The Ecology of Scale: Further Examples and Comments.

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Background, Aims and Scope

As a conclusion of our latest studies, presented at InLCA/LCM 2003, we supposed, that the ecology of food production and distribution is depending on the number of produced items. At the same time, the previous supposition, that the transport distance should determine the energy turnover, was definitely falsified. Even a global business chain can be more effective than a regional one, in terms of specific energy turnover per functional unit.

Additionally, our results pointed on a minimum business size, which should be necessary for energy saving food production and distribution. Regional food business can compete with global process chains, only in case, the business size is big enough. Hence, we recommended the foundation of regional cooperatives of food production and/or of food marketing.

But, on the other hand, at InLCA/LCM 2003 only two food items as examples were presented: juices (fig. 1) and lamb meat (fig. 2), as a result of five years of field research worldwide.

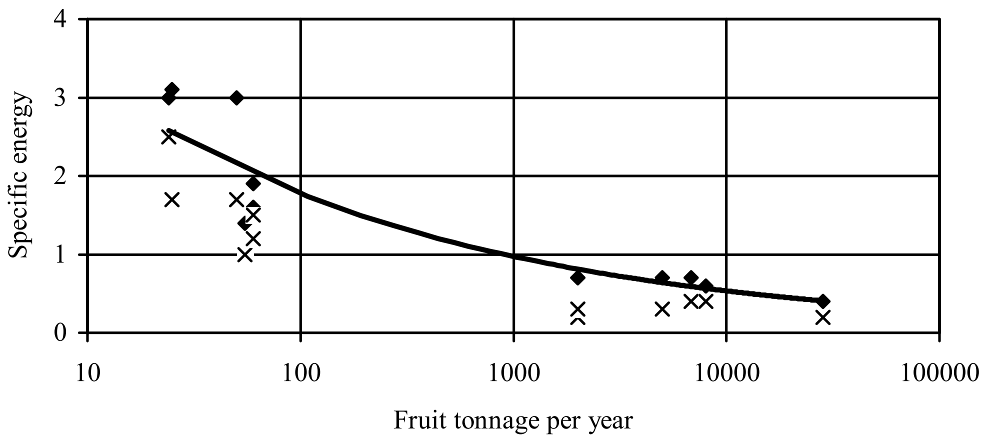

Fig. 1: Specific energy turnover in kWh/l versus fruit tonnage in tons/a: Production (marked by x) plus transports and distribution (marked by ♦)[3]

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3 [Schlich 2003] Schlich E, Fleissner U: Comparison of Regional Energy Turnover with Global Food. InLCA. Seattle (2003).

Based upon primary data of all global and regional process steps of fruit juices, it was concluded that the specific energy turnover of fruit juices produced from small companies turns out to be higher than comparable fruit juices from companies with more than 2,000 tons per year, in all investigated cases, not dependent on the marketing distance.

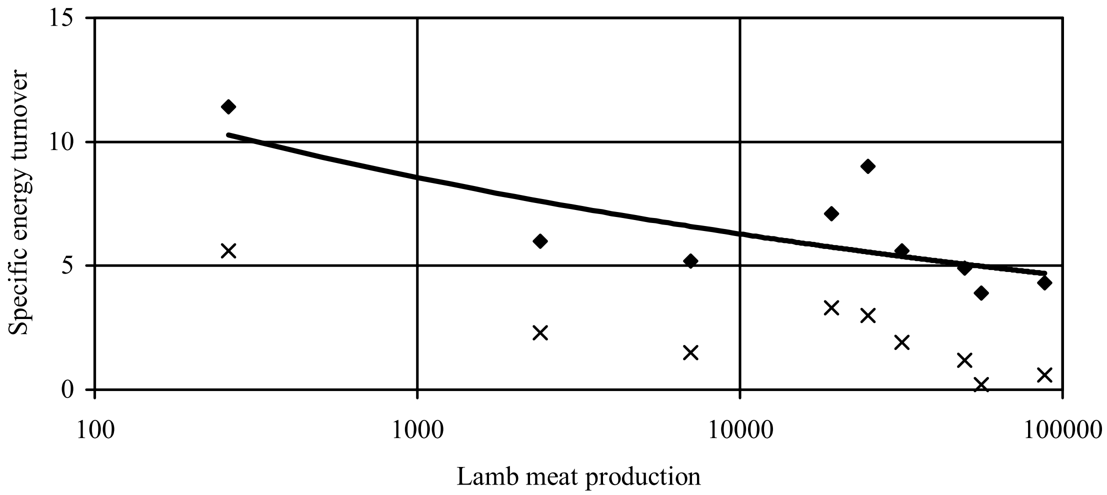

Fig. 2: Specific energy turnover in kWh/kg versus lamb meat production in kg/a: Production (marked by x) plus transports and distribution (marked by ♦)

