of energy – electricity. Although electricity from photovoltaic units is still very expensive, the growth rates are enormous. PV modules can be fabricated in any form and color and can be placed on roofs, facades and any free place. The main problem with photovoltaics is the fact that the energy is not always available if it is needed. This leads to a need for storage installations and demand side management. Small amounts of electricity will be stored within the buildings or city quarters in future. Larger storage will be necessary within the grid, most likely with hydro power plants. There is also the possibility to convert electricity with surplus CO2 into gaseous or liquid fuels [14]. This technology might grow in importance in the next decades.

Urban wind systems

Wind turbines at present are located outside living areas in order not to reduce the quality of life through noise or optical influences. But there is a need for bringing production closer to consumption and so urban wind energy systems will gain market share. Small units with vertical or horizontal axes can be built on houses.

Geothermal and environmental energy

Ambient energy can be an enormous resource for heating and cooling. Generally ground water temperature is lower than comfortable room temperature. Direct cooling with ground or surface water can therefore replace the need for electricity powered air condition systems.

Bio-waste

Waste is an important source of energy. In the first place, waste has to be minimized as much as possible or reused on a material level before it is incinerated. But there will be a certain amount of organic waste that cannot be reused, but should be utilized as an energy resource. Wet bio-waste can be used together with the effluent from toilettes in biogas plants in order to produce electricity and heat in cogeneration units. As an alternative, the methane produced can be cleaned and used in cars.

(Industrial) waste heat

The postulation of short distances includes the integration of living, work, education and material supply into areas that can be reached by food or bicycle. Therefore waste heat from industrial operation will be available near living areas. The integrated utilization of power, heat and cold in smart heat grids offers advantages to all actors.

Urban planning:

Webs of green corridors and parks combined with open water surfaces will act like a natural air conditioning system. Smart cities should facilitate the flow of cool air through narrow passages, shady gardens, water courts and the appropriate organization of streets. The relevance for resiliency and flexibility of the structural elements of a city together with densification strategies, the accessibility for traffic and the connection to the regional economic and ecologic context, lead to high quality public spaces for human communication. Awareness rising by participation of citizens and stakeholders leads to successful implementation of energy concepts with a safe strategic financial background.

Cleaner Production and Smart Cities

Chouinard and Stanley describe the five responsibilities of a company out of their 40 years of experience with Patagonia Inc. [15]:

- Responsibility to the health of business
- Responsibility to the workers
- Responsibility to your customers
- Responsibility to the community
- Responsibility to nature

If we demand a city of short distances, it has to be possible, and even more desirable to live near the working place. On the other hand, this also requires that places near companies are worth living. Companies in Smart Cities therefore have to be close to Zero Emissions. They should not cause any emissions (solids, liquids, gases, smell, noise, vibration, …) that reduce the quality of life in the neighborhood. More than this, “the best companies have also recognized their significance to the economic health of their communities and have avoided closing plants when possible, or have helped soften the impact of a closing by phasing out rather than shutting down production, offering generous severance pay to laid-off workers, and supporting the community institutions that aid the unemployed.” [15].

The visionary approach in the City of Graz

Graz started its Smart City project in 2011 with a grant from the National Austrian Research Foundation FFG. The project has been managed by the City of Graz through its buildings authority. The main research partner was the Graz University of Technology which was responsible for mediating the decision processes. The methodological background was a systematic innovation process similar to that proposed by Mann [16]. In the Graz Process, we did not start with the present situation in the city, but by defining the desired outcome: an ideal city for living, working, learning, culture and leisure (comp. Fig. 2).

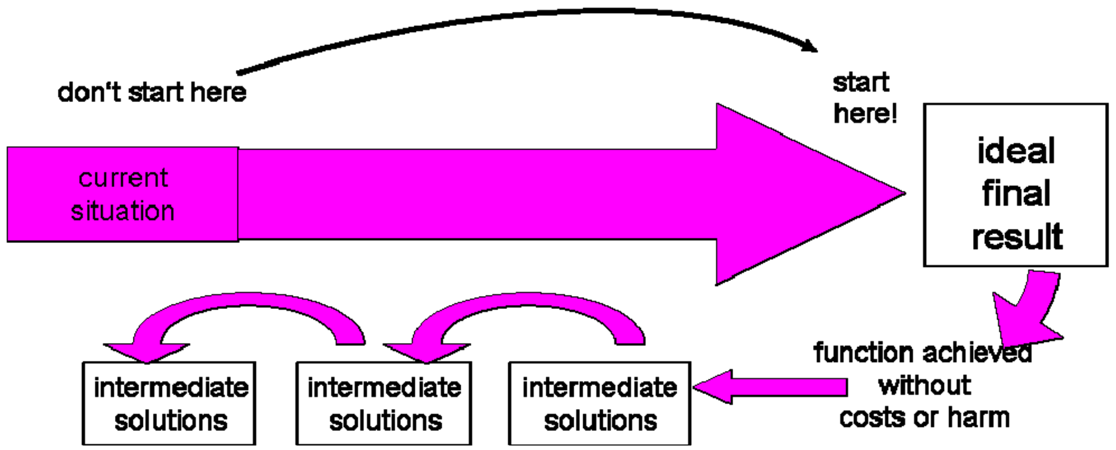

***Figure 2**. Starting innovation with the ideal final product*

In order to be able to find the "ideal city" independent of present interests (internal drivers) and (mega-)trends (external drivers), seven expert groups were established, as shown in Fig. 3.

