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Abstract

All physiological processes inside the human body present exergy–entropy processes. The process of thermogenesis and thermolysis at different environmental conditions can be, with a rational degree of precision and accuracy, evaluated with exergy analysis. The exergy analysis of human body enables us to identify the interactions between the processes inside the human body and those in the environment. The purpose of the paper is to analyse the physiology of thermoregulation in different climate types (temperate, hot/dry, hot/wet and cold) using human body exergy balance model. Two test subjects with different physical activities and clothing were exposed to selected climate conditions. Human body exergy balance was calculated with spreadsheet software developed by Hideo Asada Rev 2010. Human body exergy consumption rate (hbExCr) was compared with predicted mean votes (PMV) index. Results showed that climate conditions in combination with activity level and clothing insulation had large influence on separate parts of human body exergy balance. Both test subjects had the lowest hbExCr in hot/wet climate. Subject A had the highest hbExCr in cold climate and subject B in hot/dry climate. Thermally comfortable conditions with PMV index closer to 0 did not always result in lower hbExCr. The value of hbExCr strongly depends on environmental parameters as well as physical activity and clothing. To maintain homeostatic conditions, it is important that the exergy consumption and stored exergy are at optimal values with a rational combination of exergy input and exergy output. Understanding the influence of environmental parameters on the separate parts of human body exergy balance presents a key factor for identifying effective bioclimatic measures and attaining health and comfort conditions.

Keywords: Thermoregulation; Human body exergy balance; climate types

List of Symbols, abbreviations

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH_in</td>
<td>relative humidity of indoor air (%)</td>
</tr>
<tr>
<td>RH_out</td>
<td>relative humidity of outdoor air (%)</td>
</tr>
<tr>
<td>T_air</td>
<td>room air temperature (°C)</td>
</tr>
<tr>
<td>T_o</td>
<td>outdoor air temperature (°C)</td>
</tr>
<tr>
<td>T_cl</td>
<td>clothing temperature (°C, K)</td>
</tr>
<tr>
<td>p_vs(T_cr)</td>
<td>saturated water–vapour pressure at body–core temperature [Pa]</td>
</tr>
<tr>
<td>T_mr</td>
<td>mean radiant temperature (°C)</td>
</tr>
<tr>
<td>T_cr</td>
<td>body core temperature (°C)</td>
</tr>
<tr>
<td>T_sk</td>
<td>skin temperature (°C)</td>
</tr>
<tr>
<td>T_o</td>
<td>operative temperature (°C)</td>
</tr>
<tr>
<td>va</td>
<td>air velocity (m/s)</td>
</tr>
<tr>
<td>p_vo</td>
<td>water–vapour pressure of the outdoor air [Pa]</td>
</tr>
</tbody>
</table>
1. Introduction

All physiological processes inside the human body present exergy–entropy processes. The physiological process of thermoregulation can be precisely evaluated with exergy analysis. Exergy analysis enables us to consider all interactions between the processes inside the human body and those in the environment. Understanding the interactions presents the key factor for the prevention against negative side effects of the environment on the human body as well as for defining measures for the attainment of comfort and healthy living and working conditions. The purpose of the paper is to analyse the physiology of thermoregulation in different climate types (temperate, hot/dry, hot/wet and cold) using human body exergy balance model. The effect of personal factors and environmental conditions on separate parts of human body exergy balance is well considered.

2. Physiology of thermoregulation

Homeostasis (Greek: ὅμοιος, "hómoios", "similar", and στάσις, stásis, "standing still") is a built-in, automated, and essential property of living systems (cell, tissue, organ, human body) that regulates its internal environment to maintain stable, relatively constant conditions. Thermoregulation is part of homeostatic mechanism that maintains organism in null energy and mass balance [1, 2].

Man as a homoeothermic organism has the ability to maintain body core temperature ($T_{cr}$) almost constant (approx. from 36.2 °C to 37.7 °C). Skin temperature ($T_{sk}$) varies depending on the ambient temperature and is usually lower than core temperature (approx. 32.5 °C). Stable temperature conditions are achieved by two mechanisms that are important for optimal cellular metabolism: chemical (cellular metabolism thus increasing heat production) and physical thermoregulation (heat dissipation) [2,3]. The metabolic heat production depends on the physical activity, type of nutrition, fitness level, individual characteristics and environmental conditions. At the basal conditions and environmental temperatures from 25 °C to 26 °C and 50% RH, 4.2 kJ (1 kcal) heat/kg of body weight/hr are produced (i.e. 60 kg, 60 kcal/hr). During heavy physical activity, 10-16 times more heat can be produced than at basal conditions (600 kcal/hr). If heat dissipation is not possible, the body temperature may be increased by 1 °C/hr with normal activity, and 1 °C/5 min with great physical effort. During prolonged physical activity (i.e.

---

| breath air | sum of exergies contained by the inhaled humid air |
| C/W       | cool/warm exergy                                      |
| hbEx      | human body exergy balance                            |
| Inner part| metabolic thermal exergy                              |
| hbExCr    | human body exergy consumption rate                    |
| stored    | stored exergy in the core and in the shell           |

---

**PMV**: predicted mean vote index
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07-09 July, 2013, NISYROS - GREECE

marathon), the $T_c$ is increased by a few degrees (marathon rectal temperature is approx. 41 °C), skin blood flow is enhanced and the heat is dissipated. The effectiveness of heat dissipation depends on the environmental conditions [2,4,5].

2.1 Thermoregulation and environmental conditions

Human body is able to control its temperature at the conditions of normothermia ($T_a$ from 0 °C to 43 °C, 50% RH) where heat gain is balanced with heat loss. At thermoneutral conditions (0 clo, closed environment, $T_a$ from 27 °C to 29 °C), the body temperature stays constant, additional heat generation is not needed, and no sweating appears. If the environmental temperature drops below 27°C, the generation of heat depends on the heat loss and the thermoregulatory mechanisms are activated. Thermolysis or physiology dissipation of heat is performed by mechanisms of radiation, conduction, convection, perspiratio sensibilis (evaporation) and perspiratio insensibilis (water diffusion from the core to the skin and lungs, evaporation from surfaces; unconscious process, constantly ongoing, regardless of the environmental conditions). At conditions $T_a<T_{skin}$, the heat is dissipated mainly by the mechanisms of conduction, radiation, convection, perspiratio insensibilis and evaporation. At conditions $T_a>T_{skin}$, the evaporation presents the only mechanism of heat dissipation. At high $T_a$, human body may lose up to 12 L of sweat per day (water, electrolytes) and may lead to dehydration, which is especially problematic for non-acclimatized persons [2,4].

In cold environments, the heat generation achieves its maximum at 0 °C and is typically 3 to 5 times higher than at the basal rate. At lower temperatures that 0 °C, temperature regulation is slowed down. In cold environment, human body tries to retain the heat with the mechanisms of vasoconstriction, horripilation (hair retains a layer of heated air), and with the body fat (acts as thermal insulation). Vasoconstriction results in reduced blood flow, decreased heart minute volume, reduced skin temperature, and contracted mass of the core. Protective mechanisms against heat loss are shivering, increased muscle tone, movement and hormonal effects (thyroid hormone increases metabolic rate) [2,3,4,6].

In hot environment, the heat dissipation achieves its maximum at 43 °C, and any further temperature increase may cause a failure in thermoregulation (hyperthermia). The upper temperature limit depends on the air humidity (i.e. 50 °C at 20%, 30 °C at 100%). Studies by Wenzel and Piekarski [7] demonstrated that in a humid and hot environment (34°C, 95%) higher skin and rectal temperatures appears (approx. 0.5 °C) than compared with hot and dry conditions. In hot environment, the human body tries to dissipate the heat with the processes of vasodilation that increases the blood flow, skin temperature and causes the expansion of the mass of the core [3,4,6]. The increased environmental temperature results in perspiratio sensibilis, which is the most effective loss of heat (1L of sweat, 2430 kJ) [4,5]. Beside perspiration sensibilis, the water loss process includes the water transmission through the skin (perspiratio insensibilis, 20-40 g/hr of liquid) and breathing (important for heavy dynamic work) [8].
Negative health effects of the thermal environment may result from the excessive heating or cooling of the whole body or its local part. Exposure to cold environment may lead to serious health effects, especially in combination with higher air velocities. Conditions in which heat loss is greater than heat production may cause hypothermia. If body temperature declines below 27 °C, a coma or even death may occur. Alcohol consumption, use of drugs, medicines, CO poisoning and some infections have major influences on the individual's tolerance to heat or cold environment. Especially sensitive people are patients with angina pectoris. Local adverse health effects of cold environment include vasoinstruction, ischemia, frostbite and immersion foot [5].

Health effects of hot environment are heat exhaustion or heat collapse, heat cramps and insolation. Local effects include burns, papulovesicular eruptions, edema, interigo and erythema. Work in hot (especially in combination with high humidity, still air) or cold environment may cause decreased perception, lower sensoric coordination and longer reaction times. Especially sensitive groups are infirm persons, obese or underweight people, chronically ill persons and patients with heart or lung diseases [5].

An important process of physiological adaptation to the extreme environment is called acclimatization. It leads to the reduction of negative health effects of the environment on human body. Generally, the process is developed within 10 days, and loss within 2-3 days. Persons acclimatized to hot environment have increased sweating rate, decreased heart rate, decreased body core temperature, reduced amount of urine and the concentration of NaCl in sweat compared to non-acclimatized person [4,9]. During the process of adaptation to cold environment the surface of the body cools down and the temperature gradient is reduced. In contrast, in hot environment the body surface is heated, the temperature gradient is increased, so heat dissipation is more efficient [4,9].

Most of the current studies on thermoregulation in different climates are based on the energetic analysis. Our study is focused on the exergetic issues of the physiology of thermoregulation in different climates.

3. Methods

The physiology of thermoregulation is analysed in different climate types (temperate, hot/dry, hot/wet and cold) using human body exergy balance model. Two virtual subjects with different physical activities and clothing were selected for our analyses and exposed to selected climate conditions (Tables 1, 2). The climate characteristics were defined according to climate database [10]. The effects of metabolic rate and effective clothing insulation as well as environmental conditions on separate parts of human body exergy balance are analysed.
**Table 1: Subject characteristics**

<table>
<thead>
<tr>
<th>Subject</th>
<th>M [met]</th>
<th>Icl [clo]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>0.3-4.0</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>0.3-4.0</td>
</tr>
</tbody>
</table>

*M = metabolic rate [met], Icl = effective clothing insulation [clo]  
*Icl* variates according to climatic conditions.

**Table 2: Climatic conditions for selected locations**

<table>
<thead>
<tr>
<th>Climate type</th>
<th>Temperate</th>
<th>Hot/dry</th>
<th>Hot/wet</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Ljubljana, Slovenia</td>
<td>Riyadh, South Arabia</td>
<td>Belem, Brazil</td>
<td>Yakutusk, Russia</td>
</tr>
<tr>
<td>Latitude/Longitude</td>
<td>46.22° North 14.48° East</td>
<td>24.7° North 46.8° East</td>
<td>1.38° South 48.48° East</td>
<td>62.08° North, 129.75° East</td>
</tr>
<tr>
<td>Time zone from Greenwich</td>
<td>1</td>
<td>3</td>
<td>-3</td>
<td>9</td>
</tr>
<tr>
<td>Data source</td>
<td>IWEC Data 130140 WMO Station Number</td>
<td>IWEC Data 404380 WMO Station Number</td>
<td>IWEC data 821930 WMO Station Number</td>
<td>IWEC Data 249590 WMO Station Number</td>
</tr>
<tr>
<td>Elevation [m]</td>
<td>385</td>
<td>612</td>
<td>16</td>
<td>103</td>
</tr>
<tr>
<td>Selected month</td>
<td>May</td>
<td>August</td>
<td>November</td>
<td>March</td>
</tr>
<tr>
<td>$T_{ao}$ [°C] (avg monthly)</td>
<td>14</td>
<td>36</td>
<td>27</td>
<td>-21</td>
</tr>
<tr>
<td>$RH_{out}$ [%] (avg monthly)</td>
<td>72</td>
<td>10</td>
<td>82</td>
<td>61</td>
</tr>
<tr>
<td>$v_a$ [m/s] (avg monthly)</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

$T_{ao}$ = outdoor air temperature, $RH_{out}$ = relative humidity of outdoor air, $v_a$ = wind speed

### 3.1. Human body exergy balance model

The thermodynamic system of human body consists of a core and a shell and is positioned in the different climatic conditions. Thermal exergy balance of human body [11] was derived by combining the water balance equation, the energy balance equation and the entropy balance equation under steady–state condition. All of them are the resultant equations of the mathematical operations described by Shukuya et al. [11], together with
the environmental temperature for exergy calculation. The general form of the exergy balance equation for human body as a system is represented in Eq. (1) [11]:

\[
\text{Exergy input} - \text{Exergy consumption} = \text{Exergy stored} + \text{Exergy output}
\]

(1)

Table 3: Components of exergy input and output [11]

<table>
<thead>
<tr>
<th>Exergy input</th>
<th>Exergy output</th>
</tr>
</thead>
<tbody>
<tr>
<td>warm exergy generated by metabolism;</td>
<td>warm and wet exergy contained in the exhaled humid air;</td>
</tr>
<tr>
<td>warm/cool and wet/dry exergies of the inhaled humid air; warm and wet exergies of the liquid water</td>
<td>warm/cool and wet/dry exergy contained in resultant humid air containing the evaporated sweat;</td>
</tr>
<tr>
<td>generated in the core by metabolism;</td>
<td>warm/cool radiant exergy discharged from the whole skin and clothing surfaces;</td>
</tr>
<tr>
<td>warm/cool and wet/dry exergies of the sum of liquid water generated in the shell by metabolism and dry</td>
<td>warm/cool exergy transferred by convection from the whole skin and clothing surfaces.</td>
</tr>
<tr>
<td>air to let the liquid water disperse;</td>
<td></td>
</tr>
<tr>
<td>warm/cool radiant exergy absorbed by the whole skin and clothing surfaces.</td>
<td></td>
</tr>
</tbody>
</table>

To maintain comfort and healthy conditions, it is important that the exergy consumption and stored exergy are at optimal values with a rational combination of exergy input and output. Thermal comfort conditions were analysed by human body exergy balance, calculated human body exergy consumption rates (hbExCr) and predicted mean votes (PMV) index with spread sheet software developed by Hideo Asada [11]. For exergy calculations, the reference environmental temperature (the outdoor environmental temperature, \( T_{ao} \)) and \( RH_{out} \) are set to be equal to \( T_{ai} \) and \( RH_{fr} \).

4. Results and discussion

3.1 Temperate climate

Figure 1 presents the human body exergy balances for subject A (1 met, 1.5 clo) and subject B (4 met, 1.5 clo) in temperate climate (14 °C, 72%, 1 m/s). Human body exergy balances differ between subjects even when they are exposed to the same climatic conditions. Warm/cool radiant exergy rate absorbed by the whole skin and clothing surfaces is zero for both subjects, because \( T_{ao} (= T_{ai}) \) is equal to \( T_{mr} \).
Fig. 1: (a) Human body exergy balance for subject A in temperate climate; (b) Human body exergy balance for subject B in temperate climate

The sum of exergy rate contained by the inhaled humid air is also zero (breath air in Figure 1), because outside conditions $T_{ao}$ and $RH_{out}$ are equal to room $T_{ai}$ and $RH_{in}$. Warm/cool convective exergy rate absorbed by the whole skin and clothing surfaces is also zero for both subjects, because $T_{ao}$ is equal to $T_{ai}$, even when temperature of clothing ($T_{cl}$) is higher than $T_{ao}$. The main input exergy is presented by metabolic thermal exergy rate (inner part in Figure 1). This means that the thermal exergy rates of 5.14 W/m$^2$ for subject A and 20.15 W/m$^2$ for subject B are generated by bio–chemical reactions inside the human body. It is mainly influenced by the metabolic rate and the differences between $T_{ao}$, body core temperature ($T_{cr}$) and skin temperature ($T_{sk}$). Subject B has approx. 3.9 times higher metabolic thermal exergy rate due to higher activity level than subject A. 5.14 W/m$^2$ and 20.15 W/m$^2$ of exergies have to be released into ambient environmental space to keep the body structure functioning and present output exergies. The rates of warm exergy stored in the core and in the shell are 0 W/m$^2$ for subject A and 3.603 W/m$^2$ for subject B and present part of metabolic thermal exergy rate, which is influenced by the difference between $T_{ao}$, $T_{cr}$ and $T_{sk}$. The exergy rates of exhalation and evaporation of sweat are 0.31 W/m$^2$ for subject A and 1.27 W/m$^2$ for subject B. They are influenced by the difference between $T_{cr}$ and $T_{ao}$, $T_{cl}$ and $T_{ao}$, and by the difference between $p_{vs}(T_{cr})$ and $p_{vo}$. Subject B has higher exergy rate of exhalation and evaporation of sweat due to higher difference between $T_{cr}$ and $T_{ao}$, and $T_{cl}$ and $T_{ao}$. Warm radiant and warm convective exergy rates discharged from the whole skin and clothing surfaces are higher for subject B than subject A, mainly due to higher difference between $T_{ao}$ and $T_{cl}$. The rates of exergy consumption valid for thermoregulation that present the difference between the rate of input exergy, the rate of stored exergy and the rate of output exergy are 4.28 W/m$^2$ for subject A and 14.31 W/m$^2$ for subject B. Subject B has much larger $hbExCr$ than subject A, mainly due to the higher activity level and higher input by metabolic thermal exergy rate.
3.2 Hot/dry climate

Figure 2 presents the human body exergy balances for subject A (1 met, 0.3 clo) and subject B (4 met, 0.3 clo) in hot/dry climate (36 °C, 10%, 3 m/s). Human body exergy balances for subject A and subject B in hot/dry climate differ from those in temperate climate. The metabolic thermal exergy rates (9.39 W/m² for subject A and 32.66 W/m² for subject B) are approx. 1.7 times higher than in temperate climate (5.14 W/m², 20.15 W/m²), mainly due to lower differences between $T_{ao}$, $T_{cr}$ and $T_{sk}$. The rates of warm exergy stored in the core and in the shell are 0 W/m² for subject A and 0.026 W/m² for subject B. Subject B has much lower value of stored exergy than in temperate climate due to lower difference between $T_{ao}$, $T_{cr}$ and $T_{sk}$. The exergy rates of exhalation and evaporation of sweat are 0.43 W/m² for subject A and 1.72 W/m² for subject B and are higher than in temperate climate, due to much drier environment (higher difference between $p_{vs}(T_{cr})$ and $p_{vo}$). Warm/cool radiant and convective exergy rates discharged from the whole skin and clothing surfaces for both subjects are much lower in hot/dry climate than in temperate climate, mainly due to the lower differences between $T_{cl}$ and $T_{ao}$. The rates of exergy consumption valid for thermoregulation are 8.95 W/m² for subject A and 30.91 W/m² for subject B. Both subjects have much larger hbExCr than in temperate climate, mainly due to the higher input exergy rates, lower output and stored exergy rates.
3.3 Hot/wet climate

![Diagram of human body exergy balance for subject A in hot/wet climate](a)

![Diagram of human body exergy balance for subject B in hot/wet climate](b)

**Fig. 3:** (a) Human body exergy balance for subject A in hot/wet climate; (b) Human body exergy balance for subject B in hot/wet climate

Hot/wet climate (27 °C, 82%, 1 m/s) results in different human body exergy balances for both subjects (Fig. 3) compared to hot/dry climate. Due to much larger differences between $T_{ao}$, $T_{cr}$ and $T_{sk}$ Subject A (1 met, 0.3 clo) and subject B (4 met, 0.3 clo) have in hot/wet climate much lower metabolic thermal exergy ($2.02 \text{ W/m}^2; 9.68 \text{ W/m}^2$) than in hot/dry climate ($9.39 \text{ W/m}^2; 32.66 \text{ W/m}^2$). Both subjects have in hot/wet climate much lower $hBExCr$ valid for thermoregulation (mainly due to lower input exergies) and lower exergy rates of exhalation and evaporation of sweat (lower difference between $p_{vs}(T_{cr})$ and $p_{vo}$). Hot/wet climate results in warm radiant exergy rate discharged from the whole skin and clothing surfaces (higher $T_{cr}$ than $T_{ao}$) and presents $0.09 \text{ W/m}^2$ for subject A and $0.22 \text{ W/m}^2$ for subject B. Exergy rates of $0.36 \text{ W/m}^2$ and $0.88 \text{ W/m}^2$ are transferred by warm convection from the whole skin and clothing surfaces into surrounding air, mainly due to the difference between $T_{cl}$ and $T_{ao}$.

