316: Urban Tissue: the representation of the Urban Energy Potential

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Abstract

Growing urbanization puts more and more pressure on urban areas. The demand for energy is increasing and cities have to find new, innovative ways to fulfil energy demand. In order to do that, there is need for methods to map energy potentials of urban areas.
The urban tissue is a conceptual approach towards visualising energy demand and energy supply potential of an urban area. The tissue can help to discover if an urban area can become energy neutral. The whole urban area has to be taken into account, for more options to be possible.
The tissue shows the energy potentials of an urban area and indicates where, how and how much energy sources can be harvested. This paper will present the results of the Dutch average urban tissue.
City planners can use this approach when planning new developments or when refurbishing, to achieve or improve self-sustainability in cities. The possibilities should be practiced without changing or adapting the existing urban area largely. Local energy generation and the interconnections between different urban functions make it possible to reach the target of 0-energy at the urban area level.

Keywords: urban tissue, exergy, energy cascading

1. Introduction

Energy is a hot issue at the moment. Climate change, depletion of fossil fuels and also becoming energy dependent on a small number of countries are arguments. They make that a shift towards a more sustainable energy system is obviously at the policy agenda.
Growing urbanisation puts more and more pressure on urban areas. The energy demand is increasing and cities have to find new, innovative ways to fulfil energy demand. This research focuses on the possibilities in the urban area itself. The urban area contains many untapped sources of energy, such as energy plants and other industries. Those industries dump a lot of produced heat as waste, which can be useful for another urban function. Applying renewable energy sources, such as solar energy, wind power and geothermal energy, are other examples of untapped urban energy sources. We have to find out if urban areas, via a sustainable route, can become energy neutral.
A sustainable urban area, or a neighbourhood, is also an area with a sustainable energy system. Therefore, understanding pathways to sustainable development means taking into account our energy system. The question is how to make a transition towards a more sustainable and new energy system. The so called Trias Energetica is a concept that supports such a transition [1,2]. The concept is based on three steps. First limit the demand for energy through a rational use of energy. Secondly, use renewable energy to fulfil the remaining demand. Finally, use fossil fuels, if necessary, as efficiently and cleanly as possible.

1.1 Exergy

As mentioned, limiting the demand is closely related to a rational use of energy. Dincer and Rosen [3] point out, that an understanding of thermodynamic aspects of energy can help understand pathways to sustainable development. A relevant thermodynamic aspect that bridges the gap between a rational use and sustainable development is exergy. Based on thermodynamic principles, exergy refers to the quality of energy [4]. When using energy for a single activity, only a percentage of the quality of energy is used. The remaining percentage is wasted. Then, the crucial point is that with the same amount of energy multiple activities, with different energy quality requirements, can be performed. By doing this, less energy quality is wasted. Examples of this are re-using waste heat of different temperatures, or making use of the incoming solar energy instead of letting the solar radiation reflect back unused.
Exergy has been defined in many ways, but all these definitions do not provide a very practical definition. There is need for a definition that is easily to understand for use in daily practice. The researchers have given this issue some study. The researchers based their study on the assumption that when only a fraction of the energy is used, which is only partial exergy, the remaining exergy is the unused part of the energy source. When analysing this for several conversion processes, improving the use of full exergy of a source can be summarised as using

the unused energy of that source. Everyone understands that an engine uses only a fraction of the energy for movement, the rest is waste heat. And this accounts also for other conversion processes. So finding the unused energy sources and searching for useful applications, provides a very understandable and practical way to handle the exergy theory [5]. Using waste energy, for instance heat, to prevent the unnecessary extra use of energy certainly is a way of a rational use of energy.

