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Rural Metabolism:

Material flows in an Austrian village in 1830 and 2001

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Abstract

This working paper presents material flow data for a small rural settlement for 1830 and 2001. By analyzing the material flows it can be shown that while in 1830 extraction had to satisfy consumption plus a small surplus for tithes or market sale in 2001 extraction went almost completely into exports leaving consumption to be satisfied mainly by imports. This can be interpreted as a spatial decoupling of production and consumption. At the same time the level of material input has been increased by a factor 3. While the complete working population was engaged in agricultural activities in 1830, the employment and income situation was very diverse in 2001. Further disaggregating into household types reveals that the metabolic profiles in 2001 vary considerably. A differentiation into production and consumption at household level shows that variation can mostly be explained by the degree of involvement in agricultural activities and by the farming type (mainly mixed farming and perennial cropping). However, data provide insights that 1830 biomass flows are still persistent in the metabolic flows of 2001 due to similar production practices and property rights. This offers some hints where sustainability policies could achieve substantial effects when supporting such persistent processes during recent transitions in rural areas from biomass to fossil based societies in Eastern Europe, Asia, Latin America and Africa.

Keywords:
Social metabolism, material flow accounting, sustainable consumption, rural systems, agriculture.

1. Introduction

The impact of socio-economic activity on nature is a biophysical phenomenon realized through the magnitude, concentration, dissipation and transformation of material and energy flows (Daniels and Moore, 2001) or in other words, through society’s metabolism. In turn, impacts may reduce nature's ability to provide raw materials, to assimilate wastes and emissions and many other important ecosystem functions. Consequently, the investigation of social or industrial metabolism and the corresponding methodological framework of material and energy flow accounting (MEFA) has gained attention during the last decades and meanwhile obtains a prominent place in the field of industrial ecology. The spectrum of available MFA studies is wide and ranges from the investigation of substance flows to overall socio-economic material use and from the company to the national and global scale. Most of the existing work, however, focuses either on the national or global scale or on the investigation of the metabolism of industrial and urban systems. In contrast, material flows in local rural systems are rare. Only in recent years a number of local MFA studies have been published, among them an MFA for a Thai village (Grünbühel et al., 1999 and 2003), the Nicobar Islands (Singh, 2003; Singh and Haas 2012), a Vietnamese village (Hobbes 2007), a village in the Bolivian Amazon (Ringhofer 2007) and a watershed in Ethiopia (Andarge 2014). Recently also a manual for local studies in social metabolism (Singh et al. 2010) and a comparison of local case studies was published (Fischer-Kowalski et al. 2011a).

Several studies also have applied the approach to reconstruct biophysical exchange processes between society and nature in historical rural systems. The focus on urban-industrial systems in MFA studies is comprehensible – as urban and industrial development drives much of the changes in social metabolism and the resulting pressures and a better understanding of their metabolism is crucial for a transition to a more sustainable social metabolism. However, also rural systems deserve attention. On the one hand, more than 50% of the world population are considered rural (Fischer-Kowalski et al. 2014, UNPD 2011) and rural systems both in the countries of the global south and the industrialized countries are highly dynamic and with their development also their metabolism changes.

While most local studies were performed in the global south, in this paper we focus on material flows in a rural community in Austria. The village of Theyern in Lower Austria inhabits 77 people in 21 households and agriculture is the most important economic activity in the village. To investigate material flows in a small local system we applied the framework of economy wide material flow accounting (Fischer-Kowalski et al. 2011b) which we adopted for its application at the local level. We collected material flow data for individual households (used extraction, imports and exports) for major material types (biomass, fossil energy carriers, metal ores and industrial minerals, construction minerals) and calculated MFA indicators (DMI and DMC). We discuss the patterns of material use across household types and compare current with historic patterns from the early 19th century. We investigate the material use patterns in different household types and assess the significance of economic activities for the metabolic profile of individual households. In order to gain insights in the long term historical development of the metabolism of the rural community we compare the results for the year 2001 with a reconstruction of material flows in Theyern at the advent of the industrial revolution, some 170 years earlier. These data are available from a previous study (Krausmann 2009).

In the methods section we briefly outline the methodological background of the collection of MFA data and highlight a number of system boundary issues of importance for the application of economy-wide MFA at the local level. This is followed by a section, which presents the overall results for important material flow indicators at the level of individual households and the village total for major material groups. We distinguish between a production and a consumption subsystem, which allows us to draw a more differentiated picture of material flows in rural households and to highlight the significance of agriculture for rural metabolism. In the discussion section we highlight the differences of metabolic profiles among household types, consumption-production and through time. Finally we compare the results for Theyern with those obtained from other local studies. We conclude with some insights from studying Theyern 1830 and 2001 for ongoing rural transitions in the global South and with remarks on the usefulness of methodological specificities applied in this study.

2. Methods and data

In this paper we present data on material flows in a rural village in 1830 and 2001 and analyze household level MFA data for the year 2001. In general, we applied the accounting principles and methods of economy wide material flow accounting to collect data and calculate aggregate material flow indicators as they are outlined e.g. in the guidelines applied by the European Statistical Office (Eurostat 2001 and 2009). We quantify used domestic extraction, imports and exports. For the calculation of material flow indicators DMC and DMI we distinguish three major material categories (biomass, fossil fuels and minerals). Direct material input (DMI) is defined as the sum of DE and Imports, domestic material consumption (DMC) is calculated as DMI minus exports. However, the application of current standard methods available for economy wide MFA is not straight forward and requires further considerations in particular with respect to the important issue of system boundaries.

2.1 System boundaries

Material flow accounting is a balancing approach and in any form of balancing the definition of appropriate system boundaries is an issue of crucial importance. For MFA accounts two types of system boundaries have to be defined: a) the boundary between the observed socio-economic system and its natural environment and b) the boundary between the observed and all other socioeconomic systems (Eurostat 2009). With respect to a) the definition used in economy-wide MFA can be applied straight forward for local studies. More difficult is setting an appropriate boundary with respect to b), the boundaries between socio-economic systems, an issue also debated in urban metabolism studies (Pincetl and Bunje 2009, Kennedy et al. 2010). In general, it is agreed upon that material flow accounts should follow the residence principle, that is, all material flows, which can be attributed to transactions of resident units, should be accounted for. In practical terms, at the national scale, administrative boundaries are often used as a proxy. This means that all extraction from the national territory is counted for as DE and that import and export flows can be assumed consistent with the system boundaries applied in trade statistics. In most cases the infringements of the residence principle resulting from these pragmatic assumptions are of minor significance and can be ignored. For some cases (e.g. fuel consumption in cross boundary mobility) correction procedures have been suggested (see e.g. Eurostat guidelines for material flow accounting (Eurostat 2009)).

For studies on a local scale differences between the various accounting approaches are more significant. Therefore, in contrast to the national level, it needs a clear decision what accounting principle is implemented. In our study, as a general rule, we tried to be consistent with the residence principle and account for all used extraction, imports and exports of materials that can be associated to local resident units (individuals and economic entities such as farms). Thus, we consider all land under legitimate control of the local population or local economic entities. Such an approach assumes so called functional boundary (Singh et al. 2010). Compared to the administrative boundary and the territorial principle this has significant implications on what is accounted for as DE or import/export, in particular in the context of agriculture.

To illustrate this lets assume the case of a farmer from village A who owns or leases a plot of land in a neighboring village B from which s/he harvests crops. If the administrative boundary (territorial principle) is applied the harvested crops have to be accounted for as import into the investigated system. Despite the fact that the relevant decisions about management of the land are made and the related material flows are generated in village A, the flow is accounted for as extraction in system B. Contrary, all materials that the farmer applies to produce and harvest that crop (e.g. diesel, fertilizer, pesticides, etc.) have to be accounted for as exports from village A if s/he takes it from her/his farm to the land in village B. This not only causes significant practical problems of data generation (flows have to be separated in surveys) but also contradicts the economic entity and reproductive unit of the farm operations. Therefore, we apply a functional boundary and thus flows related to land under legitimate control of a farmer of Theyern, whether the land is in or outside the administrative boundaries of Theyern, are considered as material flows of Theyern.