3.4 Cold climate

Subject A (1 met, 4 clo) and subject B (4 met, 4 clo) have in cold climate (-21 °C, 61%, 2 m/s) the specially high $hBExCr$ ($14.59 \text{ W/m}^2; 28.38 \text{ W/m}^2$) mainly due to the high input exergies by metabolic thermal exergy rates ($16.70 \text{ W/m}^2$, $46.67 \text{ W/m}^2$) (Fig. 4). Metabolic thermal exergy rates are the highest in cold climate due to much larger differences between $T_{ao}$, $T_{cr}$ and $T_{sk}$ than in other climates. Both subjects have in cold climate the highest exergy rates of exhalation and evaporation of sweat, due to the highest difference between $T_{cr}$ and $T_{ao}$ and higher difference between $p_{vs}(T_{cr})$ and $p_{vo}$. Warm radiant exergy rates discharged from the whole skin and clothing surfaces are lower in cold climate than in hot/wet and temperate climates, because of lower differences between $T_{cl}$ than $T_{ao}$. Vice-versa, warm convection exergy rates discharged from the whole skin and clothing surfaces for Subject A are higher in cold climate than in hot/wet and temperate climates, mainly because of higher air velocity.
Results of previous studies [12-14] proved that at thermally neutral conditions, lower hbExCr appeared. Results of our study show that more comfortable conditions (PMV closer to 0) do not always result in lower hbExCr. Separate parts of hbExB with hbExCr are affected by mutual impacts of personal factors (activity and clothing) as well as climatic conditions. Subject B (4 met, 0.3 clo) has the highest hbExCr (30.91 W/m²) in hot/dry climate, where PMV is 1.5. Subject A (1.50 W/m²) has the lowest hbExCr has in hot/wet climate, where PMV is -0.2. Cold climate results in high hbExCr (28.38 W/m²) for subject B, where PMV is 0.2. The opposite situation appears in hot/wet climate that results in low hbExCr (8.10 W/m²) for subject B and PMV 3.0. Similar conclusions were made in the study by Dovjak [15] that emphasised the concept of individual factors that strongly influence separate parts of human body exergy balance.

5. Conclusion
To maintain homeostatic conditions, it is important that the exergy consumption and stored exergy are at optimal values with a rational combination of exergy input and exergy output. Understanding the influence of environmental parameters on the separate parts of human body exergy balance presents a key factor for identifying effective bioclimatic measures and attaining health and comfort conditions. Identifying effective bioclimatic measures with exergetic approach will be the subject of further studies.

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BRINE MANAGEMENT & SUSTAINABILITY: THE EXAMPLE OF AN ENERGY AUTONOMOUS PILOT SYSTEM IN TINOS ISLAND

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Abstract
This paper presents the development of an innovative, energy autonomous system for the treatment of brine from seawater desalination plants. The system is installed in Tinos Island, Greece and has been designed according to the Zero Liquid Discharge (ZLD) principle, converting the wastewater produced by the desalination units (brine) to water and salts. The system comprises i) the energy supply system and ii) the brine treatment system.

Keywords: brine, desalination, solar energy, renewable energy sources, vacuum evaporation

1. Introduction

In recent decades, an increasing exploitation of water resources has led to several forms of water shortage in many European regions, a problem assuming more alarming levels especially in semi-arid climate areas, where human and agricultural water consumptions are not being satisfied under the scope of availability or quality criteria. Numerous low-density population areas lack not only fresh water availability, but in most of the cases electrical grid connection or any other energy source as well, except for renewable energy sources, mostly referring to solar radiation.

Often in the South Mediterranean regions underground aquifers constitute the main water resource. Over drawing from them enhances the probability of saline intrusions, soil contamination, desertification or accelerated soil erosion problems. The Mediterranean is a region where water is scarce and unevenly distributed. Access to sufficient fresh water limits economic development, while the overwhelming demand for new supplies is creating negative environmental and social effects.

Given the abundance, in such regions, of seawater and solar irradiation resources, water desalination may very well become the main medium-term sustainable process for potable water production, in turn associated with the development of energy and environmental efficient technologies. Water desalination processes have contributed to a better standard of living in a number of countries during the second half of the 20th century, following an increase in water demand for drinking purposes as well as industrial, tourism and agricultural uses. The same applies for the case of Cyclades (where Tinos Island is located). Cyclades are island complexes belonging in the South Aegean Prefecture and located in the southeastern region of Greece and the European Union. Traditionally water has been a very valuable resource in the Aegean Sea region, mainly because of the low precipitation and the specific geomorphology of the islands. Hence, the water resources in most of them are not of sufficient quantity or quality to cover the continuously increasing
needs. The water shortage problem in Cyclades is very acute [4]. In order to deal with water scarcity problem, desalination plants were developed in Greece and mainly in the area of Aegean resulting in 300% increase from year 2000 (10.810m³/d) to year 2009 (29.190m³/d) of water production per day [2].

Any desalination process produces two streams; a clean water product stream and a reject concentrate stream (called brine) that must be disposed of. Most impacts on the marine environment arise from the brine discharge and their effects could be worse in the Mediterranean Sea than in other areas due to the existence of marine life observed [9]. Brine disposal is, thus, causing significant pressure to aquatic ecosystems in the Mediterranean Sea. Seawater contains about 35,000 parts per million (ppm) salinity. During the reverse osmosis process, water molecules are forced through membranes, while the salt particles are retained by the membrane and end up in a "reject stream" that is about twice as salty (70,000 ppm) as seawater. If this was discharged directly back into the ocean or into a coastal estuary there would likely be some negative impacts to sea life in that immediate area of the discharge. The brine impact on marine communities and biodiversity is high, due to the stenohaline feature of the majority of marine organisms.

Brine discharge can cause serious osmotic problems resulting to the death of the benthic flora and fauna. Oxygen depletion and temperature increases may have a great effect causing large scale destruction of flora produced by temperatures exceeding 35°C [1, 6, 7, 8, 11, 12]. The extent of vulnerability of the marine environment to salinity differs from place to place. It is measured by the nature of the marine habitat (coral reef, rocky beach or sandy surfaces) and by the origin of the surrounding organisms [10].

Taking into account the proximity of sensible ecosystems, such as marine/tidal ecosystems, eventual negative impacts related with desalination effluent (brine) discharges must be considered.

Although data that document the effects of the hyper-saline desalination plant effluents are scarce, it is now clearly documented that, especially in the Mediterranean region, the Posidonia meadows (Posidonia oceanica, endemic plant in the Mediterranean sea) habitat is very sensitive to high salinities derived from brine discharge. EU Habitats Directive 92/43/CEE of 21/05/1992 and posterior adaptation at 97/62 CE of 27/11/1997 include Posidonia oceanica, habitat 1120, as a priority in conservation [3, 9]. It has been verified, without doubt, that fanerogamme marine Posidonia is little tolerant to the increase of salinity, with different negative effects when the salinity is increased above its habitual values (increase of mortality, appearance of necrosis in weaves and greater fall of leaves). Mortalities of the order of 50% of the plants are reached with salinities around 45.000 ppm [5].

Posidonia oceanica meadows are key ecosystems within the Mediterranean Sea. The high rate of plant production and the abundance of epiphytes (which can reach up 20–30% of the biomass of leaves), support a high secondary production in situ, thereby sustaining complex food webs from beaches to bathyal areas. The meadows of Posidonia oceanica are of great importance for the marine ecosystem, not only in view of producing oxygen and organic substances (approximately 20 tons/ha/year) but also as a biotope for
an infinite number of marine organisms dependent on such meadows in terms of their diet, habitat, shelter, etc. There are also many sessile organisms, which live attached to the surface of the leaves and rhizomes [3, 5].

Over the last decades, following increased coastal urbanisation and industrialisation among which desalination activity is included, many meadows have disappeared or have been altered. A sample of 39 studies in 135 sites shows that 46% of the underwater meadows in the Mediterranean have experienced some reduction in range, density and/or coverage, and 20% have severely regressed since the 1970s. In European coastal waters, the most dramatic losses have occurred in the northern Adriatic Sea where meadows that were present at the beginning of the 20th century have almost disappeared [3].

Also important is a rational energy use, regardless of the fact that solar energy is the main energy contributor, to minimize other environmental impacts, and to have an overall economic viability.

In addition, desalination plants are being widely used in the inland areas of many countries to supply water for domestic purposes. When these areas are far from the shorelines of salt-water bodies, the opportunity to dispose of the reject brine back into these water bodies no longer exists.

Considering the arguments above, the NTUA team decided to work on the concept of Zero Discharge Seawater Desalination and the development of an advanced solar – driven brine treatment system, promoting the use of renewable energy sources in the reject effluent (brine) treatment processes within the LIFE+ SOLBRINE project ([http://uest.ntua.gr/solbrine](http://uest.ntua.gr/solbrine)).

2. **Methodology**

The overall scope was to develop an energy autonomous brine treatment system for total elimination of brine produced from Tinos seawater desalination plant, contributing to high water recovery (>90%) and to the production of a dry salt product with market opportunities, adding one more valuable output to the entire system. In order to succeed in doing so, the steps included literature review, design of the prototype, construction, operation, optimization, overall evaluation (LCA and economic) and suggestions of the full scale application.

3. **Development of the brine treatment system**

The SOL-BRINE concept is summarized in the following Figure.
Fig. 1: Summary of the SOLBRINE concept

The innovative features of the system include:

- **Total brine elimination.** The system has been designed in line with the Zero Liquid Discharge principle
- **Water Recovery** (>90%)
- **Production of useful end-products.** Through the operation of the prototype system the following two products are produced: (a) distilled water of high quality and (b) dry salt. These products have potential market opportunities.
- **Energy autonomous operation.** Solar thermal collectors are used for delivering hot water (10 kWth at approximately 70°C) and a photovoltaic generator (10 kWel) for electricity. All energy requirements are covered exclusively through the use of solar energy.
- **Use of state-of the art technology:** the evaporation of water is realized through custom designed vacuum evaporation technology (evaporator and crystallizer) and solar dryer.

The single line diagram of the pilot brine system is provided below.
Fig 2. Single line diagram of the pilot brine treatment system

Next, the developed system is presented. In order to present in a more comprehensive way, the overall brine system (photo 1) is divided in two parts (a) Brine Treatment System and (b) Energy Provision Unit.

Photo 1. Pilot system for the treatment of brine, Agios Fokas, Tinos Island
(A) Brine Treatment System

It consists of the following three (3) treatment stages:

1. **Evaporator Unit:**

   The evaporator unit is consisted of two (2) consecutive effects operated at decreasing levels of pressure:
   - 1\textsuperscript{st} effect pressure: 0.30 atm(a);
   - 2\textsuperscript{nd} effect pressure: 0.15 atm(a).

   In each of the evaporator effects, the brine is evaporated and two subsequent streams are produced: (a) a water vapor stream, which is subsequently condensed and recovered as fresh water, and (b) a more concentrated brine stream, which is driven to the subsequent treatment stage. The vapor stream of the first effect is used for heating the concentrated brine produced which is sprayed on the top of the bundle and runs down from tube to tube by gravity. This way, the required latent heat for the vaporization of the brine in the second effect is provided by internal heat gain (heating steam from the first effect) and thus energy recovery is achieved.

   The vapor stream produced by the second effect is used for pre-heating purposes. More pertinently, the vapor is passed through and condensed in a plate heat exchanger, transferring its thermal energy to the inlet feed brine stream. Thus, thermal energy and fresh water is recovered to the best possible extent.

   The concentrated stream produced by the second effect is then passed to the crystallizer unit where it is further concentrated. The concentration of the evaporator exit stream is designed to be near saturation point (~26%). The evaporator unit is shown in Photo 2.

2. **Crystallizer:**

   Both the crystallizer and the evaporator unit are based on the physical process of vacuum evaporation. The crystallizer is consisted of a single vessel maintained at lower levels of pressure (normal operating conditions: 5kPa ≅ 0.05 atm(a)). The crystallizer unit is equipped with scraping blades inside the boiling vessel for allowing high evaporation rates through cleaning of the heat transfer surfaces from the formed salt crystals and good agitation. The vacuum is maintained through the combined use of a pump and an ejector.

   Its purpose is to crystallize the brine effluent, producing a slurry (magma) with humidity levels of approximately 50%. The whole process is characterized by energy efficiency through the combined use of vacuum technology and heat pump. The crystallizer unit is shown in Photo 2.

3. **Dryer:**

   The magma leaves the crystallizer with an amount of moisture. In order to obtain the dry salt products a solar dryer was employed. The dryer unit is shown in Photo 2.
(B) **Energy provision**

The energy requirements of the pilot brine treatment system are covered through the use of solar energy. The thermal requirements are supplied by concentrating evacuated tube
collectors through hot water at 80°C, while the electrical requirements through the use of an autonomous photovoltaic generator (equipped with batteries for one day autonomy).

**Fig 3.** Prototype solar system for the provision of hot water in the brine treatment system

The mass balance is summarized in the Figure below.

**Fig 4.** Mass balance of the developed system for the treatment of brine

### 4. Conclusions

The developed brine treatment system constitutes a first step towards sea environment protection from the brine generated by seawater desalination units. The next steps for the extraction of valid conclusions regarding the developed autonomous brine treatment system are:
• Operation of the system throughout a whole year in order to test its performance under different climatic conditions
• Development of a software tool for the simulation of the prototype’s performance. The simulator will be validated through the use of real experimental data
• Evaluation of the system’s performance in economic and environmental terms (LCA).

Acknowledgements

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EXERGETIC THINKING: AN INSIGHT

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Abstract

Present paper, authors show what is “Exergetic Thinking” and how it can help in the different tasks we have to do as teachers and researchers in nowadays society.

We have ordered these tasks in four different classes. We document other researchers work and our own work in each one.

1) Global insight: Nowadays world need, more than in any other age, deep tools for analysing reality from a rigorous perspective. These tools should be CLEAR, COMPLETE and FURNISH COMPARABLE VALUES. Exergy is, no doubt, a convenient magnitude for this objective.

2) Teaching: As teachers we show the path from final high school knowledge to exergy concept using the powerful idea of “state function” developed for Thermodynamic studies and applying to topics of interest.

3) Research: In our last topic of research, we have developed a graphic method (exergetic triangles method) in order to show in a quick and friendly way exergetic results and an initial explanation. We show examples for the building scale.

4) Applications: Interest of modern society requires, each time more, to jump to a bigger scale like quarters, cities and regions. In that sense we are preparing a work for a big quarter (250000 inhabitants) of a city and we have joined TU 1104 Cost Action about Smart Energy Regions.

Keywords: Exergy, Energy Concepts

1. Introduction

Exergy is stated as

1) “the maximum work we can obtain by means a reversible cycle” has been used for a lot of interesting application and
2) as “the minimum energy that is needed for passing from one state to another” to other applications.

- For the former, Work has always some limits. For example, for temperature cycles, we can obtain from a process between to temperatures is limited by Carnot formula:
  \[ W = Q(1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}) \] \hspace{1cm} (1)

As \( W \) increases positively (more production of work), we have better performance.

- For the later, minimum energy needed for desalinization of sea water, say 3.5% of salt, will be:
  \[ E = R.T.\ln(1/(0.035)) \] \hspace{1cm} (2)

As \( E \) decreases (less use of energy for the same objective, we have better performance. Interesting efforts had been devoted for explaining straightforward how exergy accounts for this “good use of energy—and matter”—[1, 2, 3].

Our idea is trying to combine a good explanation of these type of formulas with a deep insight in its “philosophical” sense.

We think Exergy is a good magnitude because it has been enough developed for dealing with any kind of transformations between different types of energies and masses.

Plan of the paper:

- Section 2 shall try to establish what is “exergetic thinking” and at what extent we have to develop in order to propose applications in Teaching, Research or Applications.
- Section 3 is devoted to explain some of our works related with teaching. How, coming from a usual knowledge in Thermodynamics, we emphasize more general topics.
- Section 4 is devoted to our own piece of research in the topic: exergetic triangles
- Section 5 is devoted to applications of exergetic thinking. How, we try to jump to a bigger scale in order of “make an exergetic use of materials and energy” and arrive to more than 100.000 people.

Discussion, conclusions and some ideas about future will finish the paper

**2. Exergetic thinking**

Mankind is dealing with good use of natural resources. Goran Wall’s [4] ideas about democracy and exergy are inspiring.

Exergetic thinking could be defined as a way of thinking (or working) trying to optimize the use of different types of energies and masses.

For us, optimization should be **qualitative** (each type of “energy” or “mass” has a preferable use) plus **quantitative** (numbers have to be considered).
In “qualitative” we can include: safety of supply, easiness of application and others, we mean, concepts that you cannot evaluate in a straightforward manner (it is not the same having fresh water in a Greek Island than by a big mountain).

We think on Exergy as a possible summary of the quantitative parts when trying to evaluate different phenomena.

3. Teaching about exergy

Any good transmission of knowledge has to fulfill characteristics as Clarity, Completeness and Disposal of Values and avoid Saturation and “Physical Lies” [5]

Main idea: A magnitude (units of energy) trying to ascertain goodness or not of energy and mass processes.

Different specialists to be trained at different levels (Bachelor / Master ...). Each specialist has to receive specific teaching in order to cope with her/his previous knowledge. Table 1 shows some of these characteristics.