2. Background

2.1 Urbanization

The world is urbanising rapidly. In 1950 around 25 % of the countries or areas in the world had about 50 % of their population living in urban areas, by 2000 this increased to nearly half of the countries or areas, and projections even estimate that by 2030 over three-quarters of all countries or areas will have over half of their population in urban areas [6]. This indicates that urban regions become more and more important in the world of today and tomorrow. The rapid expansion of cities throughout the late 19th and 20th centuries, with urban sprawling as one of the characteristics, was a direct outcome of the fossil fuel economy. Today, the growth and operation of cities and urbanised areas absorbs roughly 75 % of the world's fossil fuel production. This is a staggering amount given that fossil fuels supply 85 % of total global commercial energy use – and their use is increasing rapidly. Understanding is growing though that urbanised areas become more and more vulnerable since they depend largely on import of fossil fuels. Therefore, economic regions, nations and cities worldwide will soon be under great pressure to find alternative sources [7].
However, the rapid urbanisation can also be used as a chance to change things. The new urban regions – the expanded cities with their suburbs – offer ample possibilities for changing the future of cities. The urban region can be seen as a system – an urban system – with a lot of sources and flows usable in that urban region.

2.2 Trias Energetica

The researcher's definition of a sustainable energy system depends on the Trias Energetica-concept [1,2]. The focus is mainly on the first step – prevention: limit the demand for energy through rational use. It is always better if we do not have to find a source for an unneeded energy demand. The second step is substitution: use renewable energy sources for the remaining demand. The efficient use of fossil fuels is the third step. But, the researchers see this last step as an aspect that works on all levels: efficiency can contribute to more rational use of both fossil and renewable energy sources.
The applied exergy definition in this research reflects mainly the first two steps of the Trias Energetica-concept. People should use energy rationally and should focus more on renewable energy. Sources of renewable energy, e.g. the sun, wind, or geothermal potential, are not used to their full potential.
The Trias Energetica-concept is broadly applied already: it is part of the thinking of, e.g. planners, geographers, landscape architects. An example of a project that applied the concept is Grounds for Change. In that project, renewable energy generation was combined with, and interdependent on spatial planning. Housing and biomass for energy should be, for instance, close together to optimise the conversion chain. It was an attempt to define strategies for sustainable development of the northern part of The Netherlands [8]. The main emphasis was to detect the potentials for renewable energy sources, the second step of Trias Energetica. Acting more preventive, limiting the demand for energy was the next step in the 'Grounds for Change'-project. Their focus is on unused, renewable, sources of energy, so the researchers also applied the used exergy definition of this paper.

2.3 Energy cascading

In order to live up to the Trias Energetica-concept, a community/neighbourhood has to find out all the possible sources of energy. If a community focuses only on the obvious ones – the fossil and renewable energy sources, society will not act preventive or efficient. There is a lot of unused energy hidden in society, think e.g. at waste heat of both power plants and large industries. At the moment, the plants do not use the waste heat and dump it in water or air. For example, even the most efficient Dutch power plant, the Eemscentrale, reaches only an efficiency-level of 55%, because 45% is wasted as heat [9]. If a community, on the other hand, sees this waste heat as an opportunity, this waste – or residual heat – can help a community to live up to the Trias Energetica-concept. The land-use pattern of a region or city determines if waste energy can become useful. In that case the waste energy can become an unused potential source of energy. It is considered as an important step for applying energy cascading.
Figure 1 shows energy flows between different spatial functions. Most emphasis is on the heat exchange flow. Crucial characteristic is that this flow is implicitly losing heat from the power plant at the top to the residential areas at the bottom of the figure. The highest function in the system has residual heat at the highest temperature. All functions that follow have residual heat at a lower temperature. The order of functions in the cascade is depending on the quality of energy the spatial function needs, in this case heat at different temperatures. A function that needs a high-temperature heat is located higher in the cascade. If quality of the waste heat is high enough to meet the need of another function, then the next step in the cascade is possible [10].