Another example are transport activities and commuting across administrative boundaries. A large fraction of the population may cross the boundaries of the local system for work, shopping and consumption. A farmer of the local system A might drive the car to the next city center, fills up the car with fuel, goes shopping in a nearby mall, goes out for food and comes back. Applying the territorial principle would mean that only what finally crosses the administrative boundary is accounted for and everything that is consumed outside the boundary is excluded. Whereas when applying the residence principle and functional boundaries, as we do in our study, all related material flows like petrol, purchased goods and consumed meals have to be accounted for as imports into system A as soon as it is bought by a resident of village A irrespectively from the fact that consumption occurred outside the administrative territory. In the case of an employee who drives to his/her job outside the studied village the petrol for driving to and from work is at his/her private expenses and therefore a flow of the studied system. In contrast, a business trip the employee undertakes for her/his employer is not accounted for since it is part of the employer's business operations (given that the business is based elsewhere but not in Theyern). The strict application of the residence principle further also implies, that all material flows of a large company based in a rural system have to be accounted for in the local MFA. So far, no standardized solutions exist for the application of MFA at the local level and in practical terms often pragmatic solutions have to be made which are based on the respective research focus and also data availability. It is, therefore, crucial for the interpretation of results to make these case specific solutions as transparent as possible

2.2 Specific methodological assumptions

- Resident units are regarded persons who had their principal residence in Theyern in a specific year (1830 or 2001) for a minimum period of 6 months. The group of students was a special case: Students commuting on a daily basis were considered residents whereas students boarding outside of the village were not included in the survey. The only economic resident units in Theyern were farms. All farms and private homes located in Theyern were considered resident units. The only communal building is from the fire brigade which was considered as resident unit, however, flows are marginal.

- Territory and land use: All land that is used by a resident farm is accounted for as part of the system independent if its location. Biomass harvest from these fields is accounted for as extraction. Contrary, if plots of land within the administrative boundaries of Theyern are used by farms from outside the village they are not assigned to the territory of the village and flows associated to the use of these plots are not accounted for (for actual information on land owned and used please refer to figure 2).

- The material flows caused by activities of the system's residents which occur outside the administrative boundaries are considered in the MFA account. This mostly refers to fuel use for traveling and food consumption outside the village. The later were estimated by using information on Austrian average per capita food consumption (Elmadfa, 2003).

- Fossil fuels: All fossil fuels that are purchased by a residing person or economic entity (e.g. a farm) are accounted for as imports.

- Waste: Theyern is not equipped with a waste disposal site and all waste is collected and dumped at a municipal dump in a neighboring village. Consequently, municipal waste flows are accounted for as exports.

2.3 Production vs. consumption

A specific feature of agricultural households is that they combine production and consumption at the household level. In order to reproduce the distinct metabolic patterns of production and consumption of rural households, we implemented a subdivision of the household in a production and a consumption subsystem. We quantified flows between the two subsystems (domestic use of extracted firewood, food).

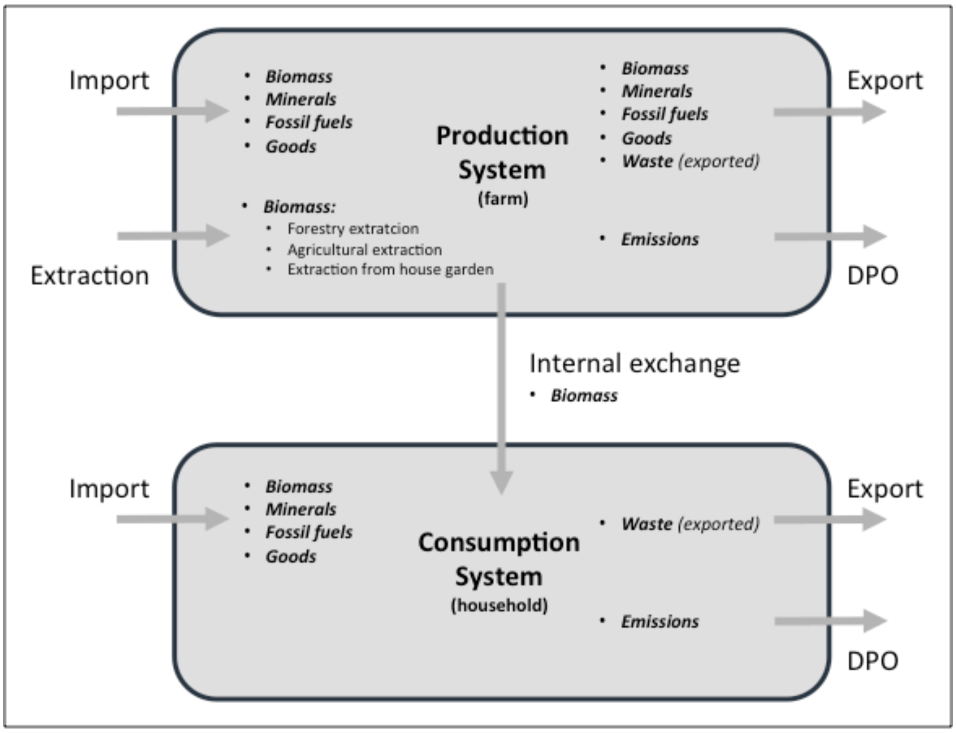

Figure 1: Scheme of material flows in a farm household divided in a production and consumption subsystem.

2.4 Data collection 2001

Material flow data for 2001 were collected via a household survey. This survey was based on interviews with one or more members of each individual household and representatives of the village administration. Of the 21 households only 19 were considered resident households. Of these, three households were not included in the survey (and consequently in the material flow account) because household members were absent or unwilling to participate in the survey. Hence, our sample consists of 16 households with a total population of 63 (88% of the total resident population). For these we collected data on used material extraction (predominantly agricultural harvest from farmland and kitchen gardens), imports (e.g. fossil fuels, imported food, all types of consumer goods, agricultural inputs, vehicles, machinery, construction materials), exports (e.g. agricultural produce, sales of stock, collected municipal waste) and material stocks (buildings, agricultural machinery, vehicles, household appliances, workshop facilities, live stock, agricultural and other land). In addition to MFA data basic demographic information (number of household members, age, sex, education, occupation, time use) was collected. In addition, data from statistical sources (regional data on agricultural yields and consumption surveys, food balance sheets) has been used to cross check and complement the information gathered in field work. In several cases annual flows have been extrapolated on the basis of information provided on weekly or monthly purchases (e.g. consumer goods).

The largest flows are harvest from agriculture and forestry and agricultural inputs (fertilizer, feed). These data are of high quality.

In order to arrive at a reasonable estimate of fossil fuel use for transportation and agricultural traction we used information on vehicle and machinery stocks, annual mileage or operating hours and specific factors of fuel use per service unit.

The estimation of material flows related to the accumulation of artifacts with a lifespan longer than one year (buildings, vehicles and durable goods) deserves special attention. Some of the flows related to building up or maintaining material stocks are very large, but, depending on factors like the average lifespan, the size of flows may vary extremely from one year to another: The material flows associated with the construction of a new house are huge in the year of construction, but small during decades of mere maintenance. At higher scales these annual fluctuations are equaled out over a large sample size. At the local or household level, this is not the case and the overall amount of materials used in a year when a new house is built or a car is purchased maybe much larger than in years with no such activity. Two approaches to account for these flows are possible: a) the actual flows occurring in the specific year of observation can be recorded (snap shot approach) or b) the long term annual averages of flows related to maintenance and building up of stocks can be calculated (depreciation approach). In this study we were interested in average annual flows rather than a picture of the particular year and we used approach b). The mass of stocks of durable goods as recorded in the household survey was depreciated to annual flows by the application of item specific lifespan and depreciation rates based on Austrian fiscal regulations (5 years for electrical appliances, furniture, cars and machinery and 20 years for buildings). Additionally, material requirements for annual maintenance were estimated on the basis of household data.

