Planning eco-cities, the case of Huai Rou New Town

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Urban design has a tremendous impact on urban energy consumption, because of its strong influence on buildings and transport sectors. Guidelines for low energy – low emission urban design are based on different strategies aimed to minimize energy demand and energy wastes, to improve urban metabolism by recycling energy and materials and to substitute fossil fuels with renewable energy. At urban scale, energy demand can be minimized by optimizing shape, orientation and distances between buildings in order to control solar radiation and the effect of winds; at the same time the heat island effect, and the consequent energy demand for cooling, must be reduced by emphasizing the use of green areas and making use of appropriate surface materials.
In this contest, a new methodology has been developed and applied to a case study regarding a project that took place in the framework of a collaboration and knowledge transfer between Italy and China. This research is related to the energy planning of Houi Rou, a new town near Beijing that will host about 80 thousand people with more than 3,5 million of m^2 distributed by residences, commercial buildings and parking. Huai Rou New Town is an example of the concrete possibility, with today's technologies and in a context of cost-effectiveness, to design a fully renewable energy supplied with very small energy footprint and greenhouse emissions settlement.

1. INTRODUCTION

According to UN [1], a very fast process of urbanization is taking place, especially in developing countries, with a world population expected to reach 9 billion people in 2050 (medium forecast). It has been estimated that, to accommodate the urban population, in the next years the equivalent of a new town of one million inhabitants will be built every week. China, especially, is experiencing an extraordinary expansion of its building stock; the construction sector grows at a rate of about 1.8 billion square meters per year [2].
Just in settlements, on the other hand, is mostly concentrated the world's final energy consumption (for heating and cooling buildings, for lighting, for electric and electronic appliances, for transport), accounting for more than 70% of the total. Thus, more than two thirds of total energy consumption is needed for urban metabolism, and more than two thirds of the CO_2 emissions are due to it.
Apparently, our future is dark because fossil fuels are ending and ever more expensive, while renewable energy sources cannot have any significant role in the present energy system because the large amount of energy needed to keep it running cannot be provided by them, due to their low density, territorial distribution and availability.
On the other hand, it is well known that, adopting appropriate techniques and technologies, the same services could be provided with far lower energy consumption. If this is done, then renewable energy sources can easily meet the energy necessary to preserve our civilization and planet ecosystem.
Putting together all these data, the need arise for very strong actions for curbing the fossil energy consumption trend in cities, were most of the energy is consumed. It is necessary, in other words, to develop a new urban design approach based on a new urban energy system, to avoid the catastrophic effects of global warming on one side, and to cope with the unavoidable constant increase of oil cost on the other.
Taking into account this approach, a new methodology has been defined and applied to the case study of a 80 thousand people Chinese town to be realized.

2. METHODOLOGY

The energy system of a city can be considered as a thermodynamic system in which high quality energy (exergy) is transformed into low quality energy [3]. To design a renewable built environment means, first of all, to maximise its thermodynamic efficiency, i.e. to minimise the amount of primary, high quality, energy consumed. In low energy urban design, thus, the main aim is to minimise primary energy consumption, that presently is due for more than two thirds to residential, commercial and transport sectors. The fulfilment of this aim involves several combined actions i.e.:

- optimise the energy efficiency of the urban structure
- minimise the energy demand of buildings
- maximise the efficiency of energy supply
- maximise the share of renewable energy sources.
- minimise primary water consumption and exploit energy potential of sewage water
- minimise the volume of waste generated and going to disposal, and use the energy content of wastes
- minimise transport need and optimise transport systems
- minimise the primary energy consumption of transport means
- maximise the share of renewable energy sources in transport.

From a more practical point of view, when the methodology is defined, it is important to identify the aims that should be reached. For example, in the case of Huai Rou New Town, first aim was the reduction of the greenhouse emissions and of the ecological footprint; as maximum limit of the last was indicated the boundary of the District on which the town will depend for its energy supply, as it will be explained in the following paragraphs.

2.1. To optimize the energy efficiency of the urban structure

Low energy urban design implies that shadows and surfaces illumination analysis, combined with wind analysis, must be used for optimising shape, orientation and distances between buildings, in order to obtain maximum solar radiation and wind protection in winter and minimum solar radiation combined with openness to ventilation in summer. These rules, taken into account in designing Huai Rou New Town, were always followed in the traditional Chinese urban planning, but unfortunately they are often forgotten in the present urbanisation process. Urban solar radiation balance affects also temperature distribution, giving raise to the so-called urban heat island effect. Increased urban temperatures have a direct effect on the energy consumption, positive in winter and negative in summer. There is to take also into account the positive feedback due to the hot air blown by air conditioning units in the urban environment, contributing to the urban temperature increase.

