Planning 0-energy cities using local energy sources

Wouter Leduc, Ribuilt, Research Institute Built Environment of Tomorrow, Hogeschool Zuyd Heerlen, and Landscape Architecture Chairgroup, Wageningen University and Research Centre, wouter.leduc@wur.nl

(Author is researcher within the SREX-project, a Dutch abbreviation for Synergy between Regional Planning and Exergy, website: www.exergieplanning.nl; supported by NL Agency, Ministry of Economic Affairs)

Abstract

The world is urbanizing rapidly and cities’ resources demand is increasing. Cities are mainly depending on foreign fossil energy sources. Incoming resources are used inefficiently, only part of energy input is used and remaining is wasted. To reduce dependency and increase self-sufficiency, cities have to search for local and renewable energy sources. Cities are a reservoir of untapped energy sources, which can support them to reach 0-energy status and to become independent. Cities have unused space available to capture incoming energy. Most technologies are available, but at the moment not used fully. Therefore, further effort should focus on planning and implementing those technologies; and urban planning should also address resources management.

Proposed method, based on Urban Harvest approach and exergy principle, towards planning 0-energy cities, consists of five steps. It gives an overview of urban energy demand and potential supply, and describes how supply and demand can be coupled effectively.

Introduction

For centuries, cities have been seen as consumers and waste producers, not considering their own resource potential. Cities depend highly on external inputs and have almost no connections with their resource locations. Evidence are ecological footprints of cities: cities largely overshoot their bio-capacities (Doughty & Hammond, 2004). Resources are coming in and waste is going out. Steel (2008) illustrates the concept of a “hungry city” and links it to what might be called a fossil fuel focused energy system. Accelerating urbanization, increasing scarcity of resources and climate change press us to think about means to manage and design our cities sustainably: towards closing cycles, minimization of impacts and strategic management of resources. Former research, Leduc & Rovers (2008) and Agudelo et al. (2009) indicated that cities offer ample possibilities to harvest local resources, and thus becoming less dependent.

Therefore, interaction is needed between urban planning and resources management. This paper proposes a method, based on Urban Harvest approach and exergy principle, to change urban energy planning to reach 0-energy cities. The 5-step method, tested on Kerkrade-West, gives an overview of urban energy demand and potential supply, and describes how supply and demand can be coupled effectively.

Theoretical background

Urban Metabolism

The concept of urban metabolism gives a holistic framework for analyzing a city’s input–output relationships with its surrounding biophysical environment. City is seen as organism, i.e. “chemical process within organism involving intake of resources, their transformation into more or less complex forms, and subsequent excretion of wastes” (McDonald & Patterson, 2007). In the last decades, “urban metabolism has been used as a useful framework for providing valuable information about energy efficiency, material cycling, waste management and infrastructure in urban systems” (Kennedy et al., 2007). Urban metabolism is a way to quantify overall flux of resources of a specific region, or city.

Nowadays cities show a linear metabolism: non-renewable resources are imported, inefficiently captured and applied, and after use waste is exported and valuable resources disposed (fig. 1a). Towards 0-energy cities,
cities have to evolve to a circular metabolism – a closed cycle resource management (Rovers, 2008). Circular metabolism implies that incoming, renewable, resources are captured and transformed for efficient and effective use within the city, and waste is minimized by applying recycling, and cascading (fig. 1b). Therefore, functions and resources flows within the built environment should be optimized.

Urban Harvest, sustainable resources management and urban planning

The Urban Harvest (UH) approach, based on the urban metabolism concept (fig.1b), is developed as strategy to investigate all possible options for harvesting local resources and (re)using emissions and wastes within the city. UH addresses capture of any renewable primary resource and secondary resource within an urban system, aims for (re-)use, and thus a closed cycle resources management (Rovers, 2007, 2008). An important principle in UH-approach is exergy. Exergy, or quality of energy, refers to the second law of thermodynamics: “energy can never be lost” (Wall, 1977, 2009; Dincer & Rosen, 2005). An example for urban metabolism is “waste”-flow: outgoing flow, remaining after activity completion, is not seen as waste, but as flow with lower quality. In an open system, remaining qualities will be wasted. In a closed cycle approach, flows with lower quality can be useful to execute a lower quality required activity. Cities can be seen as reservoirs of un-used energy qualities, both renewable and residual.

