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Social Ecology Working Paper 72

Land Use and Socio-economic Metabolism in Pre-industrial Agricultural Systems: Four Nineteenth-century Austrian Villages in Comparison

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Vienna, December 2008

ISSN 1726-3816

iff Social Ecology | Schottenfeldgasse 29 | A-1070 Vienna | www.iff.ac.at/socec/

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ISSN 1726-3816

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ABSTRACT

This paper proposes a methodological framework to analyse the socio-ecological dynamics of pre-industrial agricultural villages based on the concept of socio-economic metabolism. The Franziscean Cadastre, a land survey conducted in the first half of the nineteenth century, serves as a data source for modelling energy, material and nutrient flows in agricultural systems at the village level. The paper presents a comparative analysis of different types of land-use systems ranging from a lowland arable system to a high mountainous grassland system. It focuses on a detailed description of the applied methodology and empirical results and aims at providing a source for further evaluations. Biophysical aspects of the different types of agricultural systems are discussed in a comparative way in order to contribute to the discussion of relevant topics in environmental and agricultural history, including issues of soil fertility and nutrient management, the role of livestock in pre-industrial agriculture, agricultural productivity and the exploitation of forest resources.

CONTENTS

1. Introduction

The analysis of the material basis of agricultural systems and their energy and material throughput has a tradition in various disciplines ranging from human ecology[1,2] and geography[3] to environmental history[4,5]. Traditional approaches in agricultural history and economy[6,7], however, often neglect (bio)physical aspects when analysing the functioning of agricultural systems and their historic development and often natural conditions are conceived of as hardly more than a static matrix of the socio-economic system[8]. In recent years, a "biophysical" perspective on the development of socio-economic systems has been demanded – especially in newly-emerging fields like ecological economics[9], social ecology[10] or environmental history[4,11,12]. Accordingly, socio-economic systems are conceived of as systems which are based on a continuous exchange of matter and energy with their environment and therefore in a close and mutual relation with the natural systems. This approach, often referred to as socio-economic metabolism[13] is becoming increasingly prominent within the research of global environmental change.

This paper refers to the metabolism concept and proposes a methodological framework for using the data provided by the Franciscean Cadastre (FC) as a source for quantitative research in environmental and agricultural history. The FC was the first complete land survey of the Austro-Hungarian monarchy. It was established for tax calculation between 1817-1856 and represents a valuable source for data related to land use, covering an area of over 300,000 km² (Austria) and 230,000 km² (Hungary). It provides data on the spatial level of single land-parcels, farmsteads or cadastral units (municipalities) and all aggregate levels. The Austrian part of the cadastre covers 30,556 cadastral units with 49 million land parcels on 164,357 maps (1:2,880). The FC has proven to be a unique source for comparative historical agro-ecological studies, the analysis of pre-industrial land-use systems, and a wide range of research questions in economic and environmental history[8,14-17].

The paper proposes a methodological framework based on the concept of socio-economic metabolism for using the FC as a source for modelling energy, material and nutrient flows in pre-industrial agricultural systems at the level of villages. It presents a comparative analysis of different types of land-use systems in Austria (alpine grassland system, arable system, wine growing system). The paper focuses on a detailed description of the methodology applied and presents empirical results in order to provide a source for further interpretation and analysis. It will discuss biophysical aspects of different types of agricultural systems in a comparative way and contributes to the discussion of current topics in environmental and agricultural history, including issues of soil fertility and nutrient management, the role of livestock in pre-industrial systems, agricultural productivity and the exploitation of forest resources.

2. Data

2.1 The case studies

Four case studies at a micro-regional level are analysed in this paper: Theyern, Nussdorf, Voitsau and Großarl are villages (cadastral municipalities) with populations ranging from 100 to 650 and a territory of 2.2-29 km² (Table 2). They are located in different agro-ecological regions of Austria, ranging from climatically favourable lowlands (Theyern and Nussdorf) to highlands (Voitsau) and central alpine conditions (Großarl). These specific case studies were chosen because they represent a good part of the variety of Austrian [and Central European] agricultural landscapes and production systems. Moreover, they have been extensively studied before[18]; thus a sufficient amount of historical data was available[19]. As a reference system, I refer to an aggregate of provinces of the Austro-Hungarian monarchy which are roughly equivalent to the current Austrian territory. This was analysed with the same methodology as the local case studies, largely using published data referring to the same sources as the local studies[20]. The local case studies (and the reference system) refer to the year when they were surveyed for the Franziscean Cadastre, i.e. 1829 for Theyern and Nussdorf, 1834 for Voitsau and 1835 for Großarl.

2.2 Sources

The main data source for primary data on land use, yields, population and livestock is the Franciscean Cadastre (FC) (Franziszeischer Kataster or Stabiler Kataster). In the first half of the nineteenth century, beginning with 1817 and completed in 1856, the whole territory of the Austro-Hungarian Empire was surveyed for tax calculation. This included a geodetic survey of the territory, estimations of physical yields for all land-use classes and the calculation of monetary yields. Gross yields for each land-use class were calculated based on prices from 1824 and reduced to net yields by subtracting estimated cultivation costs (e.g. labour input, etc.)21,22. In general, the data provided by the FC are regarded as very reliable However, due to the fact that the surveys were conducted over a period of several decades, and for provinces differing in many aspects, regional inconsistencies have to be considered14,23. Furthermore one has to be aware that the survey was made for tax calculations, which may have biased the outcome to a certain extent.
The cadastral survey offers a variety of sources for environmental history[14,24].

a) the cadastral map of each *Katastral Gemeinde* (cadastral municipality - KG) on a scale of 1: 2,880, which gives information on land use and cover at the level of single land parcels. Up to 39 land-use classes and up to four distinct quality types of land for many classes (e.g., arable land I = best quality arable land to arable land IV = poorest quality) are differentiated on the maps.
b) the *Parzellen Protokoll* (survey protocols - PP) gives information on ownership as well as the size and land-use type for each parcel of land or building.
c) the *Catastral Schätzungs Elaborat* (Cadastral Elaborat – CE), which is the basic data source for the calculations presented in this study, was prepared for each KG and offers a large variety of aggregate information on land use and land cover, yields, population, livestock, land use and farming practices as well as products, feeding practices, manuring-standards, general information on number of farms, wealth of the community, use of animals, markets, etc.
d) the *Darstellung des Kulturaufwandes und des Reinertrages* gives aggregate information on factor costs and estimated monetary gross and net gain (based on local prices of 1824) for each land-use category in a cadastral unit. In combination with the parcel protocols, this was the basis for tax calculation.

In addition to the data provided by the FC, a wide variety of sources and literature data concerning local, regional and general aspects of structure and functioning of pre-industrial farming system was used[23,25-35]. Furthermore, the presented study relies on previous evaluations of cadastral data and previous empirical studies concerning the four villages under consideration (Theyern, Voitsau, Großarl and Nussdorf). These studies, however, referred to material/energy/nutrient flows only in a qualitative way. From these previous studies, a variety of published data and analysis concerning the villages under consideration were available[8,15,18,19]. In addition, unpublished evaluations of data referring to the cadastral maps and the cadastral protocols were provided by Projektgruppe Umweltgeschichte (PGU) and especially Klaus Ecker. This material included digitised versions of the original cadastral maps of the villages (see Fig. 2-4) as well as certain evaluations of the parcel protocols, e.g. quantification of the extent of external land use (*Überlandgründe)* and land-use data at the farm level as well as data concerning specific estimations on factor costs (*Kulturaufwand*) at the farm level. The original cadastral sources are available at the Niederösterreichische Landesarchiv for Theyern, Nussdorf and Voitsau: *Operate zum Franziszeischen Steuerkataster zur KG Theyern (OWW), KG Voitsau (OMB), KG Nussdorf* and at the Salzburger Landesarchiv for Großarl: *KG Dorf Großarl*.

3. Methods

3.1 Accounting for material and energy flows

A central aim of this study was to evaluate the data given in the FC in order to develop a quantitative model of the structure and functioning of pre-industrial agricultural systems and their energy system on the local level. The most important task was to quantify the flow of biomass (expressed as matter as well as energy and nitrogen) within pre-industrial production systems at the level of villages (i.e. KG). The applied methodology is based on a systemic and model-based approach as presented in WILFING et al.[36] in this issue. The proposed general model for a pre-industrial agricultural production system[36] was specified and adapted for this purpose (Figure 1).