Further, the manner in which the different functions of a settlement are distributed has a strong impact on energy consumption, for several reasons. The first, most obvious, is that if the three main functions, i.e. work, leisure and living, are closely integrated, the need for transportation is strongly decreased. Another important advantage of compact mixed use developments is that they allow energy and power to be shared between activities in a more efficient way.

All this considerations have been taken into account in defining the urban structure of Huai Rou New Town. In this case, the shape of the town, the choice of the main streets, the sky-line of the town, the plan of transportation and inter-modality and the distribution of the buildings are basically guided by micro-climate and morphology.

Figure 1 Lay out of Huai Rou New Town (main areas, axes, parking and accesses) [5]

For example, in Huai Rou New Town the axes of the public transport are combined with the functions and the shape of the urban structure. The inter-modality, with many interchange points where people can switch from one mode to another, improves also urban accessibility and plays a relevant role in controlling energy consumption, air and acoustic pollution.

2.2. To minimise energy demand of buildings

Buildings design, after urban design, has the second major impact on long-term energy consumption and new buildings should therefore meet the best energy performance.
In the past years, heating has been the main issue addressed by low energy design, and there are many examples of very well performing buildings; in the recent years, space cooling has begun to create concern for its fast growth all over the world and the consequent energy consumption.
Appropriate building shape and orientation, internal layout, the position of openings and sun shielding can enhance ventilation in mid seasons and reduce the need for air conditioning in the hottest periods. Naturally, the implementation of most of these rules is possible or made easier if the layout of urban settings has been properly configured.
The building stock of Huai Rou New Town, as useful square metres per each use, is plotted in Figure 2.

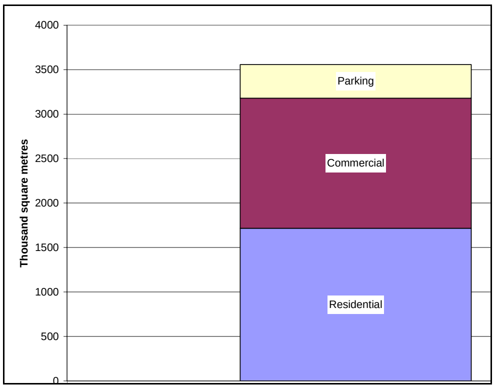


Figure 2 Areas of the building stock of Huai Rou New Town according to functions

The energy demand scenario has been evaluated (Table 1) on the basis of the following assumptions, all derived from best practices implemented in countries with similar winter and/or summer climate (Swiss Minergie, German advanced low-energy buildings and Passivehouse standard, Göteborg, Kronsberg City District in Hannover etc).

Table 1: Specific energy demand (gross average values)

	kWh/m^2y	kWh/m^2y	kWh/m^2y	kWh/m^2y
	Heating	Cooling	Lighting	Equipment/ Appliances
Residential	30	30	3	15
Commercial	25	60	15	20

2.3. To maximise efficiency of energy supply

Once the energy demand has been minimized, with appropriate urban and buildings design, the time comes to evaluate the use of the most energy efficient technologies for providing heating and cooling, hot water production, lighting, etc.
Within this framework, and considering the context of the case of study, only two technologies seem to be more consistent with the second law of thermodynamics for supplying the final services required in buildings to assure our well being: combined heat and power (CHP) and heat pumps.
CHP or co-generation plants are most efficient energy supply systems, when their waste heat is used not only for heating but also for cooling by means of devices such as the absorption chiller, that use low temperature heat to produce chilled water (tri-generation).

Cogeneration and tri-generation by absorption chillers have been integrated in the energy supplying strategies of Huai Rou New Town.

2.4. To maximise the share of renewable energy sources efficiency of energy supply

As the energy consumption is minimised with appropriate technological systems, renewable energy can have a significant role in the energy balance of an urban settlement. According to available data, it is possible to single out the available local energy sources into Huai Rou district: biomass from forest, biomass from agriculture, biomass from farms, solar, hydro, wind, waste, sludge from waste water treatments. Among these, the most largely available renewable source is wood biomass. Another important available renewable is solar radiation. As mentioned before, the appropriate orientation of buildings favours the use of solar thermal and photovoltaic energy, for both heating and cooling. Technologies such as evacuated solar thermal collectors coupled with combi-systems, absorption chillers and desiccant cooling units can reduce significantly the need for fossil fuel.