However, in order to harvest and convert local resources within a city, we need to know at what time and location resources are available (Leduc et al., 2009). If resources/flows with remaining un-used qualities are not available at right time and location, or cannot be converted or stored, these flows are lost. The four parameters, quantity, quality, location and temporal characteristics, link the field of resources management with urban planning practices. Towards 0-energy cities, integration of those four parameters in urban planning is necessary, planning has to include urban circular metabolism, and should explore infrastructure patterns and networks. Therefore, cities have to consist of a mixture of urban functions and structures, connected to each other, and in close proximity, so residual and renewable flows can be used in an optimal way (Van Kann & de Roo, 2009; Van Kann & Leduc, 2008). Infrastructure integrates the four parameters, but to use infrastructure effectively, urban planning should develop synergies between clusters of spatial functions on appropriate distances (Leduc & Van Kann, 2010).

Method

The UH-approach uses the Urban Tissue (UT) as functional unit: a quick scan visualizing “urban land-use distribution, resources demand and supply potential” (Leduc & Rovers, 2008). UT is a standard unit, 1 hectare, that makes identification of several urban flows possible and is a means to express typologies of built environment (Rovers, 2007).
Formula 1 describes the important parameters within the UH-approach:

\[
\text{Urban Max Tech Harvest} = \text{Potential Urban Harvest} \times \phi_{\text{tech}} \times \phi_{\text{urban}}
\]  

(1)

Potential UH is maximum amount of source available, or collectable within boundaries of UT. However, to calculate how much of this maximum potential can be captured, and converted within the city – Urban Maximum Technical Harvest (Urban Max Tech Harvest) – some reduction applies: \(\phi_{\text{tech}}\) relates to technical efficiency restrictions, and \(\phi_{\text{urban}}\) relates to urban characteristics and typology restrictions (Rovers, 2007; Agudelo et al., 2009).

The proposed method builds on description of Dutch Urban Average Tissue, UrbAT-NL (see Rovers, 2007; Leduc & Rovers, 2008). The method to develop the specific urban energy tissue (see also Agudelo et al., 2009) consists of 5 steps (fig. 2):

1) **Urban land-use distribution**: Inventory of urban spatial functions and surfaces;
2) **Demand inventory**: Hierarchical quality identification and quantification of urban energy use;
3) **Demand minimization strategies and supply inventory**: Inventory of urban demand limiting measures; hierarchical quality identification and quantification of urban energy sources, renewable and residual; calculation of technical feasibility;
4) **Couple supply – demand**: Try to ensure that quality of energy is as high as required for use, but not higher, by using principles of multi-sourcing and cascading; use decision tree (fig. 3) to define if resource can be applied locally;
5) **Optimize supply – demand**: Apply recycling principles; identify, localize and connect clusters and install networks; optimize storage and exchange with other systems; calculation of Urban Max Tech Harvest by scenarios development.

![Diagram of urban energy tissue](image)

**Fig. 2: Application of UH-approach in cities**

The specific urban energy tissue, EN-UrbAT, is developed to support accounting, coupling, and planning of urban energy demand and potential supply. The author defined the tissue for a case-study, Kerkrade-West, based on description of EN-UrbAT by Leduc and Rovers (2008), and Agudelo et al. (2009).
Fig. 3: Decision tree – existing built-up area

Results

The author developed EN-UrbAT and tested UH-approach at Kerkrade-West; district of Kerkrade municipality, in the south of The Netherlands (map 1). Kerkrade is located in the former coal mining region, and this shaped the municipality. Kerkrade-West has a surface of about 1000 hectares and almost 16,000 inhabitants; various building densities, mix of spatial functions, and also agricultural, forest and water areas. Kerkrade-West was an energy supplier, referring to coal mining, but is now an energy demander and dependent on foreign resources supply.
The first step of the method is to show urban land-use distribution with inventory of urban spatial functions, see map 2 and figure 4 – quick-scan of urban land-use distribution downscaled to one hectare. Tables 1 to 3 show land-use distribution surfaces, and further urban function specifications.
Fig. 4: Abstraction of land-use distribution, urban tissue Kerkrade-West, on 1 ha (100 m by 100 m)

Main part of urban area is built-up area: houses, business, retail, schools, etc. Next to that, Kerkrade-West has a large agricultural and green area (t. 1). Specification for total business area (t. 3) shows that most surfaces are for warehouses, there is quite some heavy industry, and large-scale shops. In Spekholzerheide-business park, there is: machinery industry; medical appliances production industry; chemical film production industry; and brick producing industry. In Dentgenbach-business park, there is: an aluminum smelter; a large bakery; four chemical industries, producing synthetic fibers and pharmaceutical products; two paper/cardboard industries; two synthetic material processing industries; and rubber processing industry.