We depreciate building stocks over a comparatively short period of 20 years, i.e. only construction activities during the last 20 years are considered with their relative annual share. Most of the built infrastructure is much older, only 20% of the built up area (by m2) has been built in the last 20 years, one individual storage facility with low material requirement accounting for a third of all these recent constructions. Extending the depreciation period might double or triple the DMC of construction materials, but still the amount would be small compared to the Austrian average. The reason for this is the relatively low share of infrastructure in a small village like Theyern. Besides residential and farm buildings there are only the fire brigade and the chapel. However, due to the infrequent purchasing by professionals and different household members data for construction minerals have to be regarded as a rough proxy and bear considerable uncertainty.

2.5 Material flow data for 1830

In order to gain insights on the long term temporal development of material flows in a rural village we compare current metabolic patterns with MFA data for the early 19th century. Material flows for 1830 have been estimated based on information gathered and published in a series of research projects investigating the biophysical characteristics of pre-industrial agriculture. These studies assessed land use and material flows in the village of Theyern in 1830. Based on published data on land use, biomass harvest and material balances we have reconstructed material flows in a way which is consistent with the system boundaries and conceptual decisions applied for 2001. These data allowed us to model agricultural harvest, biomass flows within the agricultural production system, food and wood output and to estimate surplus and exports. For a detailed discussion of sources and methods used to estimate material and energy flows for Theyern see Krausmann 2004 and 2009. The historic data are available for the aggregate village only but not for individual households.

3. Results

3.1 Socioeconomic characteristics

Theyern is a small rural settlement, located about 60 km west of Vienna between St. Pölten, the provincial capital of Lower Austria and the city of Krems in the midst of the rolling hills of the Lower Austrian agricultural landscape. Theyern is a compact settlement situated in the centre of a small plateau. The village is surrounded by an inner belt of cropland and fruit orchards and an outer belt of woodlands. Agriculture is the only economic activity; there are no business operations, shopping facilities or restaurants and very little public infrastructure: Theyern is equipped with a chapel and the firehouse of the voluntary local fire brigade but it is not connected to any public transport system. Water supply is based on a local well. The next settlement with infrastructure is Nussdorf ob der Traisen at a distance of 5 km.

3.1.1 Population

In 2001 68 persons living in 19 households were considered permanent residents of Theyern of which 88% have been included in our survey. Table 1 shows the age structure of the population of Theyern. Compared to the Austrian average a higher percentage in the age groups up to 19 and above 65 can be observed, whereas the age group 20-64 is relatively smaller in Theyern.

Population	Theyern		Austria
	number	%	%
	By age		
0-19	18	28,6	22,8
20-64	32	50,8	61,7
65-	13	20,6	15,5
	By sex		
m	31	49,2	48,4
w	32	50,8	51,6

Table 1: Population (annual average) 2001 by age groups and sex for Theyern and Austria (source: Theyern: own survey; Austria: Statistics Austria, Populations Statistics - 2001-2007: revised data. Compiled on 27 May 2009)

3.1.2 Labor force

Until the 70s the whole labor force of Theyern was involved in farming or household reproduction activities. The downturn of the economic significance of agriculture in Austria and the reduction of the number of farms has contributed to significant changes in the local economy of Theyern. In 2001, the employment structure had become more diverse. Of the economically active population only one third was considered full time and another 18% part time farmers (Table 2). Following the definition applied in EU statistics two thirds of the total population is economically inactive, most of them are students or retired persons:

	Numbers	Percentage
Economic active population	22	34.9
Agriculture (full-time farmer)	8	12.7
Part-time farmer	4	6.3
Other Sector (full-time)	10	15.9
Inactive population	41	65.1
Household chores	8	12.7
Student/child	18	28.6
Retired person	15	23.8
Total	**63**	**100.0**

Table 2: Economic active and inactive population[1] in Theyern 2001

3.2 Material flows

3.2.1 Material flows in 1830

In 1830 agriculture was the only economic activity in Theyern and all of the 20 households (inhabited by a total population of 102) were engaged in agriculture. Farm size varied considerably from 3 to 20 ha. According to our estimate domestic extraction of biomass amounted to 5.7 t/cap/yr. Additionally, minor amounts of non-metallic minerals for construction and agricultural use (e.g. fertilizing minerals such as marl) have also been used. Exact quantitative information of these flows is lacking, but in 1830 the overall use of mineral materials in rural areas was very low and based on a rough calculation we assume that it did not exceed a few hundred kg per capita and year. Crops and crop by-products accounted for roughly 60% of total DE, wood for 31% and the rest consisted of grapes and grazed biomass. Imports included durable goods such as farming tools or salt but were of negligible quantitative significance (less than 1% or 0.05 t/cap/yr). Market integration was still very low in Theyern in 1830 and the largest share of the extracted biomass was used within the farm. Most agricultural products, firewood and timber were consumed within the household. At the aggregate level of the village the surplus above local

[1] In accordance with the European Union Labor Force survey the following basic definitions and concepts were used (http://circa.europa.eu/irc/dsis/employment/info/data/eu_lfs/index.htm) (in brackets minor changes are mentioned): The economic active population comprises employed and unemployed persons. Employed persons are persons aged 15 year and over who during the reference week performed work, even for just one hour a week, for pay, profit or family gain or were not at work but had a job or business from which they were temporarily absent because of, e.g., illness, holidays, industrial dispute and education and training. (Some students and some retired persons were helping out with minor farming activities. In order not to mix these persons with full time active persons instead of the one hour rule 5 hours were used as limit.)
Unemployed persons are persons aged 15-74 who were without work during the reference week, were currently available for work and were either actively seeking work in the past four weeks or had already found a job to start within the next three months. (According to interviews there were no unemployed persons in the village.)
Inactive persons are those who neither classified as employed nor as unemployed.

food demand amounted to roughly 0.2 t/cap/yr. We assume that this biomass was sold on local markets respectively had to cover tithes and taxes. Timber and firewood were not exported. Our data indicate, that the rural economy was almost entirely based on biomass and that both exports and imports were extremely low compared to domestic extraction. Altogether extraction and imports minus exports results in an average DMC of about 5.5 t/cap/yr.

The internal flow from the production to the consumption subsystem amounted to 2.3 t/cap/yr (60% firewood and 40% food). That is, 40% of all extracted biomass was converted into biomass products for domestic consumption while exports were extremely small and amounted to only 2% of DE.

				Production					Consumption		
	DMI total	Export	DMC total	DMI prod	Import	DE	Export	**Internal flows**	DMI cons	Import	Export
Theyern 1830 [t/cap/yr]	5.7	0.2	5.5	5.7	0	5.7	0.2	2.3	2.3	0	0

Table 3: Metabolic profile of Theyern in 1830; biomass flows in tonnes per capita and year for the production and consumption system and the flow from the production to the consumption system (internal flow). Flows of mineral materials were small and extraction/import of building materials, fertilizer minerals and tools did not exceed one or two hundred kg per capita and year.

3.2.2 Material flows at village level in 2001

In 2001 domestic extraction amounted to 12.0 t/cap. It consisted only of biomass, no mineral resources were extracted in Theyern. Fruit harvest accounted for about 63% of total extraction, crops, straw and grazed biomass made up some 20%, the reminder (17%) was firewood extraction from local woodlands.

The land used for biomass extraction by residents of Theyern was about 76 hectares. This is less than two thirds of the forest and agricultural land which is actually owned by the local population (123 ha) (see Figure 2). More than a third of the land owned was leased to farmers from outside the village (45 ha). Of the 22 ha of land owned or leased by local farmers that is situated outside the administrative boundaries of Theyern, 18 ha were used.