<table>
<thead>
<tr>
<th>Learning People</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physicists, Chemists, Engineers, Calculating Economists</td>
<td>Most Maths</td>
</tr>
<tr>
<td>Architects</td>
<td>Some Maths / Good Drawing</td>
</tr>
<tr>
<td>Biologists, health doctors</td>
<td>Some Maths</td>
</tr>
<tr>
<td>Lawyers, geographers, psychologists, Other Economists</td>
<td>Most Description</td>
</tr>
</tbody>
</table>

Exergy topic is usually explained by chemists or physicists when dealing with Thermodynamics state functions and so on. An important amount of work is needed for transforming this knowledge for a broader people.

4. Research on exergy representation

Our group has developed some ideas trying to better explain Exergy concept.

4.1. Exchange of energy (and mass): Exergy and Anergy

“Normal” phenomena will have some part of energy/mass well used (exergy) and other bad used (anergy), so “normal” graphics will be:
Some question remain: going for the newspaper and having the kiosk closed would be only anergy. Is it a zero or a negative value?

4.2. Some triangles approximations

When it is possible to put our system in a scale between zero and a maximum value, relative values could be normalized (it is between 0 and 1).

Our idea is to enhance the use of graphical tools and, if possible, to connect them with some software of calculation. Representations should be: CLEAR, COMPLETE and EVALUABLE

On one hand, we try to define CLEAR, in a graphical sense, representations. So, right use of colors and use of well known figures (as triangles are) was enhanced. COMPLETENESS would be ensured if we could fix numerical limits. Normalization (use values between 0 and 1) would be intended [6]. Using vertexes for Blue (materials), Green (work) and Red (thermal processes) a “first” exergetic triangle was prepared:

**Fig. 1: Exergy and Anergy**
**Fig. 2:** First exergetic triangle (2006): Showing the relative “success” of using materials, work and thermal processes.

For our group vertexes are not immobile: we have also prepared a “resources” (water, electricity, gas) triangle.

**Fig. 3:** Exergetic triangle representing: Electricity (14%), Water (91%) and Hydrocarbons (0%).
4.3. Some possible extension of the research

We have to make some work in order to ascertain if there are possible negative values situations. As a fit, it has to be possible to represent ALL possible situations. On the other hand, a particular case has to be possible to EVALUATE in a unique and repeatable manner (result should be the same for all possible people calculating). We want to present part of a software “drawing” from a “usual worksheet” this particular point in our (triangle) representations.

About values between 0 and 1

<table>
<thead>
<tr>
<th>NEGATIVE</th>
<th>0</th>
<th>1</th>
<th>MORE THAN 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Use of energy and worsening situations](image1)

Use of free energy and improving situations

![Fig. 4: Scope of a normalised representation.](image2)

More work is needed in order to face these problems and to obtain a more clear picture of reality.

5. Applications

Study of a quarter an explanation in “exergetic terms”: we are studying two different quarters, one is Montbau quarter in Barcelona (Spain) and the other Novo Beograd in Belgrade (Serbia).

In Serbia, we have a key figure in trying to diminish energy consumption for heating (as much as to reduce consumption from 200 kWh/m2 to about 70 kWh/m2).

In Barcelona, we do not have so much expense (for heating), so we are trying to deal with a set of solutions trying to incorporate cooling, ventilation, etc

6. Conclusion

From our applications, we have realized the need of international points of view. Our work in EU Action TU1104 about Smart Energy Regions goes in this sense.

Our research has concentrated in a way of presenting results on exergy. Our idea is showing in a clear, complete and evaluable manner the different test representative cases we have proposed.
Triangle is proposed as a straightforward way for representing simple cases. Exergy related to materials, work and heat is represented by vertexes (Blue, Green, Red). This way can be extended changing the meaning of the vertexes. For sure, new vertexes have a unique connection with old vertexes.

Teaching should be done in a very careful way, trying to furnish precise material for any different collective (craft-workers, engineers or economists). At an optimal situation, each person should be particularly taught.

Exergetic thinking, in the sense of an optimal and ethical use of all kind of resources, should be developed in order to arrive to everyday life.

Acknowledgments

We want to thank Sabine Jansen, Christopher Koroneos and Efthimios Balomenos (National Technical University of Athens) for having inspired us this extension of the Exergy mathematical concepts.

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METHODOLOGICAL APPROACH FOR SUSTAINABLE DEVELOPMENT IN A RURAL AFRICAN COMMUNITY (NYAHO’O, CAMEROON)

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Abstract
Nyahoo is a rural dwelling situated in the Sanago-Maritime division belonging to Littoral Region on south-west Cameroon. At this time, local farmers in this area start organizing in a new cooperative that aims to achieve a sustainable development for their community. The present work analyzes the state of the question in order to set up the premises and fetch a methodological approach.

Agriculture of the traditional crops (basically cacao, bananas, tropical fruits and tubers) grounded in ecological principles is regarded as the powerful driver that initiates the economic growth in the area. New ways of linking cooperation activities and tourism could create the wanted synergies reversing a negative situation of isolation and need into opportunities.

New infrastructures and buildings should respect sustainable urbanism and bioclimatic architecture. New activities would include the installation of an ecologic swimming pool with macrophyte systems for wastewater treatment. This method is useful for sewage purification.

Bases for the methodological approach:

- Use of building materials with short life cycle and few environmental impact (palm tree leaves, tuff bricks, bamboo, ...)
- Recycling the activities subproducts (biomass, water, waste...)
- Optimization of energy consumption
- Ecological footprint reduction (minimization of carbon emissions, etc)

The development proposal for this town would consider the bellowed stated bases for the methodological approach, but should also adapt to the characteristics and singularities of the place, the climate and the community needs and aims in order to achieve its autonomy and continuity in time.

Keywords: Sustainable development

1. Introduction

1.1. Context

The settlement for present research is a small Black Africa rural town called Nyaho’o, which is located in South-west Cameroon, Commune of Nyanon, in the Sanago-Maritime Department belonging to Littoral Province. The place is quite good situated by the Sanaga River and near the railroad line Douala-Yaoundé (see figs 1,2). The little population living in this region is spread over a wide area organized in districts named Mouanko, Pouma, Ngambe and Ndom, connected by many roads, most of them without asphalt pavement.
The town is situated in a steep hill slope standing over a wide tropical plain crossed over by the River Sanaga (see photos 1,2,3). This area homogeneous landscape remains practically untouched and undisturbed. The more representative biotopes in this area are the savanna and the humid tropical forest. The climate characteristics follows the pattern of a guinea equatorial type with 4 seasons, annual precipitation comprised between 1500-2000 mm, an average temperature of 25ºC, with a closed range of average monthly temperatures of 2-4 ºC. [1]

1.2. Economic, social and ambient issues:

Nowadays is accepted as a true that there are three different connected systems - economy, society and environment- that interact and all of them ought to be considered when the goal is attaining a sustainable development (see fig 2).
1.2.1. Social approach:

Nyanon is a poor rural area, situated in a zone with difficult access, where the inhabitants do not have many technical and economic resources. The majority of the active population segment finds little employment opportunities in town and is obliged to migrate to the capital Yaoundé, distanced two hours by car, searching for fulfilment of their work expectations out of place. The local administrations have not had much care of the rural zones and have not carried out any serious project related to rural population professional education. The rural population school attendance finishes up to the age of 14 years old, and very few scholars continue their studies into the university.

Access to health care is quite difficult to achieve, for it is no public health system organization, no continued availability to professionals in medicine, nursing and dentistry and lack of health facilities. Most of the existing health services are out of reach due to distance and price. Volunteer professionals and associations are making unflagging efforts to fill the existing gap but, despite their valuable task, the amount of adult and children affected from blindness, epilepsy, articular problems, digestive disorders and parasites is still increasing everyday.

1.2.2. Economic approach:

In spite of the importance and value of the local agriculture as motor for economic growth, despite the excellent conditions found in place for its development (i.e. high quality of the soil and fair climatic conditions), the fact is that nowadays it is little competitive, due to different causes:

- High vulnerability to illnesses of plants and animals,
- Few full-time and vigorous farmers (most of them elder persons, single women charged with children and ill people),
Enrolment of the population to other tasks and works more rentable as an economic support

Lack of technological resources and need to apply marketing strategies in order to attune the final product characteristics for suiting the demand and expectations of the potential market

Need for land rights formalisation which permit the access to land property to women and other marginalized ethnic minorities and enhance the rights of community participation in forestry governance [2]

1.2.3. Environmental approach:

Environmental risks due to global climatic change related to:

- Water risks (torrential rains, aquifers pollution, flood),
- Fire risks and increase of the global temperature,
- Extreme atmospherics phenomena and climate change (wind, storms, etc)
- Pollution (waste, atmospheric pollution)
- Harmful natural resources management

2. Background and premises

2.1. Sustainable development definition

The term Sustainable development appeared for the first time at the Conference results of the UNCED carried out in Rio in 1992. During the 70’s and 80’s several meetings, conferences and discussions related with sustainability were held around the world allowing its concept evolution, but it was not yet stated as a premise for future development.

In the 3th UNCED was found that sustainable development ought to balance the necessities of human growth and environmental protection for both the present and future generations, while in the 4th was stated that, for the purpose of achieving a sustainable development, the environmental protection ought to be an integral issue in the process of development, without seeing it as an isolated element. [3]

The concerns of Sustainable development are rather general, but one of the most important achievements of the Rio Conference was the conception of the need to concentrate efforts and actions in the local area, thus it is the most operative an appropriate scale for giving a efficient ambient response in a global level. [4]

The principal elements of the sustainable development are: population, new technologies, efficient use of the natural resources, reducing residues and preventing contamination,
redefining market economy, formation and changes in the social and cultural areas.

2.2. Nyahoo’o’s Sustainable development concerns

For the local point of view of our study area, the central issue that a such-called Sustainable development should undertake is the challenge of offering strategies and targeted actions which guaranteed the needed growth and gave all the people integrated in this community the work formation and opportunities required for leaving ahead poverty, in order to achieve better life conditions and a self-directed and autonomous life. Once this first goal was achieved, other secondary necessities would appear.

The work hypothesis for the present methodological approach is that sustainable development should stand in ecologic agriculture, supported by cooperation activities and tourism that would allow the flourishing and growth of this community.

3. Methodological approach

3.1. Ecologic agriculture:

Ecologic agriculture should ensure an equilibrium between the three parties involved (society, economy and environment), as explained before. For doing so, agriculture has to match all the conditions listed next: [5]

- Fauna and flora productivity,
- Environment quality,
- Ecologic sustainability,
- Economic viability

In the rural zones of our study area, the landowners practice forest farming; that is, the cultures are directly placed under the tree cover of the tropical forest. This technique has the advantage that the cultures are protected from sun heat and maintain a high level of humidity.

Objectives:

Combination of forest farming and agriculture intensification, seed improvement and use of new techniques. [6]

Actions:

Recycling crop waste, planting legume crops for soil improvement, using green-source energy supplies, accumulating water for agricultural use, avoiding soil erosion, warranting equilibrium between agricultural and forest land, avoiding chemical additives and
amendments, using biologic engineering or mechanic techniques against plagues and plant diseases instead of chemical pesticides. [7]

3.2. Prime product transformation / marketing strategies

Small landowners should make an effort for adopting marketing strategies that allow their little production to find its own market.

Objectives:

Emphasize efforts in obtaining a high quality targeted product and giving best service to customers, targeted to a more selective market that appreciates organic and ethic offer.

Actions:

Transforming product, adopting high quality standards for process and final product.

3.3. Cooperation, tourism and transportation

Linking cooperation, tourism, environment management and people/products transportation could solve in some way the problem of isolation and lack of resources. [8]
**Objectives:**

Creation of synergies between above listed concepts.

**Actions:**

Developing a medium sized vehicle fleet allowing income/outcome of people, international help and production.

### 3.4. Infrastructures, Services and Sustainable mobility

Underdeveloped countries and societies suffer from a lack of infrastructures and services related both to the spread of the existing lines and the absence of maintenance.

**Objectives:**

Creation of new infrastructures and service lines. Maintenance for old infrastructures.

**Actions:**

Constructing new irrigation/water capitation infrastructures. Maintaining roads and ways.

#### 3.4.1. New buildings’ construction

Nyaho’o’s vernacular construction is changing; habitants are using the manufactured products in spite of the natural ones. They use concrete blocks for the walls and sheet metal on the roofs. These materials need a lot of energy to be produced and transport, and at the end of his life cycle is difficult to reuse or recycle them in a rural area (see fig. 4).

**Objectives:**

For a sustainable development, Habitants have to recover the ancient construction, it’s important to use the natural resources of the local area for the buildings such as bamboo and earth for the walls “poto-poto”, palm leaf for the roofs and wood for the doors and windows. Natural resources are easy to reuse and recycle; it is a way for reducing the big amount of energy and the footprint spend in introducing the materials inside the process for a second time (see fig.4). Otherwise the destruction of the exergy reservoirs of natural resources has to be minimized in order to not damaging the environment.[2]

**Actions:**

Using traditional materials and techniques for the construction of new buildings and service facilities.
3.4.2 Water cycle management

It is important for a sustainable development to control the cycle of water. As you see in fig 5, the two water sources in Nyaho’o are the rainwater and the phreatic water. The uses of the resources are for potable water, WC, agriculture and for a green swimming pool. The construction of the first and second wetlands related to the green swimming pool permit to recycle water, closing the cycle and reducing the exergy of the natural resources.

The scheme proposed of the water system reduces the among of water spend during a year and permit to use the treated wetland as a enjoining area for the population of the village and also as a formation place for learning to swim, specially for young people.

Objectives:
Improve water cycle management

Actions:
Construction of watering, accumulation and sewerage infrastructures.
4. Local evaluation with indicators

There are different kinds of indicators for evaluating the sustainable development going from a global to a local area. A lot of organizations have work about it. It’s important to define indicators related with the context studied. [9]

These are the most relevant sustainable development indicators for a rural area:

- Agriculture (product and consume)
- Natural resources (life cycle, exergy), (see fig.4)
- Mobility and transport
- Pollution (air, water)
- Energy
- Economy (cooperation, sustainable tourism)
- Social movements (cooperative, formation)

These indicators have to be managed efficiency and in a defined period of time to be effective.

5. Conclusions

Sustainable development is related to the economic development of the society and also to the social and environmental aspects of the local area.

The community ought to bring into this sustainable development process its own powerful contribution in the form of social awareness and participation that finally will return the fruit of empowerment and self-satisfaction.

Nyaho’o has a lot of natural resources and a productive land for agriculture.
It is important to economically stimulate improved exergy efficiency and use of renewable resources.

A methodological approach of the development has to be related with the evaluation indicators.

The indicators are related between them and all of them have the same importance for the sustainable development.

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THERMAL COMFORT IN PUBLIC SPACE AND SUSTAINABILITY
Test of alternative solutions for the renovation of a square in Porto, Portugal

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Abstract
The phenomenon of urban heat island and the increase in temperature extremes brought about by climate change represent a challenge for urban designers. Higher outdoor temperatures are often uncomfortable, aggravate heat-related illnesses and therefore make heat waves a serious health risk. Furthermore, they also accelerate summer smog formation and the need for air conditioning inside the buildings.

Urban designers must be able to choose the best options to mitigate urban heat island and guarantee outdoor thermal comfort of public spaces meant for pedestrians. Different thermal comfort needs exist between different groups of individuals. Though it is impossible to anticipate the needs of all users, it is possible to combine such differences and minimize the discomfort felt by individuals of each group. The key is to provide adaptive opportunities through a carefully planned urban design strategy.

This article discusses the renovation of public spaces in compact urban areas envisioning the creation of better conditions for outdoor thermal comfort and for the mitigation of the heat island effect. The importance of choices made for paving materials and vegetation, in this context, is focused through a field survey undertaken at a public space in Porto, Portugal – Poveiros Square. The potential for microclimatic improvement of different combinations of paving materials and vegetation was explored through the use of the ENVI-met micro scale climate model.

The main options for the simulation exercise are addressed, the objectives and fundamentals for the alternative scenarios are defined and the main results of the simulations are presented and discussed. A brief evaluation of Life Cycle Assessment related factors is also performed. Then the best improvement scenario is pointed out, stressing the relevance of the use of ‘cool’ paving materials and vegetation and the need for a sustainability analysis in all phases of the process.

Keywords: Bioclimatic urban renovation; Thermal comfort; Field survey; Simulation; Sustainability

1. Introduction
The pedestrianization of outdoor public spaces, i.e. the «removal of vehicles from an urban area allowing free access to people on foot» [1], has been given an ever-growing importance in the past few decades. However, pedestrianizing may not be as simple as just simply displacing vehicles from an outdoor space – faced with the urban heat island
effect and the increase in temperature extremes brought by climate change, pedestrianizing should come up with the consideration of microclimate and the conditions offered for people’s thermal comfort alongside common parameters such as appearance, relaxation, safety or accessibility.

Considering that the success of a public space depends on the social role that it might assure and that the degree and intensity of the activities held at public spaces «depend on the level of satisfaction or dissatisfaction under the prevailing climatic conditions» [2], the chances created for people to be engaged in physical and social activities in public spaces should deal with the extent to which pedestrians can fit their personal requirements with the surrounding outdoor thermal environment. Designing for outdoor thermal comfort deals with attenuating climatic extremes since those conditions are the ones pedestrians most want to avoid [3]. Public spaces can offer significant adaptive opportunities by being built through climate-conscious planning and design, offering access to, or shade from, wind or sun [4].

Bioclimatic urban design holds important notions for addressing urban microclimates since it is a way of conceiving public spaces committed to the increased harmonization between man, climate, and environment, without neglecting the full spectrum of parameters typical of ‘classical’ urban design. Through parameters such as orientation, height/width ratio, colours, water features, facing materials, or vegetation, bioclimatic urban design can help providing «protection from negative and exposure to positive aspects of the climate, increasing the use of outdoor space throughout the year» [5].

Bioclimatic urban design can also create a ‘first line of defence’ of the building from the outdoor climate. This will help to improve the energy efficiency of buildings and, consequently, reduce the energy consumption related to the use of mechanical devices to control indoor air temperature and reduce the correspondent CO2 emissions. As Alves, Cortesão et al. [6] argue, «if an outdoor space is thermally improved so will an indoor one be improved as well, reducing CO2 emissions related to mechanical devices to control air temperature». This relates to the idea of passive design of the city, from a sustainable point of view.

Whenever addressed as a series of environmentally sensible principles «sustainable design can create a new baseline for high-performance building and urban development, appropriately adaptable to location, culture, and time» [7]. Taylor e Guthrie [8] offer a hierarchy of measures for improving the energy efficiency of buildings and thus reducing CO2 emissions, according to the idea of «passive design of the city, or of a group of buildings, as ‘the first line of defence’ in this hierarchy».

It is however vital to highlight that pursuing energy efficiency is not only about buildings and urban infrastructure. While new «buildings must be designed to be as near ‘zero carbon’ as possible, existing buildings must be modified to make considerable reductions in energy use, urban transportation must be designed in harmony with building development, and renewable energy supply and storage mechanisms must be applied to the urban built environment» [9].
The achievement of long-term reduction in CO₂ emissions is dependent in first instance on reducing energy demands and a bioclimatic urban design strategy can help reducing the thermal load on the buildings. This collaborative work between urban design and architecture should not be disregarded during the sustainable planning of cities in both new urban expansion and compact urban areas.