| Table 1: Urban land-use distribution, statistical data, ha (CBS, 2003, 2008) |
|-----------------------------|-------------|-------------|-------------|-------------|--------|
| Total Land | Water       |
| 1006 | 1006 | 987 | 987 | 19 |
| Urban | Non-urban (agri & forest) |
| 426 | 120 | 61 | 279 |
| Built-up* | Recreation | traffic |
| 100 | 61 | 279 |
| Semi built-up** | **: mainly vacant land and wreck storage |
| 338 | 61 | 279 |

*: area for houses, business, retail, hotels & restaurants, education, care

| Table 2: Number of houses, total and specified, and estimated surfaces other urban functions |
|-----------------------------|-------------|-------------|-------------|-------------|
| Houses, total number | Detached | Semi-detached | Row | Apartments |
| 7215 | 866 | 1443 | 3968 | 938 |
| Surfaces, ha |
| Schools | 3.2 |
| Care | 14.0 |
| Hotel & catering industry | 3.0 |
| Retail | 13.0 |
| Offices | 4.0 |

(Gemeente Kerkrade, 2003; CBS, 2008)
Table 3: Estimated business area specification, in ha (Parkstad Limburg, 2003)

<table>
<thead>
<tr>
<th>Business area</th>
<th>Offices</th>
<th>Large-scale Shopping</th>
<th>Hotel &amp; catering industry</th>
<th>Warehouses</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>De Locht</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rodaboulevard*</td>
<td>1.1</td>
<td>1.9</td>
<td>0.6</td>
<td>25.4</td>
<td>8.2</td>
</tr>
<tr>
<td>Spekholzerheide+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Willem-Sophia**</td>
<td></td>
<td></td>
<td></td>
<td>23.2</td>
<td></td>
</tr>
<tr>
<td>Dentgenbach</td>
<td></td>
<td></td>
<td></td>
<td>85.3</td>
<td>25.1</td>
</tr>
</tbody>
</table>

*: soccer stadium is in this area, total area (stadium + parking) is 9 ha
*: also waste collection point and storage, 8.5 ha
**: also quarry, 9.9 ha

As second step, the author made an inventory of current urban energy demand, categorized according type of energy demand, quality, and amount of energy demand, quantity. Table 4 shows results for four studied energy qualities: electricity, heat, other fuel, and transport fuel. All business areas together represent largest demand for different specified energy qualities, and heavy industry accounts therein for largest contribution. Further, all houses represent a substantial energy demand, and also retail within district. Another large consumer is transport & traffic. Table 5 shows specification for industrial heat demand and possible sources.

Table 4: Energy demand quantities of several energy qualities for studied urban functions per year

<table>
<thead>
<tr>
<th>Function</th>
<th>Elec, MWh</th>
<th>Heat/gas, GJ</th>
<th>Other fuel, GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houses</td>
<td>24,300</td>
<td>481,000</td>
<td></td>
</tr>
<tr>
<td>Schools</td>
<td>880</td>
<td>11,250</td>
<td></td>
</tr>
<tr>
<td>Care</td>
<td>760</td>
<td>6800</td>
<td></td>
</tr>
<tr>
<td>Hotel &amp; Catering industry</td>
<td>3700</td>
<td>26,500</td>
<td></td>
</tr>
<tr>
<td>Retail</td>
<td>15,000</td>
<td>54,000</td>
<td></td>
</tr>
<tr>
<td>Offices</td>
<td>520</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>Public lighting</td>
<td>670</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business area</td>
<td>435,000</td>
<td>2,072,000</td>
<td>3300</td>
</tr>
</tbody>
</table>

Transport & traffic, liter 17,000,000

Table 5: Demanded heat, different temperatures, and possible urban sources

<table>
<thead>
<tr>
<th>Industry</th>
<th>Demanded temp., °C</th>
<th>Source</th>
<th>Delivered temp., °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick production</td>
<td>1200</td>
<td>Cooling-water industry</td>
<td>40-100</td>
</tr>
<tr>
<td>Aluminum smelter</td>
<td>600-700</td>
<td>Steam industry</td>
<td>100-300</td>
</tr>
<tr>
<td>Synthetic materials</td>
<td>95-240</td>
<td>Biogas, hydrogen</td>
<td>600-1800</td>
</tr>
</tbody>
</table>

The third step is inventory of measures to limit urban energy demand, and quality identification and quantification of available urban energy sources. Firstly, urban demand can be limited by measures to improve processes efficiency, or adjusting performance of processes; see table 6 for overview of possibilities, for two studied scenarios (see also step 5): Scenario-moderate (Sc-mod) and Scenario-max (Sc-max).