Again, the investigated data of lamb meat demonstrate definitely two facts: first of all, the specific energy turnover is again dependent on the business size, as seen before with the data of fruit juices; secondly, the sea transportation - under strict cooling conditions in accordance to HACCP - takes less energy than local transportation and distribution efforts, even in the long run. Again, the marketing distance does not play any role at all, because the efficiency and the logistics of production and distribution are absolutely dominant!

Because of these findings the term of **"Ecology of Scale"** was claimed, defined on the analogy to the term **"Economy of Scale"**. To support that idea, further examples are investigated and presented here.

Objective

The main objective of our studies is to clarify the influence of the marketing distance and/or of the business size upon the specific energy turnover of food and non food items. The topic of this paper is on the one hand, to explain the qualitative empirical approach. On the other hand, we present more data from further studies. Again, the specific energy turnover is investigated, calculated in kJ or kWh per functional unit. The results are related to adequate units, describing the capacity or size of the actual example. Examples from traffic, housing and physiology are described. In a case study the transport by car, bus, train and plane inside Germany is evaluated.

Additionally, different types of households are compared, investigating the energy for heating and the turnover of electricity. These examples of human economy are compared with physiological data from different mammals, to find out similarities, looking at the dependency of specific energy turnover and size.

Method

Obviously, the scientific method of our investigation is **qualitative** field research, by empirical investigation. The research topic, to compare different business or household units of differing size, demands the application of this qualitative method. As a matter of fact, quantitative scientific methods would not answer the actual questions of our project. As a part of LCA, the energy turnover of comparable units is investigated, by personal interview worldwide. All the interviews are prepared by a qualitative questionnaire. The answers are supported by energy bills and business data sheets.

This qualitative research method is well established as a admissible scientific method. The results are representative in a qualitative understanding. Any other scientist, using the same qualitative scientific method, would come to the same results, even in case, different business units would be researched. The primary results are allocated to the functional units. Regarding the traffic example, the basic data are in all cases related to 100 Pkm[4]. The household data are related to the number of people living there. The physiological data of mammals are related to their body mass, in order to get specific data.

Example 1: Traffic carriers

This example compares three different carriers: private cars (A), train (B) and plane (C) inside Germany. Assumed, 600 people would like to travel from Frankfurt to Hamburg, which is approximately a distance of 600 km, we can calculate the energy turnover of the different carriers, due to their capacity. Tab. 1 shows the data assessment.

Tab. 1: Specific data of different possible carriers from Frankfurt to Hamburg

		Seats	Average utilization[5]	Duration	Energy turnover
A	Car	5	25 %	5 h	8 l per 100 km
B	Train	750	80 %	4 h	19,800 kWh per h
C	Plane	220	91 %	1 h 20 min	4,000 l per h

[4] 100 Pkm: German term 100 Personenkilometer, calculated as the product of distance (km) and the number of transported people, divided by 100.

[5] Average utilization of total carrier capacity, in accordance with statistical data of German government.

Based upon this data assessment, for the transport of 600 people from Frankfurt to Hamburg, 480 cars or one train or three planes are needed, in accordance with the statistic average utilization data of these carriers. The 480 cars need 23,040 liters of gas for that transport, which is about 230,400 kWh [6]. The train takes 79,200 kWh, and the three planes need 16,000 l gas, equivalent to 160,000 kWh. Related to the functional unit of 100 Pkm (the total is 360,000 Pkm), the final results are calculated. The cars turn out with nearly 64, the plane with 45 and the train with 22 kWh/100 Pkm. In terms of gas these results correspond to 6.4 l/100 Pkm for the cars, 4.5 l/100 Pkm for the plane and 2.2 l/100 Pkm for the train. In order to ask the question of scale, the results are shown as a function of the capacity of the carriers (fig. 3).