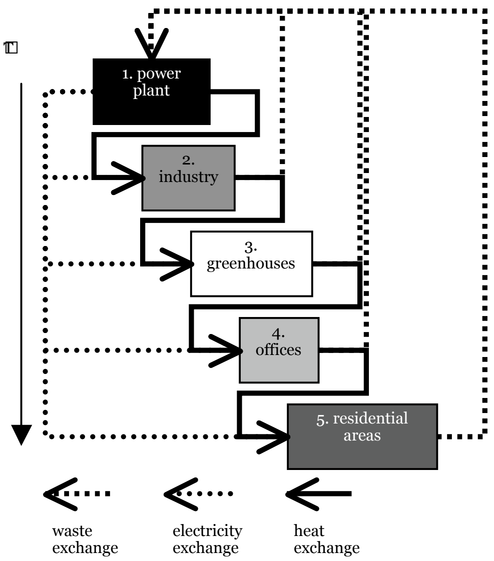

Fig 1. Possibilities for energy cascading in the city [10]

In this example exergy and cascading are coming together: we will look for a list of cascade forms, from low to high quality, and thus their exergetic useful form. We have to combine in such a way that the supplied quality can best provide the demanded quality. In that way less exergy is unused.

2.4 Planning towards 0-energy community

In order to reach a low energy community the energy cascading principle is a helpful tool. Planners should find out the largest scale and look for existing patterns within the city, like in figure 1. The city planners have to find out where the power plant or large industrial facilities are located. And then the residual heat potential of those functions has to be studied. In the next phase of the process towards a 0-energy community, the planners have to determine the other functions, e.g. greenhouses, within an urban area. It should be studied if those functions are available or possible to become available. If such a cascade can be identified, the region or city can reach higher energy efficiency. And the cascade can contribute to reach 0-energy communities more easily.

The application of the Trias Energetica-steps can take place on different levels of communities. For example, local power plants or large industries can act as the starting point for an energy cascade. Another example, a municipality or community can install a system to collect both urban and rural green waste to generate green energy. The application of combined heat and power on district level is still another example. More examples show applications at dwelling level: energy cascades within one building; improvements of efficiency; demand limitations; application of renewable energy sources; planning rule changes – orientate dwellings according to the optimal solar orientation.

This part of the research has not focused on demand (reduction), but on closing the urban system on the output side: to collect all resources within a system and (re-)use them. These resources are both primary, renewable, potentials within the system as well as secondary resources that are otherwise unused flowing out of the system, like waste heat. When fewer resources get lost, the demand for virgin resources is limited automatically. This fits in an overall concept, addressing not only energy, but also other resources and their residues, resulting from utilising them, like solid waste, construction and demolition residues, water related flows and more, called Urban Harvest [11]. If the idea of a closed cycle is applied to Trias Energetica, the third step should be eliminated. The first two steps at the contrary, apply the idea of searching for existing resources and ways to re-use them. In the optimal situation, the demand can be decreased and fully provided by sources within the system, and the cycle can be closed.

Planners and policymakers should start re-thinking the way cities or regions are planned. When looking to planning, planners and policymakers have to keep two main conditions in mind: increasing efficiency and limiting energy demand. In that case, it may be better to work towards a spatial multi-functions arrangement with different functions connected and close to each other instead of function separation.

The former mentioned energy efficiency, limitation of energy demand, less wasted energy, and use of renewable energy sources, resulting in e.g. energy cascades, can all contribute to reach 0-energy communities.

3. Method

3.1 Urban tissue

An average urban area is quite chaotic and it can be difficult to define/classify the characteristics. That is why the researchers tried to develop a more useful, manageable approach for the classification. The result is a graphical and calculation-technical approach of an average urban surrounding of e.g. a country or a specific city.

The researchers developed the urban tissue as an approach that can give an indication of the energy and exergy potential of an urban area. The urban tissue can add to the study of the exergetic possibilities and the potentials for sustainable energy use and exergy in the urban area. The tissue represents the urban area, in an easy to grasp visualisation. This tissue can help to get a better insight in the characteristics of an urban area. It is not easy to grasp the characteristics of an urban area when people can only look at the real scale. This tissue gives a first impression of the potential of a certain urban area. The potential is the total of a resource coming available from that tissue [11].