Secondly, the author studied potentials of local renewable and residual resources: solar and wind energy; road potential; biogas and hydrogen; hydropower; and biofuel production, from algae. Table 7 and figure 5 give overview of maximum technical feasible amounts, according to quality and quantity of energy.
Table 6: Estimated reduction potential, fossil, for studied efficiency, and function change measures

<table>
<thead>
<tr>
<th>Measures, changes</th>
<th>Electricity, MWh</th>
<th>Heat, GJ</th>
<th>Other, GJ</th>
<th>Transport fuel, l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive house</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>standard a</td>
<td>Sc-mod</td>
<td>1800</td>
<td>157,200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max</td>
<td>3600</td>
<td>314,000</td>
<td></td>
</tr>
<tr>
<td>Adjustments</td>
<td>Sc-mod</td>
<td>5000</td>
<td>20,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max</td>
<td>180,000</td>
<td>410,000</td>
<td>3300</td>
</tr>
<tr>
<td>business area b</td>
<td>Sc-max</td>
<td>180,000</td>
<td>410,000</td>
<td>3300</td>
</tr>
<tr>
<td>Transport +</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mobility c</td>
<td>Sc-max</td>
<td>-9150*</td>
<td>8,500,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max</td>
<td>-18,300*</td>
<td>17,000,000</td>
<td></td>
</tr>
<tr>
<td>Public lighting d</td>
<td>Sc-mod</td>
<td>330</td>
<td>165,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max</td>
<td>330</td>
<td>165,500</td>
<td></td>
</tr>
<tr>
<td>Full-service</td>
<td>Sc-mod</td>
<td>700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>laundry shop e</td>
<td>Sc-max</td>
<td>1400</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*: passive house standard applied on existing housing stock, not full passive standard reachable; Sc-mod: 50 % of houses, Sc-max: 100 % of houses;
: see t. 3 for specification; Sc-mod: 50 % of shopping and office area is virtual, results in 30 % lower energy demand; Sc-max: IDEM Sc-mod + changes in heavy industry (some remain, some deleted and changed to warehouse, new industry → only when renewable energy and materials);
: split up in cars, vans, trucks; small distances (>5 km): no motor transport allowed, car sharing (12 %), car and van kilometers electric, truck kilometers: 50 % electric, 50 % biofuel (see t.6); Sc-mod: 50 % electric and biofuel potential applied, Sc-max: full electric and biofuel potential applied;
: use of more efficient materials and less lights, maximum reduction of 50 %; already for Sc-mod;
: change of 10 individual household laundry machines/dryers by 1 full-service laundry shop (larger laundry machines/dryers); Sc-mod: applied for 25 % of houses, Sc-max: applied for 50 % of houses;
: change to electric mobility and transport demands more electricity