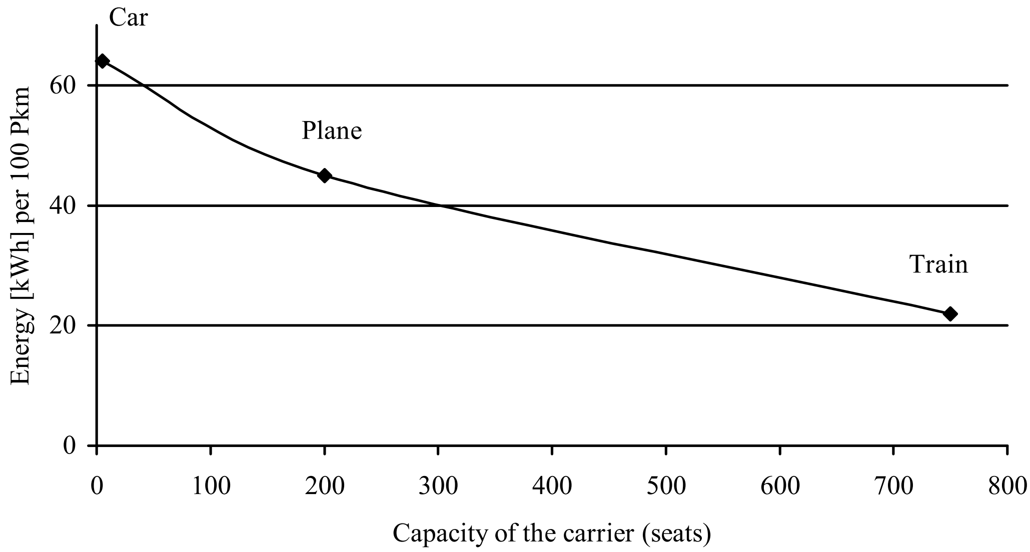

Fig. 3: Specific energy of traffic carriers in kWh per 100 Pkm, dependent on the capacity of the carrier

Again, we find a digressive function, demonstrating the disadvantage of smaller carriers. As a matter of fact, these results are valid only for the actual data assessment, as shown before. Obviously, the cars would benefit very much from using their full loading capacity. But, in Germany the average utilization of cars with five seats is very low, as shown in tab. 1.

Example 2: Housing

This example compares different types of households, reporting at first German macrostatistics, and calculating secondly a typical example of living. In Germany, the way of living is changing dramatically. Especially the number of persons, living in households or families, is decreasing. Fig. 4 shows the correlation between population and number of households within the last 50 and estimated for the next 50 years.

[6] 1 liter of gas corresponds roughly to 10 kWh.

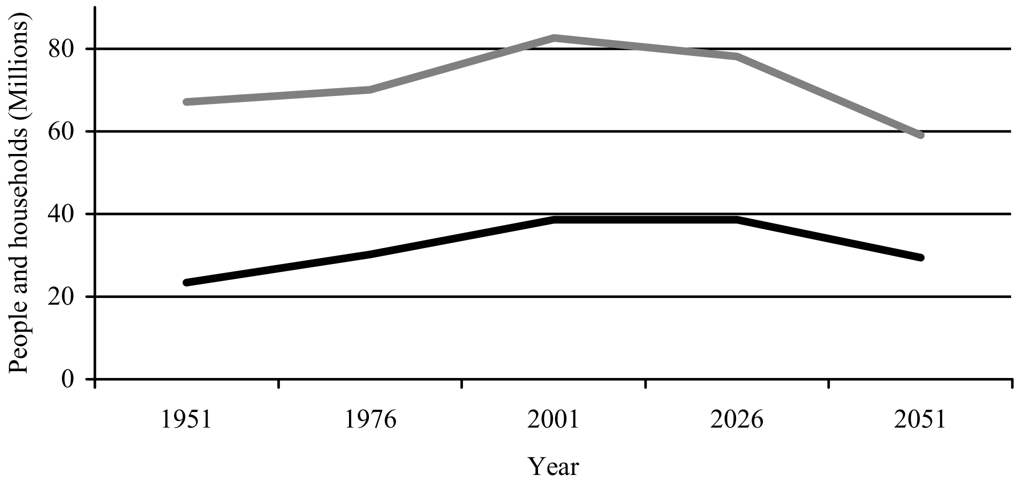

Fig. 4: Millions of households (black line) and population (grey line) in Germany [7]

The specific numbers of persons per household is shown in fig. 5.