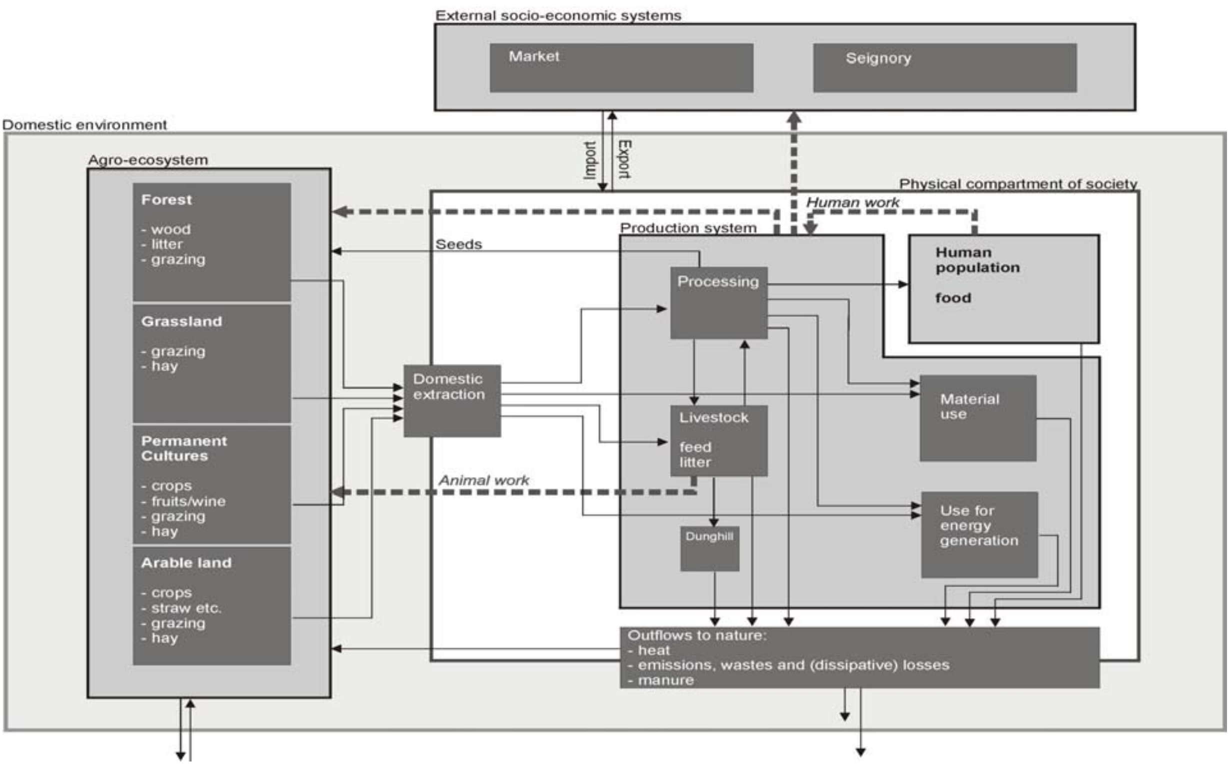

Figure 1: Model for material and energy flows in pre-industrial agricultural production systems. For explanation, see text.

This model for material and energy flows in pre-industrial agricultural production systems can be applied at different levels of scale – from the farm level to the level of national states. The graphic representation of the model (Figure 1) used in this case study shows flows and processes analysed at an aggregate level:

The territorial boundaries of the system (e.g. a village, state) are determined by the land used by all farmsteads considered part of the system. It is important to note that this does not necessarily match exactly with the territory of the village, but may include so-called *Überlandgründe* (external land used) – i.e. parcels of land in neighbouring communities used by the farmers of the village under consideration. Parcels of land within the community farmed by non-resident farmers are excluded in a symmetrical way.

Furthermore this study refers to the methodological framework of material and energy flow analysis (MEFA)[13] which is based on accounting for flows of matter and energy between natural and socio-economic systems. As the boundaries between the natural and the socio-economic compartment of the system are not explicitly referred to in the proposed general model[36] they had to be defined accordingly[37, 38].

MEFA operates with the following basic parameters[38]: "Domestic Extraction" (DE) refers to all matter or energy that is appropriated (extracted) by the socio-economic system – i.e. all material or energy flows that cross the system boundary between the domestic environment and the socio-economic system. With "Imports" of material or energy from other socio-economic systems (e.g. firewood bought at a market), DE adds up to "Direct Input" (DI) and DI reduced by all "Exports" (e.g. tithe) into other socio-economic systems is referred to as "Domestic Consumption" (DC). From a MEFA perspective it is, therefore, crucial to define consistent boundaries between the natural and the socio-economic system (and between different socio-economic systems). The issue of where to draw these system boundaries and, hence, which flows should actually be accounted for has been debated intensively within the MFA community[13,38]. The outcome of this discussion was a convention which considers the production of livestock as a process within the economy while forests and agricultural plants are treated as part of the natural system[39,40]. This means that the harvest of all biomass, including the biomass grazed by domesticated livestock is accounted for as a flow from the natural into the socio-economic system.

This study focuses on flows of biomass and energy and does not consider flows of mineral materials. Accordingly, DE comprises of all types of harvest of biomass, be it grain or straw or hay harvested or biomass grazed by livestock.

All biomass extracted (i.e. crops and by-products of the arable land, hay and grazed biomass of grassland, wood, litter and grazed biomass of woodland, etc.) enters the production system where it is stored and processed. Within the production system the compartments processing, livestock system and dunghill, material stocks (i.e. wooden buildings or tools) and energy generation are differentiated. Flows into the livestock compartment are feed and litter, while outflows are live animals, milk and eggs into the processing compartment, manure to the dunghill and all sorts of wastes, emission and heat into the natural system.

All biomass intended for human nutrition enters the "processing" compartment, including the primary steps of processing agricultural products for food purposes (e.g. milling of grain, slaughtering of animals). Outflows of processing compartment are foodstuff (i.e. flour, other vegetable food, meat, milk, etc.) into the "population" compartment, feedstuff as input into the "livestock" compartment (bran and other processing wastes) and biomass for material and energetic use as well as wastes and losses into the natural system. The compartments "material use" and "energy generation" are final use compartments within the production system. Flows out of the production system are flows of food into the population

compartment and exports into other socio-economic systems (i.e. food, feed or wood sold on the market or delivered to the land lord).
However, no quantitative data were available concerning import and export flows. The CE only provides very rough qualitative information on the extent of market participation of the respective communities and on the basic types of agricultural produce that were sold or bought at markets. Estimates of the order of magnitude of these flows were made by relating the calculated demand for subsistence to the actual supply (e.g. local demand for firewood and timber vs. actually logged wood). The difference between supply and demand can be regarded as a rough proxy for eventual imports or exports, which can serve as an indication for the amount of produce that could have been exported under the specific conditions and under the assumption that the village systems can be conceived as subsistence economies predominantly aiming at self sufficiency[8].
Flows out of the production system into the natural system include seeds (leaving the production system and entering back into the agro-ecosystem), the flow of manure from the dunghill to the agro-ecosystem and furthermore all sorts of losses, wastes, emissions and heat that re-enter the natural system.
To emphasize the intimate relation between land use, the production of food and feed, the livestock system and population system, we have also added an arrow for the work performed by humans and animals that is necessary to keep the land-use system and the production system working. These relations, however, were not quantified in this study.
All other flows were quantified or estimated for the four villages (KG) under consideration and for Austria as a reference system. Additionally to the bottom-up quantification of these flows based on the production/supply of biomass, calculations of demand for feed, litter, food and wood were performed to cross-check (and eventually adjust) the calculations on supply according to the flow model.
Basically, all flows that were accounted for can be expressed (and were actually calculated) in mass units (i.e. fresh weight as given in the source, dry matter and reduced to nitrogen content) as well as in energetic units (i.e. gross calorific value, nutritive (calorific) value, feeding value (starch equivalent)). For different research questions, the accounted flows are referred to in different units (e.g. for the discussion of demand and supply of feed-stuff data on biomass flows were analysed in units of feed value (starch equivalent), while with respect to questions of soil fertility, data are presented in kg of nitrogen). For the analysis of socio-economic energy flows, gross calorific values were used because they are an appropriate unit for relating socio-economic energy flows to energy flows in ecosystems[37,38].

The following abbreviations and indexes are used to distinguish between the different units: DM refers to dry matter (e.g. kg_{DM}/ha); FW refers to fresh weight (e.g. kg_{FW}/ha) as it is reported in the source (e.g. fresh weight of grazed biomass is reported as hay equivalent with 14% water content, Table 13); GCV refers to gross calorific value (e.g. GJ_{GCV}/cap*yr); NV refers to nutritive value (e.g. GJ_{NV}/cap*yr); SE refers to starch equivalents; N refers to nitrogen (e.g. kg_N); LU_{500} refers to livestock units with 500 kg live weight; smc refers to solid cubic metres. Furthermore, the index AGR refers to “agricultural” (e.g. kg/cap_{AGR} refers to kg per capita agricultural population; kg/ha_{AGR} refers to kg per ha agricultural area)

3.2 Land Use

The land-use and land-cover data were used as documented in the cadastral operates. However, as the CE only provide information on land use within the political boundaries of the respective KG, it was necessary to evaluate the parcel protocols of neighbouring communities to get the necessary information on external land use. As evaluations have shown, it was quite commonly the case that farmers had the right of use of land in a neighbouring KG[8,18]. These parcels were called *Überlandgründe* (i.e., external land used). Data on the extent of external land use for the villages Theyern, Voitsau and Großarl were available from previous studies[18]. For the KG Nussdorf, a survey of external land use in neighbouring communities was not available.

The Cadastre usually allows for differentiation between the following main land-use categories: arable land, back gardens, orchards (usually meadows with apple/pear trees close to the farmstead), vineyards, meadows, rough grazing, high mountain grassland, woodland, built-up land and unused land. A special land-use type common for alpine grassland farming (e.g., in the KG Großarl) are the so-called *Egarten*: This is an alpine type of rotation between grassland and arable. Typically, the land is used one year as cropland every 4-6 years and becomes grassland for the remaining years[41].

Each land-use class was split in up to 4 "quality classes". With respect to arable land, the CE provides data on the crop rotation system and the yearly acreage of the sown crops (in the KGs under consideration, mainly rye, oat, wheat, barley, potatoes, fodder beet, cabbage, clover) and the fallow land. The number of land-use classes (including crops and quality classes) was 26 in Theyern, 23 in Voitsau, 27 in Großarl and 30 in Nussdorf. Digitised land-use maps of the villages Theyern, Voitsau and Nussdorf were produced on the basis of the original cadastral map prints by Klaus Ecker[18,42].