New buildings are only part of the equation concerning passive design of the city. It is upon the existing buildings and infrastructures that the main effort should be made if a more sustainable built environment is to be achieved [10]. In opposition to new urban expansion areas, in compact urban areas the hard structure cannot, or can hardly, be changed [11] because the built environment is already defined. It follows that in compact urban areas one must try to obtain the greatest benefit from the existing structures [11], namely, for the outdoor spaces, through an adequate choice of paving materials and vegetation.

The combination of high-albedo and high-emissivity (‘cool’) paving materials with vegetation, in particular, can be rather relevant for public spaces in compact urban areas since in often subtle ways it can help improving microclimates through smaller-scale interventions when compared to other morphologic elements. This combination can, on one hand, increase the heat losses taking place at the ground level, where pedestrian circulation is held, and on the other hand reduce the portion of solar radiation striking the surfaces of a space through shading.

Provided paving materials and vegetation are carefully brought together, beyond constituting an easy way to conserve energy, save money and eventually reduce air pollution, the combination of these two elements could also significantly reduce urban air temperatures [12]. Thereby, it is important that the choice of paving materials and vegetation is done bearing in mind not only common parameters such as aesthetics, safety or costs, but also parameters related to microclimate.

Furthermore, sustainability which comprehends environmental, social and economic aspects should also be addressed in terms of the chosen materials and processes. Besides their effect on the operating conditions of the built environment during their service life, construction materials can have an important impact in all their life cycle phases (extraction, processing, transportation, installation, maintenance, demolition, recycling or disposal). A brief discussion on these questions is presented, in paragraph 4, for the studied alternative paving materials.

2. Field survey

In order to assess the importance of paving materials and vegetation in the microclimatic performance of public spaces in compact urban areas, two public spaces in Porto, Portugal, were analysed: Poveiros Square and São Lázaro Garden (figure 1). Although this article focuses on Poveiros Square, the preliminary comparison between these two spaces can illustrate the importance of paving materials and vegetation in influencing the microclimate of pedestrian public spaces. The subsequent focus on Poveiros Square goes
deeper in this subject by exploring the potential for microclimatic improvement of different combinations of paving materials and vegetation.

The square and the garden present no significant morphologic differences, except for paving materials and vegetation, and yet exhibit a dramatically different intensity of use during summer: while the square is barely used, the garden is significantly used. Considering that the analysed spaces are side by side, the interpretation of this difference can provide a useful insight on the subject discussed in this article.

![Aerial view of the two analysed spaces: Poveiros Square and São Lázaro Garden](image)

The field survey was undertaken during the first two weeks of July 2011, covering a 15-day period related to ‘typical summer days’ in Porto between 11 a.m. and 2 p.m. The field survey consisted of a functional and morphologic analysis through observation, a questionnaire on thermal comfort evaluation and microclimatic monitoring with a meteorological station.

The field survey allowed understanding from a functional perspective, although both spaces were conceived as spaces for pedestrians, their intensity of use was quite different: no significant pedestrian activities take place at the square while the garden exhibits an intense usage.

The morphologic analysis showed that the hard paving of the square accounts for 99% of its area while the garden presents 98% of soft surfaces; and that the green coverage of the square is 3% whereas the garden presents a green coverage occupying 77% of its area. All other morphologic parameters were similar in one space and the other. In functional terms this is not a problem per se. The issue herewith discussed is its impacts on the intensity of use of the analysed spaces: the (desirable) functional differences between a square and a garden are not questioned but rather the amount of people in spaces created for pedestrian use.

The most fundamental findings of the questionnaire on thermal comfort evaluations were that the potential users of the analysed spaces are the same; that the large majority of users of the square were uncomfortable due to hot conditions (93%) while most users of the garden were comfortable (91%); and that the majority of respondents (84%) stated
that the square was usually uncomfortable during summer whilst the garden was considered by all respondents to be a usually comfortable place during summer.

The results from the microclimatic monitoring are presented in table 1. $T_a$ is the air temperature; RH is the relative humidity; $K_\downarrow$ is the direct solar radiation on horizontal surface; $W$ is the wind speed and MRT is the mean radiant temperature.

<table>
<thead>
<tr>
<th>Table 1: Microclimatic values recorded at Poveiros Square (PS) and São Lázaro Garden (SLG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>$T_a$ (°C)</td>
</tr>
<tr>
<td>RH (%)</td>
</tr>
<tr>
<td>$K_\downarrow$ (W/m²)</td>
</tr>
<tr>
<td>$W$ (m/s)</td>
</tr>
<tr>
<td>MRT (°C)</td>
</tr>
</tbody>
</table>

The values indicated in Table 1 show that all variables have different performances at one space and the other. Direct solar radiation and mean radiant temperature present the most distinctive values. Vertical surfaces were found to have little or no influence on the microclimates of the analysed spaces due to their low H/W ratio.

The nature of paving materials and the amount of vegetation are clearly the reason for the remarkably different thermal comfort perceptions and the totally different intensity of use of each space. The field survey proved that two public spaces can present significantly different intensity of use, even when side by side and offering the same facilities to its potential users, depending on their microclimate.

Considering that the last intervention in Poveiros Square aimed at promoting its use by pedestrians, not only as a passage place but a place for permanence, the question to be raised is: how can its microclimate be improved in order to guarantee thermal comfort for pedestrians and promote its use, without compromising the character of the place as a square? Transforming it in to a garden is not intended nor needed. Alternative scenarios for its renovation were tested and evaluated.

### 3. Alternative scenarios

Renovating the square through a programme of ‘cool’ materials and vegetation, on a bioclimatic perspective, could eventually improve it by delivering a more thermally-balanced microclimate. Five alternatives based on the layout presented in figure 2 were tested with a microscale climate model, ENVI-met, in order to quantify their potential for microclimatic improvement.
The layout presented in figure 2 results from the following measures concerning new vegetation:

- Planting of a row of six Betula papyrifera on concrete raised flowerbeds at the square’s southern edge (each flowerbed includes also six Lantana camara);

- Creation of a concrete raised flowerbed at the northern edge of the underground car parking eastern staircase (this flowerbed is planted with one Betula papyrifera and sixteen Lantana camara);

- Creation of a flowerbed at the eastern end of the southern row of raised flowerbeds, planted with five Hydrangea macrophylla;

- Replacement of grass at the pre-existent raised flowerbed at the square’s northern edge by twenty Hydrangea macrophylla;

- Creation of a concrete raised flowerbed in the continuity of the pre-existent northern edge flowerbed where one Betula papyrifera and four Hydrangea macrophylla are planted.

![Base for the alternative scenarios](image)

**Fig. 2: Base for the alternative scenarios**

Each defined alternative scenario preserves these strategies related to vegetation and is based on the replacement of the paving solution. All alternatives were selected with consideration to their suitability to the space’s function. The central area of the square, highlighted in figure 2 in dark grey, is covered with the different paving materials (Table 2).

In scenario 4, asphalt was chosen as paving material. Although asphalt is definitely not a ‘cool’ material, it was tested to allow for a comparison, working as a negative reference.
### Table 2: Tested paving solutions and associated albedo, emissivity and impermeability values

<table>
<thead>
<tr>
<th>Paving Material</th>
<th>Current</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
<th>Scenario 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paving Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granite cubes with mortar joints</td>
<td>0.40</td>
<td>0.40</td>
<td>0.45</td>
<td>0.72</td>
<td>0.05 (new)</td>
<td>0.45</td>
</tr>
<tr>
<td>Limestone cubes with mortar joints</td>
<td>0.45</td>
<td>0.45</td>
<td>0.72</td>
<td>0.05 (new)</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>Light-grey polymer resin bound gravel</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.90</td>
<td>0.00</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Compacted soil</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

By allowing water and water vapour to pass through them (or be stored within the voids of the pavement), permeable (or pervious) pavements can take advantage of the cooling effect of evaporation. The paving materials in scenarios 3 and 5 can benefit from this characteristic.

A high emissivity of a facing material can help it to cool at night through intense long-wave radiation to the sky. A lower emissivity can be compensated however by a higher albedo. If a high percentage of solar radiation reaching the surface is reflected the surface temperature will not increase too much and so a high emissivity is less needed. This balance was expected for the paving material of scenario 3.

The simulations were run for the 13th July 2011, which is representative of the day when the climatic variables recorded at Poveiros Square exhibited the highest values. All values herewith referred report to 12:30 p.m. The average values recorded for each climatic variable during the microclimatic monitoring were taken as the baseline for running the ENVI-met simulations.

### 4. Discussion of alternatives

#### 4.1 Potential for microclimatic improvement

Comparatively to the space’s current situation all defined scenarios have the potential for improving Poveiros Square’s microclimate, with the expected exception of scenario 4.

The spatial distribution of the values of each microclimatic variable, given by ENVI-met simulation, is presented and analysed below.

Figure 3 presents the spatial distribution of the air temperature for the current situation and for the five simulated scenarios. As could be foreseen, the new vegetation considered in all the alternative scenarios creates an area where there is a significant decrease in air temperature, due to shading and also due to evapotranspiration (darker blue areas).
The paving material has also an influence on the air temperature. In comparison with scenario 1 (where the existing paving material is kept, granite cubes with mortar joints) the choice of limestone cubes in scenario 2 leads just to a slight decrease in air temperatures. This decrease is more expressive in scenario 3 with an extension of fresher areas. On the contrary, as expected, scenario 4 does not improve comfort conditions outside the shaded areas. In this scenario there is a significant extension of warmer areas. Scenario 5, although fresher than scenario 4, has larger areas with higher temperatures than scenarios 2 or 3.

**Fig. 3:** Outputs from the ENVI-met simulation for air temperature at a height of 1 m above the ground.

The spatial distribution of relative humidity is presented in figure 4. Comparatively to the current situation, RH suffers an increase in all scenarios except 4. This increase is due, in the first place, to the decrease of air temperature and possibly also to a slight increase of absolute humidity due to the new vegetation. Scenario 3 is the one with the highest values of RH.

**Fig. 4:** Outputs from the ENVI-met simulation for relative humidity
The spatial distribution of direct solar radiation ($K_d$) reaching the pavement of the square at the time chosen for the simulations is presented in figure 5.

The expected reduction of solar radiation beneath and near the plants is very significant. It should be remembered however that the calculations were done at a time close to solar noon when the sun is at its highest point in the sky and so the shading areas are at their minimum expression.

**Fig. 5:** Outputs from the ENVI-met simulation for direct solar radiation on horizontal surface

Fig 6 gives us the spatial distribution of wind speed throughout Poveiros Square. Comparing the simulated scenarios with the current situation, the influence of the row of plants in the southern part of the square is very clear, working as a wind barrier. $W$ does not change significantly with the variations of paving materials between scenarios.

The small zone coloured in red at the southeast corner of the square corresponds to a sensitive increase in wind speed at a corner of a building, very much felt by the users of this urban zone. As figure 6 shows, the foreseen vegetation would clearly reduce that effect.

**Fig. 6:** Outputs from the ENVI-met simulation for wind speed (for a wind speed in open space of 1.13 m/s; coming from NW)
Figure 7, presenting spatial distribution of mean radiant temperature, shows that high values of this variable are reached. As expected, in all alternative scenarios MRT is significantly reduced beneath and around vegetation.

\[\text{Fig. 7: Outputs from the ENVI-met simulation for mean radiant temperature}\]

Figure 7 shows that scenario 1 does not have the ability to reduce MRT values in sunlit areas comparatively to current situation, which is obviously related to the maintaining of the existent paving material (the capacity of this scenario to significantly reduce MRT values is restricted to shaded areas). Scenario 2 leads to a reduction of around 5 °C in a great extent of the central part of the square. In scenario 3, this phenomenon is enlarged reaching other parts of the square. On the contrary in scenario 4, due to the asphalt, MRT increases in large areas. In some of them, MRT is about 10 °C greater than in scenarios 2 and 3. Scenario 5 corresponds to a situation not much different from scenario 1 in terms of MRT and slightly warmer in some zones namely at the edges of the square.

4.2 On life cycle assessment

Nowadays it is not acceptable to neglect the environmental impacts of design options and, for their evaluation, there is already a large amount of valuable information available. Beyond potential for microclimatic improvement, the choice for one or another paving solution of a public space should therefore be made paying attention to sustainability indicators of each solution from a life cycle assessment (LCA) point of view.

A complete LCA approach is basically a ‘cradle-to-grave’ analysis of each construction solution (element, system or material) [15] used in a construction work. On one hand, it deals with the environmental impacts related to extraction, processing, transportation, installation, maintenance, demolition and recycling or disposal; on the other hand, it deals
with the influence the chosen solutions have on the environmental performance of the whole construction (a building, a public space, etc.) [14].

The performance of a complete LCA is a time consuming analysis and it demands a great number of details that must be defined at the design stage. For example: to evaluate the impact of transportation (energy consumption, emissions, etc.) the suppliers of the different alternative materials must be identified, as well as their distance to the site and the conditions of the transportation. Thus each evaluation relates to a specific situation. Those specificities can have a great impact and determine different choices.

For environmental reasons it is preferable to choose materials the least transformed and/or able of fulfilling their function with a minimum consumption of resources [16] since materials close to their natural state tend to have less associated energy consumption, waste generation and pollution [17]. Transportation needs should also be minimized to the utmost, being so preferable the use of local materials.

The use of recycled or reused materials can also save primary non-renewable resources [17]. From an environmental point of view, reuse is better than recycling, since recycling is a process which also consumes energy and resources. But, obviously, both are better than waste disposal by incineration or transportation to landfills [14].

When selecting materials and vegetation species, attention should be given to natural stocks as well as to the ability for nature to replenish them. A balance must be found between «the resources used to achieve a good quality of life and the pollution and waste created as a result of using these resources» [18]. Materials should come from renewable sources as far as possible in order to avoid depleting stocks of non-renewable materials [17].

In the construction sector, it is possible to contribute to a balanced use of natural resources basically in four possible ways: by building less, in the first place, building long-lasting, building recyclable and by using renewable natural resources [14]. The amount of materials used for a specific purpose should be minimized to the utmost [17]. In addition to using a material sparingly, «the choice of material, the combinations and their proper interconnection determine the overall ecological outcome» [15].

The waste generated during construction and demolition or, in the case of vegetation, during planting and removal, should be minimized through co-ordinated design and site practices [17]. Reducing waste reduces the amount of material lost and to be removed after installation or demolition to incineration or landfill sites. Also the need for transportation to these sites is reduced.

Pollution related to production, construction process and use of buildings «consists of emissions, dust and radiation from materials that are exposed to chemical or physical activity such as warmth, pressure or damage» [19].

For the sake of the quality of the environment and of human health, it is important to avoid hazardous materials [17]. Materials should not contain environmentally-contaminating
substances in order to preserve the quality of the soil or groundwater or to prevent the emission of irritating gases [19].

For the case study in this paper, as a complement of the simulation exercise, a short analysis of sustainability is performed. For each alternative paving material the main environmental issues are identified and briefly discussed. Indicators of life cycle environmental impact are estimated in a LCA ‘cradle-to-gate’ perspective (meaning that only a partial product life cycle is considered, from extraction (‘cradle’) to the factory gate, passing through the processing or manufacturing). For this estimation a database available in [27] was used.

Bearing the considerations on environmental aspects presented above in mind, relatively to the defined alternative scenarios for Poveiros Square, some aspects should be mentioned here according to Mendonça [16], McNally [20], and Everett [21].

Relatively to scenario 1, granite presents a high level of embodied energy, some entailed pollution and toxicity during extraction. Quarries present serious problems of landscape degradation, noise, blast vibration, dust, and also to local flora and fauna. However, granite can be easily reused or recycled and presents good resistance to weathering, soiling, or damage.

Limestone, composing scenario 2, presents a lower embodied energy and outcomes from reasonable natural stocks but extraction has profound environmental impacts. Limestone mining presents a number of environmental problems usually more severe than those created by other types of quarrying because of its potential impacts on landscape (carbonate deposits usually occur in areas of great scenic beauty), groundwater, archaeological and zoological remains, and local flora and fauna, and because of noise, dust and blast vibrations produced. The dust from limestone mining is more severe due to the high proportion of fines released which can result in pollution and toxicity. Limestone is also easily reused or recycled.

With respect to scenario 3, gravel paving, if recycled has a low level of embodied energy. This is also an easily reusable and/or recyclable material. It comes from fairly abundant natural stocks but extraction may have serious environmental impacts. Many of the best gravel deposits are located beneath prime agricultural land or within level and well-drained alluvial terraces. Moreover, the extraction of gravel from rivers or from the sea can disturb underwater habitats and lead to an unbalance in the erosion/deposition of offshore sand bodies. Recycled gravel (from crushing stone) should be clearly prioritized.

In what concerns scenario 4, asphalt, this solution presents a very high level of embodied energy. The production of bitumen-based materials is intensive in its usage of energy and involves the production of highly pollutant gases. In the case of asphalt, oil has to be refined, which means that it has to be burnt till the sublimation point. Although it may be reusable and/or recyclable, asphalt, as a bituminous product deriving from oil comes from an extremely limited resource. This material has also a high associated pollution during production and toxicity during its application on site due to the emission of dangerous fumes during its heating.
Finally, scenario 5, compacted soil is the solution presenting the lowest environmental impact, especially if it is available at the construction site and can be used for this purpose. It has a very low embodied energy related to the process of its compaction. Soil can be easily excavated, requires light extraction methods and may not need any industrial treatment. Soil is highly reusable and/or recyclable and comes from an abundant resource and has no associated pollution or toxicity. The need for transport must be considered.

Table 3 presents estimated values for some indicators of life cycle environmental impact (cradle-to-gate), for each studied paving materials. In the case of compacted soil, only a rough estimation of the embodied energy is given.