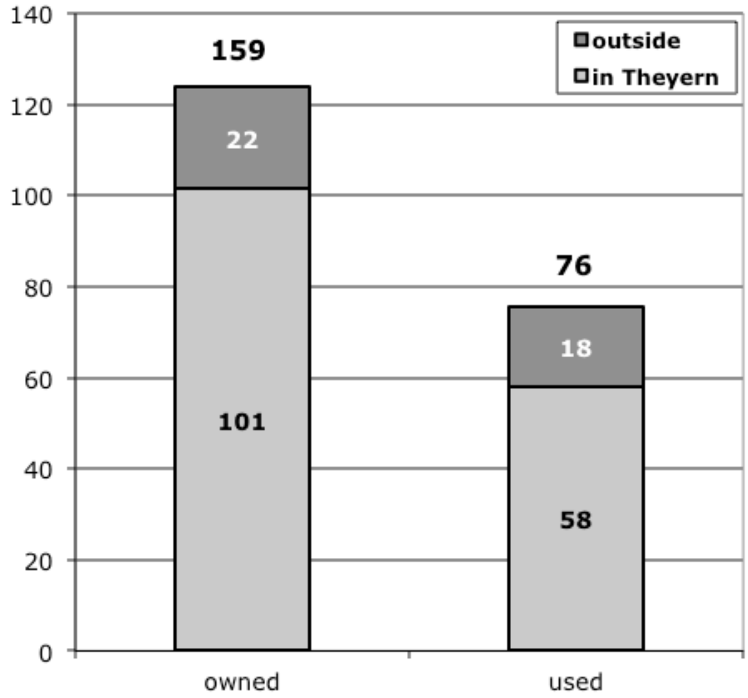

Figure 2: Land owned (or leased) and used by the population of Theyern in 2001 within the administrative boundary of Theyern and outside (land area in hectares). Of the 123 ha owned 76 ha were used.

Extensively used forests account for the largest land use category of the total amount of land used by the local population for biomass extraction (31% of 76 ha). Cropland, vineyards and fruit orchards are intensively used and together make up almost 60%. Pasture is due to the low number of livestock relatively small. While garden area is also small (0,2 ha), it is quite intensively used (see Figure 3).

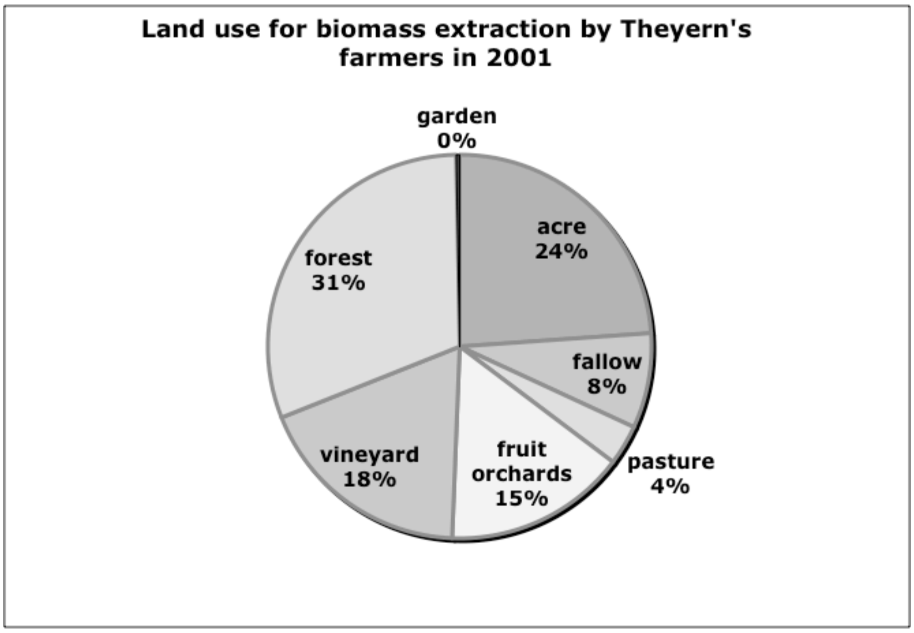

Figure 3: Land used for biomass extraction by Theyern's farmers in 2001

Imports of the production system amounted to 1.5 t/cap/y and were dominated by fossil fuels to run farm machinery (provision of mechanical labor), feed for livestock and fertilizer. The import of live animals, mineral materials for construction and farming tools and machinery was small and accounted for only 10% of the production system's DMI. The consumption system of the village imported 1.9 t/cap/y. Biomass for human nutrition accounted for more than 40% of imports. 37% were fossil fuels for motor vehicles (22%) and for space heating (15%). Minerals for construction and repair of residential buildings as well as durable goods (furniture, vehicles and household appliances) accounted for the reminder. Together, imports of the production and consumption subsystem amounted to 3.4 t/cap adding with DE to a total DMI of 12.0 t/cap/y. The exports from the production subsystem amounted to 8.2 t/cap/y and consisted mainly of agricultural products (cereal grain, livestock, fruits, juices and wine). Exports of the consumption subsystem were small (0.04 t/cap/y) and consisted of household waste only. The aggregated DMC in Theyern amounted to 6.8 t per capita in 2001. The internal flow from the production to the consumption system added up to roughly 2 t/cap/y. It consisted mostly of fuel wood; fruits and vegetables from kitchen gardens were of minor importance in the total DMC of the village. However, our data suggest, that measured in weight local agricultural produce contributed roughly one quarter to local food demand: The local demand for eggs, milk, fruit juices, fruits, and alcoholic beverages (wine) was largely met from local production.

	DMI	**DE**	Biomass	Fossil Fuels	Minerals	**Import**	Biomass	Fossil Fuels	Minerals	***Export***	Biomasse	Fossil Fuels	Minerals	***DMC***	Biomasse	Fossil Fuels	Minerals
Theyern 2001	**15.4**	12.0	12.0	0	0	3.4	1.4	1.4	0.6	**8.4**	8.4	0	0	**7.0**	5.0	1.4	0.6

DMI ... Direct Material Input
DE ..... Domestic Extraction
DMC … Domestic Material Consumption

Table 4: Theyern's Material Flows in 2001 in tonnes per capita and year

3.2.3 Material flows at household level in 2001

The analysis of material flows at the household level reveals huge differences between individual households. Among the 16 households in our sample DE ranges between 0 and 40 t/cap/y, imports between 1.3 and 11 t/cap/y, exports between 0 and 23 t/cap/y and internal flows from the production to the consumption subsystem between 0 and 20 t/cap/y. In order to allow for a systematic discussion of these differences we have grouped households according to their socioeconomic activities (Duchin, 1998, p68), distinguishing between (A) farming households, (B) households with part-time farming and (C) households with no farming activity at all (see Table 1).

Household type	Sub-category	Sample
A Farming households	A.1 Mixed farming	1
	A.2 Perennial cropping (fruit production)	2
B Part-time farming households		6
C Non farm households	C.1 Employment outside the village	4
	C.2 Income from pension fund	3

Table 5: Typology of households in Theyern 2001

Full time farming households (Type A households) have been subdivided according to farming type: Mixed farming (combination of crop production and livestock) (A.1) and perennial cropping (specialized in fruit production) (A.2) (cf. Arnold, 1997, p118). Part time farming households are subsumed in Type B households. This type includes all households with farming activities that do not suffice to sustain the household, and additional income is gained by other economic activities by one or more family members. Although most of these households do not depend on farming economically, farming is still significant in terms of their economic expenditure, infrastructure and time use.

Households with no farming activity are subsumed under Type C households and subdivided by their main source of income: Type C.1 denotes all households in which one or more persons are engaged in an economic activity other than farming. Type C.2 includes households where income is generated by an inactive person receiving income from a pension fund. It has to be noted, however, that a subdivision of a sample of 16 households into five household types results in very small sub samples for individual household types. Although this restricts any generalization of our findings, the observed differences are significant and allow for interesting insights into patterns of rural metabolism.

	DMI total	Export	DMC total	Production				Internal flows	Consumption		
				DMI prod	Import	DE	Export		DMI cons	Import	Export
A.1 Mixed farming	52.6	17.1	35.6	52.3	11.3	41.0	17.0	7.1	7.5	0.4	0.1
A.2 Perennial farming	31.7	23.4	8.3	30.0	1.9	28.1	23.4	1.5	3.2	1.7	0.0
B Part-time farming	9.9	4.5	5.5	8.1	0.7	7.4	4.4	2.4	4.2	1.8	0.0
C.1 Employment outside village	5.2	0.0	5.1	2.7	1.6	1.1	0.0	0.9	3.4	2.5	0.0
C.2 Income from pension fund	4.8	0.0	4.8	2.9	0.0	2.9	0.0	2.6	4.5	1.9	0.0
Average Theyern 2001	15.4	8.4	6.8	13.6	1.5	12.0	8.3	2.0	3.9	1.9	0.0
Average Austria 2001	22.9	5.0	17,9								

Table 6: Metabolic profiles of the various household types represented in Theyern 2001 (in tonnes per capita and year)

"Farming households" (A) showed by far the highest material input: The DMI of the “mixed farming” household amounted to 52.6 t/cap/y and that of “perennial cropping” to 31.7 t/cap/y. In the “mixed farming” type the internal flows from the production to the consumption subsystem were considerable (7.1 t/cap/y) indicating a significant self-supply of food and firewood. In contrast, the “perennial cropping” households are characterized by small internal flows. “Perennial cropping” required a DMI of 1.4 tonnes per tonne of export, whereas “mixed farming” demanded 3 tonnes DMI for 1 tonne of export. The imports of the "mixed farming households" (A.1) are dominated by biomass (52% of imports are feedstuff and livestock) and fossil fuels (38% consist of mostly diesel fuel for farm machinery). DE consists mainly of agricultural harvest (90%) and firewood (10% or 4 t/cap/y). Exports are made up mainly of agricultural products (mostly corn).