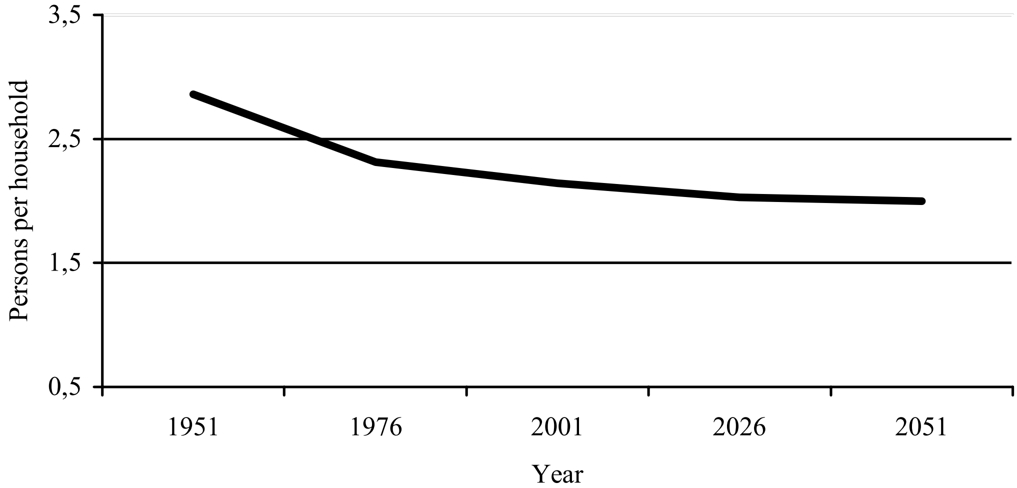

Fig. 5: Persons per household in Germany [8]

The consume of electricity in German households is increasing, as demonstrated in fig. 6. The data are based upon macrostatistics of the German association of power stations. To look for the influence of smaller households, the cross-relation between the number of persons per household (fig. 5) and the specific electricity turnover per household (fig. 6) is calculated. Obviously, the results (see fig. 7) demonstrate a digressive function, because the increasing number of persons per household is closely connected with a decreasing turnover of electricity per person. This is leads to **Ecology of Scale** again, comparable to the former examples.

[7] Data base and prediction in accordance with German governmental statistics, including statistics of former Federal Republic of Germany (FRG) and German Democratic Republic (GDR).

[8] Data base and prediction in accordance with German governmental statistics.

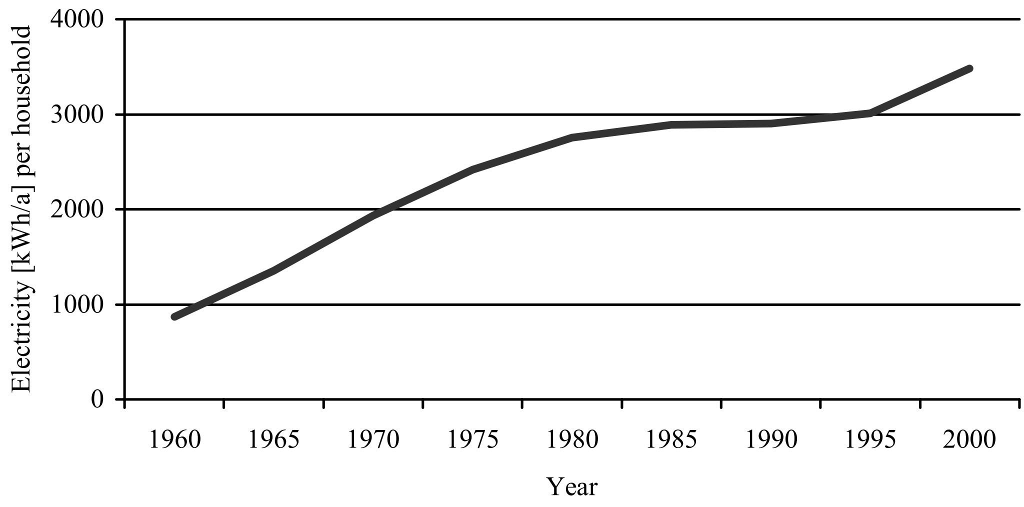

Fig. 6: Electricity turnover in kWh/a per household in Germany [9]