**Table 3:** Indicators of life cycle environmental impact (cradle-to-gate) for the simulated paving alternatives, associated with the production of one kg of material (estimated from data in [27])

<table>
<thead>
<tr>
<th>Paving solution</th>
<th>ADP</th>
<th>GWP</th>
<th>ODP</th>
<th>AP</th>
<th>POCP</th>
<th>EP</th>
<th>EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite cubes with mortar joints</td>
<td>2.74E-03</td>
<td>4.11E-01</td>
<td>5.06E-08</td>
<td>2.34E-03</td>
<td>7.19E-05</td>
<td>4.61E-04</td>
<td>1.38E+01</td>
</tr>
<tr>
<td>Limestone cubes with mortar joints</td>
<td>6.02E-05</td>
<td>2.12E-02</td>
<td>1.00E-09</td>
<td>6.18E-05</td>
<td>1.77E-06</td>
<td>1.19E-05</td>
<td>1.78E-01</td>
</tr>
<tr>
<td>Light-grey polymer resin bound gravel</td>
<td>3.38E-03</td>
<td>2.09E-02</td>
<td>1.19E-09</td>
<td>1.91E-04</td>
<td>4.55E-06</td>
<td>3.39E-05</td>
<td>4.63E+00</td>
</tr>
<tr>
<td>Asphalt</td>
<td>2.35E-02</td>
<td>5.81E-01</td>
<td>7.27E-07</td>
<td>1.94E-03</td>
<td>1.98E-04</td>
<td>3.02E-04</td>
<td>5.34E+01</td>
</tr>
<tr>
<td>Compacted soil</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9.70E-02</td>
</tr>
</tbody>
</table>

**ADP** – Abiotic Depletion Potential, in Kg of SB equivalent per kg of extracted resource;

**GWP** – Global Warming Potential, in kg of CO₂ equivalent per kg of emissions, over 100 years;

**ODP** – Ozone Depletion Potential, in kg of CFC-11 equivalent per kg of emissions;

**AP** – Acidification Potential, in kg of SO₂ equivalent per kg of emissions;

**POCP** – Photochemical (tropospheric) Ozone Creation Potential (summer smog), in kg of C₂H₄ equivalent per kg of emissions;

**EP** – Eutrophication Potential, in kg of PO₄ equivalent per kg of emissions;

**EE** – Embodied Energy (including renewable and non-renewable sources), in MJ per kg of ready to use material.
4.3 Defining a final improved scenario

The evaluation of the potential for microclimatic improvement suggests that, in that perspective, scenario 3 represents the best alternative. This hypothetical scenario, in which some new plants are installed and light-grey polymer resin bound gravel is used as paving material, presents the highest potential for reducing discomfort related to the studied climatic variables. This reduction of discomfort corresponds also to a reduction of the urban heat island effect and therefore it contributes to a lower need of cooling energy consumption in the surrounding buildings.

The compacted soil used in scenario 5 presents, in principle, the lowest environmental impact of all the tested paving materials. Its ease of extraction and predictable proximity to application site, its almost natural state suffering little or no transformation beyond compaction, its ease of reuse and/or recycling, as well as its absent pollution and/or toxicity are the reasons underlying its good environmental performance. However, for specific conditions (source location, transportation, means of extraction and compaction, etc) an evaluation should be made.

The environmental impact of the paving material in scenario 3 is clearly lighter than the current paving material but predictably more significant than the one of compacted soil. If recycled gravel is used, its impact can be lower. Considering that this is the scenario where the potential for microclimatic improvement is the highest, a weighted evaluation of the different implications of this choice should be made. This implies the need for the consideration of all phases of the life of solutions using a LCA approach.

5. Conclusion

The definition of scenario 3 as the best improvement scenario for Poveiros Square, in microclimatic terms, puts into evidence the potential of programmes of ‘cool’ materials and vegetation for improving the microclimate of outdoor public spaces. This improvement is relevant for outdoor thermal comfort as well as to the energy performance of buildings and, thus, is able of contributing to meeting the goals of the sustainable city.

The thermal retrofitting of public spaces in compact urban areas through programmes of ‘cool’ materials and vegetation is then feasible. Although the focus of such sort of interventions is delivering the conditions for outdoor thermal comfort, these should also take into account its environmental costs. This is imperative for a true ‘sustainable’ intervention which is necessarily holistic and cross-related.

The simplified evaluation of life cycle environmental impact indicators pointed to a different solution for paving material, defined as scenario 5. A complete and integrated analysis of both solutions, in terms of sustainability, would be of relevance for a final choice.

Bioclimatic urban design and architecture should work together with aspects as compactness, shared mobility, public transport, responsive dialogue with surroundings, diversity of public realm, interconnected places of encounter, architectural diversity, social
cohesion, communal infrastructure, use of renewable energy sources, complete water cycle management, waste management and treatment, integration of new and clean technologies, and identity of place [24] in order to achieve more sustainable cities. Moreover, the parameters contributing to the whole environmental experience include access, security, safety, health, civility, comfort, vitality/sociability, housing and habitat, urban design, provision of public services, natural features, or local culture both in the immediate and the longer term [25].

Adaptation strategies to climate change according to a sustainable reasoning can largely benefit cities especially in what pertains to their place as vital elements of a civilized society. Making cities more resilient to the predicted climate extremes can bring better welfare, safety and health conditions to urban populations while placing a lesser load on the environment – an action that can no longer be postponed.

References


APPROACH FOR THE PRACTICAL APPLICATION OF EXERGY ANALYSIS WITHIN BRANCH-ORIENTED ENTERPRISE NETWORKS, TOWARDS THE REALIZATION OF AN EXERGY LIFE CYCLE ASSESSMENT (ELCA)

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Abstract

Usually efficiency is defined in energetic terms without taking into account the quality of the energy. Another way to analyse and optimise processes and systems is in terms of exergy. The concept of exergy incorporates both qualitative and quantitative properties of energy. Exergy analysis makes the exact determination of the energetic and resource saving potential of industrial processes or systems possible.

This paper presents a framework for the practical application of the exergy concept into the reality of industrial enterprises. The starting point is the project “ReMo Green. Energy Efficiency for SMEs in Berlin”¹. The new approach of this project is a branch-specific proceeding and an application of the reference modelling for the development of an “Energy Efficiency Reference Modell” and a “Reference Standard Software for Energy Efficiency”. The enterprise network structure and the compiled energetic data from “ReMo” can be used as a basis for an exergy project. The new exergy approach expands the analysis beyond the limits of the company in order to consider the whole life cycle of the products and includes not only energetic resources but also those that are material.

The cooperation within enterprise networks reduces the required time and effort for the exergy data calculation and enables the realisation of an Exergy-Benchmarking as well.

In this framework, high data quality is achieved because enterprises of the same branch share basically the same production processes and products. Therefore the calculated exergy data can be used as a data source of a Life Cycle Inventory Data Base.

Keywords: Exergy Analysis, Enterprise Network, Exergy-Benchmarking, Cumulative Exergy Consumption, Exergy Life Cycle Assessment, Life Cycle Inventory.

List of Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>CDP</td>
<td>Cumulative Degree of Perfection (%)</td>
</tr>
<tr>
<td>CExC</td>
<td>Cumulative Exergy Consumption (J)</td>
</tr>
<tr>
<td>E</td>
<td>exergy (J)</td>
</tr>
<tr>
<td>E_in</td>
<td>exergy input (J)</td>
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<tr>
<td>E_out</td>
<td>exergy output (J)</td>
</tr>
<tr>
<td>E_pr</td>
<td>exergy product (J)</td>
</tr>
<tr>
<td>E_waste</td>
<td>exergy waste (J)</td>
</tr>
<tr>
<td>T_0</td>
<td>temperature of the reference state (K)</td>
</tr>
<tr>
<td>ΔE</td>
<td>exergy destruction (J)</td>
</tr>
<tr>
<td>ΔH</td>
<td>enthalpy variation (J/kg)</td>
</tr>
<tr>
<td>ΔS</td>
<td>entropy variation (J/kg)</td>
</tr>
<tr>
<td>η_ex</td>
<td>exergy efficiency (%)</td>
</tr>
</tbody>
</table>

¹ The project “ReMo Green. Energy Efficiency for SME in Berlin” is supported by the European Fond for regional Development (EFRE) and the Senatorial Administration for Economics, Technology and Research in Berlin, Germany. The project started in January 2012 and runs until February 2014.
1. Introduction

The interests of societies change along its evolution and development. The history of the human race shows that in our cultures, what prevails is immediate gratification and not future planning; and perhaps that is why they sometimes face its unquestionable degradation. Our culture is not an exception. The necessity of change in our mentality, of our way of life, of industrial activity and economical interaction is necessary to avoid the level of human suffering and ecological degradation and to ensure a sustainable development. But despite the knowledge of these intentions for over 30 years, we are still far away from global sustainability (see e.g. [1]).

Once the need for sustainable development is established, one of the challenges on the way to sustainability is the development of tools in order to measure and improve the efficiency and the sustainability of processes and products.

The combination of Life Cycle Assessment (LCA) and exergy analysis provides an additional impact category to LCA in order to apply exergy as an indicator for energy efficiency and resource quality demand (see e.g. [2]). The calculation of exergy indicators within branch-oriented networks enables one to perform an Exergy-Benchmarking. Through the comparison of the exergy indicators between companies belonging to the same branch, arises a "Best Practice" of the branch, which acts as an enhancer of the “Learning from the best” process. At this point the enterprises can identify the best practices in the field of the material and energy use and implement measurements for the improvement of their own processes or products.

The obtained exergy data of processes taking place in the network enterprises can contribute to the complementation of the already existing exergy database. In many studies that consider the exergy concept, they stress the necessity of a database of exergy values for basic processes to fill data gaps and to maintain data consistency (see e.g. [2]).


The Project “ReMo Green” is carried out in the framework of energy efficiency enterprise networks. Energy efficiency networks have been known for over 30 years. This idea comes from Switzerland, where the first of its kind was founded in 1987 with the aim of reducing the energy consumption and consequently the energy costs. In Germany, the first energy efficiency network was established in 2002 and currently there are about 25 active regional networks all over the country.

The new approach of the “ReMo Green” project is the establishment of energy efficiency enterprise networks with a branch-specific oriented proceeding, in order to provide the SMEs with more rigorous, comprehensive and efficient support for the increase of energy efficiency. Due to the great variety of industrial processes, it is not possible to develop a single standard of procedures to increase the energy efficiency that would be available for all the SMEs. Because of this, this project develops branch-specific reference models,
which are valid for SMEs of the same branch. These reference models are an “Energy Efficiency Reference Modell” and a “Reference Standard Software for Energy Efficiency”. The compilation of energetic data and the measurement of energetic values are essential for the development of these models. And these data together with the enterprise network structure is proposed in this paper as a starting point for the implementation of exergy analysis in the network enterprises.

The comparison of both approaches, the energetic and the exergetic one, could be very interesting and useful for a better interpretation of the results. Through such a comparison, it is possible to determine which method is more suitable for the analysis of production processes and which of them shows the more realistic saving potential.

![Fig. 1: Schematic representation of the activities within the project “ReMo Green. Energy Efficiency for SME in Berlin”](image)

The project “ReMo Green” is a complex and ambitious project, in which come into play a number of know-how carriers that provide the enterprises not only the know-how, but also experience, information, training and motivation for energy efficiency themes. All of these activities are guaranteed without compromising the financial resources of the enterprises, because it is a funded project. The coordination and the development of the whole project correspond to the IMBC GmbH². A schema of the activities within “ReMo Green” is presented (see Fig. 1).

² The IMBC GmbH (Institute for Information Management) develops concepts for IT-based sustainable solutions in the area of environmental computer science for more than 8 years.
3. Description of the exergy approach in the framework of branch-oriented enterprise networks

The following describes an approach for the application of the concept of exergy for the improvement of the efficiency of processes within enterprises of the same branch. These exergy analyses are the first step of a procedure, which is aimed at combining the exergy-based methods and LCA, in order to consider the sum of exergy of the energetic and material resources consumed in all the processes involved in the whole life cycle of the products that are produced in the network enterprises.

The schematic representation of the methodology is shown below (see Fig. 2).

![Schematic representation of the exergy approach in the framework of enterprise networks](image)

**Fig. 2: Schematic representation of the exergy approach in the framework of enterprise networks**

The beginning of this approach and its framework is the creation of solid and good organised branch-oriented enterprise networks. The selection of branches with an intensive consumption of material and energetic resources has already been made by “ReMo Green”. The advantage of applying this approach in the companies participating in the “ReMo Green” project is the availability of the collected data and the possibility of making use of the network structure. But this approach could be applied, of course with more required time, to new enterprise networks.

The network promotes the active collaboration between the companies and its engagement with a sustainable development. With the support of institutions contributing
the know-how and management capacities, all the actions taking place within the network benefit the economic, environmental and social situation of the enterprises.

The approach starts with the application of the exergy analysis to the production processes and products within the enterprise. This would correspond to an LCA in terms of exergy within the physical boundaries of the company, which is understood as “Gate-to-Gate LCA”. In this phase values of exergy related to industrial processes are compiled, calculated or measured. These data form the primary database of exergy values and are a source for gate-to-gate Life Cycle Inventory (LCI) information (see e.g. [3]).

Within the exergy analysis, the exergy losses and the exergy efficiency are calculated. In order to make appropriate improvement decisions, these values are analysed together with the exergy flow diagrams of the processes carried out within the companies. These values can be considered as exergy indicators, which can be used for the realization of an Exergy-Benchmarking. Through the comparison of these exergy indicators, the optimization potential of the participant enterprises is revealed and the energetic quality of the resources is improved. The cooperation of enterprises in branch-oriented networks is very important to the obtainment and use of exergy life-cycle data in the operational context.

The boundaries of the exergy analysis are expanded to include the contribution of all the intermediate processes from the natural resources to the desired product through the application of the Cumulative Exergy Consumption (CExC) Analysis.

The next step is to include the use-phase of the product and its recovery or disposal. Thus, the whole life cycle of the product can be considered and assessed in terms of exergy, resulting in an Exergy Life Cycle Assessment (ELCA).

The steps of the procedure are explained in more detail separately in the following paragraphs.

4. The concept of exergy and exergy analysis: exergy losses, efficiency and flow diagrams

The exergy concept is relatively young. The term “exergy” was suggested for the first time by Zoran Rant in 1956 (see e.g. [4]) but the concept was developed by Josiah Willard Gibbs in 1873 (see e.g. [5]). Exergy is a measure of the maximum amount of useful energy that can be obtained when matter is brought to equilibrium with its surroundings. In other words, exergy is defined as the maximum work or ability to produce work during the process towards equilibrium (see e.g. [4]). The concept of exergy incorporates therefore both qualitative and quantitative properties of energy and has been developed to provide a coherent and congruent quantification of the quality of an energy form (see e.g. [6]).

The only way to describe the concept of the energy quality is by using the second law of thermodynamics. “In a world rapidly running out of fossil fuel, the second law of thermodynamics may well turn out to be the central scientific truth of the twenty-first century” (see e.g. [7]). The second law explains that the exergy is always conserved in a
reversible process, but is always consumed in an irreversible process, i.e. real processes. On the other hand, the first law of thermodynamics is the law of energy conservation and says that energy cannot be created or destroyed, only transformed. In these transformations the energy is converted into other forms of energy that are less suitable for the realization of real processes. In other words, exergy is destroyed, producing the loss of energy quality and consequently the ability to produce work.

The goal of the exergy analysis in this approach is the optimization of the production systems and processes consuming energy and materials in two dimensions, the quantitative and the qualitative.

The expression for the calculation of the exergy of a system is given below (Eq. 1) (see e.g. [8]):

\[ E = \Delta H - T_0 \cdot \Delta S, \]  

where \( E \) is the exergy content, \( \Delta H \) and \( \Delta S \) are the change in enthalpy and entropy from the reference state (the surroundings) and \( T_0 \) is the temperature of the reference state.

The analysis of the exergy losses enables the localization of the improvement potential of the system efficiency. For real processes, the exergy is never balanced; this means that the exergy input is always greater than the exergy output, i.e. \( E_{in}^{tot} > E_{out}^{tot} \) and this is due to the irreversibilities occurring during the process. The work of Mei Gong and Göran Wall (see e.g. [9]) called this type of exergy loss, exergy destruction \( \Delta E \). The total exergy output consists of a utilized part and a non-utilized part. This unused exergy output is called exergy waste \( E_{waste} \). Both of them are exergy losses, but the exergy destruction caused by irreversibilities have, by definition, neither exergetic nor environmental effects. Irreversibility is considered as the wasted work potential or the lost opportunity to produce work.

The exergy destruction \( \Delta E \) is related to the entropy generated during the process and is given below (Eq. 2) (see e.g. [9]):

\[ \Delta E = T_0 \cdot \Delta S_{tot} = E_{in}^{tot} - E_{out}^{tot} = \sum_i \Delta E_i \]  

where \( T_0 \) is the temperature of the environment, \( \Delta S_{tot} \) is the total entropy generated during the process, \( E_{in}^{tot} \) is the total exergy input, \( E_{out}^{tot} \) is the total exergy output, and \( \Delta E_i \) is the exergy destruction of the process i.

The calculation of exergy losses enables the detection of inefficiencies and therefore the determination of the possible improvement potential of processes. Once we have this information, the logical approach would be to improve the part of the system with higher exergy losses. But taking into consideration that every part of a system depends on each other, the improvement of a single part may produce extra losses in another. That could lead to equal or larger total exergy losses in the “improved process” (see e.g. [9]).

The improvement of processes should be analysed in combination with the exergy efficiency and the exergy flow diagrams to obtain better results.
The exergy efficiency is usually defined as the utilized exergy divided by the used exergy (see e.g. [9]). But there is more than one way to define these two concepts. We use the approach of Mei Gong and Göran Wall (see e.g. [9]), which is based on the following figure (fig. 3):

![Fig. 3: Exergy input and output of a system (see e.g. [9])](image)

Sometimes there is a part of exergy output that is not utilized because it is an exergy waste $E_{waste}$ to the environment. Therefore, the utilized exergy output is called the exergy product $E_{pr}$ and it is expressed below (Eq. 3)(see e.g. [9]):

$$E_{pr} = E_{out} - E_{waste},$$

and the exergy efficiency (Eq. 4) is thus:

$$\eta_{ex} = \frac{E_{out}/E_{in} - E_{waste}/E_{in}}{E_{pr}/E_{in}}$$

The best approach to the improvement of processes is the combination of the exergy efficiency and the exergy input and output flow diagrams, like the one showed in fig. 3. From an exergy flow diagram we obtain very useful information for improvement-decision-making. Such a diagram not only shows the exergy efficiency, but also the distribution of the different exergy flows and the destroyed exergy of each process (see e.g. [9]). Therewith one can decide what to improve and in which order.

The calculated process exergy values can be the basis for the realization of an Exergy-Benchmarking (i.e. comparison) of the production processes within the branch-oriented enterprise networks. The results of Benchmarking processes are Best-practice examples and the exergy indicators characterising them can be used as reference exergy values for a better interpretation of the results of future exergy analyses in enterprises of the same branch. The experience with energy efficiency analysis within enterprise networks enables the networkers to exchange experiences with one another and to facilitate mutual learning processes and meet optimization goals faster and more easily.

Simultaneously we are providing primary exergy data for gate-to-gate Life Cycle Inventory. The enterprise networks can be seen as “collectors” of LCI exergy data for the processes occurring in the network enterprises. Collecting data in several enterprises belonging to the same branch, and thus with very similar production processes and technology, improves the quality, the reliability and the usability of the data sets.
A study in Sweden has been devoted to studying the limitations and obstacles to the application of the concept of exergy for the integration of processes and the detection of inefficiencies. The result of the interview study is a weighted summary of obstacles for exergy analysis and the most important factor seems to be the lack of a strategy to work with exergy analysis, of information regarding opportunities for exergy analysis and of competence within the organization (see e.g. [10]). The introduction of the missing know-how into the enterprise networks through institutions and experts in the exergy field enable the application of exergy analysis in the industrial and process reality.

5. Analysis of cumulative exergy consumption (CExC)

The application of exergy analysis within enterprises can be complemented in order to consider the whole production chain from the extraction of natural resources to the final product (cradle-to-gate).