Table 2: Self-sufficient Huai Rou New Town, energy demand satisfaction by local renewable sources

Sources/demands	Electricity	Heating	Cooling	Domestic hot water	Fuels (*)
Biomass	x	x	x	x	x
Waste (2)	x	x	x	x	
Sludge from waste water (2)	x	x	x	x	x
Solar radiation	x			x	
Wind (1)	?				
Hydro	x				

(1) To be investigated in the future.
(2) Treated in a CHP plant; cooling is provided both by compression chillers (electricity) and by absorption chillers (heat).
(*) For cooking and transportation

The supply for all energy final uses has been identified for both residential and commercial building designed for Huai Rou New Town. Electricity generation has been assumed completely renewable by using sources like waste, sludge, biomass, hydro and sun (see figure 3). These electricity is given to the grid and used for lighting and equipment in buildings and parking, for public lighting and for public transportation.
Plants fuelled by waste, biomass and sludge cogenerate also heat that is used for space heating, domestic hot water supply and, in summer, for space cooling due to absorption chillers. In general, CHP plants are based on gas (Bryton) cycle (against Rankine Cycle); to that end, pyrolysis-gasification of biomass and waste and anaerobic digestion of sludge are previewed. Further, a feasible integration of solar systems is previewed on the roofs of some residential (solar collector for supplying, globally, the 50% of the heat demand needed for domestic hot water; and PV systems connected to the grid) and commercial buildings (PV systems connected to the grid).
In residential buildings, space heating and space cooling are provided to the final users due to district networks; domestic hot water is provided both by district heating and by solar thermal collectors (50% and 50%, respectively). Heat is generated by biomass fuelled CHP plants, as mentioned before (figure 4).
In addition to common residential buildings, in Huai Rou, there will be also villas (high quality buildings). In villas, heating and cooling are provided by high performance Ground Source Heat Pumps, powered with the electricity produced by their PV roofs. Also the electric demand is met with the production of their PV roofs (figure 4). The electricity exchanges with the electric grid permit to guaranty a safe electricity availability during all the year; PV integrated systems have been designed with the aim to have a positive electric balance within a year, taking into account climatic data (during a year, only for villas, electricity sold to the grid is more than electricity bought from the grid).
In commercial buildings (figure 5), domestic hot water and space heating are provided to the final users due to district networks. Heat is generated by CHP plants, fuelled by biomass, syngas from biomass and waste and biogas from anaerobic digestion of sludge, as mentioned before. Space cooling is provided both by compression and absorption chillers: the first ones are feed by electricity from the grid, the second ones are able to transform heat generated by the CHP plants.
The PV installations on the roofs of residential and commercial buildings are able also to empower private or shared electric cars and vans.

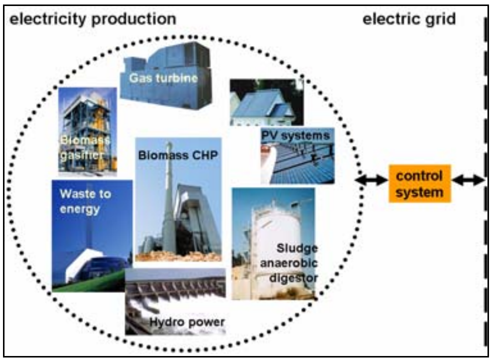
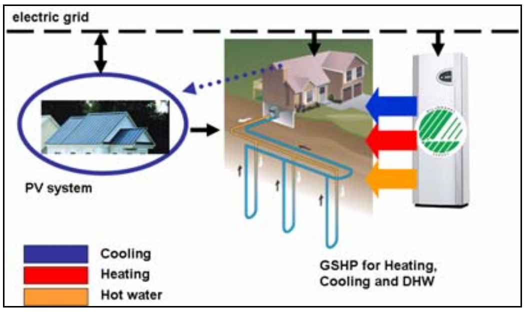