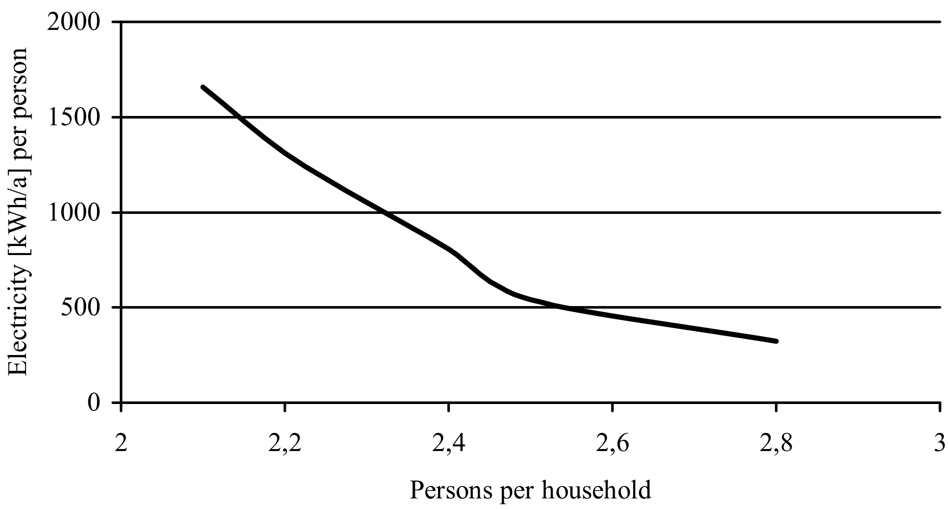

Fig. 7: Electricity turnover in kWh/a, dependent from the number of persons per household [10]

Although the number and the use of electrical devices in German households increase, and despite of the technical progress in energy saving, a digressive correlation between the specific turnover of energy and the number of people living in one household can be seen. As a matter of fact, all statistical data reconfirm the negative impact of single households upon the energy turnover, in coincidence with the term of **Ecology of Scale**.

To investigate the influence of more energy expenses for heating of small households, a further example is performed. Three related families are living in three different types of buildings, assuming the following facts (tab. 2).

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[9] See: www.hea.de

[10] Calculation by cross-relation of fig. 5 and 6.

Tab. 2: Specific data of different households

	Persons	Area	Type (Year)	EKZ[11]
Junior	4	120 m^2	Dwelling (2000)	120 kWh/(m^2 a)
Widow	1	80 m^2	Dwelling (1920)	225 kWh/(m^2 a)
Senior	2	160 m^2	Bungalow (1970)	180 kWh/(m^2 a)

Each household consumes energy for heating. The junior household needs 14,400 kWh, the widow 18,000, and the senior household 28,800 kWh per year, in order to heat the rooms. Altogether these three parties consume 61,200 kWh per year for heating. Due to their relationship, the three households think about building a new home for all of them. The new home should be equipped with three dwellings, one for each of them. Altogether they will have 300 m^2, 120 m^2 for the juniors, 60 m^2 for the widow and 120 m^2 for the seniors. Because of modern insulation and good construction the type of the building meets the requirements of low-energy-houses, needing only 25 kWh/(m^2 a). Therefore the total energy turnover for heating is estimated with about 7,500 kWh/a only. This data assessment is compared in fig. 8.

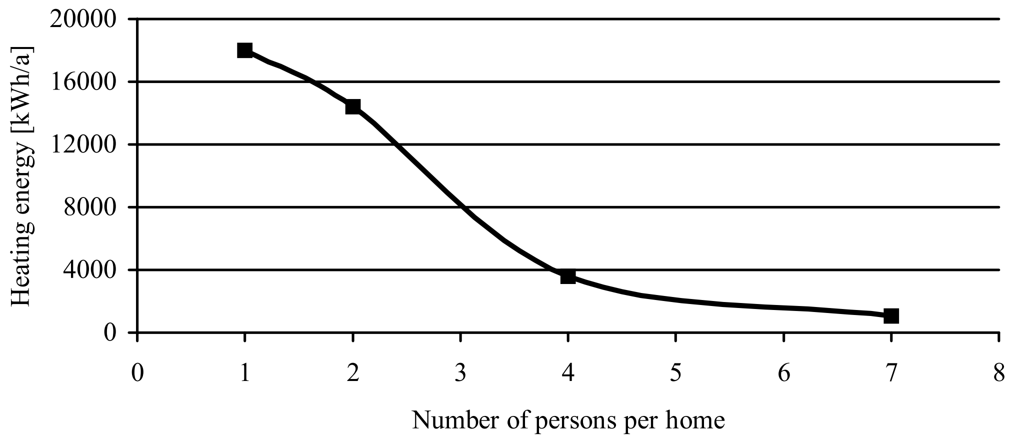

Fig. 8: Heating energy in kWh per person and year, dependent on the number of persons