The original figures for area given in *niederösterreichische Joch* were converted to metric units assuming the standard conversion factor (1 *nö. Joch* = 5,755 m^2)[23,43].

Aggregated land-use classes used in this study are "agricultural land", which includes all types of cropland, gardens, permanent cultures, meadows and rough grazing but excludes woodland, built-up land and unused land. The term "arable land" usually subsumes all types of cropland including fallow land, gardens and permanent cultures while "grassland" refers to meadows, classified rough grazing areas (*Hutweiden*) and high mountain grassland (*Almen*).

3.3 Yield and Biomass Extraction

Biomass extraction in the form of agricultural harvest, forestry, litter removal and livestock grazing was calculated by using the yield estimations provided by the cadastral elaborates. Yield figures in the FC are given in volume-units for certain crops (1 *niederösterreichischer Metzen* = 61.5dm^3) and were converted by using regional standard values for nineteenth-century agricultural products (Table 13)

Yields given in the mass unit *Centner* were converted into kg using the relation 1 Ctr = 56.0 kg.

Yields for rough grazing given in the CE range from between 97.3 kg of hay equivalent/ha in Großarl to 389 kg in Nussdorf seem to be too low. Assuming that only 50% of the aboveground net primary production (ANPP) were actually grazed, this amounts to an ANPP of 200 kg_{DM}/ha to 750 kg_{DM}/ha, while according to the scientific literature, the poorest rough grazing land has an ANPP of 1,000-2,000 kg_{DM}/m^2. Agricultural textbooks usually assume yields for very poor rough grazing land within a range of 300-600 kg hay equivalent/ha[44], while BÖHM[45] assumes 730 kg/ha for dry rough grazing in Bavaria and ZOEPF[29] 800 kg for rough grazing in upper Austria. Therefore, the rough grazing yields were adjusted by factors of 1.5-3. This yield adjustment has a significant effect on the total supply of feed only in the KG Voitsau and Großarl where considerable areas were classified as rough grazing

The data provided by the FC on timber harvest were based on estimates of local productivity of woodlands, yearly increment and average felling periods (rotation periods) according to

local practice. Based on these data, a yearly yield of woodlands was estimated in volume units (*30" Klafter*). *Klafter* were converted into solid cubic metres (scm) by using the relation one *30" Klafter* = 1.99 scm of wood.
Harvested biomass was calculated as fresh weight (kg_{FW}) and converted to dry weight (kg_{DM}), gross calorific values (MJ_{GCV}), nutritive values (MJ_{NV}), feed values (starch equivalent SE) and nitrogen content (kg_{N}) using standard conversion factors presented in Table 13.
Harvest of straw (and other by-products) was calculated using average grain-to-straw ratios (harvest indices) for nineteenth-century grains[17].
Additionally, biomass extraction due to various forms of grazing on fallow land, arable land after grain harvest, meadows before an after cutting and wood grazing were estimated by using yield estimations according to literature reviews[29,45] (Table 1).

TABLE 1
RANGE OF GRAZING YIELDS ON DIFFERENT LAND USE TYPES IN KG HAY EQUIVALENT/HA

	Yield (kg/ha)
Rough grazing	200-490
Meadow (after hay-cutting)	140-510
Stubble field	200
Fallow	500
Woodland	120-180
High mountain grazing	605

kg/ha – kilograms per hectare
Source: own calculations, see text.

Potential litter-yields for different forest types were calculated according to data given in REHFUESS[46], MITSCHERLICH[47] and DANKELMANN[48]. These sources give an average of 2 to 3.5 $tonnes_{FW}$/ha of litter at a three-year removal interval.
Data on agricultural yields given in the cadastral surveys were estimated under the assumption of a "year of average natural fertility;" i.e., they have to be regarded as long term average values, probably on the lower end of the range. However, yearly variations were probably high due to climatic variability.
The estimations of both yields and rates of the regional or seasonal exploitation of potentials for additional grazing, litter removal, and other types of land use should be considered to be rough estimations and variable. However, these estimations serve as a first indication of the potential significance of these land-use types concerning feed supply, animal husbandry and nutrient cycling – especially as hardly any quantitative estimations on the relevance of these forms of land use exist.
The model used in this study allows us to simulate variations in yields and land use area and their effect on food and feed supply and therefore to analyse the relative variability or stability of the local agricultural production system.

3.4 Animal husbandry

The FC provides data for the number of livestock and qualitative information on feeding practice as well as for use of the different animal species and their outputs. When modelling the livestock compartment - i.e. supply and demand of feed, supply and requirement of litter, accumulation of manure and output of meat and milk - the following methodology was applied:

In the 19th century, livestock, above all on a local level, was subject to significant seasonal variations[49]. In general, livestock number were lowest during the winter months when food was scarce, and it was common to sell or slaughter animals in fall. Unfortunately, the cadastre does not specify the time of year when livestock was counted. In the absence of any better data, the numbers given in the cadastre are regarded as a valid average of the stock that was maintained for the whole year. Furthermore, the cadastre gives only insufficient information on the number of young cattle. Although there are numbers on calves and heifers in the CE, they do not seem to be reliable because they don't match with the requirements of biological reproduction. One reason for this is that, while the number of cows, oxen and horses was fairly constant during the course of the year, high seasonal fluctuations can be assumed for calves and heifers as well as pigs – as these were the animals that were fattened, sold or slaughtered according to seasonal feed availability[45,50].

By far the most relevant type of animals in all villages were cattle (70-90% of the total stock measured in livestock units of 500 kg live weight (LU_{500})). To model their reproduction, it was assumed that the number of cows given in the CE was balanced over time by natural reproduction. Assuming a slaughter rate for cows of 12%[23,45] (cows were replaced after about 8 years – i.e. at an age of 10-11 years) [31] requires a stock of young animals (aged 1-2.5 years) amount to 18% of the number of cows. Oxen (which were of importance only in Theyern and Voitsau) were usually replaced after 5 years, i.e. at an age of 6-7 years, which requires a stock of young animals amount to 15% of the total number of stock (except for Theyern, where ,according to the CE, oxen were not reproduced locally but bought). It was further assumed that there would have been a calving rate per cow of 70% and that calves not used for reproduction were slaughtered after a fattening period, resulting in a slaughter rate for calves of 35-70%[45,50,51]. Reproduction of horses, pig and sheep was not explicitly modelled. Slaughter rates for all types of animals are given in Table 14

Live weight of different types and age classes of animals is the most essential parameter for modelling the livestock compartment. Unfortunately, the cadastre does not provide data on average live weight, therefore the specific values had to be estimated according to a literature survey. The animal types under consideration are horses, oxen, cows, heifers, sheep, goats and pigs. To estimate the average live weight of 19th century livestock, a large number of sources including both current literature and 19th century writers[23,28,31,45,50-53] were used.

The basic values chosen for average live weight are given in Table 14. For some animal types in Großarl, average live weight was reduced by 10-15% based on regional data on live weight (lighter cattle in alpine regions) and available feed (see also section on feed demand).

For the methodological problems concerning the modelling of historical livestock populations, see SCHÜLE[50], STEIGER[51] and BÖHM[45].

To calculate figures for meat production, data on slaughter rates and edible portion of carcass for the different types of animals are required. These data were compiled by a literature review[23,44,45,54] and are shown in Table 14.
Gross milk yield was set at 1300 kg/cow per year, according to a literature survey[28-30,45,52]. The assumption that 15% of the gross milk yield per cow was used for feeding[51] calves and other animals results in a net yield of milk for human nutrition of 1100 kg/cow per year. The milk yield from goats was estimated at 300 kg/goat per year.

Feed supply includes grazing (on designated rough grazing areas (*Hutweiden*) as well as on all other areas grazed temporarily), harvested biomass from meadows (hay) and arable land (straw, feed grain and forage) as well as the by-products of food processing (bran).
According to the CE, *Linsgetreide* (mixed grain) and oats were primarily used for feeding. Furthermore, wine leaves, fodder beet, a fraction of the potato harvest and clover were used for feeding. The CE provides semi-quantitative information on the amount of straw and other by-products, such as beet leaves, that werefed to animals. According to the information in the CE and an extensive literature review[28,29,45], a large fraction of the available straw was fed to animals (either cut as *Häcksel* or as a component of feed preparations). According to these data, it was assumed that 60-100% of the available straw was fed to animals (Austria 60%, Voitsau 70%, Theyern 70%, Nussdorf 70% and Großarl 100% because of the serious shortage of barn feed). The remaining straw was used as litter and to a small extent as raw material (e.g. for roofing).
Furthermore, bran produced as a by-product of grain milling together withsome other processing by-products were accounted for as available feed and it was assumed that some 15% of the gross milk yield was used for feeding calves and pigs.
Feed supply was converted into dry matter and starch equivalents according to average conversion factors[43,55].