With this intention Jan Szargut has developed the “Analysis of Cumulative Exergy Consumption” (see e.g. [11]). The concept of CExC is similar to the Cumulative Energy Consumption (CEC) (see e.g. [12]) but considers the quality of the energy and includes material resources, not only energetic ones. The indicator CExC represents the total exergy destroyed along the entire production chain of a product, accumulating the exergy of all the resources required, i.e. from cradle to gate (see fig. 4) and depends on the pathway followed by the whole process. If we want to consider the total exergy losses, we have to take not only the exergy irrevocably destroyed by the irreversible entropy generation into account (see e.g. 6), but also the exergy waste due to unused exergy (see e.g. [11]).

Through the application of this method, the total exergy losses, the CExC of the product and the Cumulative Degree of Perfection (CDP) can be calculated as shown below (Eq. 5-9):

*Cumulative Exergy Consumption:*

\[
CExC_{13} = \sum_{j=1}^{12} E_{in,j} = E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7 + E_8 + E_9 + E_{11} + E_{12}
\]  

(5)

*Total Exergy Destruction:*

\[
\Delta E_{tot} = \sum_{k=1}^{4} \Delta E_k = \Delta E_1 + \Delta E_2 + \Delta E_3 + \Delta E_4
\]  

(6)

*Total Exergy Waste:*

\[
E_{waste,tot} = \sum_{i=1}^{4} E_{waste,i} = E_{waste,1} + E_{waste,2} + E_{waste,3} + E_{waste,4}
\]  

(7)

*Total Exergy Losses:*

\[
\Delta E_{tot} + E_{waste,tot} = \sum_{k=1}^{4} \Delta E_k + \sum_{i=1}^{4} E_{waste,i}
\]  

(8)

*Cumulative Degree of Perfection (CDP):*
The CDP is the ratio of the exergy of the final product to the cumulative exergy consumed to produce it, this is the CExC.

\[
CDP = \frac{exergy \ of \ the \ product \ (E_{13})}{CExC \ of \ the \ product} = \frac{E_{13}}{\sum_{k=1}^{12} E_{in,j}} = \frac{\sum_{k=1}^{12} E_{in,j} - (\sum_{k=1}^{12} \Delta E_k + \sum_{j=1}^{12} E_{waste,j})}{\sum_{j=1}^{12} E_{in,j}}
\]  

(9)

The possibility of associating a value of exergy to all raw materials allows for its implementation in Inventory Analysis and Databases. The combination of the CExC and the LCA enables the consideration of the whole life cycle of a product in terms of exergy of energetic carries and non-energetic materials.

6. Exergy Life Cycle Assessment (ELCA)

The Life Cycle Assessment according to the ISO 14040\(^3\) is a method for the detection and assessment of the environmental impact of products, processes and services throughout the life cycle, i.e. cradle-to-grave. The four components of a LCA are (see e.g. [12]):

- goal and scope definition

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The core of a LCA is the Life Cycle Inventory (LCI). The collection of data is the phase of the LCA, which consumes more time. LCI leads to obtaining reliable and representative information of the processes involved in a production system (see e.g. [3]).

The life cycle impact assessment is also a complicated phase of the LCA and represents a critical part of it due to the numerous existing impact categories. This phase translates the analysis of all the input and outputs through the system boundaries (LCI) into environmental impact. One of the impact category indicators dealing with the impact of the energetic resources is the Cumulative Energy Consumption (CEC). This cannot be considered as a unique impact category indicator within the framework of LCA but it well complements the resource demand impact categories (see e.g. [12]).

The aforementioned Cumulative Exergy Consumption (CExE) is associated with the CEC and considers energetic and non-energetic resources in terms of exergy. But the production factors, Energy (exergy) and Material, are only two of the four classical production factors. The other two are: the Capital and the Labour factors (see e.g. [6]). The environmental impact is also not included in the CExC approach. All these factors are considered in terms of exergy, of course. Anyway, CExC can be considered as an additional impact assessment category indicator, which must be complemented with other impact categories in order to assess the sustainability of a production process or product (see e.g. [12]).

Some scientific works, such as those of E. Sciubba and J. L. Hau and B.R. Bakshi, have dealt extensively with the issue of boundary expansion of the exergetic consideration. E. Sciubba has developed the concept of "Extended Exergy Accounting" which computes the flows Material, Energy, Labour, Capital and Environmental Impact in terms of exergy (see e.g. [6]). J.L. Hau and B.R. Bakshi have expanded the concept of CExC to include the contribution of ecosystems, leading to the concept of Ecological Cumulative Exergy Consumption (ECExC) (see e.g. [13]).

But the goal of this paper is not to combine all impact categories into a single indicator but to propose a feasible framework for applying the concept of exergy to real production processes. Thereby we acquire knowledge and experience, we obtain exergy data and we attempt to eliminate the big gap between theory and practice.

By combining the concept of exergy (represented by the indicator CExC) and the LCA arises the Exergy Life Cycle Assessment. Since the ELCA makes use of the LCA framework using the CExC as an impact category indicator, the ELCA can be considered the cumulative exergy analysis of entire life cycle of a product.
7. Exergy Databases

The practical experience with the concept of exergy and the indicator CExE in real LCA is not very extensive. However, this research field has such a great potential that it has attracted the interest of many researchers. In recent years, several data sources and databases, including exergy and CExC values, have been developed. Three examples within the European scientific community are listed below:

- “Applying Cumulative Exergy Demand (CExD) Indicators to the ecoinvent Database” of the Institute of Environment Engineering, ETH Zürich, 8093 Zürich, Switzerland (see e.g. [2]). In this work, the indicator CExC was calculated for 2630 ecoinvent product and process systems.

- “The Exergoeconomy Portal” (see e.g. [14]) includes an “Exergy Calculator” for the automatically calculation of the chemical exergy of chemical compounds and a software tool called “TAESS – Thermoeconomic Analysis of Energy Systems”. The work of the expert in the exergy field, Prof. Jan Szargut of the Institute of Thermal Technology, Silesian University of Technology in Poland, lies behind the development of this portal.

- The “Global Exergy and Carbon Database” (see e.g. [15]), developed by the Stanford University in the framework of the “Global Climate & Energy Project” – GCEP. The three types of easily accessed data in this database are: Carriers, Transformations and Accumulations.

The data acquisition required for the realization of the exergy analysis is carried out in the enterprise by following the steps of the exergy analysis methodology. This requires not only the calculation of exergy flows, but the flows of matter and energy involved in the production process as well.

On the other hand, the data included in the aforementioned databases are essential for the exergy calculations of the production phase from the extraction of natural resources to the beginning of the production process in the company producing the final product. The databases are also used as a data source for the exergy calculations relating to the use, recovery and disposal phases of the assessed product.

8. Conclusion and Outlook

All production systems need energetic and material resources. Exergy is able to determine both resources in terms of maximum useful work. The establishment of exergy as a measure of energy and materials is invaluable for the improvement of the efficiency of industrial processes. Exergy is therefore a powerful tool for product resource accounting, and moreover, its implementation in the framework of branch-oriented enterprise networks offers the possibility of enlarging the exergy databases and is a starting point for the realisation of Exergy Life Cycle Assessment for products and industrial processes occurring enterprises of the same branch.
The IT-support of the exergy calculations and exergy data collection would facilitate much more the realization of these duties. Therefore this paper pushes for the development of a software tool to support the application of the exergy concept in enterprises.

References


THE URGENCY OF ENERGY CONSERVATION:
REQUIRED BEHAVIOUR AND SOCIAL NORM CHANGE FOR
DEMAND-SIDE MANAGEMENT

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Abstract
Governments struggle with achieving their targets (often set in legislation) towards developing low carbon regions in Europe, i.e. smart energy regions. On top of the problem of climate change, concerns for security of supply and ‘peak oil’ and other resource shortages have added to the urgency of energy conservation. However, it is still thought that we are currently wasting up to 86% of our energy (cf. [1]) and that we will not utilise 2/3 of the energy efficiency potential in our economy by 2035 (cf. [2]). Supporting research in energy efficiency is therefore contributing to the European objectives in resource efficiency (cf. [3]). Today, energy efficiency is promoted under a variety of headings, including climate change mitigation, sustainability, eco-efficiency, conservation or energy self-sufficiency.

Within the IEA DSM Task 24 Subtask 1, different programmes, pilots and policies (focussed on achieving better energy conservation, energy efficiency and peak load management) have been analysed in different countries in order to find out if and what behaviour change models or frameworks were used to design, implement and evaluate them, and with what success. Programmes, pilots and policies were also characterised in terms of targeted actors, scope, domain and durability of behaviour, using the framework of [4]. Of special interest is the question if there are models or frameworks which are better suited for certain programmes and energy sectors (this Task is concentrating on building, transport, SMEs and smart metering technology) than others. First outcomes of this analysis, revealing approaches for best practice and some main challenges, will be presented in this paper.

**Keywords:** Energy Conservation, Behaviour Change, Demand-Side Management

1. Introduction
A new Task of the International Energy Agency (IEA) concentrates specifically on energy end user behaviour change to improve design, implementation and evaluation of pilots, policies and programmes that are geared towards energy efficiency or energy conservation outcomes. There is a great opportunity for Demand-Side Management
(DSM) programmes if this behavioral potential (to be as vast as 30% of total energy demand, estimated by [5]) could be easily accessed and directed. As many other IEA DSM Tasks have discovered, the ‘market failure’ of energy efficiency is not due to technological challenges but often due to the vagaries of human behaviour and choice.

There are several reasons for these challenges and this new Task sets to uncover, unravel and define them in order to provide clear recommendations to policy-makers and DSM implementers (cf. [6]). It is imperative to uncover the context-specific factors (from infrastructure, capital constraints, values, attitudes, norms, culture, tradition, climate, geography, education, political system, legislature, etc.) that influence human behaviour in specific sectors (as the factors that influence e.g. our transport behaviours often differ from the ones driving our hot water usage or our investment plans a new heating system in our house, for example, cf. [7]).

In addition, there is a large variety of research disciplines that endeavour to study human behaviour (social and environmental psychology, environmental and behavioural economics, anthropology, science technology studies, practice and innovation diffusion theory, etc.), each with their own models and frameworks, advantages and disadvantages.

In recent years, DSM programmes have increasingly acknowledged the untapped potential of changing the patterns of energy consumption by focusing on end-user energy demand reduction through behavioural changes (cf. [8]; [9]; [10]).

To date, much effort has been concentrated on the research and development of technology - to acquire fine-grained consumption data; to present cost (in terms of money or emissions) to the consumer; and to use the acquired data to schedule consumption and generation automatically. However, an equally important area of development must be how such information is assimilated into knowledge (or rejected) by the various actors within the system and, further, how this knowledge, mediated by other influences, translates into behaviour change (cf. [11]). In this respect, social learning is a term which describes the process of adapting behaviour in response to influence from social contacts. It intrinsically links learning of new ideas or behaviours (or knowledge and actions) to the social context in which they exist (cf. [12]). One opportunity is to include cultural aspects and compare response behavior between different regions of the world.

With the advent of ‘smart metering technologies’ (cf. http://www.smartregions.net/) and the consequential auspicious potential of a ‘smarter’ electrical grid, the question of how end-consumers can be motivated to save energy or change their energy consumption patterns has attracted increased attention. Hence, a growing body of related research and valuable contextual information has addressed this problem over the last years. It is increasingly stressed, though, that research should go beyond mere quantitative studies of individual consumption levels or load patterns and ask for the social and cultural practices that may lead to changed behaviour in households as a whole.
1.1 Definition and Potential of DSM

Behavior change in the context of this Task thus refers to any changes in said human actions which were directly or indirectly influenced by a variety of interventions (e.g. legislation, regulation, incentives, subsidies, information campaigns, peer pressure, infrastructural changes etc.) aimed at achieving specific behaviour change outcomes (cf. [13]).

Demand Side Management in this Task refers to interventions (top-down and bottom-up policies, programmes and actions) developed and performed by intermediaries (government agencies, utilities, DSM implementers) that seek to influence the ways end users consume energy at home, at their workplace or whilst traveling. The changes sought by intermediaries may include the quantity of energy consumed for a given service, the patterns of energy consumption or the supply management and type of energy consumed. The intended outcome of DSM will differ with the aspirations of intermediaries but include energy efficiency, energy conservation, sufficiency, reduced greenhouse gas emissions, financial or social gains or (peak) load management. In the short-term, it may not always lead to a total reduction in energy consumption (although this is the medium to long-term goal), but to the most efficient and environmentally friendly use of energy to derive the services that underpin social and economic wellbeing (e.g. comfort, mobility, entertainment, cleanliness, production etc.).

2. Theories and Models concerning Behaviour Change

Much research in many different fields, including behavioural sciences, economics and sociology, has been carried out to understand and possibly influence domestic energy consumption patterns (cf. [14]).

Despite some tentative moves towards using behavioural economics and psychology findings to better design policies, humans are usually still regarded as economically-rational actors whose behaviours can be largely influenced by fiscal incentives or regulation targeted at the individual. However, the complexities influencing human behaviour are so vast and manifold that such approaches almost invariably fail. Both economics and psychology focus mainly on the individual and his/her attitude, motivation, and the resulting behaviour. Although these perspectives and their approach to changing behaviour may work out well when adopted for the duration of DSM projects, once these projects are terminated (and the information and incentives stop), the participants to such programmes often relapse into their old habits. One of the biggest challenges is to sustain the changed behaviour after the DSM intervention has stopped. In other words, people may respond to incentives and encouragement in the short-term and behave more energy efficiently, but in the longer run they easily revert to their old behaviours, habits and routines. Relevant theories and models of understanding behaviour change include all theoretical approaches and insights to investigating, assessing and measuring energy-using behaviours and theories to change them on the individual and/or societal level.
Unfortunately, the researchers from the various disciplines often do not communicate their findings enough – not to each other and not to the end users of their research – the policymakers, technology developers, and DSM programme designers and implementers. This leads to confusion and lack of context-specific programme or policy design that is based on the behavioural information or models best tailored to the specific task at hand.

One of the most used models is the theory of planned behaviour (TPB) by [15]. It should be emphasised that attitudes are defined as being specific to the behaviour in question. Indeed in the TPB it is stressed that the attitudes must be measured in relation to the specific behaviour in question (and not behaviours of that type) in order to maximise the predictive power of the attitudinal construct. Expectancy value theory shows that beliefs are antecedent to attitudes; in the TPB beliefs are shown as the “underlying foundations” of behaviour (cf. fig. 1).

![Fig. 1: Theory of Planned Behaviour (by [15])](image)

Another approach is the application of behavioural economics (cf. fig. 2) to energy consumption reduction. In this way, the role of different information policies on the energy consumption of individuals/ househoulds is assessed. Correlating the electricity data with individual characteristics, such as social preferences, self-evaluation, individuals’ preferences for temporal discounting, and a number of personality traits provides interesting insights into behaviour change options.

People have limited information and attention, and differ in terms of patience, self-evaluation, and social preferences. This means that supplementary information will generate behaviour change in terms of energy consumption / conservation. The response to information will differ depending on patience, self-evaluation, and social preferences.
Fig. 2: Applied Behavioural Economics (by [16])

A more comprehensive behavioural model of residential energy use is presented by [17] in fig. 3, in which the relevant factors influencing energy use (e.g. energy-related attitudes and social norms, socio-demographics, personal values/personality, household/lifestyle and characteristics of home appliances, energy prices and costs as well as climate, season and weather) are pulled together.

Fig. 3: Behavioural model of residential energy use by (by [17])

The model provides researchers and policymakers with as extensive review of factors relevant for the explanation of energy use and a means for evaluating the effects of different policy options. Through recommendations, general information, prompts and information about the energy costs of certain behaviours, energy-related behaviour might be changed without changing attitudes first. Feedback methods are promising for behavioural change.
3. Framework for Analysis

A fundamental challenge is how to understand energy behaviour change processes. There are diverse social scientific models of understanding behaviour, but to date there has been little interaction and exchange between the various theories and disciplines. Too little use is being made of existing behavioural change theories by policymakers and DSM implementers. An explicit aim of the Subtask is to improve and better understand the interaction between theories, projects (pilots, cases) and the impacts/outcomes of these. As a first step in the challenge of better understanding behaviour change, literature on behaviour change theories and models has been reviewed (e.g. [18]) and the diverse behavioural models and theories of change have been analysed in terms of what they offer both theoretically and empirically. The Subtask is developing this inventory with input from the national and contributing experts. In addition, various models/theories will be developed and underpinned by a range of empirical (case) studies that have used them in real life. Pros and cons of each approach will be discussed.

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Theories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy</td>
<td>Classical economic theory (rational choice)</td>
</tr>
<tr>
<td></td>
<td>New economics</td>
</tr>
<tr>
<td></td>
<td>Evolutionary economics</td>
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<tr>
<td></td>
<td>Behavioural economics</td>
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<tr>
<td></td>
<td>Cognitive psychology/ Theory of Planned Behaviour</td>
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<tr>
<td></td>
<td>Learning psychology</td>
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<tr>
<td></td>
<td>Social psychology – energy infrastructure</td>
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<tr>
<td></td>
<td>Social psychology – climate perception attitude theory and ABC linkages</td>
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<tr>
<td></td>
<td>Social psychology – smart metering and behaviour change</td>
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<td></td>
<td>Social psychology: object-centred approaches</td>
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<td></td>
<td>Social psychology: place-based approaches</td>
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<td></td>
<td>Organisational psychology</td>
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<tr>
<td></td>
<td>Schwartz model on activation of moral norms</td>
</tr>
<tr>
<td>Psychology</td>
<td>Community-based behavioural change</td>
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<tr>
<td></td>
<td>Cultural aspects of consumption</td>
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<td></td>
<td>Sociology of consumption</td>
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<td></td>
<td>User innovation</td>
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<tr>
<td></td>
<td>Sociotechnical Practice theory</td>
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<tr>
<td></td>
<td>Social norms</td>
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<tr>
<td>Sociology</td>
<td>Constructivism as a learning theory</td>
</tr>
<tr>
<td>Education</td>
<td>Nudge</td>
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<tr>
<td></td>
<td>Social marketing</td>
</tr>
<tr>
<td></td>
<td>Segmentation</td>
</tr>
</tbody>
</table>

The inventory is done at the level of conceptual/theoretical frameworks that provide explanations of how behavioural changes come about and specific examples in policy and practice where these behavioural models and theories of change have been implemented. When assessing their (potential) contribution to better understanding energy DSM and behavioural change, we will also attempt to address underlying key issues and challenges.
In table 1, a list of disciplines and corresponding theories about behaviour change is presented. The list is a product of the several scientific experts contributing to Task 24.

Based on this list of theories, different DSM-Programmes in Switzerland were analysed. In addition, the case studies were described with regards to actors and durability, in line with the 4DB-Framework (4 Dimensions of Behaviour) of [4].