First, the researchers determined the total urban surface of The Netherlands. A next step was to indicate different functions that are part of the urban area, and their surface. Then, the researchers recalculated all function surfaces to m² per hectare – functional unit applied for this approach. By doing that, the researchers created a visualisation that shows all the urban functions, fitting in an average Dutch hectare. So, with the help of abundant available statistical material in The Netherlands, the researchers modelled the 'Dutch Urban Average Tissue' (UrbAT-NL), on a basis of one hectare. UrbAT-NL creates insight in the distribution of functions in an urban area, percentage-wise and building-wise. Figure 2 shows this Dutch Urban Average Tissue.

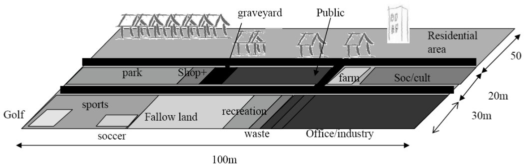

Fig 2. Dutch average urban tissue

The areas or functions that are part of the urban area are those that consume energy, materials, etc. Thus, that can also be functions that are physically outside the, administrative, borders of a city, but because they are consuming functions they are considered part of the urban area: e.g. roads, railroads, industrial areas and harbour complexes [12].

The defined functions of an urban area are: built-up areas – residential area, retail area and hotel & catering industry, public services, social/cultural services, and business area; semi built-up areas – graveyards, waste dumps, car wrecks storage, and construction sites; recreational areas – parks and public gardens, sports terrain, urban gardens, and day-recreational terrain; and roads.

Besides the different functions, the urban tissue will also indicate the energy demand of the functions of an urban area/community and their supply potential. The urban tissue can indicate if a community is on the right way towards the 0-energy target.

4. Research results

The researchers performed a thorough analysis of the different urban functions and their surfaces. Table 1 gives an overview of some of the collected data on the aspect of surfaces. All the earlier discussed functions will be stated, with specifications.

Some background data: the total Dutch surface is 4,150,000 ha; the Dutch urban surface is 507,020 ha, or 12 %.

Table 2 shows the results for the possible urban energy potentials, classified in electric and thermal potential because the technologies exist and there is a large demand for electricity and heat. The urban tissue gives an indication of the potential of a certain function or land-use. Former research [11] resulted in an approach that shows how to utilise that potential.

Table 1: Function surfaces in m^2 per urban hectare

Urban function		Area (m^2)
RESIDENTIAL AREA		4,415
Housing density, *Units per type*	Terraced, row	*4*
	Corner	*2*
	Semi-detached	*1.5*
	Detached	*2*
	Apartment	*4*
Education	Primary	20
Local shops, retail[a]	Medical & cosmetics	4
	Specialised prod.	48
SOCIAL/CULTURAL AREA		305
Hospitals		24
Nursing & care		35
Education	Secondary	11
	Universities	9
	HBO	5
Gathering buildings		4
Public libraries		0.2
Theatres, concert buildings		1
Museums		1
SHOPPING + HORECA		
Shops, retail[b]		86
	Shop, not specialized[c]	5
	Shop, food	11
	Second hand + antiques	3
	Not in shop	12
	Repair consumer goods	3
Hotel & catering industry[d]		43
	Hotels, rooms	14
PUBLIC SERVICES		240
SPORT FACILITIES		635
Swimming pools		6
Indoor facilities		12
Outdoor facilities		439
	Football	138
	Other, of which *golf*	236 *124*
	Tennis	65
INDUSTRIAL/BUSINESS AREA		1,400
Industrial buildings		56
Offices		89
RECREATIONAL AREA		
Day recreation		210
Parks & public gardens		525
URBAN FOOD GARDENS		79
SEMI-BUILT-UP AREA		
Waste dumps		55
Wrecks storage		11
Graveyards		81
Construction sites		500
ROADS		
Municipal roads		1,415