Feed demand of the different types of animals depends on live weight, on the average activity level (animals performing work and grazing animals have a higher feed demand than animals kept in the stable) and on production (weight gain, milk yield). Modelling the feed demand of the livestock system of a nineteenth-century village is not a straightforward task[45,50]. In this study, feed demand was calculated according to different methods and data, but in general all calculation methods rely on values for average feed demand per kg of live weight at different levels of activity/production:
In "DM" method, values for daily feed requirement in kg (dry matter) per kg of live weight for all animal classes under consideration according to HITSCHMANN[44] were used. To estimate minimum feed requirement, the lower values given in HITSCHMANN for animals with no working activity and very low milk yields were applied. To estimate standard feed requirement, the corresponding values for animals with medium work activity and average milk yields (5-10 kg /day) were used. According to this method, the average feed requirement for milk cows ranges from 4.6 to 5.9 kg per animal per day. For oxen, this amounts to 5.9-8.2 kg per animal per day. These values tally with other values suggested in the literature and historical sources for nineteenth-century feed demand[45,50,56]. To cross-check these results and because dry matter does not directly relate to feed quality, feed demand was also calculated in units of feed value ("SE" method). Although today species-specific units of digestibility of feed are used for calculating feed balances, for historical calculations, the less sophisticated unit "starch equivalent" seems to be appropriate[50]. One starch equivalent (SE) equals the digestive value of one gramme of starch and allows the different feed stuff to be aggregated according to its specific digestive value. For species-specific values for feed requirement in

SE, data given in the literature[57-60] had to be relied on. Once again, minimum and standard feed requirement were estimated, based on the same assumption as for the DM method, using values of feed demand given in SE per kg of live weight (Table 13).

Apart from relating feed supply to total feed requirement, it is important to obtain information on feed provision during the course of the year. The "feeding year" under nineteenth-century agricultural conditions can be split in a grazing period and a period of stable-keeping. Feed requirement and feed supply can be analysed accordingly.
I assume that in Voitsau animals were kept in the stable from the beginning of October to the end of April. Additionally, as horses, oxen and cows were partly kept in the stable overnight even during the grazing period, their grazing days were reduced by 20-30%. The average grazing period in Voitsau amounted to 130-180 days per year.
In Theyern, more barn feed was available. It was assumed that animals were kept in the stable for a longer period: with the exception of sheep and heifers – which were probably kept on rough grazing for a longer period – 100 grazing days and 265 stable days were assumed. Similar values were assumed for Nussdorf.
In Großarl this issue is more complicated: A core element of the grassland based livestock farming in Großarl was the availability of (semi-) natural grasslands at high altitudes and transhumance[11,41,49,61]. The alpine grasslands accounted for more than 25% of the total area of the KG Großarl. Around 50% of these pastures were *Nieder- and Mittelalmen* at an altitude of 1000-1700m and the other half were *Hochalmen* at more than 1700m above sea-level. The alp-period lasted for 120 days, from mid-May to mid-September and it was assumed that all cows and heifers and around 25% of horses and oxen were kept on the alps during this period. Most of the draft animals were needed for agricultural work at the farmsteads in the valley and were not brought to the alps. Furthermore, it was assumed that all animals were pastured before and after the alp-period on the valley-pastures in the vicinity of the farmsteads, adding three more months to the grazing period. The period during which the herd was kept in the stable was determined by climatic conditions but kept as short as possible because barn feed was scarce. It was assumed that it lasted for an average of 5 months for most animals[41,49,62].
For Austria as a whole, it was assumed that on average about one-third of all cattle and sheep were kept on high mountain pastures for about 100 days per year. The grazing period for all other animals was calculated as the average grazing period of the four villages.

The litter requirement was calculated according to different sources[44,58,63] for species-specific values of litter demand in kg/animal and per day and a calculation method applied by BÖHM[45] for a litter estimation for the German state of *Bayern* (Bavaria). According to these data, the daily litter requirement of cows ranged between 2 and 2.4 kg_{FW} litter. The number of days for which animals were kept in the stable was estimated, based on the values discussed above. Average litter demand over the course of a year ranged between 3.4 and 4.9 kg/LU_{500} per day. Although these figures have to be regarded as rough estimations, they can serve as an indication of the order of magnitude and they can be related to calculations of the potential supply of litter in the system.

3.5 Human nutrition

The CE contains some basic information on the utilization of agricultural products for human nutrition and the qualitative structure of the diet common in the villages.
In general, the total net harvests (reduced by seed demand) of rye and wheat were used for human nutrition as well as a certain fraction of the potato harvest. In addition, vegetables

grown in back gardens, apples and pears from orchards and wine production were used for human consumption. It is assumed that all grain for human consumption was milled, using a factor of 80% for flour yield and 20% for the bran fraction, which was fed to livestock[44]. The amount of grapes harvested was converted to wine using a yield factor of 0.75[55,64].
Production of meat was calculated by applying species-specific slaughter rates (see above) and values for edible portion of carcass (Table 14) to livestock numbers.
Net milk production (i.e. gross production reduced by 15% for utilization of milk for feed) was accounted for as human food. Although it is evident that a certain amount of milk was used to produce cheese and butter, this conversion process was not accounted for because no quantitative information on the proportion of milk converted into cheese and butter was available. This may results in an overestimation of the actual contribution of milk to total food supply (especially in Großarl), because cheese production is connected with losses (e.g. whey) that are commonly used for feeding.
Food supply in FW was converted into nutritional values according to factors given in food composition tables[65]. Average nutritive value of the production of slaughtered animals was calculated by using data on meat and fat content of the edible portion of carcass[66,67].

Average food demand was calculated according to standard figures on recommended food intake for different age classes (at a level of moderate activity and for current average in height and weight)[68,69]. Data on population number (absolute number of males and females) provided by the CE were disaggregated into age classes by applying average age distribution in the respective province according to the results of the Austrian Census of 1869[70] and according to a reconstruction of population structure by an evaluation of birth register data (*Kirchenmatrikeln*) for Theyern.
According to these calculations, average food requirement per capita was estimated to range between 8.8 and9.3 MJ/cap. For comparison with food supply in the systems under consideration, an average of 9.0 MJ/cap per day (equal to 2148 kcal/cap per day or 3.29 GJ/cap per year) was assumed[68].

Monetary valuation of agricultural production
In addition to the quantification of agricultural output in physical units (GJ_{NV}), a rough estimation of agricultural productivity in economic units is provided. Two approximations were used to relate the food output of agriculture in physical units to economic parameters:

a) For reference purposes, the monetary net gain of agriculture (*Bodenproductivität* – land productivity) according to the estimations provided in the CE as a basis for taxation[22] was calculated. The CE provides data on monetary gross gain, which were achieved for each land-use category by multiplying the estimated gross yield by the local product price of 1824 (which represented a year of very low prices). Monetary net gain –underlying the taxation - was calculated by subtracting the estimated factor costs (monetary value of human and animal work, seeds, etc.) of each land-use category – as provided by the *Darstellung des Kulturaufwandes* - from gross gain. However this only relates to estimated land productivity (harvested biomass) and not to agricultural output (food and feed production). Nevertheless, it seems worthwhile to relate these data to physical net output. Data on monetary net gain are reported in *Gulden*.
b) To get a rough estimate of the gross monetary value of the total food output of systems, the data on physical output (vegetable and animal products) were converted into monetary values using average product prices for meat, milk, flour and wine in the cities of Vienna, Linz, Graz and Innsbruck as compiled by MÜHLPECK et.al.[71].

Prices are reported in *Kronen*: According to these data, the product with the highest market value per MJ/nutritive value was wine (0,11 Kronen per MJ_{NV}) followed by meat (0,06 Kronen per MJ_{NV}), milk (0,04 Kronen per MJ_{NV}) and grain (0,02 Kronen per MJ_{NV}).

3.6 Nitrogen flows

To tackle questions of management and maintenance of soil fertility in pre-industrial agricultural systems, nitrogen (N) flows into and out of the land-use system were calculated. The emphasis of this calculation was placed on socio-economic nitrogen flows and not on a systemic modelling of all aspects of the nitrogen cycle of pre-industrial agro-ecosystems. The following flows of nitrogen were estimated: N-removal from natural systems due to harvest of biomass ; socio-economic input of N into the natural system as N contained in seed and manure; symbiotic N-fixation due to leguminous crops. Additionally, to provide an indication of the relative extent of socio-economic interference with ecological N flows, certain natural inputs were roughly estimated as well. Natural inputs of nitrogen into the agro-ecosystem not directly controlled by the farmer are: atmospheric N-deposition; N-fixation by free living organisms; N-fixation by native leguminous plants in grassland and fallow. Soil processes such as N-leaching and N-gains due to decay of soil minerals, etc. were not estimated. Therefore, these calculations can only serve as a rough indication on the effect of pre-industrial practices for management of soil fertility and the human impact on the local nitrogen cycle of the agro-ecosystem.

All nitrogen contained in harvested biomass (agricultural harvest; grazing; logging and litter removal) was accounted for as socio-economic removal of nitrogen. Nitrogen output due to the different types of harvested biomass was calculated according to standard values for nitrogen content of biomass[43,55,72,73] (Table 13).

Atmospheric nitrogen-deposition is closely correlated with industrialisation and urbanisation. Current nitrogen balances for Austria assume an average value for wet and dry deposition of 20kg/ha[72,73]. In the early nineteenth century, however, deposition was probably much lower, ranging between 2.5 and 4 kg/ha[74-77]. A value of 3 kg/ha for all land-use types was assumed in the calculations.
Rates for nitrogen-fixation by free-living organisms and native legumes for pre-industrial agro-ecosystems given in the literature are scarce and typically range from 1 to10 kg/ha[76,78]. CUNFER[75] estimates a value of 0.5-1 kg/ha in his study on a county in the US Great Plains region in the nineteenth century, while LOOMIS and CONNOR[76] estimate the inputs of N into an ideal-type farming system of the Middle Ages due to deposition and free-lining fixation to be a total of 8 kg/ha. A value of 3.5 kg/ha for grasslands and fallow and a lower value (2 kg/ha) for woodlands and cropped arable land was used.