The examples of housing demonstrate clearly, that larger units in all cases need less energy per person than smaller. Especially singles are wasting a lot of energy. By the way: nature knows this result very well, e. g. in the ecology of ants and bees. These animals construct big colonies, to save energy and to control the climate of their home. As final conclusion, ants and bees form their colonies, to get a small specific surface to the environment, in order to survive. In all cases, we find a more or less strong digressive relation between the specific energy turnover and the size, leading again to our term of **Ecology of Scale**.

[11] EKZ (Energiekennziffer): Specific energy turnover per area and year, dependent on the type and year of the construction.

Example 3: Physiology

Small mammals have a larger specific body surface than big mammals. The heat exchange of the body mass with the environment is proportional to the body surface, due to the thermo-dynamic laws of heat transfer. This correlation is described by equation 1:

$$\mathbf{d}\boldsymbol{Q}/\mathbf{d}\boldsymbol{t} = \boldsymbol{\alpha} * \boldsymbol{A} * \boldsymbol{\Delta T} \quad [\mathrm{W}] \qquad \text{(eq. 1)},$$

with: Q = thermal energy [J]; t = time [s]; α = heat transfer coefficient [W/(m^2 K)]; A = surface area [m^2], T = temperature [K].

Because the temperature of mammals is usually higher than the temperature of their environment, a positive heat exchange rate from the body to the environment takes place. In order to keep the body temperature physiological high, energy turnover is necessary. All the energy of mammals is consumed by nutrition. Physiologists describe the energy turnover of living organisms, using the term of metabolic rate. The metabolic rate (here: the specific oxygen turnover) per unit body mass of a small mammal is higher than the metabolic rate of a larger one (see fig. 9). The oxygen turnover of a shrew (body mass 0.0048 kg) is 7.4 l/(kg*h), of a human (body mass 70 kg) 0.21 l/(kg*h) and of an elephant (body mass 3,833 kg) 0.07 l/(kg*h).

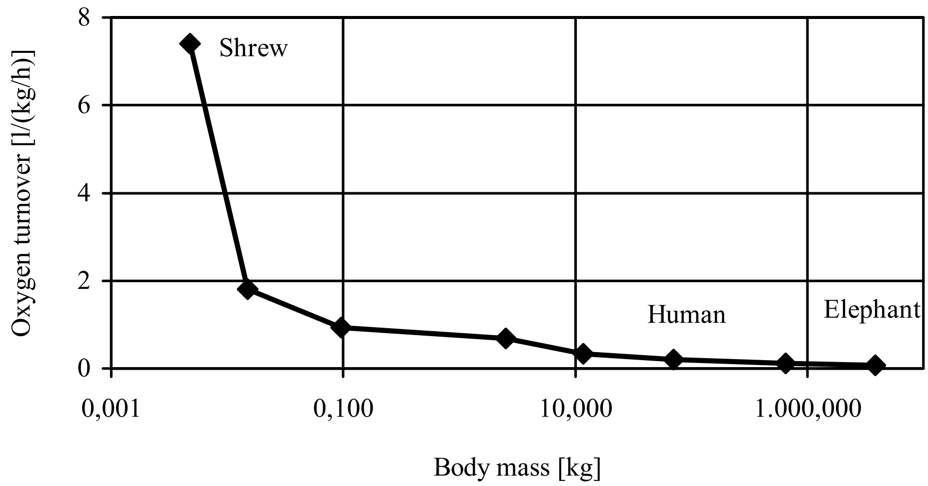

Fig. 9: Specific oxygen turnover of different mammals [12] [13]

Fig. 9 demonstrates, that the energy turnover of mammals depends on the specific surface of their body. Small mammals have a high surface per kg body mass. The body surface area determines the heat exchange ratio, due to eq. 1. Hence the small mammals show up with a high metabolic rate, measured in terms of oxygen turnover per kg body mass and per hour.

[12] [Schmidt-Nielsen 1999]: Schmidt-Nielsen, K.: Physiologie der Tiere. Heidelberg: 1999.

[13] The units are written in German notation. 1.000,000 kg means 1,000.000 kg in American notation.