Table 7: Estimated renewable potential, qualities and quantities of energy

<table>
<thead>
<tr>
<th>Technology/application</th>
<th>Electricity MWh</th>
<th>Heat GJ</th>
<th>Transport fuel l</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV on roofs, vacant land, floating, railway cover a</td>
<td>Sc-mod 134,000</td>
<td>165,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max 223,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar turbines on roofs houses b</td>
<td>Sc-mod 171,000</td>
<td>165,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max 405,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind turbines on vacant, low density land c</td>
<td>Sc-mod 171,000</td>
<td>165,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max 405,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat producing road technology d</td>
<td>Sc-mod 80,400</td>
<td>15,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max 165,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydropower, outlet lake e</td>
<td>Sc-mod 200</td>
<td>27,300</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max 200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biogas, from green household waste and black water f</td>
<td>Sc-mod 15,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max 27,300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen production, via electrolysis (wind turbines) g</td>
<td>Sc-mod Not included</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max 1,500,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biofuel production, algae ponds h</td>
<td>Sc-mod 1,020,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sc-max 2,040,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*: estimated industrial building roof area = 41.6 ha, roof houses = 15 ha (25 m²/house) + 1.9 ha (20 m²/apartments), PV-field on vacant industrial land = 11 ha, roof stadium = 2.2 ha, floating on lake = 6 ha, railway cover: railway area = 15 ha, assumed 2/3 available; Sc-mod: PV-efficiency = 15 % (for NL = 150 kWh/m²), Sc-max: PV-efficiency = 25 %;
: estimated surface per house = 3 m² = 35 GJ heat/house; 500 houses already equipped with solar boiler; Sc-mod: half of remaining houses get solar boiler (yield of existing added); Sc-max: all of remaining houses get solar boiler (yield of existing added);
: 2 wind turbines (WT) of 2.5 MW each already existing, added 5 WT of 1.5 MW & 28 WT of 2.5 MW (see fig. 5); formula: \( E_{\text{par}} = b^*V^2*A \) (b = measure for total returns, NL average = 3.7); Sc-mod: average wind speed = 6 m/s; Sc-max: wind speed = 8 m/s;
: see de Bondt & Jansen, 2004; total road area = 37 ha; Sc-mod: 1/3rd of road available for heat production; Sc-max: 2/3rd of road (25ha) available, not complete surface due to less future asphalt roads;
: rainwater run-off to lake to increase discharge; 1,400,000 m³ rain; exchange rate: water discharge of 1 m³/s = 35 kW power → 100 MWh produced; doubled by adding treated grey water run-off of houses; Sc-mod & Sc-max: max. potential; \( \text{local collection of green household waste and black water of houses, & local conversion into biogas (added to grid); Sc-mod: half of potential possible; Sc-max: full potential reached;} \)
: hydrogen production via electrolysis, extra electricity delivered by WT (included in WT-estimations); Sc-max: 1 MJ = 1/12 m³ H₂, 1 m³ H₂ demands 2.5 kWh electricity (and 0.5 l water), improved process (normally 5 kWh and 1 l);
: for trucks assumed that 50 % of fuel (or km) can be electric, other 50 % has to be produced via biofuel; assumed BTU for diesel: 36,500 BTU/l; assumed algae production: 1 m² algae pond produces 5,000,000 BTU; Sc-mod: 50 % of remaining truck fuel via algae; Sc-max: 100 % of remaining truck fuel via algae.
In step 4, the decision tree (fig. 3) is used to couple available potential, via multi-sourcing and cascading, with local energy demand. This decision tree indicates points where decision about continuation of process has to be made. To fulfill a certain demand, there should be a local potential, e.g. incoming sun, and demand. If not, potential can be captured and stored for later use, or exported to be used for another system. If there is demand, capture and convert harvest potential, and couple received quality and quantity, of certain value, with demand, of same value, at certain location and time. And further, try to limit use of higher-valued sources for lower-valued demand. For example, use PV-cells to capture sun and convert it to electricity for direct use, or feed it into the grid and store for later use. When demand is fulfilled, collect remaining quality and cascade within system, and limit waste of un-used qualities; e.g., use outgoing, heated ventilation air to pre-heat incoming ventilation air, lowering demand for heat energy. If remaining quality cannot be re-used in system, capture and export it to another system where it can be useful; wasting, non-capture, should be minimized, to limit quality loss.

In step 5, the author used two scenarios, Sc-mod and Sc-max (step 3, t. 6-7), to calculate Urban Max Tech Harvest of Kerkrade-West. The scenarios are used to link demanded quality and quantity of energy to potential energy supply. Figures 6a-c show scenario-results; vertical dimension represents demand (downwards) and supply (upwards). Table 8 gives an overview of demand vs. supply. By using the decision tree, based on exergy-principle, remaining qualities are captured and converted to be re-used; e.g., capture heat of industrial exhaust air and deliver it to heat network to supply other industries or other urban functions. In order to apply cascading, recycling optimally, and thus to use remaining qualities, it is important to localize clusters and identify missing links, and to connect them; e.g. cluster several industrial facilities to one system, or even expand system to other urban functions close by, like houses, shops, offices, greenhouses; or offer potential for specific new industry or function to fill in gap, e.g. industry that functions on lower temperature heat, greenhouses that need CO₂ and heat.
Fig. 6a: Electricity demand (left) and supply, sc-mod (middle) & sc-max (right); business area demand in 1 bar, houses represents all other demand; houses 1 is reduction due to passive house, full-service laundry and public lighting changes; houses 2 is PV-option; wind turbines on vacant land (3); 4, represents business area function changes.

Fig. 6b: Heat demand (left) and supply, sc-mod (middle) & sc-max (right); business area demand in 1 bar, houses represents all other demand; houses 1 is reduction due to passive house standard; houses 2 is solar boiler option; road heat potential (3); 4, represents business area function changes; hydrogen produced with wind turbines (5).