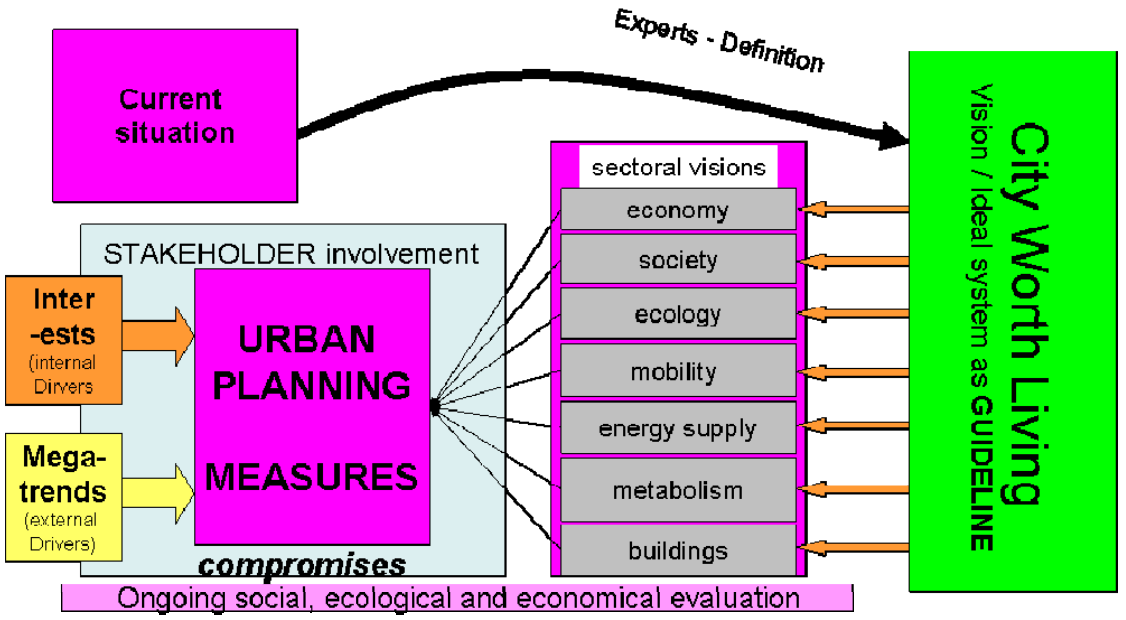

***Figure 3**. From sectoral visions to urban planning measures*

Each of the groups was led by a representative of a (semi-)public institution (city, utility company,…). Researchers from eleven institutes of the Graz University of Technology, representatives from various departments of the City of Graz, from business, from NGOs and from the general public joined the process.

The process management defined the tasks for each of the working groups:

- Define the vision of the sector
- Build a set of indicators
    - "hard" indicators that can be quantified by numbers
    - "soft" indicators, text only
- Draw a roadmap
- Specify the main actors and assign duties to them
- Define the supporting (mega-)trends and most likely barriers

Based on the results of the seven working groups, the experts on urban planning defined their visions and measures.

Conclusion

The supply of universal services like energy and information has historically justified the existence of national carriers, which operate under a monopolistic regime in both the supply and the management of the system. A monopolistic structure is in fact able to guarantee the supply of a universal service, irrespective of the real supply costs, due to cross-subsidies among categories of users. One single carrier in a monopolistic market can in fact guarantee [17]:

- Continuity in the provision of the service
- A universal service provision
- Equal tariffs treatment for each category of users, irrespective of the real supply costs for the service to each category.

These principles are the basis for a monopolistic structure in the energy sector. But there are reasons to think, that such a structure is not suited to provide the various forms of energy in a Smart City. Each entity in the city now has the possibility to be a "prosumer" – a consumer and a producer at the same time. Small wind power plants and solar units on dwellings or CHP-units in companies will be connected to the electricity and district heating grid, operated by a company which also manages the load and storage tasks.

Energy, information and telecommunication infrastructures (ITT) are converging, as distributed renewable resources become poised to play the leading part in the supply of urban systems. "The emergence of more horizontal power markets based on very large numbers of two-way transactions is an exciting prospect for cities, enabling them to perform as virtual power houses comprised of manifold, embedded suppliers no longer supplied from outside, but empowered from within. This process will require institutional changes in the energy industry and offers at the same time the possibility for the citizens to take part in the decision process as well as in the financing through private-public-partnership (PPP) models. In an advanced renewable-power economy many small and medium sized providers supplement, and can eventually assimilate or replace the comparably few large and central plants and suppliers currently operating to supply national and international economies and their urban centres. This process can engender a form of energy democracy in action, and challenge the power behemoths that have thrived in a carefully managed hothouse of protective policies and regulations" [18]. Or as Jeremy Rifkin puts it: "The creation of a renewable energy regime, loaded by buildings, partially stored in the form of hydrogen, distributed via smart intergrids, and connected to plug-in, zero-emission transport, opens the door to a Third Industrial Revolution" [19]. These technologies and systems give the chance to develop cities as power stations [20].

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