Figure 3: Mix for electricity generation



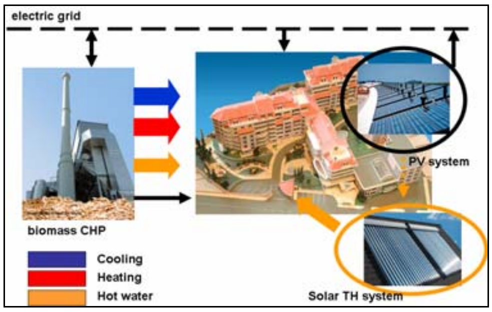


Figure 4: Energy supply for villas (left) and other residential buildings (right)

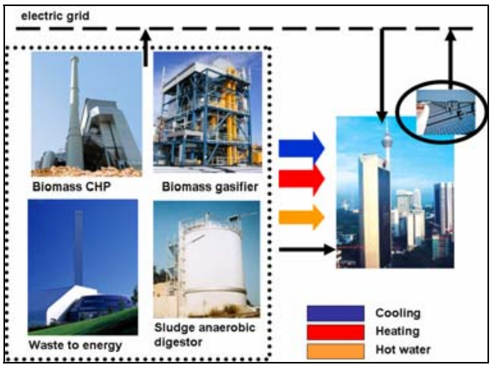


Figure 5: Energy supply for commercial buildings

2.5. To improve urban mobility

In Huai Rou new Town, the private transportation demand has been reduced due to the adoption of sustainable strategies as: urban planning towards compact mixed use and short distance zones, the availability of "comfortable" pedestrian and bicycles paths, an effective public transportation in which vehicles are fuelled by carbon neutral electricity and biofuels, an effective car sharing scheme. Electricity supplied to public transportation is cogenerated from renewables, as mentioned before, while biofuels are produced by biomass available within the boundary of Huai Rou Region. Where possible, pedestrian and bicycle paths are mitigated due to the integration of systems for a partial heating or cooling and with protections from rain and sun.

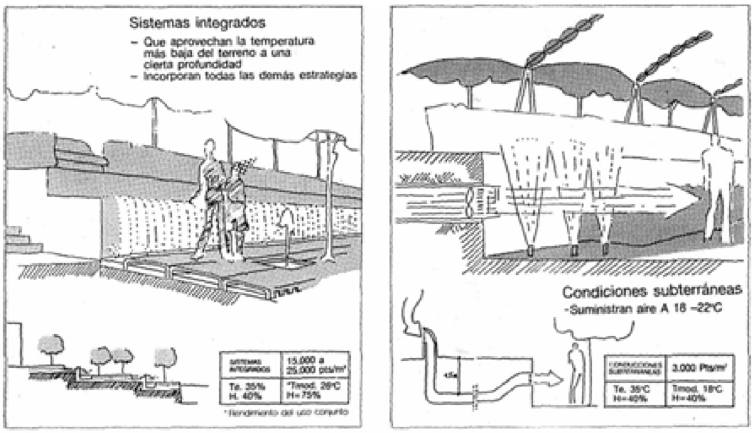


Fig. 6. Mitigation of the climatic conditions in pedestrian paths

In short, Huai Rou New Town has been planned assuming:

- compactness, mixed use structure for reducing energy demand for transportation
- priority to pedestrians and cyclists
- good network of public transport (hybrid and all electric buses, tram)
- advanced mobility like plug-in hybrid cars.

Due to this approach, the use of private cars is significantly reduced (6,000 km/year instead of the average 12,000 in present European cities, 80% of which for urban mobility). Public and private mobility is fuelled by local sources, as shown in next tables. Transport system is based on biofuels replacing fossil fuels and electricity produced either from PV systems or biomass powered generators, according to Table 4 and Table 5. Private cars for urban use are assumed to be electric and plug-in hybrid the ones for extra-urban use; it is also assumed that 50% of families owns an electric car and that a car sharing system is available and used.

Table 4: Vehicles and fuels for transports in Huai Rou New Town

Type of vehicle	**Renewable energy source used**
Lorries	Biofuels
Buses	Biofuels
Trams	Electricity from CHP units
Vans	Electricity from PV
Cars (urban use)	Electricity from PV
Cars (extra urban use)	Biofuels

Table 5: Gross estimation of the yearly energy demand for transports in Huai Rou New Town

Transportation	Bio-fuels GWh/y	Electricity GWh/y	Electricity kWh/m^{2}y
Parking			3
Public lighting		6	
Tram (1)		33	
PV cars and vans (2)		17	
Lorries (3)	5		
Hybrid buses (4)	4		
Cars (5)	10		

(1) 8 trams lines; 18/24 hours of operation at 20 km/h [16].
(2) (5) 16316 cars (c.a. 1 car each 5 people) and c.a. 1300 vans. Plug in Hybrid cars are previewed (80% PV and 20% bio-fuels). A car/van drives 6,000 km/year (instead of the average 12,000 in present European cities), 80% of which for urban mobility.
(3) about 10 lorries per day for biomass transportation (300 km/day) and 5 for waste management (100 km/day) [16].
(4) 8 bus lines; 18/24 hours of operation at 30 km/h [16].