Rates for nitrogen-fixation due to sown legumes (clover, etc.) was assumed to be 110 kg/ha[72,74,76]. Nitrogen inputs due to seeding were calculated by using average nitrogen content of sown grain.

To estimate the nitrogen contained in animal faeces and manure, different methods were used:

a) Nitrogen excreted in faeces and urine can be calculated as a specific portion of N ingested with feed uptake by farm animals. The amount of excreted N ranges from 70-80% of the N contained in the consumed feed[79-81]. For feed uptake, the estimations of minimum and standard feed requirement in DM and an average value of N contained in feed according to the available feed were used. Besides the excreta of animals, manure also contains litter (straw or wood litter). Therefore, the N contained in litter (calculated supply) was added to the N contained in the excreta.

b) Nitrogen in manure was calculated by using standard coefficients of manure production per animal (based on live weight) and N-content in manure fresh weight[79-82]. The results of this method are within a range of 90-150% of the results obtained with method a). However, as this method does not include any direct relation to actual nitrogen uptake with feed and it involves considerable uncertainties (manure production, water content, N-content of manure), minimum and maximum values obtained by method a) were referred to for further analysis.

Besides estimating the amount of manure production and its N-content, the crucial question in quantifying nitrogen inputs due to manuring is 'how much manure N can be collected in the stable, applied to the field and transferred into the soil?'
Total manure production has to be reduced by the amount of manure which is lost during the grazing period: It is assumed that all N-uptake due to grazing, with a certain reduction (10-25%) in order to take into account the fraction of livestock kept in the stable over night during the grazing period, was lost for manure production. N lost due to grazing amounts to 10-30% of total N excreted by animals. Furthermore it was assumed that 50-60% of the N contained in faeces and urine dropped during grazing is lost due to volatilisation and not available for the agro-ecosystem. The remaining fraction is accounted for as socio-economic N input into the agro-ecosystem.

Losses of N during storage and application of manure can be large[79-82]. In general, manure management was still rather poor in the early nineteenth century: Nitrogen was collected in open lots, where it was exposed to sun and rain and commonly stored for several months until it was applied to the field. Due to this treatment, a large fraction of N was lost due to runoff and volatilisation. Studies on N budgets of historical farming systems assume losses of nitrogen during storage and application within a range of 50-80%[74,76,83]. For the calculations presented in Table 12, losses of nitrogen ranging between 45 and 60% of total content were assumed.

3.7 Wood

Supply of wood was calculated according to the data on logging yields provided by the CE. Demand for firewood and timber was quantified according to a rough estimation. According to a literature review[20,25,34,48,84-86], wood demand of nineteenth century (agricultural) households ranges between 5 and 40 solid cubic metres (scm) per household per year, most sources giving rather high values of 20-30 scm. However, wood demand must have been subject to large regional variations, depending on climate conditions, land use and, above all, the regional availability of wood. For the presented calculations, and with reference to the limited supply of wood in most villages, a total wood demand ranging between 10 and 20 scm/household per year was assumed. Firewood usually accounted for 80-95% of total demand.

4. Results and discussion

4.1 Austrian agriculture in the 19th Century

All villages and most parts of the reference system Austria 1830 were surveyed for the FC in the early nineteenth century, predominantly in the 1820s and 1830s, a period when state power increasingly began to erode the feudal organization of agriculture in the Austro-Hungarian monarchy. The feudal system of land tenure and serfdom formally ended, however, only with the land reform (*Grundentlastung*) of 1848. All the cases studied represent seigniorial farmingsystems [49,87]. The farmsteads and the affiliated land were owned by a landlord/seigneur (*Grundherrschaft*) and were leased to tenant farm-families (*Untertanen*) for cultivation. In return, the farmers had to provide the landlord with tithes (*Zehent*) and taxes in the form of agricultural products or monetary values and they were obliged to render human and animal workdays to assist the landlord in the cultivation of his estates (*Robot*). Furthermore, the landlord/seigneur had extensive rights concerning various aspects of farm life and land use on “his” farmsteads. This seigniorial character of the villages is an important aspect concerning economic structure (e.g. market integration vs. subsistence economies) and the structure of the land-use system[8,19,23,35,49,87]. In the case of the villages studied, the landlords were predominantly clerical institutions (e.g. monasteries)[19]. Beside the landlord, the village-community may be considered as an important institution[36,49] with respect to regulating the structure of the local land-use system. Individual scope was strictly limited and a considerable part of the social organisation and the seasonal rhythm of land use was influenced by the village as a whole and not by the individual farmer[49]. Among other things, this related to the use of local commons, the seasonal rhythm of sowing, ploughing and harvesting within the typical three-field rotation system (see below) or the organisation of grazing on various types of land (see below) [8,19,35,88].

Table 2 provides an overview of important structural parameters including population, livestock and land use in the four villages of Theyern, Voitsau, Nussdorf and Großarl and for Austria 1830.

TABLE 2
STRUCTURAL PARAMETERS CHARACTERISING THE CASE STUDIES THEYERN, VOITSAU, GROßARL, NUSSDORF AND AUSTRIA 1830: NUMBER OF POPULATION, FARMS, AND LIVESTOCK; LAND AVAILABILITY AND USE; AGRICULTURAL YIELDS.

		Theyern	Voitsau	Großarl	Nussdorf	Austria
Population	(number)	102	129	650	462	3,592,000
Households	(number)	20	29	122	77	653,000
Farms	(number)	17	25	50	62	no data
Land use						
Total area of KG	(km²)	1.99	3.04	29.00	3.63	85,906
External land use	(km²)	0.26	0.21	0	no data	0
Total area of land used	(km²)	2.25	3.25	29.00	3.63	85,906
Arable land	(%)	54%	62%	5%	20%	22%
Garden; Permanent cultures	(%)	6%	1%	0%	17%	1%

Grassland	(%)	3%	33%	53%	2%	31%
Woodland	(%)	35%	1%	27%	58%	38%
Other areas	(%)	2%	3%	15%	3%	7%
Use of external commons	(km²)	0	0.5-1	0	no data	0
Population density	(cap/km²)	45	40	22	127	41,813
Average farm Size	(ha/farm)	8.3	11.0	3.0	2.2	
Livestock						
Horses	(number)	5	0	22	19	208,000
Oxen	(number)	24	76	2	0	408,000
Cows	(number)	26	45	411	115	1,128,000
Other cattle	(number)	29	56	390	115	1,071,600
Pigs	(number)	42	36	16	144	483,000
Sheep	(number)	77	45	463	0	1,282,000
Goat	(number)	0	0	91	0	250,000
Poultry	(number)	80	42	0	308	2,000,000
Total livestock unit	(LU)	51	99	287	96	1,417,532
Livestock density	(LU/km²)	23	31	10	26	17
Yields						
Average rye yield	(kg/ha)	863	818	819	1,177	925
Average cereal yield	(kg/ha)	819	732	862	1,085	890
Potatoes	(kg/ha)	7,200	7,405	0	5,950	7,165
Hay	(kg/ha)	1,906	1,553	651	1,299	2,304
Wood	(scm/ha)	2.54	1.38	4.10	2.22	3,100

cap/km² - persons per km², ha/farm – hectares per farm, LU – livestock unit, kg/ha – kilograms per hectare, scm/ha – solid cubic metres per hectare
Source: Cadatral elaborat of Theyern, Voitsau, Großarl and Nussdorf, Krausmann 2001 for Austria 1830, own calculations, see text.

“Austria 1830” is a construct comprising the provinces of the Austro-Hungarian monarchy which are roughly equivalent to the territory of the newly-founded Republic of Austria after WWI[20]. The population of “Austria 1830” amounts to 3.5 million and average population density was comparatively low, at 42 people per km². 38% of the total area was covered by woodlands, 31% by grassland and only 23% was used as arable land and permanent culture. However, land use and population density were very heterogeneous due to the Alps that dominate large parts of the country. The central part was scarcely populated, dominated by woodlands and mountainous grassland farming with a focus on milk production, while the lowlands in the north(eastern) and southern part were characterised by cropland systems and a higher population density. The eastern part in particular was influenced by the rapidly growing metropolitan area of the city of Vienna, capital of the Austro-Hungarian monarchy, with a population of 400,000 in 1830. In general, Austrian agriculture in the early nineteenth century is characterised as rather backward and subsistence-oriented[23,35]. More than 70% of the population were still working in agriculture at the beginning of the nineteenth century. Cropland farming was still dominated by three-field rotation systems with large fractions of cropland lying fallow each year. Yields were considerably lower than in other central European countries. The socio-economic energy system was almost exclusively based on solar energy, with fossil energy accounting for less than 1% of total energy consumption. The few industrial centres relied almost exclusively on wood and charcoal[37].