Fig. 6c: Fuel demand (left) and supply, sc-mod (1) & sc-max (2); road represents demand; agricultural area represents biofuel production.
Table 8: Overview of demand and potential supply, Sc-max, for Kerkrade-West

<table>
<thead>
<tr>
<th>Demand</th>
<th>Type/measure</th>
<th>Elect. MWh</th>
<th>Heat. GJ</th>
<th>Other fuel. GJ</th>
<th>Transport fuel, l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>Total</td>
<td>480.800</td>
<td>2.652.000</td>
<td>3300</td>
<td>17.000.000</td>
</tr>
<tr>
<td><strong>Renewable energy generation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renewable potential, existing + added</td>
<td>PV</td>
<td>223.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solar boilers</td>
<td></td>
<td>252.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Road technology a</td>
<td></td>
<td>165.500</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind turbines</td>
<td></td>
<td>405.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydropower</td>
<td></td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biogas</td>
<td></td>
<td></td>
<td>27.300</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrogen production</td>
<td>-306.000</td>
<td></td>
<td>1.500.000</td>
<td></td>
</tr>
<tr>
<td><strong>Further energy reduction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Function change and efficiency improvement measures</td>
<td>Passive house standard</td>
<td>3600</td>
<td>314.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adjustments business area</td>
<td>180.000</td>
<td>410.000</td>
<td>3300</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Public lighting</td>
<td></td>
<td>330</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport + mobility</td>
<td>-18.300</td>
<td></td>
<td>17.000.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Full-service laundry</td>
<td>1400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remaining</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

a: technology also generates cold, 52.000 GJ;

Discussion/Conclusion

Results show that by integrating quality, quantity, location and temporal characteristics of the energy flows, it is possible to supply urban energy demand with local potential. Applying the UH-approach and exergy principle, all available renewable and residual urban potential should be harvested, captured and converted within the urban area to minimize external inputs and outputs.

To reach the 0-energy option completely, the author proposes some major adjustments in industry. It will result in less, heavy, industry available, and could result in fewer jobs. Contrary, if planners take local potentials into account, industry can change from energy dependent to energy-neutral or even producing industry, via, e.g., cascading of residual heat. And a city should not only maximize for energy, but planning should also focus on where materials come from and how food can be produced sustainably. This increased focus on local potential and characteristics will increase production leading to increased number of jobs.

0-energy cities can only be reached by harvesting maximum potentials. This implies that significant adjustments and measures have to be implemented, which will have an impact on urban environment.

Therefore, urban planning needs to adapt and include UH into planning, to facilitate capturing and harvesting available energy potential. UH assists in coupling urban supply and demand more effectively and in reaching urban circular metabolism, and thus more optimal urban systems. This transition is needed towards 0-energy cities.

The proposed method shows the importance of taking inventory of the urban land-use distribution and its respective energy demand and potential supply; to couple supply and demand in an optimal way towards 0-energy cities. The decision tree is a tool to support the decision making process, by evaluating multiple scenarios based on the local context.

Encountered difficulties should be seen as challenges and not as threats; they offer possibilities for innovative ideas. Further, including this approach towards 0-energy cities in planning practice means that planners should also look outside administrative boundaries because synergies might emerge right across those boundaries.

The author tested the method for an existing built-up area, but it is feasible to expand the method to new-to-built urban districts as well. Then, planners do not face restrictions imposed by existing conditions, thus planning can be directed optimally to apply UH-approach towards 0-energy cities.

To reach 0-energy cities, proposed measures maximize urban energy potential, but to reach optimal urban systems focus has to be broader than energy. Urban planning has to include other urban flows, like materials and water. And in order to optimize cities, urban planning should aim for an integrated urban system.
focusing on harvesting all urban flows and finding a way to combine flows to reach 0-energy, 0-material and 0-water cities.

The proposed method to study urban energy demand and supply and couple them, based on UH and exergy, shows how urban planning can transition itself and how optimal urban systems can be developed towards 0-energy cities.

References


McDonald G W, Patterson M G, 2007, “Bridging the divide in urban sustainability: From human exemptionalism to the new ecological paradigm” Urban ecosystems 10 169-192


Wall G, 1977, Exergy – a useful concept within resource accounting (Chalmers University of Technology, and University of Göteborg, Göteborg)

Wall G, 2009, Exergetics (Exergy, Ecology, Democracy, Bucaramanga)