### 4. Analysis of Case Studies

In order to fulfil these challenging objectives, a template was developed to collect the various theories and approaches using examples in policy, programmes and pilots where they have been applied in practice. These templates were filled out by the national experts and other participants of the expert platform, who are known to have specific knowledge on the theories or practices. One of the key learnings from this exercise so far has been that, although in the past, the most commonly used theories and approaches were from economic and psychological disciplines, a change is taking place where more sociological approaches are also used to design DSM interventions. Another emerging hypothesis is that the stakeholders using these sociological approaches are often not policy stakeholders, but intermediaries designing interventions in a more bottom-up fashion. In addition, it is becoming clear that when theories and models have been made actionable, they usually focus on the individual level or households, and in an increasing number of cases, the social environment of friends, family or community. However, there are yet very few approaches focusing on SMEs, schools or offices. Although many approaches do emphasise the context-sensitivity necessary to develop effective approaches, segmentation beyond the traditional socio-demographic and psycho-social segmentation is lacking. This is despite the fact that it has become clear that households with very similar segmentation characteristics can demonstrate a 100% difference in their energy behaviour. The current approaches are also often insensitive to the different types of behaviour, and target behaviour change as a homogeneous unit of analysis. These are just very preliminary observations but they already indicate the need for more tailored theories and approaches if these are to be taken on board in the design of better DSM interventions (cf. [13]).

DSM-programmes are situated in a lot of different themes (cf. fig. 4). For this analysis we only included programmes in Smart Metering, SMEs and Building Retrofitting.

The main selection criteria for the case studies in these 3 topics were the availability of information, especially about results and impacts of the programmes on energy behaviour. There are a lot of on-going programmes in Switzerland, but only few are documented and evaluated regarding their behaviour change outcomes. This is a problem encountered in general, which is why Task 24 has a Subtask (ST 3) wholly focused on evaluation of behavioural outcomes – with regard to different stakeholder needs and interests.
4.1 Description of Swiss Case Studies

Due to the difficulties regarding evaluation described above, the Swiss national experts only looked at 3 Smart Metering programmes, 1 SME programme and 2 Building Retrofitting programmes.

4.1.1 Smart Metering Zurich, EWZ

The study analyses electricity consumption over a 15 month period for around 5000 randomly selected households in Zurich. The objective of the study is to assess the role of information on electricity consumption. Information is improved in four different dimensions: (i) continuous and detailed feedback about the electricity consumption by Smart Meters, (ii) expert advice on electricity conservation, (iii) unilateral information about electricity consumption of others (social comparison), and (iv) bilateral information about the electricity consumption of a comparable household (social competition). The design allows to estimate the causal impact of each type of information on behaviour (cf. [16]). It is based on classical economics thinking, the so-called ‘Expected Utility Theory’ which
includes notions around information deficits [18] and Cialdini’s focus theory of normative conduct [36].

Surveys before, during and after the field experiment allow to collect information on values, attitudes, and further household characteristics of the participants and to assess the impact of the treatments on outcomes beyond energy consumption, such as awareness of energy conservation potentials, and customer satisfaction with the services provided by ewz.

This is an ongoing project and results cannot be provided yet.

4.1.2 Smart Metering Zurich, EKZ

The study analysed electricity consumption over a 24 months period for around 1000 randomly selected households in Dietikon (Switzerland). The objective of the study was to assess the role of information and visualisation on electricity consumption (using partly the behavioural economics model of [16]). Visualisation of the energy consumption took place in various ways (cf. [19]):

I. continuous and detailed feedback about the electricity consumption by Smart Meters (Ecometer)
II. a Smart Meter portal (password-protected)
III. a monthly electricity bill.

This allows estimating the causal impact of each type of visualisation type on behaviour.

Findings at the end of the two year pilot study:

- Smart electricity meters are able to support the customer in saving electricity, if the electricity consumption is visualised.
- There was up to 3% less electricity consumption on average by using the Ecometer or the Smart Meter portal compared with the control group in Regensdorf.
- Customers who didn’t use any visualisation technology weren’t able to save electricity compared with the control group in Regensdorf.

The expectations (energy saving of about 5-6%) could not be met. Energy savings of about 3% could be attained with direct in-house feedback, but only 1.5% in general (versus about 1.1% in the reference group without smart meters). Smart meters thus do only slightly support energy savings and only when the current consumption is displayed. This is a finding similar to other case studies in other countries [cf. 35].

4.1.3 Munx-Website, Repower

The users of this platform enter the meter reading of their electric power meter weekly. They get feedback of their consumption by comparing it to other households/neighbours –
based on Cialdini’s focus theory of normative conduct [36]. Users could also enter other parameters of their flat – for example which energy they use for heating, how big their flat is, how many people live in their flat etc. When they entered these parameters they would get an energy standard mark (A, B, C etc). They could also do a quiz to learn more about electric power and received a lot of tips about saving energy at home and in the office. In addition, they could plan measures to save energy (e.g. plan to buy a new and more efficient washing machine or to take a shower instead of taking a bath). They could also set a reminder (via mail or sms) for entering the electric meter reading. For all these things they could collect points and with the points they could buy devices for saving electric power (e.g. energy saving light bulbs or water reducing valves for the shower).

This is an ongoing project and results cannot be provided yet (cf. [20]).

Not surprisingly, the effectiveness of feedback information depends on the type of feedback provided (cf. [21]; [22]; [23]). [6] point out, that feedback is more effective when combined with other strategies, such as providing information on energy-efficient measures. As for the aim of energy conservation, recent overviews of the studies evaluating the effects of feedback information suggest electricity savings in the ranges of 5-15% (cf. [24]; [21]; [14]; [23]). Lower effects are estimated by [25] for Japan (1.5%) and by [26] for Denmark (3%). The wide range of estimated effects can be explained by differences in evaluation methodologies or to which extent the analyses account for moderating factors and co-variates such as energy prices, household socio-economic characteristics, or the appliance stock (cf. [27]).

4.1.4 Energy-Model and SME-Model from EnAW

The Energy Agency of the Economy (Energie Agentur der Wirtschaft, EnAW) is an association of the most important inter-trade organisations of the Swiss economy and has a public-private-partnership-agreement with the Swiss Federal Office of Energy (SFOE). The Agency’s target is to reduce energy consumption and CO₂-emissions of Swiss enterprises by voluntary and profitable measures of the companies themselves. The Agency has mainly two different programmes to support companies in this area. One is for companies that use a lot of energy (called Energy-Model), the other is particularly for SMEs (called SME-Model). The Evaluation was mostly done for the two programmes combined.

Both programmes help companies to define goals and corresponding measures concerning the reduction of energy and CO₂-emissions. Facilitators from the EnAW are consulting the enterprises in defining specific goals and corresponding measures for their enterprise. They take into account the particular situation of the organisation. To set the reduction goal, the pay-back-time of potential measures is analysed. Measures with a pay-back-time of less than 4 years (for industrial processes) and less than 8 years (for measures concerning building and facility management) respectively are considered effective, thus defining the goal (cf. [28]). The model used thus subscribe to classical economic theory [18].
Companies participating in the Energy-Model programme who reach their audited targets get a certificate, and they are allowed to ask for reimbursement of the CO₂-tax from any combustibles they have used (according to the Federal Act on the Reduction of CO₂ emissions). This exemption of the fee for CO₂ emission is a high incentive for enterprises to join the energy model. Targets of the participating firms are controlled and monitored by the Agency and by the Swiss Federal Office of Energy (SFOE).

The following conclusions can be drawn:

- Additional incentives (e.g. money for CO₂-savings, lower electricity prices) of foundations and/or power utilities increase the motivation of enterprises to participate.
- The strengthening of their image as an ecologically and socially responsible company is an important driver for enterprises.

Facilitators play an important role in the programme, but they still have to fulfil expectations from two sides: the ones from the enterprise (cost-effective measures, not too high (i.e. expensive) targets) and the ones from the ENAW/SFOE (high/strong targets).

4.1.5 Swiss Building Retrofitting Programme

The Swiss building retrofit programme promotes retrofits of buildings and investments in renewable energies, use of waste heat and optimisations in building technology. The programme gives financial incentives (aid money) for house owners to retrofit their buildings in an energy efficient way. This is also based on a classical economic model of understanding behaviour [18]. The programme started in 2010 and will last 10 years (cf. [29]).

The legal basis for the programme is the Federal Act on the Reduction of CO₂-emissions (1999, “CO₂-law”). This law enforces a fee on combustibles. A maximum of one third of the revenues of the fee are used for the Federal Building Retrofit Programme.

To get subsidies for a renovation a home owner has to submit a detailed application of the planned renovation measures. If the measures do comply with the requirements, the application is accepted and the money will be paid out once the measures have been realised and proven with a final documentation.

It is too early to know exactly by how much the rate of retrofits can be raised by the Swiss building retrofit programme. Roughly 20-30% of the funded retrofits would have been realised even without the funding money.

Most programmes use Classical Economics or behavioural economics as theory on behavioural and model of behavioural change where behaviour is understood as a decision-making process. The general incentives used are economic and informational,

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4 The amount of aid money is 10-30 CHF/m² of retrofitted building part, depending on type of measure (window, wall ceiling, ...). 1 CHF = 0.83 €
and as such only a limited number of benefits (or drivers or barriers) are tackled (social and health-related, comfort, control, inconvenience or any other important issues are disregarded). Consequently, interventions designed from these perspectives range from offering financial subsidies to free retrofitting, to penalising lack of retrofitting at sale (energy labelling case) and often are accompanied by information provision to assist the decision-making process. Ambitious programmes can create technological innovations and even professionalise a market, including the accompanying job growth, especially when the retrofitting is aimed at the comprehensive level of the house, not only on small aspects.

### 4.1.6 2000 Watt Society

How can the habits of people be changed from today’s 6500 Watt energy use to 2000 Watt? Model calculations show that the ambitious goal of 2000 Watt can be reached, although it needs a very large, concerted effort. The lifestyle we choose and our day-to-day behaviour play an important role in determining our energy footprint, and there are considerable individual choices we can make. In addition to making the appropriate changes in our consumption behaviour, we also need a range of products that can be manufactured and made available in an energy-efficient manner. Energy efficiency, substitution (fossil to renewable energy) and sufficiency are important to reach a 2000-Watt-Society. The 2000-Watt-Society is an ethical and technical concept, which tries to explore potentials, drivers and barriers on the way to such a society. Here, we will only outline the measures in the housing area (cf. [30]).

#### Table 2: Comparison of case studies in terms of underlying theory, actor and durability

<table>
<thead>
<tr>
<th>Theme</th>
<th>Programme</th>
<th>Theory</th>
<th>Actor</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart Metering</td>
<td>Smart Metering, Zurich, EWZ</td>
<td>Behavioural Economics, Social Norms</td>
<td>Inter-personal Network</td>
<td>Repeated, Dependent</td>
</tr>
<tr>
<td></td>
<td>Smart Metering, EKZ</td>
<td>Behavioural Economics, Social Norms</td>
<td>Inter-personal Network</td>
<td>Repeated, Dependent</td>
</tr>
<tr>
<td></td>
<td>MUNX-Website, Repower</td>
<td>Behavioural Economics, Social Norms</td>
<td>Inter-personal Network</td>
<td>Repeated</td>
</tr>
<tr>
<td>SME</td>
<td>Energy-Model and SME-Model from EnAW</td>
<td>Classical Economics, Social Norms</td>
<td>Community</td>
<td>Repeated, Enduring</td>
</tr>
<tr>
<td>Building Retrofitting</td>
<td>Swiss Building Retrofitting Programme</td>
<td>Classical Economics</td>
<td>Individual</td>
<td>Enduring</td>
</tr>
<tr>
<td></td>
<td>2000 Watt Society</td>
<td>Practice (Lifestyle), Social Norm</td>
<td>Population</td>
<td>Norm-Setting</td>
</tr>
</tbody>
</table>

Current state: Three-quarters of all existing residential and office buildings are more than 30 years old and do not offer a sufficient degree of energy efficiency (‘20-liter houses’). Currently at around 50 m² per person, the living area in new homes is on the rise.
Options for action: Well-insulated low or zero-energy buildings (Minergie-P, Minergie P-Eco) reduce heating needs to the equivalent of 2 liters of heating oil per m2. Moderate house size and energy-efficient appliances are important to achieve this goal. There has also been a new standard developed, SIA Effizienzpfad and a certificate for 2000-Watt-Areale, further information on www.2000-watt.ch.

As we can see in table 2, the smart metering projects are always dealing with behavioural economics and social norms, in contrast to the programmes concerning SMEs or building retrofits – besides of the 2000 Watt Society, which is more of an overall, norm-setting policy vision that enters the area of practice theory in the sense that it concentrates on overall lifestyle and practices, rather than individual actors.

5. Results

A smart grid is a socio-technical network characterised by the active management of both information and energy flows, in order to control practices of distributed generation, storage, consumption and flexible demand. Feedback on energy consumption can influence energy behaviour of residential consumers and lead to a conserving behavioural effect (cf. [7]). However, if feedback is only aimed at providing general information to individuals about their actual consumption level, it is likely to be much less effective than it could be (cf. [31]; [24]; [32]). In other words, to make feedback more than only a visual reporting of the energy consumption measurement, and also make it a tool to manage the energy consumption, it needs to be improved beyond metering and billing.

While current metering and billing practices, not least in Switzerland, imply that end-users receive only limited information on their energy consumption, more frequent and timely feedback is expected to raise awareness and to improve information about levels of energy use and costs (cf. [14]; [33]; [21]). This kind of feedback is expected to help overcome information-related barriers that prevent lower energy use. Unfortunately, it is thought that about 95% of our energy behaviour is almost entirely habitual, rather than rational, and information provision is usually not enough to change habit [37]. Smart energy monitors are also only as good as the households’ social and cultural contexts in which they are used. Ensuring that these contexts are supportive of changes in domestic energy consumption patterns seems vital, if smart energy monitors are to realise their potential (cf. [33]). Therefore, some recent studies of feedback on household electricity consumption have taken into account the effect of stimulated social interaction and social learning processes between the (family) members of households (cf. [34]).

The smart grid concept involves using enhanced system information to match consumption with generation in a situation with increased variability of generation over time (due to a larger fraction of renewables in the supply mix). This will allow making informed decisions about when a consumer should generate, store or consume electricity.

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5 MINERGIE® is a sustainability brand for new and refurbished buildings. It is mutually supported by the Swiss Confederation, the Swiss Cantons along with Trade and Industry and is registered in Switzerland and around the world and defended firmly against unlicensed use. Cf: http://www.minergie.ch/home_en.html
With smart meters and smart technologies such as home automation, consumers will get more influence on their own consumption patterns. Significant efficiency can be achieved with actions on energy use related resources such as recycling, lean manufacturing and prolonging product time life.

Investments by households and companies will have to play a major role in the energy system transformation. Greater access to capital for consumers and innovative business models are crucial. This also requires incentives to change behaviour, such as taxes, grants or on-site advice by experts, including the monetary incentives provided by energy prices reflecting the external costs. Most importantly, it involves a greater understanding of habits, habit formation and theories to change habits [cf. 37] beyond the commonly used model of a ‘Homo economicus’ who makes almost entirely rational decisions. In general, energy efficiency has to be included in a wide range of economic activities from, for example, IT systems development to standards for consumer appliances. The role of local organisations and utilities, cities and regions will be much greater in the energy systems of the future.

6. Conclusion

A critical learning of the analysis of different theories and models and practice is that, to meet the complex behaviour change challenge, different approaches are necessary that point out the importance of the direct and wider context or environment in which DSM efforts are situated. If this environment is not supportive of changing behaviour towards more efficient energy use, then it is very difficult (sometimes even impossible) for individuals to uphold these new behaviours after the support of a DSM programme has finished. The use of energy is entirely due to human needs and behaviours. Behaviour is rarely ever due to individual choices but rather driven by complex social interactions. One of the main drivers/barriers for changing behaviour is prevailing social norms. These social norms are strongly affected by our social networks. To achieve ongoing, effective DSM outcomes, individuals as well as their social, institutional, physical, technological, economic and cultural contexts need to be targeted (cf. [13]).

References


COOPERATION INITIATIVES FOR INCREASE OF ENERGY-EFFICIENCY IN REGIONS ACROSS EUROPE

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Abstract
Technological and behavioral shifts in built environments have been advocated by governmental policies across countries of Europe, due to the severe climate change and natural resource depletion witnessed today. This paper presents research cooperation initiatives aiming at improved energy-efficiency on a regional level, through a shift in planning methodology which allows capitalizing on collaborative approach and technological advancements.

Participatory planning measures promote an inclusive framework that engages policy makers and planning agencies together with civil society and business stakeholders. The procedure is applied on a wide geographical area and at different levels of government, aiming at deployment of a common vision of future development.

Moreover, technological progress allows for development and testing of innovative tools which support urban and regional planning and improve decision-making on issues related to urban management, environmental protection and energy consumption.

These planning techniques are widely investigated and deployed through diverse initiatives, programmes and projects funded by the European Commission. The overall goal is to ensure easier and more efficient transfer of people, services, ideas, knowledge and technologies within and between regions, and on the long run to overcome barriers for creation of low-carbon regions in Europe. These initiatives have been addressing both energy efficient construction of new and retrofit of existing buildings, as well as sustainable transport planning integrated with the land-use management, and energy infrastructure.

Such complex processes require a holistic, multidisciplinary approach and competent and devoted expertise. This research testifies about the state of the art of the relevant research projects and programmes, providing a benchmark for further advancement and transformation of the strategies for sustainable regional development.

Keywords: Energy-efficiency, technological progress, smart cities and regions, sustainable development, participatory planning

1. Introduction

Under severe climate change and natural resource depletion witnessed today, materialization of the sustainable development towards satisfaction of present and future needs within the limitations imposed by the state of technology and social organization on the environment has become an increasing priority.

Sustainable and resilient cities and regions strongly consider “a relationship between human economic systems and larger dynamic, but normally slower-changing, ecological systems in which 1) human life can continue indefinitely, 2) human individuals can flourish, and 3) human cultures can develop; but in which effects of human activities remain within bounds, so as not to destroy the diversity, complexity, and function of the ecological life support system.” (Costanza et al., 1991)
Across countries and continents, governmental policies advocate sustainable development, smart cities and regions and low-carbon societies, aiming at technological and behavioural shifts in the built environment.

This paper will present research cooperation methods and concrete initiatives aiming at improved energy-efficiency on a regional level through a shift in the planning measures, which allows capitalizing on technological advancements and collaborative approach.

2. The planning approach

Innovative participatory planning measures promote an inclusive framework that engages policy makers and planning agencies together with the civil society and business stakeholders. The procedure is applied on a wide geographical area and at different levels of government to develop a common vision of future development.

Moreover, technological progress allows for development and testing of e-service delivery, interoperable 3D Urban Information Models (UIM) based on urban pattern and its morphology, and long term collaboration for adopting User Driven Open Innovation. The results of this research should improve decision-making on issues related to urban planning, city management, environmental protection and energy.

2.1. Participatory Planning Measures

The concept of participation of citizens in planning and decision making has been present in social sciences since the 1960s. It refers to various mechanisms in which the public can express its opinions and ideally influence choices regarding the public interest. However, there is a big difference between “manipulation” and “citizen control” (Arnstein, 1969), namely there are levels of public participation and citizen power which are reminders that the power should truly be delegated and that participation should not exist only declaratively.