Households of the "perennial cropping" (A.2) type are characterized by relatively low imports (3.6 t/cap/y). Fossil fuels account for two-thirds of imports, the rest consists of fruits purchased for further processing and nutrition. Fruit accounts for the larger part of DE (95%). Firewood extraction is of significantly less importance in these households (1.1 t/cap/y) than in Type A.1.

In all cases, farming activity in Type B households ("part-time farming") is based on wine and fruit cultivation (perennial cropping). All MFA parameters (DE, imports and exports) are significantly lower than in Type A households. Extraction of firewood contributes about 30% to DE, and fruit amounts to roughly two-thirds of DE. Fossil fuel consumption for transport is higher than the equivalent rate for “perennial cropping” households. For generating an export of one tonne they need a DMI of 2 tonnes.

"Farming households" of Type A can be referred to as “producer households”: They are based on the extraction of biomass for exports, and most of their imports are used as resources for sustaining high levels of agricultural production.

The category "other households" (C.1 and C.2) is “consumer households”: Domestic Extraction (from kitchen gardens or forest plots) is comparatively low (1-2.9 t/cap). Imports consist of consumer goods dominated by food and fuel for heating and transport and exports of household waste, which is collected and dumped in a landfill by the disposal service. One main difference between the households of Type C.1 (employment outside the village) and Type C.2 (income from pension fund) is the higher level of firewood extraction for wood-fired heating systems in Type C.2 households, which results in a higher level of DE in these households. The other major difference lies in a higher fossil fuel consumption level in Type C.1 households, caused by the greater intensity of passenger transport (higher per capita car mileage).

4. Discussion

4.1 Long term changes in material flows

A comparison of material flows in Theyern in 1830 and 2001 reveals major changes with respect to the per capita level and the structure of material flows. Despite the considerable decrease in farming activity, per capita material extraction more than doubled. Imports surged from less than 0.1 to 3.4 t/cap/yr and exports from less than 0.2 to 8.4 t/cap/yr (see Figure 4). Consequently DMC grew only modestly from 5.5 to 7.0 t/cap/yr. Also the composition of material flows changed: Interestingly, DMC of biomass did not change much. Despite major changes in the structure of the agricultural production system and local energy supply it declined only slightly from 5.5 to 5.0 t/cap/yr. Additionally, however, almost 2 tonnes of mineral resources were used in Theyern per capita and year at the turn of the 21st century, fossil fuels for households and use in agriculture accounting for most of it. The use of construction minerals, which we have estimated to be around 0.6 t/cap/yr is probably significantly underestimated. Additionally, the MFA does not account for the immaterial electricity consumption. Thus, in 2001 Theyern consumed final energy equivalent to 0.3 tonnes per capita of oil (conversion losses are not considered) without being reflected in the material flows.

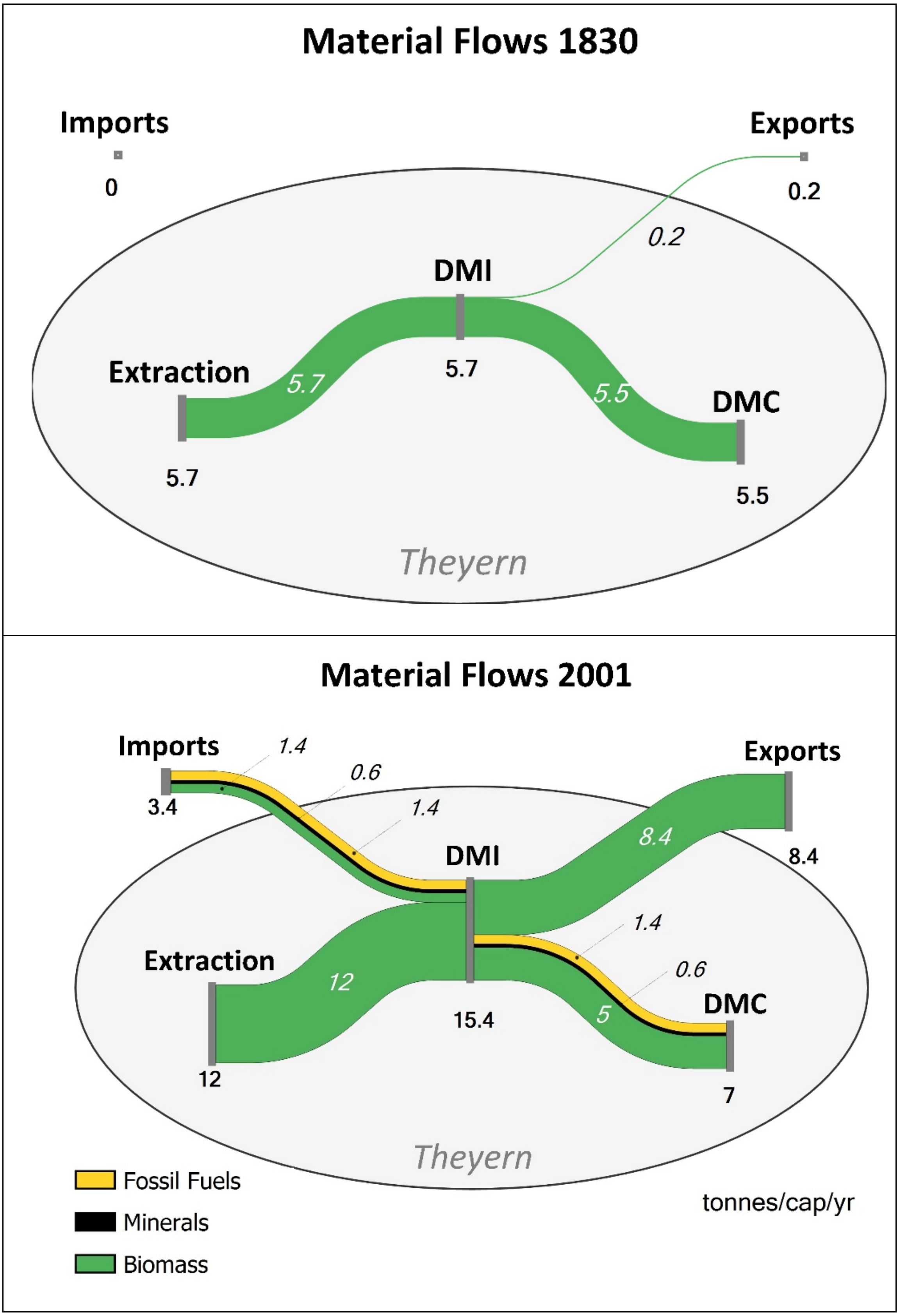

Figure 4: Comparison of material flow indicators for Theyern 1830 and 2001 (in tonnes per capita and year)

The modernization of agricultural production resulted in significant changes in biomass flows. The doubling of biomass extraction was associated with an increase in extraction per unit of area by factor 2 and even more so by an increase in extraction per capita of agricultural labor force: In 1830 roughly 67 persons engaged in agriculture and produced 580 tonnes of biomass. 170 years later 12 persons extracted 680 tonnes of biomass. This means that labour productivity in agriculture increased from 1.2 tonnes/cap/yr in 1830 to 63 tonnes/cap/yr in 2001 – that is by a factor of 50. In terms of material flows this increase was related to higher quantities of imports such as seeds, fertilizer, mechanical equipment and fossil fuels.