4.2 Characteristics of land use in the case study regions

Theyern, 370m above sea level, is located in low and hilly country to the north-east, on a hilltop. During the period surveyed, it was a small village, consisting of 17 farmsteads (20 households) and a total population of 102. The area of the cadastral unit covered 200 ha and, as a detailed analysis of the cadastral data of the surrounding municipalities has shown, another 25 ha of external land (*Überländer*). These parcels of agricultural land, predominantly arable land and vineyards, which were located in neighbouring cadastral units, were used by farmers residing in Theyern. Thus, the territorial system under consideration covered an area of 225 ha. Land use in Theyern was dominated by arable farming: More than half of the land (54%) was used as arable land – this is practically all the land on which the soil was suitable for ploughing[18]. Woodlands covered 35% of the total area and 6% of the land were used as vineyards, fruit and back gardens - most of them in the close vicinity of the farmsteads. Interestingly, despite a large livestock, only 3% of the area was classified as meadows or rough grazing.

The arable land in Theyern was farmed by a three-field rotation system (*Dreifelder-Wirtschaft*). The arable land of the whole community was split into three parts (*Zelgen*). Following a yearly rotation, one of the three fields was sown in the autumn with winter cereal (Rye), one was sown in spring with summer cereal (*Linsgetreide;* i.e. a mixture of barley, other grains and pulses), while the third *Zelge* was not cropped but left for regeneration. This fallow field was tilled several times during this period and it was used for grazing during summer and autumn[89]. In Theyern roughly one-third of the fallow land was already used to grow potatoes and clover.

The small gardens were used to grow vegetables and herbs, the “orchards” in the close vicinity of the farmsteads were actually meadows stocked with some apple or pear trees. Woodland (high forest consisting of pine trees) had remained only on the soils which were not suitable for ploughing. According to the CE, the woodlands were also used for grazing and litter extraction.

Although Theyern was dominated by arable land, livestock was considerable and consisted of 5 horses and 24 oxen that were kept to provide the necessary draught power in agriculture and forestry, 32 cows, 42 pigs and 77 sheep. In addition, an estimated number of 80 chicken and 29 heifers were kept.

Population density was 45 people/km² and livestock density was 23 LU_{500}/km² (livestock units at 500 kg live-weight).

Theyern was a strictly agricultural community with all households engaged in agriculture. Its arable farming system can be regarded as a comparably “modern”, with about one-third of the fallow land planted with new crops (clover, potato). Average grain yield amounted to 819 kg per ha annually, which was significantly below the Austrian average. Considering that Theyern was almost completely lacking in grassland, the number of ruminants seems to be fairly high.

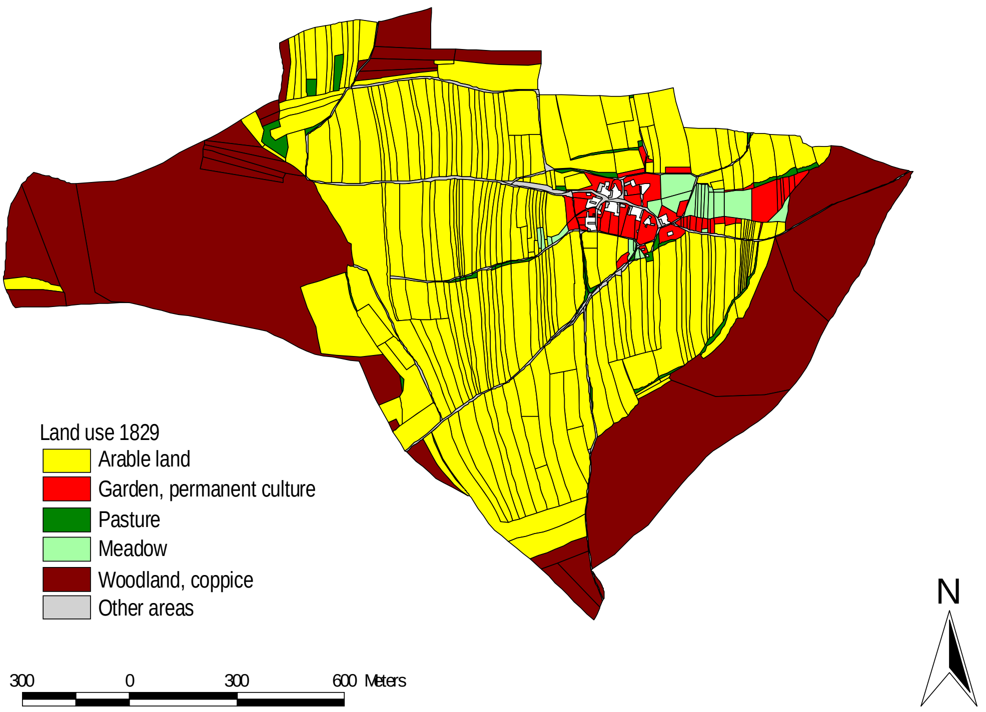

Figure 2: Land cover in the village of Theyern 1829. Digitized maps of the Franziscean Cadastre (based on data provided by Klaus ECKER and PROJEKTGRUPPE UMWELTGESCHICHTE[15, 16])

Nussdorf, 249 m above sea level and with favourable climatic conditions, is a village adjacent to Theyern in the north. With a total population of 462 and an area of 363 ha, population density in Nussdorf was significantly higher (127 people/km²) than in all other villages considered. However, we do not have any data for Nussdorf concerning external land use. This deficiency makes it difficult to interpret some of the results obtained for Nussdorf (e.g. feed supply, productivity). Despite these problems, it was decided nevertheless to include the results, due to the unique character of the village.

Despite Nussdorf being in close vicinity to Theyern, the character of the two villages was rather different: While Theyern was dominated by arable farming, Nussdorf was a community of wine growers and the only one of the four villages with a significant proportion of the population not engaged at all in agriculture (16 out of 77 households). Woodland covered 58% of the total area of the KG, 20% was classified as arable land and vineyards amounted to 13% of the area. However, it should be noted that a considerable portion of the vineyards may have been cultivated by farmers not residing in Nussdorf. Four percent of the land was used as orchards and back gardens, while grassland covered only 2% of the land. Farmers in Nussdorf only partly followed the traditional three-field rotation system. The best plots of arable land were fallowed only once every four years. Additionally, roughly one-third of the fallow land was planted with potato and clover. However, the characteristic aspect of agriculture in Nussdorf was wine growing, which was a very labour intensive but also profitable activity that allowed for a considerable participation in the market economy[8].

Livestock density was rather high in Nussdorf and amounted to 29 LU_{500}/km^2. Farmers in Nussdorf did not keep oxen and made sole use of horses to provide draught power. They held a high number of cows (2.2 cows per agricultural household compared to 1.6 in Theyern and Voitsau, respectively) and 144 pigs (2.3 pigs per agricultural household).
Average grain yield amounted to 1085 kg_{FW}/ha and was above the Austrian average. Average yield of wine was 1,600 l/ha.

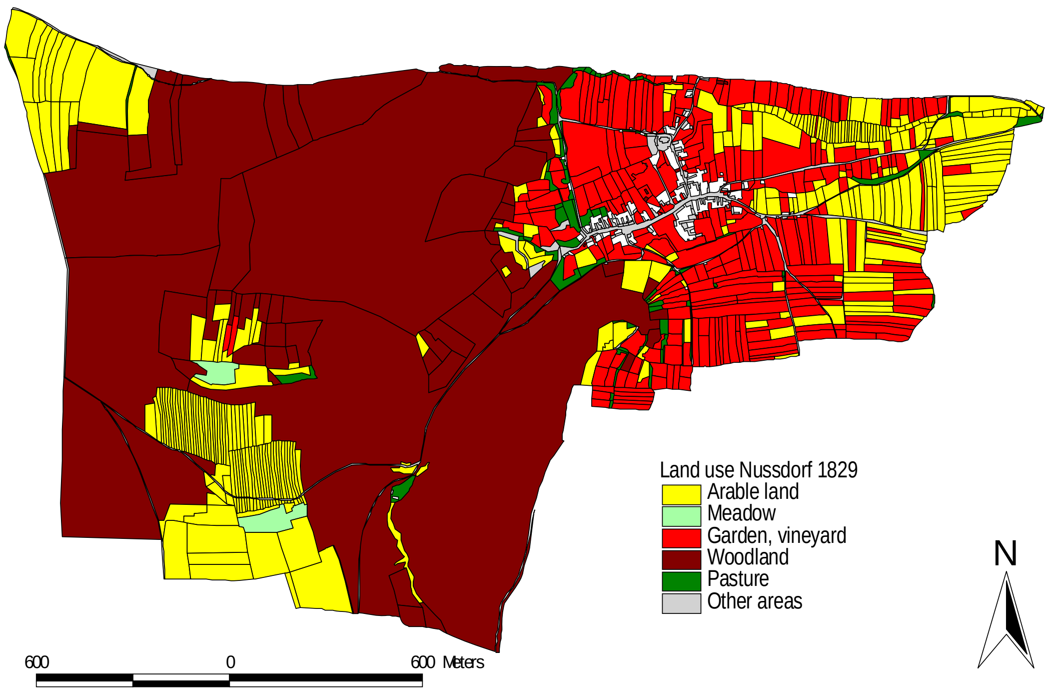

Figure 3: Land cover in the village of Nussdorf 1829. Digitized maps of the Franziscean Cadastre (based on data provided by Klaus ECKER and PROJEKTGRUPPE UMWELTGESCHICHTE[15, 16])

Voitsau ranges from 600 to 800m above sea-level and is located on an ancient granite stock in the pre-alpine uplands in the north-eastern part of Austria. The climate is rough in comparison with that of Theyern and Nussdorf and the growing season is rather short, numbering 200-220 days. Woodlands have been absent in this region since the Middle Ages and are confined to areas not suitable for agriculture. Voitsau is of a similar size to Theyern, with a population of 129 in 29 households, all of these engaged in farming. According to the CE, 2 farmsteads also operated grain mills. The territory of Voitsau covered an area of 305 ha, with an additional 20ha of external meadows and arable land (*Überländer*). Arable land accounted for 62% of the total, 33% are classified as grassland, mostly rough grazing covering the steeper parts of the hilly territory of Voitsau. Only 1% of the land was covered by woodland, and back gardens for vegetable growing also accounted for about 1%. However, as we know from historic records[90], the farmers in Voitsau had traditional rights of use (logging and grazing) in the common woodland/rough grazing areas nearby called *Voitsauer Heide* and *Kottinger Heide*.