Through decades, various methods of participation were practiced, such as Citizens Panels, Consensus Conference, Focus Groups, Surveys, Public Hearings, Community planning, etc.
3.1.1. Charette or Enquiry-by-Design Workshops

Charette is a format of collaborative group session, often multiple, in which a group is working on finding a solution for the problem, and may divide into sub-groups to analyze specific aspects of the problem more in depth, providing a material for future dialogue with the remaining group members. This working approach is often called a Workshop. In urban and land use planning, the charette has become a technique for consulting with the various stakeholders, and this type of charette is also called an Enquiry by Design.

The charette typically involves intensive and possibly multi-day meetings, including policy makers, governmental officials and planning agencies together with the residents and civil society, and developers from the private, business sector. The purpose is to come up with a common, jointly owned solution, confronting and facilitating different and often opposite attitudes and interests.

2.2. Measures driven by the Technological Progress

2.2.1. Fostering Self-Organisation and Participation by Using ICT, Social Media and Mobile Technologies

The rapid growth of use and popularity of social media and mobile communication technologies has encouraged a demand for new forms of participatory planning and self-organizing governance by citizens. Information and communication technology (ICT) allows a good connection with residents' real needs, it is easy to fit into daily activity
patterns and it provides an opportunity to citizens to be involved in neighborhood affairs and collective actions if there is a willingness to contribute.

Aforementioned tools should be carefully examined in the countries where there are insufficient public participation initiatives and the innovative methodological and procedural framework is missing, in particular in the area of Strategic Environmental Assessments (Crnčević et al, 2011).

2.2.2. Smart Cities and Regions

Moreover, technological progress has allowed for the merge of traditional urban infrastructures with the ICT, and coordinated and integrated usage of new digital technologies, which is recently recognized as a Smart City (Batty et al, 2012) or a Smart Region Model.

Smart City puts the emphasis on the innovation, particularly on technological advancement, which then leads towards innovation in governance organization and improved public services.

The aim of a Smart City concept is to use detailed sensorized information and crowd-sourced funding and social lending for achieving dynamic, demand-based and real-time pricing by the public sector and therefore more efficient use of resources.

A substantial role in the promotion of Smart Cities as “intelligent” and “green” agglomerations is played by private companies and multinational corporations, such as IBM, SIEMENS, Schneider Electric, Veolia Environment, ORACLE, etc., which all developed specific lines of products adjusted to the demand of an increased urbanization.

Therefore, knowledge, technology and systemic approach have been strongly enforced as factors of urban and spatial sustainability. Innovation and research on sustainable urban systems have been mainly translated into sustainable urban infrastructure, to ensure urban resilience in the time of climate changes through increased usage of clean energies, sustainable and green transport, and protective, good management of the natural resources.

The concept of a Smart City has been scaled up, and a term of a Smart Region has emerged, mostly referring to the cost-efficient, energy saving areas, aiming at the usage of smart meters, smart grids, innovative end-user services and high share of renewable energy sources. This term is often expanded with an additional description - a Smart Energy Region.

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6 The recent pace of urbanization worldwide has led to the fact that in 2011, for the first time, more than half of the World population has lived in cities (World Bank Urban Development, 2013)
3. Specific European Initiatives
The aforementioned planning techniques are widely investigated and deployed through diverse initiatives funded by the European Commission. The overall goal is to ensure easier and more efficient transfer of people, services, ideas, knowledge and technologies within and between regions, and on the long run to overcome barriers for creation of low-carbon regions in Europe. These initiatives have been addressing both energy efficient construction of new and retrofit of existing buildings, as well as sustainable transport planning integrated with the land-use management, and energy infrastructure.

3.1. Initiatives and Programmes: INTERREG IIIB North Sea Programme
Since the 1989, the Interreg initiative of the European Union aims at stimulating cooperation between regions by enhancing collaboration among authorities of two or more Member States through the financing of the European Regional Development Fund (ERDF).

Strand B is focused on the transnational cooperation involving national, regional and local authorities in the formation of large groups of European regions which promote integration within the Union. Regions from several different countries can cooperate in order to solve joint or comparable problems.

Several projects within the Interreg IIIB North Sea Programme were focused on the Smart Cities and Regions.

3.1.1. SmartCities, Interreg IIIB North Sea project
The Smart Cities INTERREG project explored the whole North Sea region in terms of setting a new benchmark for e-service delivery. Its aim was to create an innovation network between governments and academic partners, which led to setting a new baseline for excellence in the domain of the development and take-up of e-services.

3.1.2. Smart Regions, a joint project between three Interreg IIIB North Sea projects: LoG-IN, BIRD and ICTs4SMEs
Smart Regions is the collection of over forty projects in the domain of e-Services, e-Learning and e-Government that were realized in European regions and cities in Belgium, Germany, Denmark, the Netherlands, Sweden and the United Kingdom closely working together, between 2002 and 2007.

The regions shared infrastructure, disseminated knowledge about advanced methodologies, took up successful solutions and built strong stakeholder cross-sector cooperation. “Traditional government delivers services to people. E-Government can work with people to deliver change.”

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7 Smart Regions: Introduction
3.2. Single Projects of the CIP Framework Programme

3.2.1. Poly-SUMP

The Poly-SUMP project is funded by the Intelligent Energy Europe (IEE) framework and examines participative methods for developing Sustainable Urban Mobility Plans on the regional level, in the cases of “polycentric” regions, namely regions with diffuse cities. ‘Diffuse city’ regions are areas characterised by several centres, where services such as working, shopping, entertainment etc., and therefore transport needs, are scattered in different towns and villages. Introduction of Sustainable Urban Mobility Plans in such regions needs to relate to the wider area and take a multi-governance approach in order to be effective, since often several municipalities, sometimes even from different countries, and many stakeholders are involved. POLY-SUMP project implements a participatory approach, based on the Future Search methodology, engaging citizens and stakeholders in the whole area.

The project has been guiding six diffuse city regions through this new participatory planning approach to help the development of a shared vision for urban mobility and an action plan for the preparation of an integrated Sustainable Urban Mobility Plan.

3.2.2. The SmartRegions

The SmartRegions project, which has been running since 2010 and will be completed in 2013, aims at promoting the uptake of innovative smart metering services through monitoring of the smart metering landscape in European countries and giving recommendations for the national regulatory frameworks, defining the best practices of innovative smart metering services and analysing the economic, environmental and social costs and benefits, and promoting the uptake of the best practices.

“The strategic results of the project include that innovative smart metering services will spread to other regions and Member States, and become business-as-usual in Member States, leading to better energy management and significant energy savings in the long term (at least the estimated 10 % potential realised).”

3.3. Single Project of the Seventh Framework Programme for Research and Technological Development & European Innovation Partnership

The EU funded FIREBALL (Future Internet Research & Experimentation By Adopting Living Labs) project established a coordination mechanism for a network of Smart Cities across Europe to engage in long term collaboration for adopting User Driven Open Innovation and explore the opportunities of the Future Internet. The coordination process was based on exchange, dialogue and learning between Smart Cities.

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8 The SmartRegions project, 2012
9 About FIREBALL, 2012
In January 2012, the FIREBALL project held its final conference. Speakers from various European organizations presented their views and research results, and opened up a discussion on shaping the European ‘Smart Cities’ agenda.

In July 2012, the European Commission launched the Smart Cities and Communities European Innovation Partnerships (EIP)\textsuperscript{10}, which is a new approach to EU research and innovation: challenge-driven, and focused on societal benefits and a rapid modernization of the associated sectors and markets.\textsuperscript{11} The aim of this partnership is to ensure pooling of resources to support the demonstration of energy, transport and information and communication technologies (ICT) in urban areas. These industries are invited to work together with cities' authorities, to combine their technologies in order to address cities' needs and “enable innovative, integrated and efficient technologies to roll out and enter the market more easily, while placing cities at the centre of innovation”\textsuperscript{12}.

### 3.4. COST TU1104 Initiative: Smart Energy Regions

A recent initiative of the European Cooperation in Science and Technology (COST), one of the longest-running European frameworks supporting cooperation among scientists and researchers across Europe, has been targeting the topic of the Smart Energy Regions with the aim to enhance considerable reductions of CO\textsubscript{2} emissions. This should be achieved through application and transferability of low carbon technologies within and between regions across Europe.

Along with the energy-efficient new and retrofit of existing buildings, their operation, embodied energy and potential for using low and zero energy supply, the decrease of green house gasses (GHG) and CO\textsubscript{2} emissions from the transport sector must be achieved.

### 4. Conclusion

Complex processes of integrated participatory planning methodologies using innovative technological achievements require a holistic, cross-sectoral and multidisciplinary approach and competent and devoted experts. This research testifies about the state of the art of the relevant research projects and programmes, providing a benchmark for further deployment and transformation of the strategies for sustainable regional development.

### References


\textsuperscript{10} Energy: Smart Cities and Communities, 2012

\textsuperscript{11} European Innovation Partnerships, 2012

\textsuperscript{12} Energy: Smart Cities and Communities, 2012


SUSTAINABLE URBAN DEVELOPMENT IN PRACTICE: ZEUS 2020 - A SHOWCASE

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Abstract

A smart city is more than the sum of smart buildings; that is what this paper aims to show. The paper presented here is based on a research study (“ZEUS 2020 – Zero Emission Urban Study”). This study is an interdisciplinary approach to reduce CO\textsubscript{2} emission in urban environments. The vision of the ‘zero emission city’ has the ability to add a vivid picture to the mission of sustainable urban development that is more comprehensible than the abstract term “sustainability”. Due to the integration of topics like traffic/mobility/logistics, energy management, sociology/social demographics or climate change and its effects on cities by different experts of the consortium, the study provides basic knowledge for an orientation about the “emission free city” and develops innovative ways and models for construction, urban development and life in cities in the 21\textsuperscript{st} century.

ZEUS 2020 aimed at the discovery and formulation of a new life concept in the urban environment. Starting at the planning phase all the way to the particular use of the facilities, it examined and newly defined all steps of the process, particularly regarding the reduction of CO\textsubscript{2} emissions. The model, which was found this way, was checked in an urban area of a project partner city in general and also in regards to its flexibility concerning local/regional characteristics. Finally, the transfer of the model to other cities/regions represents an important outcome of the study. The designed model can serve as the basis for a standardized process for the development of city districts/areas, similar to an environmental compatibility evaluation.

Keywords: Zero Emission; Sustainable urban development; Holistic urban planning

1. Introduction

Our world is more and more shaped by cities. The percentage of people living in cities is increasing constantly. This development goes hand in hand with serious demographic, economic, ecological and social changes. Big cities cover around 2\% of the earth surface but are emitting 80\% of greenhouse gases and consume 75\% of the energy use worldwide (according to EU calculations). So it is the global cities where the battle for a better climate will be fought in the upcoming decades.

Cities are conglomerates of people, goods, transport and communication systems. A significant decrease of emissions cannot only be reached by the use of new technologies but has to be supported by new systems. The vision of a “Zero Emission City” has the ability to add a vivid picture to the mission of sustainable urban development that is more comprehensible than the abstract term “sustainability”. To reach the goal of a nearly
emission free city, city development and city management have to be guided by principles of a sustainable city development. This means an orientation to principles of ecological compatibleness, reversibility, elasticity, efficiency and equity. The capacity of the environment to provide resources, absorb emissions and waste is finite. But how can such a "new system" look like and how does it have to be shaped to fulfil a certain degree of “Zero Emission Standard”? 

2. ZEUS 2020

ZEUS 2020 (Zero Emission Urban Study 2020) was a project designed in 2009 and elaborated from 2010 to 2012. Right at the beginning of the project, fundamental elements and approaches were elaborated to define the characteristics of a Zero Emission strategy. This approach is highly systemic and holistic and “system-changing”. This can be seen throughout the project in which the whole development process is oriented towards an optimum model and overall concept, a goal that can only be reached though radical changes in already existing approaches to urban and regional planning. Analysing and adapting economic and ecologic impacts and social feasibility of these radical approaches in a chosen region can facilitate to start a feasible planning approach.

After defining the preconditions and basic points of the vision “Zero Emission City” and an analysis of 4 fields of actions – settlement structures, energy supply, production processes (closed loop waste management and traffic – these basic points were linked to urban and regional operating levels, resulting in a tool box for urban planners.

The question how resource and energy efficiency can be increased in the context of a Zero Emission approach and how this can be managed while reducing, at the same time, the use of fossil and nuclear energy carriers was discussed in a separate work package. The urban Zero Emission System shall be mostly energy self-sufficient which leads to a focus on energy carriers like PV and solar heat, which are available in a city. Through local provision fewer losses due to converting and transport can be achieved.

The Zero Emission approach as it was developed in ZEUS 2020 is a highly innovative planning and development tool for urban quarters. This is visible on the one hand in the different specific topics that were covered (traffic, resource management, city planning, etc.) as well as on the other hand in the monitoring of ecologic and economic aspects of the developed ideas for implementation. The composition of the consortium demonstrates that the development and the implementation of this project build on the close interdisciplinary cooperation between industry and science. With the Austrian Railway Company as project manager this is a signal for a new intellectual approach in the energy sector with high relevance to practice to create innovative reproducible models with a potential for at least medium-term economically interesting solutions.

The methodology elaborated in this project is a helpful tool especially for planning and decision of new urban quarters. Due to the reciprocal integration of so many disciplines, the study provided basic knowledge for orientation about the “emission free city” and has develop innovative ways and models for the construction and life in the 21st century.
The vision of a “Zero Emission City” consciously challenges the paradigm of the non-emission-free city, in order to point out that it is not sufficient to reduce the output of cities in small steps. It requires trend-setting overall planning. The vision of the “Zero Emission City” has the ability to add a vivid picture to the mission of the sustainable urban development that is more comprehensible than the abstract term sustainability. A clear goal and trend certainty are a given.

3. Research Methodology

Interesting in the project ZEUS is the methodology: in conventional planning, the starting point is a certain status quo, certain measurements will be fixed according to sectors and will be discussed with concerned stakeholders. Influenced by internal interests and external megatrends, the perception of measurements approach the vision of a liveable city (inductive approach, see fig. 1)

![Inductive approach](image)

In contrary to that, the methodology of ZEUS is based on a deductive approach: Zero Emission in an urban area is not seen as a vision but a concrete guideline and the starting point of the planning procedure. The „Zero Emission Urban System“ as a guideline defines the „ideal urban space system“ as the focal point, according to its emissions status. This ideal system can be divided into (likewise) ideal sub-systems, where requirements for an ideal emission-free urban space can be defined, according to the different sectors (see fig. 2).
As the ideal system can be reached in theory but rarely in practice, in a next step compromises have to be found by including stakeholders and considering interests and megatrends. Only in this way, realizable planning steps and measurements can be found.

The study ZEUS 2020 is an interdisciplinary approach to reduce CO₂ emission in urban environments. From the perspective of the consortium, this approach, combined with a sustainable involvement in the topic, will guarantee a realizable solution that, at the same time, is fit for the future.

The various issues that are considered and covered in ZEUS 2020 are:

- Cross-cutting issues:
- Ecology (including regional and federal government climate goals)
- Economy – economic and business consideration
- City planning/spatial planning/architecture
- This area handles the standards and specifications for governmental and commercial settlement areas.
- Traffic/mobility/logistic
- The traffic area covers requirements for motorized individual transport, public transport, as well as not motorized individual transport (bicycle and pedestrian traffic), and traffic and supply logistics. In addition to traffic planning per se, it also contemplates about questions regarding the formation of traffic within the spatial
system (user behavior and usage allocation throughout the room) and the possibility for traffic assignment or relocation within the system.

- Energy management – with focus on alternative or renewable energy sources
- Meteorology, climate
- Sociology – social demographics (this also includes the cultural sphere)

The interdependences of all these disciplines lead to a common approach for the topic of a emission free city with the aim to provide a basis knowledge for orientation and elaborate innovative ways and models for building and living in the 21st century.

ZEUS 2020 is geared towards the discovery and formulation of a new life concept in the urban environment. Starting at the planning phase all the way to the particular use of the facilities, it examines and newly defines all steps of the process, particularly regarding the massive reduction of CO₂ emissions. The model, which is found this way, was checked in an urban area of a project partner city, generally, and also in regards to its flexibility concerning local/regional characteristics. In the course of the project, a continuous evaluation and a continuous alignment with the needs and requirements of the model region (Linz) and the specific model area (ÖBB properties south of Hauptbahnhof Linz/Linz Central Station) took place.

First, a framework had to be done for the development of a Zero Emission System. Therefore, in work package 1, a consolidated definition of “Zero Emission in an urban context” was elaborated and a monitoring system, based on ecologic and economic parameters was defined. Work package 1 is a comprehensive work package that connects the hypothesis and interrelations between work packages 3 to 8 (see fig. 3). Work package 2 is a summary of the Status quo to complete the picture.
Fig. 3: Interdisciplinary Approach
4. Results

This is a brief summary of the results achieved in the different work packages. In work package 1, the constituent characteristics of a Zero Emission urban quarter have been defined. Besides that, an ecologic and economic framework for the different strategies in the diverse fields of actions was defined and assessments were done accordingly.

At the same time, a summary of the Status Quo was done: literature research and interviews to international, scientific publications and already realised projects (China-Shanghai, Germany, Dubai, Austria, etc.), which give practical information for possible implementation for ZEUS 2020. The needs and demands of some selected socio-demographic stakeholders to a city were also documented and analysed.

Basic information for the deduction of the concept for the model region chosen in Austria in terms of urban planning were summarized and built the basis for a toolbox with necessary and essential instructions and measurements was elaborated and is available for urban planners.

Another ZEUS Tool was developed to help apply measurements in traffic and logistics, according to saving goals ("avoid traffic – provide mobility"). The aim was to define an integrated sustainable traffic and mobility concept, which also interconnects with the environment of a city and not only with system-internal material flows. A research and analysis of available and necessary technologies for the design of a Zero-Emission-Urban-System, with special focus on material and energy flows was done in a separate work package. Also the (micro) climate in the city of Linz (the model region) was analysed and the future developments were derived, described in a report and adopted for the measurement matrix.

The last workpackage is in a way summarizing all the results: besides a description of the spatial and infrastructural preconditions and development potentials, all the results from all the other work packages were implemented and analysed at the model case. Therefore the methods and measurements were used and a comprehensive Zero–Emission-development scenario, based on the characteristics of a Zero Emission city was developed. The results obtained this way were monitored economically and ecologically and climate related, with regard to their relevance, feasibility and effects.
5. Summary and Outlook

ZEUS 2020 aims at the discovery and formulation of a new life concept in the urban environment. Starting at the planning phase all the way to the particular use of the facilities, it examines and newly defines all steps of the process, particularly regarding the massive reduction of CO₂ emissions. A very important point of the project ZEUS 2020 is the interdisciplinary approach that was chosen. Only due to this holistic view, a result-oriented outcome could be achieved.

The results are addressing funding agency, planners as well scientists. In all these disciplines the results can be used and further developed. For further projects it is highly recommended to include stakeholders (especially future inhabitants) as early as possible.

Finally, the transfer of the model to other cities/regions represents an important outcome of ZEUS 2020. The designed model will serve as the basis for a standardized process for the development of city districts/areas, similar to an environmental compatibility evaluation.