The first step is to 'capture' the potential, then limit the outgoing flows, and thirdly transform the potential into ready products, re-usable in the

a Pharmacies (part of medical), book, magazines and newspaper stores, and also postal services, bank and insurance services, laundry services, family doctors and dentists, day care centres, …

b This also includes local shops

c Food, general; and department stores

d Hotels, restaurants, pubs, canteens, cafeterias, catering, youth hostels, bungalow parks and camping sites

process. Several conversion steps take place and each step will result in some losses. There are three main measuring moments: first, the potentials, e.g. the total incoming solar radiation; second, the captured and converted output, which is the technological maximum, e.g. using PV-panels to capture, partly, the incoming solar radiation and convert it into electricity; and, third, the maximum re-use in the urban system, which is called the urban technological maximum, e.g. the captured solar radiation when taken into account available roof surface, orientation of buildings, urban structure, other characteristics, etc. [11].
So, possible urban technological maximums can be: results when applying, e.g., PV-panels, solar boilers, wind turbines, underground storage, geothermal energy application, and road energy capturing technologies. Some indication about waste heat will be given and results for capturing and converting waste into energy.
Table 2 shows an overview. It indicates the urban technological maximum per urban hectare for some applications. The second part of the table shows technological maximums for some other sustainable energy sources, not calculated per urban hectare.

Table 2: Urban hectare, yearly technological maximum

Technologies	Electric yield (kWh)	Thermal yield (GJ)
PV on dwelling roofs	27,570	
PV on other urban building roofs	34,725	
Peltier-elements [13]	35,375	
Solar boilers dwelling roofs		7,350[e]
Road energy system® [14]		heat: 950 cold: 300
Other technological maximums, total/year		
UWT[f] (GWh) [15]	110	
Waste (GWh, PJ) [16]	3,060	3.5
Geothermal (PJ) [17]		90,000

For The Netherlands, one m^2 of PV can yield about 100 kWh of electricity, yearly. The complete roof surface will not be available for collecting solar energy, due to the type of roof, orientation, etc. Therefore, the researchers calculated the potential using a yield of 50 kWh/m^{2}a. The researchers applied this same assumption for calculating the solar potential of other building roofs. The researchers calculated the solar boiler potential, using a standard yield of 27 l of 50º C water/ m^2, and half of the available roof surface. The researchers did not take into account yet how much roof surface will be available for several technologies when applying on the same roof, e.g. PV and solar boilers. The calculations for the solar possibilities do include already more aspects towards calculating the urban technological maximum. For roads, technologies exist to supply both electricity [13] and heat/cold [14].

Tables 3 and 4 give an overview of the energy demand of urban functions per year.

Table 3: Dutch energy use, 2005 [18]

Sectors	Energy use (PJ)	Of which elec. (PJ)
Energy companies	465	See others
Industry	1412	145
Households	425 gas: 315	87
Traffic & transportation	486	6
Others	523	174

Table 4: Detailed household energy use, 2000

Dwelling type	Electricity demand (kWh)	Gas demand (m^3)	
		Heating	Hot H_2O
Terraced	3,093	825	410
Corner	3,413	1,100	440
Semi-detached	3,519	1,100	440
Detached	4,548	1,500	310
Apartments	2,282	860	235
Average	3,230	1,140	360
Heating + Hot H_2O demand dwellings per house vintage			
Historical buildings (inner city)	90 – 70º		
Renovated existing buildings (pre- & post-war)	70 – 50º		
Newly built (low temperature heating)	50 – 30º		
Newly built (low-energy-demand standards)	30 – 20º		

Based on [19].

These results show how an average Dutch urban area can look like.

The next phase of the research is to apply the developed approach in more specific areas. A selection will be made of urban areas that will be studied.
Some further research resulted already in some data for a case-specific urban tissue: the urban tissue for Parkstad, a large urban area in the south of The Netherlands. Parkstad combines seven municipalities, of which four are urban and three are classified as non-urban. The focus in this research is on areas with the strongest urban characteristics. Therefore, the researchers focused on the municipalities with Statistic Netherlands-classification 'very strongly urban', 'strongly urban', and 'moderately urban'. This classification resulted in the selection of four of the seven municipalities that are further studied. Like the name indicates there are a lot of parks and public gardens to be found in the Park-City. Table 5 shows the combined data of the four urban municipalities. Some background data: the surface of the studied Parkstad-area is 10,965 ha; the urban surface is 6,895 ha, or 63 %.