3. RESULTS

On the basis of the mentioned assumptions, the resulting energy demand pattern by sector and by final uses are plotted in Figure 7 and 8.

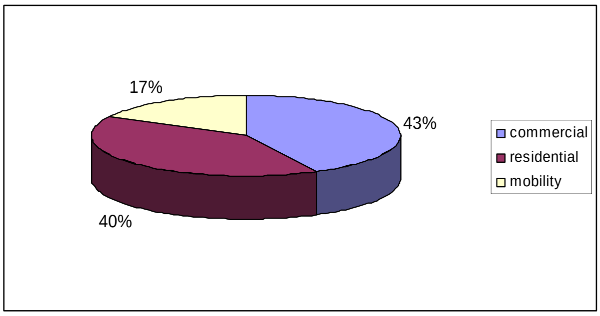


Figure 7: Energy demand by sector

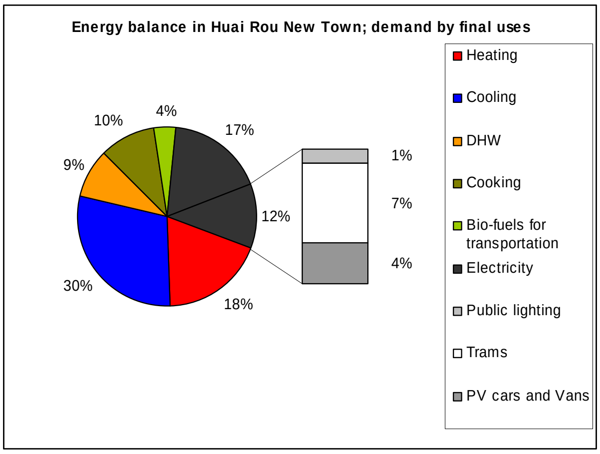


Figure 8: Energy demand by final uses

While, energy balance of Huai Rou is plotted in figure 9 (due to the lack of data, wind energy contribution was assumed to be zero).

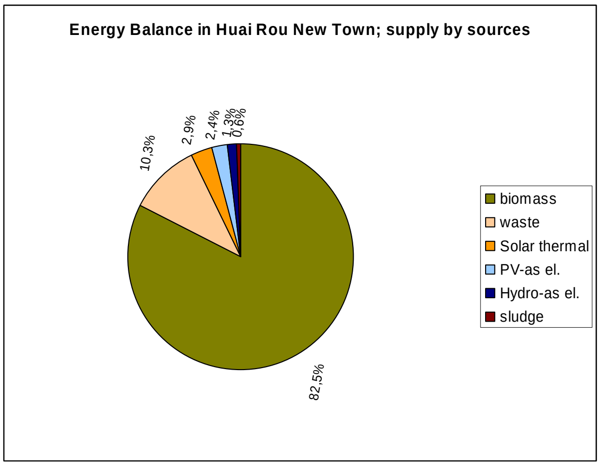


Figure 9: Energy supply by sources

For matching energy demand and energy supply and for giving a preliminary design of the plants, the software *Homer* has been used. In this way, also an estimation of the instantaneous demand with dynamic simulations has been found out. (figure 9).

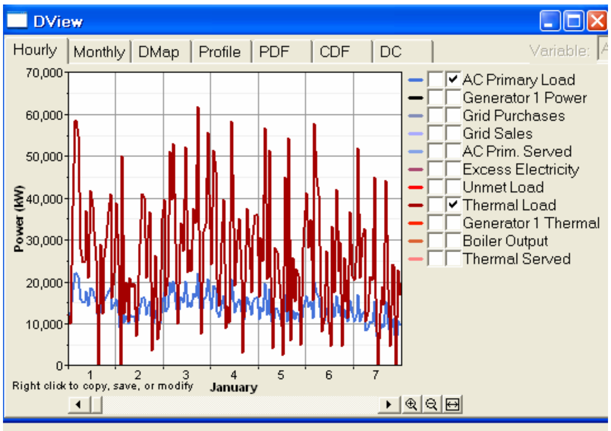


Figure 9: View of the hourly calculations by Homer (thermal and electricity demand in January); http://www.nrel.gov/homer/

Further, looking at the supply side, some key points should be underlined:

- Energy generation is totally carbon neutral
- All the sources come from Huai Rou Region
- Not the total available renewable energy potential of Huai Rou Region is exploited but a part of it remain for next generations (or other uses, or new settlements); in other words, the energy plan for Huai Rou New Town has been developed remaining on the safe side.