Theyern shifted from a subsistence production system with very low imports and low exports and a high internal turnover of biomass towards a throughput system where consumption is pre-dominantly satisfied by imports and a large share of the extraction is exported. Although the internal flow from the production to the consumption subsystem declined, the rate of self-sufficiency is still surprisingly high: Local produce (food and fuel wood) account for roughly 40% of local biomass DMC. This indicates a high significance of the local resource base in rural areas even in modern industrial societies.

4.2 Theyern's metabolism in the Austrian context

	DMI	**DE**	Biomass	Fossil Fuels	Minerals	**Import**	Biomass	Fossil Fuels	Minerals	**Export**	Biomasse	Fossil Fuels	Minerals	**DMC**	Biomass	Fossil Fuels	Minerals
Theyern	**15,4**	12,0	12,0	0	0	**3,4**	1,4	1,4	0,6	**8,4**	8,4	0	0	**7,1**	5,0	1,4	0,6
Austria	**22,9**	14,6	4,4	0,5	9,7	**8,3**	2,3	3,3	2,8	**5.0**	2,1	0,6	2,2	**17,9**	4,6	3,1	10,2

Table 7: Metabolic profile including three material categories of Theyern in comparison with Austria in tonnes per capita and year (both 2001) (source: Petrovic 2009)

Table 7 compares the structure of socioeconomic metabolisms in Theyern with that in Austria in 2001. It reveals that the per capita level of Theyern's material use (DMC) is small and amounts only to one third of the Austrian average. The smaller part of this difference is due to a lower level of material extraction in Theyern but the lions share comes from radically different trade patterns: While material imports in Theyern are much smaller than Austrian imports, exports are 50% higher than the Austrian value. Hence, Theyern is providing resources for a higher scale system. With respect to different materials the following picture emerges: The consumption of fossil fuels and above all mineral material is much lower than that of Austria. While our values for DMC of construction minerals maybe underestimated due to methodological reasons (see methods section), even a doubling or tripling of this flow would not drastically change the overall picture. The main reason is Theyern's comparatively low relative share in material intensive transport and industrial infrastructure and that consequently the per capita stock of built infrastructure and the amount of mineral materials required for building and maintaining these stocks is much lower than at the national level.

The lower level of fossil fuel consumption is among others due to a lack of energy intensive industrial activities, the high share of wood fuel in household energy supply and the fact that the upstream fuel requirement for imported electricity and other energy intensive products (e.g. fertilizers) are not accounted for in import flows.

Our data indicate the significance of the production function of rural agricultural villages such as Theyern within the national economy. Agricultural villages have a comparatively high DMC of biomass as well as of fossil fuels and they export large amounts of agricultural produce and wood to urban-industrial centers. Interestingly, per capita extraction and consumption of biomass in Theyern is not so different from the Austrian average, despite the relative importance of the agricultural sector in Theyern. This is a consequence of the comparably low significance of livestock production in Theyern's agriculture (0.4 livestock units per ha). Agricultural systems with an emphasis on livestock production show a high internal DMI while the mass of exported products is low. In contrast, the upstream biomass flows associated with crop products are much lower and a high share of the extracted biomass can be exported. Consequently apparent consumption of biomass is much lower in crop production systems compared to livestock production systems.

4.3 Material flows by household types

Our data show, that differences in the metabolic profile across rural households are large, both with respect to the size of per capita flows and the material composition (see Figure 5). Even though household level data, and in particular data on final consumption are based on rather crude estimation procedures and have to be interpreted in their details with care some general patterns can be identified: While average DMC in Theyern amounts to 7 t/cap/yr it varies by a factor of ten between individual households. And also extraction, imports and exports vary by one order of magnitude.

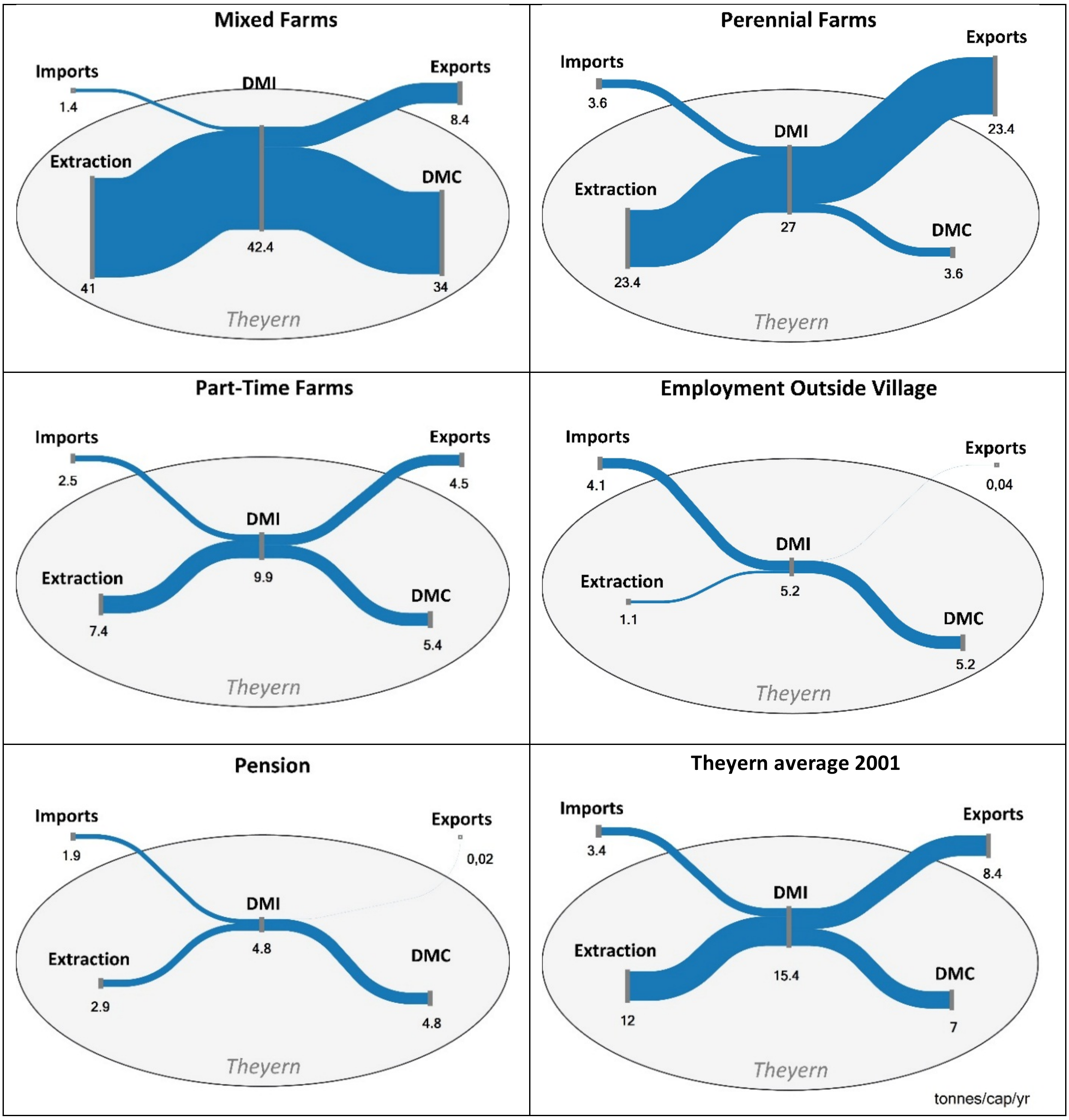

Figure 5: Per capita material flows for the different household types in Theyern 2001: Mixed farms, perennial cropping, part time farms, employment outside village and pension in comparison to the average for Theyern (in tonnes per capita)