[e] liters of water of 50º C
[f] Urban Wind Turbines, small-scale turbines applicable in urban area, e.g. on roofs

Table 5: Function surfaces Parkstad in m^2 per urban hectare

Urban function		Area (m^2)
Residential area		4,884
Housing density, *units per type*	Terraced, row	*5*
	Corner	*3*
	Semi-detached	*2*
	Detached	*1*
	Apartment	*3*
Retail, hotel & catering industry		231
Public services		133
Social/cultural services		345
Business area		1,108
Waste dumps		113
Wrecks storage		12
Graveyards		71
Construction sites		590
Parks & public gardens		899
Sports terrain		576
Urban food gardens		35
Day recreational terrain		125
Municipal roads		814
Other roads		64

5. Discussion

These both urban tissues give already some indications about the usability of the method. The data about supply potential and demand indicate that working towards 0-energy communities needs more effort. In order to reach this, demand and supply need to be coupled. Therefore we studied several types of demands in society, with different qualities, and we studied several supply potentials. When combining the potentials with cascading and exergy, much more demanded energy qualities can be fulfilled. So, studying urban areas, using the urban tissue approach, shows what the amount of available resources in an urban area can be and what the harvestable amount can be. The tissue visualises how much potential can be captured, and in what way, and which potential can be transformed into ready products to be feed back into that same urban area again. At the other hand, the tissue visualises the demands for different energy qualities. So, the tissue shows both supply and demand of an urban area, and indicates where the best spots for coupling are, according to functions and qualities.

At the moment, the urban area cannot fulfil its own demand completely with available resources. The remaining demand will have to be imported. The imported energy needs to be renewable and green, so it can contribute to using less energy, and less polluting energy sources. The three steps of Trias Energetica and exergy are important now. Because it will be difficult to fulfil the total energy demand with local potentials, it is important to apply the three steps and to search for sources of unused energy.

Comparison of the average tissue with the specific tissue for urban Parkstad indicates already some differences. Urban Parkstad has a higher grade of urbanity than the Dutch average: 63% over 12%. The residential area is somewhat larger for urban Parkstad. A reason can be that urban Parkstad is more urban than The Netherlands in average. The same applies for the shopping/retail area and the hotel & catering industry area. The area occupied by public services is smaller, probably due to the fact that besides some municipal facilities not many other public services are located in the area. The aspect of more urban can maybe also explain the somewhat larger surface of social/cultural facilities: in a more urban area, more people live, they may need more care, they may ask for diversified and more entertainment. The less industrial/business area may be explained by the fact of the higher urbanity of the area: more people, higher density, less space for industries that need a lot of space or that have to be located specifically. An area with more people needs more space to get rid of the waste. Like the name indicates, there is more area for parks and public gardens than on average. It is a more dense area, functions are closer together and that can be an explanation for the fact that urban Parkstad has less municipal roads than the average.

6. Conclusion

The urban tissue is a useful conceptual approach towards visualising energy demand and energy supply potential of an urban area. It is an approach that combines both numerical information and spatial issues. By integrating those both aspects, the approach can help cities to reach the 0-energy target.

Further research will focus further on case-specific tissues, so better comparison is possible. If several cases are studied, the usability of the method can improve and maybe broadly accepted. The more cases, the more urban area types are gathered, and the more broadly the method can be applied.

The researchers can improve the method for indicating the energy demand. Now, average data are used, but measurements in the urban areas will give a better indication of the real demand. Satellite imagery, and/or remote sensing may be a helpful tool. The same applies for the residual heat potential of industry: if more knowledge is gathered about the exact type of industry, its heat content and what is coming out, the researchers can improve the heat potential calculations.

At the moment nothing is added about transportation and mobility. This may and will be important aspects for a community aiming to become energy neutral.

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