The arable land was used in a classical three-field rotation system, with rye as winter grain, oats as summer grain and fallow land. In contrast to Theyern, only a very small fraction of the fallow field (some 2%) was used to grow potatoes. Clover was not cultivated at all in Voitsau. 76 oxen (but no horses) were primarily kept for the provision of draught power, further livestock included 45 cows (which were presumably also used for draught power to some extent), 36 pigs and 45 sheep. In addition, an amount of 36 heifers and 42 chicken was estimated. Voitsau can be characterised as a cropland farming system with a certain emphasis on livestock farming. Farmers in Voitsau held 3.4 LU_{500} per household (compared to 2.7 in Theyern).
Average grain yield in Voitsau was low with 732 kg/ha (10% lower than e.g. in Theyern), average grassland yield was 1,550 kg/ha.

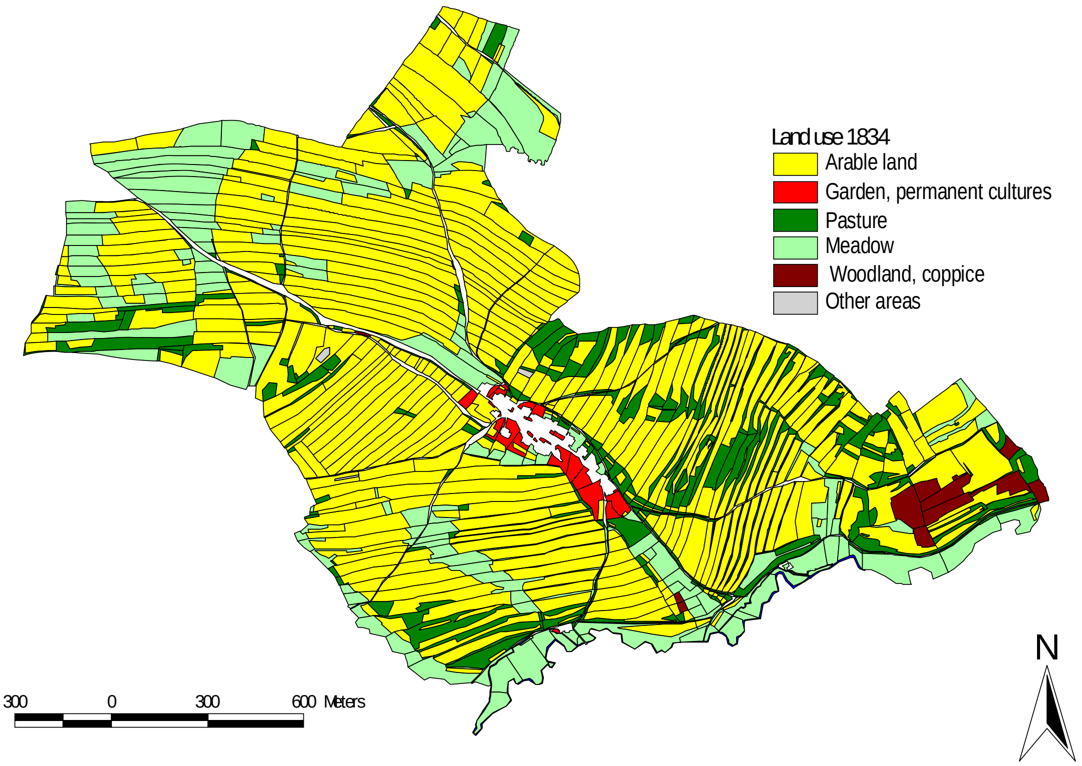

Figure 4: Land cover in the village of Voitsau 1834. Source: Digitized maps of the Franziscean Cadastre (based on data provided by Klaus ECKER and PROJEKTGRUPPE UMWELTGESCHICHTE[15, 16])

Großarl is an alpine community with the core village above 924m above sea-level, but with farmsteads spread all over the territory up to a height of 1,300m. Großarl is located in the central Alps and its area reaches up to 2,000m and above. It had a population of 650 in 92 houses with 122 households, all of them engaged in farming according to the CE (14 households were additionally engaged in craft work). However, the CE reports only 50 farmsteads with access to land and 42 households were classified as day labourers. Großarl was significantly larger than the lowland communities and covered an area of 2,900 ha. It was characterised by grassland farming based on a system of seasonal shifts of livestock to grassland at different elevations. High mountainous grazing areas accounted for 26% of the total territory, while 27% were classified as pastures and meadows. Woodland covered 27% of the land, although local farmers probably had only limited rights of use for a certain

fraction of the woodland which belonged to the *Landesfürst*[8]. Only 5% of the total area were used as a grassland-arable rotation system called *Egartenwirtschaft.* This land-use type was typical for alpine communities where fertile plots of land in the vicinity of the farmsteads were planted, for example, with winter wheat in the first year, winter rye for the second year, after which they were used as grassland (meadow) for two consecutive years before the cycle started again[49]. Depending on soil quality, different rotation periods occurred and different grain species were planted in Großarl. This rotation system allowed for work-intensive grain production (with comparable high yields) at elevations of 1,000m and more above sea-level. In Großarl, population density (22 people/km²) and livestock density (only 10 LU_{500}/km²) were significantly lower than in all other communities. Großarl can be characterised as a grassland farming system based on milk and cattle farming under alpine conditions, supplemented by grain growing for human nutrition in the vicinity of the farmsteads. With 862 kg_{FW}/ha, average grain yield in Großarl was higher than in Theyern and Nussdorf (see manure/nitrogen), while average grassland yield was only 722kg/ha, due to the low grazing yields of the extended high mountainous grazing areas.
For further information on certain aspects of the production system and the dynamics of the population system in Großarl see also VEICHTLBAUER et al.[49] in this issue, who have intensively studied this village.

4.3 Biomass extraction

Table 3 gives an overview of the amount and structure of harvested (extracted) biomass (GJ_{GCV} per capita and year) in the agricultural production systems of Theyern, Voitsau, Großarl and Nussdorf (i.e. including the external land use of Theyern and Voitsau as well as the use of external commons of Voitsau), and in Austria 1830.
Even though the structure of land use and cover in the four villages is rather different, the total amount of biomass harvested (i.e. the domestic extraction of biomass) is very similar in the villages of Theyern, Voitsau andGroßarl and ranges between 80 GJ_{GCV}/cap*yr in Großarl and 91 GJ_{GCV}/cap*yr in Voitsau, matching closely with the Austrian average of 89 GJ_{GCV}/cap*yr. The value for Nussdorf is significantly lower and amounts to only 28 GJ_{GCV}/cap*yr. However, it should be noted that a presumably significant amount of external land use could not be considered for Nussdorf because data were not available, leading to difficulties in intepretingthe values for Nussdorf (see also section “the live stock system”).

TABLE 3
DOMESTIC EXTRACTION (DE) OF BIOMASS: TOTAL DE AND CONTRIBUTION OF LAND-USE TYPES TO TOTAL DE.

	Theyern	**Voitsau**	**Großarl**	**Nussdorf**	**Austria**
Domestic extraction (GJ_{GCV}/cap/yr)	78	91	80	28	89
By land use:					
Arable land	61%	55%	10%	25%	25%
Permanent cultures, gardens	2%	1%	0%	12%	1%
Grassland	3%	22%	11%	1%	18%
Alpine pasture	0%	0%	14%	0%	2%
Woodland	34%	22%	66%	62%	53%
By type:					

Crops	16%	14%	1%	12%	8%
By-products	37%	34%	3%	21%	14%
Hay	6%	15%	10%	3%	14%
Grazing: rough grazing	0%	5%	18%	0%	6%
Grazing: other	8%	11%	6%	6%	6%
Wood	25%	16%	53%	38%	47%
Forest litter	8%	6%	9%	20%	5%
By use :					
Feed	51%	60%	37%	30%	38%
Food	10%	8%	1%	10%	5%
Litter	13%	12%	9%	21%	9%
Wood	25%	16%	53%	38%	47%
Straw as raw material/losses	2%	3%	0%	1%	2%

GJ_{GCV}/cap/year – giga Joules (gross calorific value) per person per year
Source: own calculations, see text.

In the arable systems of Theyern and Voitsau, grain and other products from cropland (and permanent cultures) accounted for 14-16% of the total biomass extraction, while 34-36% of the total harvest were crop by-products such as straw or wine leaves. In Großarl, cropland products contributed merely 1% to DE. Harvested hay ranged from 3% in Theyern to 15% in Voitsau, while accounting for only 10% in the grassland system of Großarl. Grazed biomass (including all types of rough grazing and grazed biomass) ranged from 6% in Nussdorf to 24% in Großarl (Austrian average, 12%). Wood accounted for only 16% of DE in Voitsau (practically all of it from external commons), while it accounted for 24-53% in the other villages (Austrian average, 47%). Remarkably, the amount of litter extracted from woodland contributed significantly to total DE (9-20%) in all villages.