The same correlation can be seen in fig. 10. Here the heart frequency in beats per minute is related to the body mass of mammals (fig. 10). Five typical examples are shown: The smallest mammal is the shrew (4.8 g). Here we notice a heart frequency of unbelievable 600 beats/min. The heart of a little dog (10 kg body mass) beats about 100 times/min. The heart of a human (70 kg) beats approximately 70 times/min. The horse (500 kg) has 35 heart beats and the elephant (3,800 kg) only 25 heart beats per min.

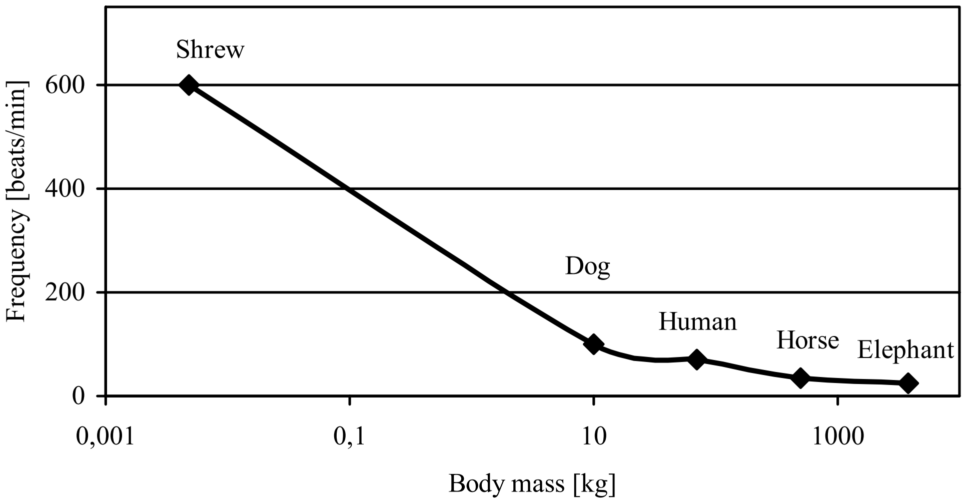

Fig. 10: Heart frequency and body mass of different mammals[14]

All these data are related to the fact, that the specific energy turnover of mammals depends upon their body size. Here we can see a strong digressive correlation. The frequency of heart beats and the specific energy turnover correlate in reverse with the body mass. Finally and not surprisingly, the physiological data of mammals support the idea of **Ecology of Scale**.

Conclusions

In all cases, the results demonstrate a strong digressive relation between the specific energy turnover and the functional units. The huge number of individual transports with private cars cannot compete with train or plane - of course only in case, there are trains or planes. On the long distance, even the plane saves energy, compared with the cars. The electricity turnover of small households is definitely higher compared with bigger units. The energy turnover, which is needed to heat the rooms, is dependent on the outer surface of the house, on the heat insulation and on the heat recovery technology. Bigger houses with more people living there need in all cases less energy. Hence the specific energy turnover per person is much lower, if the number of people living in one house increases.

[14] [Stahl 1967] Stahl, W. R.: Scaling of respiratory variables in mammals. In: J Appl Physiol 22 (1967), 453-460.

The physiology of mammals leads us to similar facts. Small mammals show up with a remarkable high number of heart beats. The metabolic rate in terms of the specific oxygen turnover is decreasing, in case of a increasing body mass of the mammal. All these findings are related to the fact, that small units have a significant greater specific surface area to their environment. Hence the specific heat exchange rate is much higher. This thermodynamic law demands higher metabolic rates for smaller mammals. Although no mammals, ants and bees know very well about these facts. They construct colonies, in order to save energy and to survive. Sheep crowd together at night, to keep themselves safe and warm.

These few examples from nature support our idea of **Ecology of Scale**. For the human economy of food, traffic and housing, the coincidence of economic and ecological facts is obvious. Human hedonism and individualism turn out to be a energy wasting lifestyle. Additionally, natural processes and biological systems know about the **Ecology of Scale** as well.

Recommendation and Outlook

In on going studies, the impact of the business size at further food items is researched. At moment, we investigate viniculture as local, regional, continental and global business. Actually, we evaluate numerous German vineyards, vinification units and distribution expenses. Additional, we collect data from Spain, France, Hungary and South Africa, expecting further results at the end of the year. People, who are interested on further results, should check our homepage www.uni-giessen.de/fbr09/hht.

Acknowledgement

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