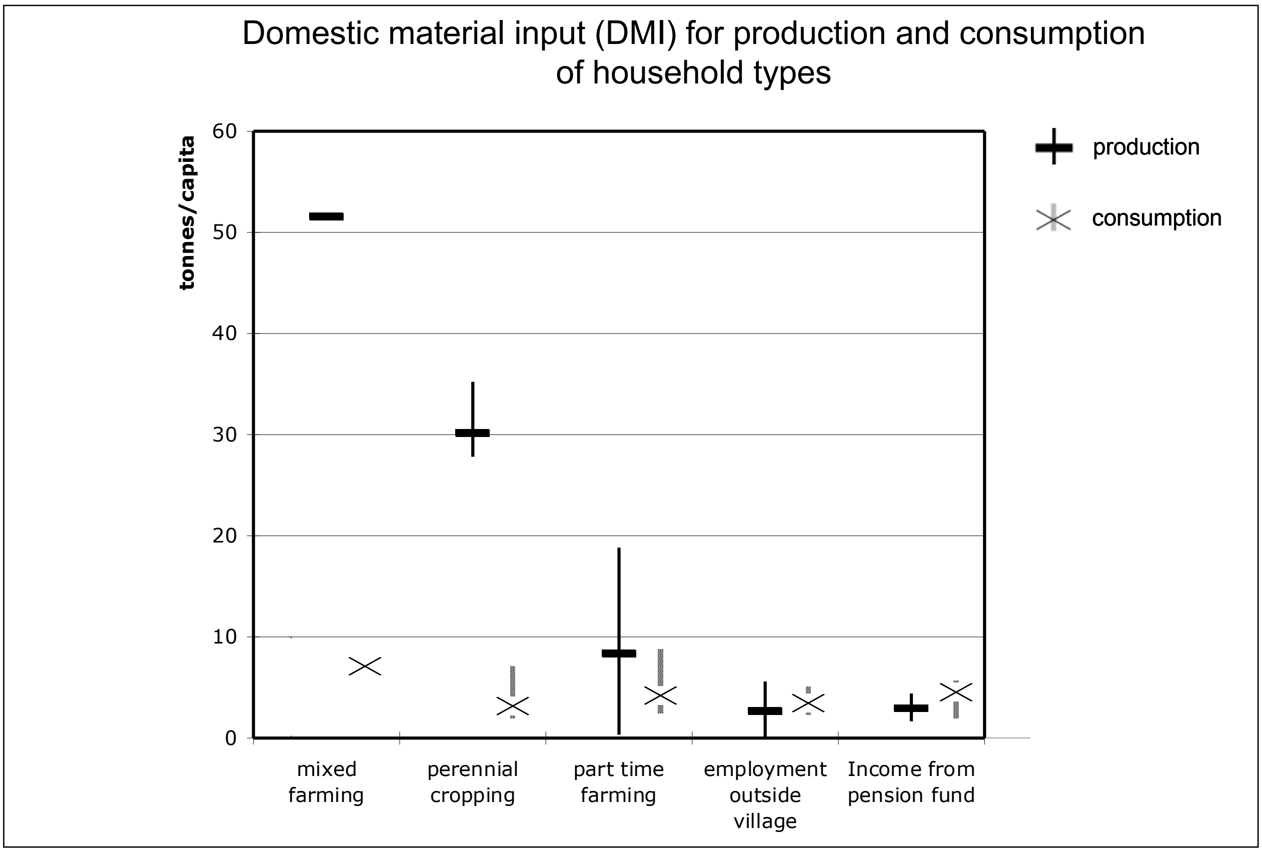

Figure 6: Domestic material input of different household types differentiated by the production and consumption subsystem (in tonnes per capita)

Our analysis shows, that these variations are related to how household income is generated and in particular to the significance that agricultural production plays. Different lifestyles also play a role, but to a lesser extent. Figure 6 shows, that differences in DMI of the production subsystem varies between 2.7 and 52.3 t/cap and year (factor of 20), while that of the consumption subsystem between 3.2 and 7.5 t/cap/yr (factor 2). Rural households that are engaged in agriculture are producing households. They extract large amounts of biomass and supply distant regions with food, fiber or fuel. To produce this biomass, significant amounts of inputs (fuel, fertilizer) are required and finally, depending on the type of farming operation, only a varying share of the extracted biomass is exported. For livestock production, the ratio of inputs to product exports can exceed a factor ten, while it is smaller for crop production. Both factors contribute to the high apparent material consumption that can be observed for agricultural households. These relations are reflected in the higher DMI and DMC of mixed farming operations as compared to those with an emphasis on perennial cropping. With reduction in number of family farms and increasing size of the farms remaining in operation the differences are bound to increase.

It is self-evident that due to agriculture there is a relatively high share of biomass visible in the metabolic profile of the households' production system. But agriculture is also appreciable in the households' consumption system by a comparatively high share of biomass self-sufficiency: Around 40% of the household consumption of food and wood is supplied from own production. And even rural households that have ceased agricultural production have a relatively high extraction of biomass. Even those households have access to woodlands and produce their own fuel and a significant share of the food supply is grown in kitchen gardens.

The mixed farming households cover a large share of their biomass demand (firewood for heating and nutrition) from their own farming operation, while imports for private consumption are comparatively low (0,7 t/cap). The more specialized farming households of type A2 use less of their smaller variety of agricultural produce for domestic consumption. Internal flows are lower and imports are higher. Part-time farming households preserve a high degree of self-supply, however, the level of imports is more or less the same as that of perennial cropping households. Households with employments outside the village use gardening and extensive fruit orchards for topping up their diet with domestic products. A few households still use farming facilities for their hobbies (wine yards and horses). In average the internal flow is the lowest while the imports are the highest. However, a certain degree of self-sufficiency can be recognized for all households. Thus, the results show that agriculture and the local resource base have a very persistent influence on the metabolism of rural households.

Another quite interesting insight is, that none of the household types has a metabolic profile that is close to the average. The household type that is closest to the average is “part-time farming” and this type will likely be phasing out according to statements of the interviewed persons in the near future. The same applies to mixed farming, where the farmers stated that they will stop farming soon due to their age and since their children already have highly qualified non-farming jobs and no interest of taking over the farm. Thus, the differentiated data base of more homogeneous household types provides some potential for projecting material flows of the village into the future. Assuming the phasing out of part-time[2] and mixed farming[3], flows will be significantly reduced: DMI approximately by 40%, the exports by 30% and DMC by 40%.

4.4 Comparison with metabolic profiles in Asia and Latin America

Finally, we compare rural Theyern with remote villages in Asia and Latin America. SangSaeng (Thailand) represents a village in a transition into a fossil-fuel-based agriculture. Campo Bello (Bolivia) and Nalang (Laos) are characterized by non-fossil-fuel-based (subsistence) agriculture.

[2] To become “employment outside the village”

[3] in this case the to become type (income from pension fund”