All these considerations are represented in figure 10. For each source, 100% corresponds:

- For biomass, to the all biomass available in Huai Rou District (on the basis of the available data)
- For solar, to the all roof surfaces (buildings and parking) adequate for solar installations (PV and thermal collectors)
- For waste, to the waste produced that can be gasified for recovering heat and power
- For waste water, to the sludge produced that can be gasified for recovering fuels, heat and power
- For hydro, to the existing plants (but other plants could be implemented in the future).

All the souses are referred to the current status of Huai Rou Region.

The quantities defined “used” represent the fractions of the available/collectable sources that are actually used in the energy balance. The quantities defined “not usable” represent the fractions of the available sources that are to difficult to reach or to collect (for solar system, the roofs that could be shaded or are not well oriented; for waste, the fraction of waste separated during the collection and destined to material recycling). And, The quantities defined “not exploited” represent the fractions of the available sources that are easily available but not needed in the energy balance, so they could be used for other aims.

It should be noted that some sources have to be better investigated (hydro and wind), while biomass potential could be increased if not a conservative approach, as in the present case, but a improved approach is assumed, taking into account a different use of the existing fields and forests, with a higher production of biomass. This eventual agricultural shift, aimed to improve biomass productivity from existing forests and fields, should be study in depth before of any actions, because it is important to select different cultivations taking into account several factors and problems, such as biodiversity, climatic conditions, landscape, human behavior etc.

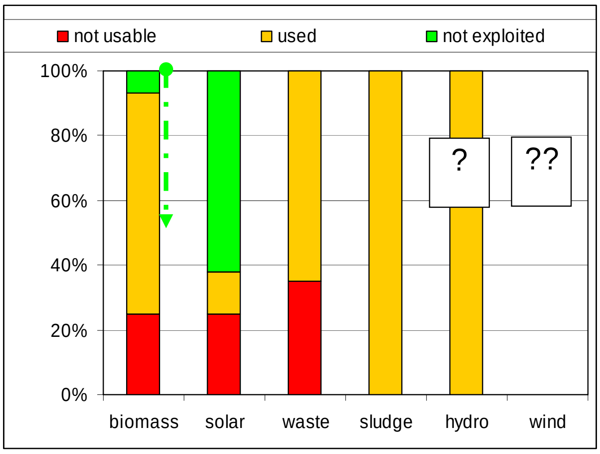


Figure 10: The sustainable and total renewable energy supply strategy of Huai Rou New Town

4. CONCLUSIONS

The methodology applied to Huai Rou New Town demonstrates the possibility of designing a new town with the aim of reaching the full sustainability, i.e. zero fossil energy consumption, negligible CO_2 emissions and negligible ecological footprint.

Even if more detailed technical and economic evaluations are necessary, the preliminary ones show that this result is fully achievable and:

- It can be obtained with presently available technologies and already adopted – in some parts of Europe – building standards for energy conservation,
- It requires minor changes of lifestyle,
- It guarantees a high standard comfort level,
- It leaves some renewable energy potential of the district still exploitable (about 3-5% of the biomass potential - considering all the needs, including syn-gas for cooking and biofuels production -; about 60% of roof area for solar collectors; plus the cover of all the protected, mitigated paths, plus the vertical surfaces of the buildings, mostly facing south, etc.; some spare hydropower not accounted for; some presumable wind power potential).

The approach, based on the Distributed Energy Resources concept, besides being energy efficient, it has also a practical value, since it is possible develop the town construction zone by zone, thanks to the modular nature of the urban subsystems. This is the only way to design cities capable to develop relying only on renewable energy sources.

Further, thanks to its centralized heating and cooling systems and to its mobility system, Huai Rou new Town will be a comfortable, clean, noiseless and hospitable place were it is pleasant to live, not just energy sustainable.

5. REFERENCES

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