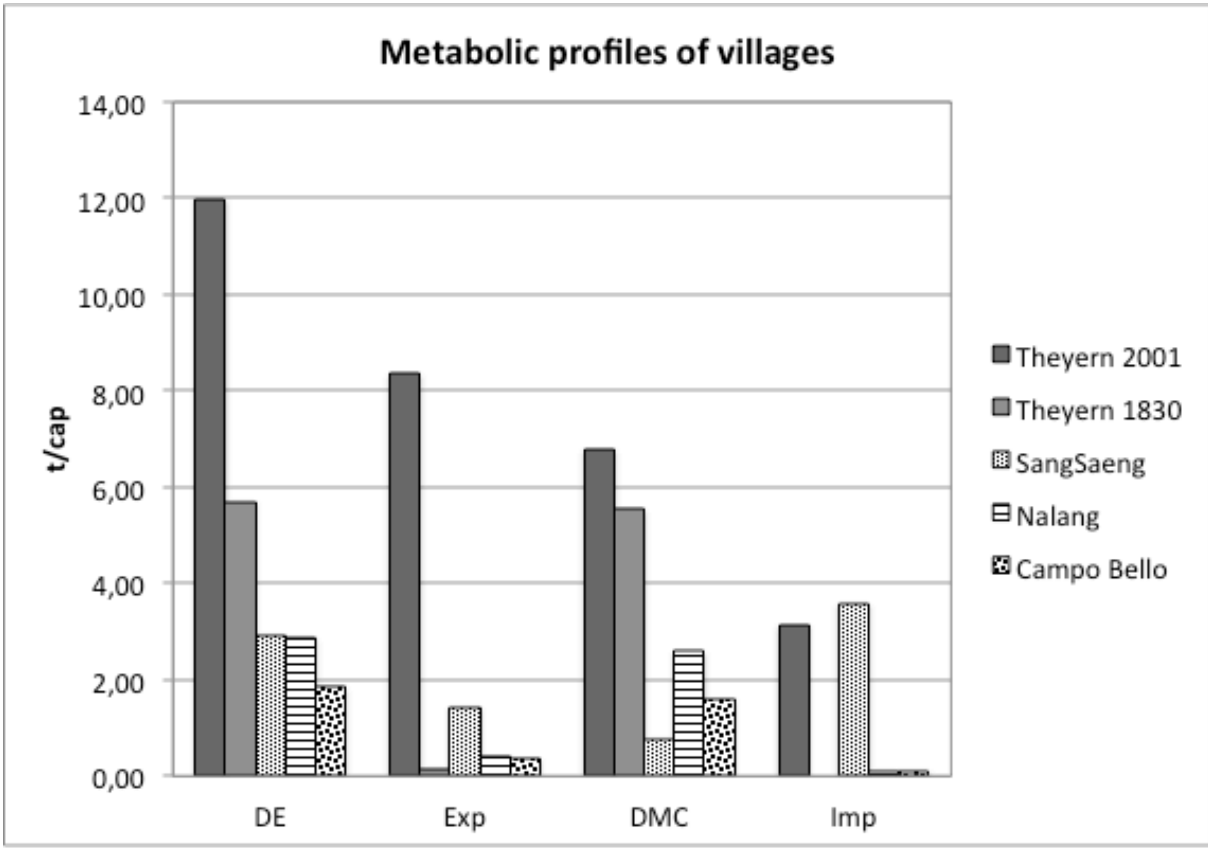

Figure 7: Metabolic profile in tonnes per capita and year of Theyern compared with those of SangSaeng (Thailand), Nalang (Laos) and Campo Bello (Bolivia) (Source: own data, Singh et al. 2010 and Fischer-Kowalski et al. 2011a)

Theyern 2001 has the highest DE, highest exports, highest DMC, and second highest imports after SangSaeng, which also is characterized by a fossil-fuel-based agriculture. The high DE is a result of higher yields per area unit, which in turn is enabled by means of artificial fertilizers and high-yielding cultivar as well as by a high degree of mechanization. Consequently, these factors cause higher imports than subsistence agricultures. Theyern 1830[4], a solar energy based subsistence agriculture, has half the DE of Theyern 2001, but more than double of the DE of Nalang and Campo Bello; other subsistence agricultures. This is related to the large size of the livestock system compared to other cases. A large livestock system leads to high grazing quantities, reflected in a high extraction rate of biomass. Due to the low conversion efficiency of livestock (from fodder to human nutrition), the higher DE does not increase the surplus significantly. This means there is little left for export and consequently, due to the calculational logic, DMC has to be high together with DE. Nalang and Campo Bello have both higher exports and imports than Theyern 1830. One reason for this might be that Theyern 1830 was part of a wider agricultural society where transport capacities were restricting imports and exports. Nalang and Campo Bello are already part of economies where the national transport system

[4] The interpretation of Theyern 1830 needs some caution, since the estimates are done on recorded agricultural harvests. In these records, for example, neither the extraction nor the exports of wood has been accounted for. Especially export could change significantly, if wood was sold. However, there is no evidence for this.

commonly uses fossil fuels, thus reducing transport limitations compared to agricultural societies.

Now we can discuss the empirical results of the metabolic profiles of the above listed rural villages against the backdrop of the theory of socio-metabolic regimes (Fischer-Kowalski et al. 2011a). The theory assumes that metabolic rates (per capita DMI and DMC) increase during the transition from passive use of solar energy in the metabolic regime of hunter & gatherers to an agrarian regime, which relies mainly on an “active” utilization by colonizing terrestrial ecosystems. Metabolic rates increase even further in the next transition, the transition into an industrialized regime, which relies on utilizing fossil fuels; stocks of historical solar fluxes accumulated over millions of years. Thus, the results of the comparison of Theyern 2001 and 1830 with the three cases from Asia and Latin America as discussed above can be seen as a confirmation of the theoretical assumptions. (For further insights on SangSaeng, Nalang and Campo Bello please see Fischer-Kowalski et al. 2011a).

5. Conclusions

The transition we have observed for Theyern during the last 170 years is similar to that which we can observe nowadays in rural areas in many countries of the global South or even southeastern European countries. Subsistence farming retreats and farming is increasingly industrialized, the number of farms declines. As a consequence rural regions depopulate or rural population begins to commute to urban industrial centers for work. From a sustainability point of view this transition entails a tremendous increase in environmental pressures. What can we learn from a metabolic analysis of a rural village like Theyern for these ongoing processes in less developed regions?

It is interesting to see that despite the diversification in different household types the agricultural past has left its traces on the metabolic profile of all households. Therefore, the use of firewood and gardening activities are still visible in Theyern's household profiles. Since both activities can be regarded beneficial from a sustainability perspective a concerted promotion of such practices could contribute to reduce environmental pressures and support rural livelihoods in transition economies:

In Theyern all households – as a heritage from their agricultural past – own forest-plots in the woodlands surrounding the village. According to Austrian law[5] they are responsible for adequate forest management, e.g. annual thinning of the forest. Despite this annual work investment (and the resulting flow of wood biomass), some households have shifted from traditional wood fuelled to oil-fuelled heating systems in the 80s. According to statements of the interviewed persons, some of them might return to technically advanced wood firing systems soon. Other households have leapfrogged this development and installed efficient wood fired heating systems (sometimes in combination with solar panels) during the last ten years. Thus, they can rely on own renewable fire wood sources with no net carbon emissions and very short transport distances.

Gardening activities for self-supplying high quality food is another example. People appreciate both home made "biological" high quality products without chemical inputs and physical exercise in the kitchen-garden. They dispose over all necessary resources: the land (the traditional back garden), the plants (even fruit orchards) and the knowledge (e.g. appreciated family recipes for jam, preserved or pickled vegetables, juices and syrup). Altogether at village level about a quarter of the food supply measured in mass units (mostly vegetables and fruits) is provided from home-production with almost no transportation requirements. Obviously, with appropriate incentives, this has a high potential to make food supply more sustainable.

Another area where leapfrogging the business as usual developments could contribute to a reduction of environmental pressures is the modernization of farming practices. In the case of Theyern it can be seen that the industrialization of the traditional subsistence farming pattern (e.g. animal production in mixed farming) results in very high metabolic rates (mixed farming: DMC of 36 tonnes per capita)

[5] see Forstgesetz 1975, Fassung vom 9.10.2014, §1

and has a relatively low outcome (exports 17 tonnes per capita)[6]. In contrast, perennial cropping is a practice that fits perfectly to existing knowledge as well as available technologies (juice presses and distilleries), the given local natural conditions (e.g. micro climate, soil quality, morphology) and local markets (close urban delivery markets). This production type has a DMC of 8 tonnes per capita and exports 23 tonnes per capita. Based on this observation a we conclude that careful planning in the phase of agricultural industrialization might have some potential to reduce environmental pressures; especially if such planning can draw on experiences made in other regions with similar transition processes. A planning with the aim to find the locally appropriate socio-economic farming portfolio might avoid cul-de-sac developments that lead into unsustainable system dynamics. However, such strategies need to carefully consider a diverse range of both positive and adverse effects (e.g. on the one hand reduced self-supply in perennial cropping households might entail food imports related to environmental damages elsewhere, on the other hand perennial cropping needs far less input like fertilizers).

As far as the methodology is concerned the brake down into household types and a production as well as a consumption part of households provides valuable insights concerning the sustainability of rural households. The material implications of different lifestyles and the shift in socio-economic activities can be discussed separately and in their interplay.

Since rural transitions at the global scale will play a major role in determining future environmental pressures more investigations into rural transitions and how this changes consumption and production as well as the composition of household types would be quite useful for identifying crucial policy domains and measures to keep future environmental pressures at bay.

[6] In 2001 the livestock system was relatively small (0.4 livestock units/ha). More livestock would even increase the DMC.

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