4.4 The livestock system

The livestock system was a central element of pre-industrial agricultural production systems[6,91]. On the one hand, it demanded by far the largest fraction of agricultural biomass harvest, while on the other hand, it provided for the necessary draught power, was essential for fertilizer management, and significantly contributed to total food output of agriculture. However, according to the type of the production system, the relation of these different aspects was variable. Knowledge about the structure and the functioning of the livestock system is therefore essential when analysing and comparing different types of production systems[11,50]. In the following section, demand and supply of food as well as the functioning of the livestock system in the systems studied are analysed.

The amount of total feed supply comprises of biomass available for grazing and barn feed. Grazing potentials not only include rough grazing but also all other land that can be grazed (woodland, fallow land, stubble, etc.). Barn feed comprises of hay, feed grain, milk, straw, wine leaves and by-products of food processing (e.g. bran). Table 4 gives an overview of the calculated supply of feed.

TABLE 4
TOTAL FEED SUPPLY IN FEED VALUE, AVAILABLE FEED PER LIVESTOCK UNIT AND CONTRIBUTION OF DIFFERENT FEED TYPES TO TOTAL SUPPLY.

		Theyern	Voitsau	Großarl	Nussdorf*	Austria
Total supply	(MSE/yr)	92	168	500	103	3,075,000
Milk		1%	1%	3%	4%	1%
Grain, feed crops, bran		25%	16%	1%	17%	13%
Crop by products		40%	28%	5%	43%	14%
Hay		13%	26%	26%	11%	40%
Rough grazing		0%	10%	10%	1%	9%
Other grazing		20%	19%	19%	24%	17%
High mountain grazing		0%	0%	35%	0%	6%
Available feed/LU_{500}	(MSE/LU_{500})	1.69	1.69	1.74	0.86	2.16

MSE/yr – mega starch equivalent per year, MSE/LU_{500} – mega starch equivalent per livestock unit (500 kg liveweight)
*Feed supply due to external land use is not considered in the case of Nussdorf, see text.
Source: own calculations, see text.

In the arable systems of Theyern and Voitsau, straw (including other crop by-products) accounted for the largest fraction of available feed. My calculations indicate that straw was an extremely important and valuable raw material and an essential element of the livestock system. Measured in feed value (SE), it contributeed 40% and 28% respectively to total feed supply in the villages, while when accounted for in dry matter, the contribution of straw was even larger due to its comparatively low feeding value (57% and 39% in Theyern and Voitsau respectively). In Theyern, feed grain (i.e. mixed corn and bran) and other crops (mostly root crops) accounted for 25% of total feed supply, while hay was less important (13%). In Voitsau, with considerable amount of meadows, hay accounted for 26% and feed crops for 16%.
Theyern had no significant areas classified as rough grazing, whereas in Voitsau rough grazing (including rough grazing within the KG (40% of total grazing) and the use of external commons for grazing (60% of total grazing)) contributed 10% to total feed supply.
In addition to the areas classified as rough grazing land, virtually all the other land was grazed at certain periods of the year as well: Large fractions of the woodland were used for grazing, meadows were grazed in the autumn (after the last cut) and often even in spring, and arable land was grazed after the grain harvest (stubble field grazing) and during the fallow period. The approximate contribution of these types of grazing to feed supply was estimated by using qualitative information on the extent and average grazing yields provided by the CE and given in the literature (Table 1). Although the grazing yields and the actual extent of the land used for grazing must be considered to be very rough estimates, my calculations give an impression of the relative importance of these types of land use for maintaining the livestock. According to my calculations, grazing (excluding rough grazing) accounted for roughly 20% of total feed supply in all case studies.

The structure of feed supply in Nussdorf was very similar to feed supply in Theyern. However, it should be noted that no information on the use of external land for feed production and grazing was available. As the analysis of feed demand suggests (see next section), one should assume that external land use (or feed imports) contributed significantly to the total supply of feed in Nussdorf.

The structure of feed supply in the grassland system of Großarl differs significantly from Theyern and Voitsau. Most of the livestock was kept at rough grazing areas at high altitudes (1300-2200 m) during the short alpine summer period (90-110 days). Grazing on these high mountain pastures accounted for 35% of the total feed supply, while rough grazing in the vicinity of the farmsteads and other grazing types (wood grazing) accounted for another 30%. Hay contributed 26% of total feed supply while straw (5%) and grain (1%) were clearly less important.

Despite the structural differences in total feed supply, average feed availability per livestock unit is rather similar in Theyern, Voitsau and Großarl and amounted to 1.7 MSE per LU_{500} per year (Austrian average 2.2). Feed availability in Nussdorf was significantly lower than in the other communities (0.9 MSE/ LU_{500}*yr), which also supports the assumption that Nussdorf relied to a considerable extent on the use of external lands or imports for feed supply (e.g. the CE reports that feed is bought from neighbouring communities (*Zukauf von Linsgetreide*)).

In Tables 5 and 6, average supply of feedstuff (Table 4) is related to the demand calculated according to the methodology documented in the methods section: Standard and minimum feed demand were calculated both on the basis of species-specific demand values given in feed values (SE) as well as in dry matter per kg live weight. Standard feed demand reflects the recommended feed intake based upon the assumed performance of nineteenth-century farm animals (concerning milk yield, weight gain, work), while minimum demand is an estimation for the required intake to maintain the stock at the assumed live weight, but allows only for very limited performance. Feed supply below the calculated minimum requirement therefore is assumed to be incompatible with maintaining the existing livestock (i.e. results in loss of weight and number of livestock).

TABLE 5

FEED SUPPLY BY FEEDING PERIOD AND CALCULATED STANDARD AND MINIMUM DEMAND AS PERCENTAGE OF SUPPLY.

		Theyern	Voitsau	Großarl	Nussdorf	Austria
Feed supply						
Total supply	(t_{DM}/yr)	223	390	1,079	231	6,742,000
Barn feed	(t_{DM}/yr)	185	287	395	185	4,624,000
Grazing	(t_{DM}/yr)	38	102	291	46	1,722,000
High mountain grazing	(t_{DM}/yr)	-	-	394	-	396,000
Supply of demand: standard						
Total demand		100%	97%	95%	45%	118%
Barn period		108%	108%	82%	47%	125%
Pasture period		73%	74%	89%	41%	102%

High mountain grazing			121%		125%
Supply of demand: minimum					
Total demand	137%	132%	124%	62%	159%
Barn period	150%	149%	108%	64%	170%
Pasture period	98%	100%	116%	53%	136%
High mountain grazing			157%		163%

t_{DM}/yr - tons (dry matter) per year
Source: own calculations, see text.

TABLE 6
FEED SUPPLY BY FEEDING PERIOD AND CALCULATED STANDARD AND MINIMUM DEMAND AS PERCENTAGE OF SUPPLY.

		Theyern	Voitsau	Großarl	Nussdorf	Austria
Feed Supply						
Total supply	(MSE/yr)	92	168	500	103	3,075,000
Barn feed	(MSE/yr)	73	119	174	77	2,085,000
Grazing	(MSE/yr)	18	49	149	25	812,000
High mountain grazing	(MSE/yr)	-	-	177	-	178,000
Supply of demand: standard						
Total demand		88%	93%	96%	42%	117%
Barn period		92%	100%	79%	41%	122%
Pasture period		75%	78%	98%	47%	104%
High mountain grazing				118%		122%
Supply of demand: minimum						
Total demand		139%	140%	138%	69%	178%
Barn period		146%	152%	114%	68%	188%
Pasture period		116%	117%	141%	74%	157%
High mountain grazing				169%		180%

MSE/yr – mega starch equivalent per year
Source: own calculations, see text.

Feed supply exceeded the calculated values for minimum demand (with respect to both dry matter and starch equivalent values) in all communities except Nussdorf, where supply was only 60-70% of demand (see remarks on external land use above). In Theyern and Voitsau, supply is 130-140% of minimum demand, while in Großarl relative supply is slightly lower but still amounts to 124-138% of minimum demand.
Feed supply is 95-100% of standard demand (dry matter) in Theyern, Nussdorf and Großarl. When calculated in starch equivalent, relative feed supply is lower, particularly in the villages relying to a considerable extent on straw feeding (e.g. 88% in Theyern). It must be noted, however, that livestock in Großarl was assumed to be significantly lighter than in the other

communities (e.g. according to my calculations, an average cow in Großarl weighed 230 kg compared with 270 kg in the other villages – see Table 14).
In Nussdorf, local supply covered less than 50% of standard demand. Feed deficit (with respect to standard demand DM) in Nussdorf amounted to 320 tonnes hay equivalent/year which would require an additional area of meadows (based on estimated average grassland yield of Nussdorf) of roughly 200-250 ha.

Relating available feed to requirements (both DM and SE) during grazing periods and house-feeding reveals that in Theyern and Voitsau, standard feed demand for house-feeding was more or less sufficient (92-108%). In these arable systems, with their limited amount of low yielding rough-grazing areas, grazing seems to have been a factor of scarcity (supply amounts to only 75% of demand). Even if we consider that the values presented for grazing represent only a rough estimation, my calculations indicate that grazing on fallow land, stubble field and in woodlands was of crucial importance for feed supply during the summer in cropland-dominated regions, where virtually all land was grazed.
In Großarl, things appear to have been different: Most animals were kept on extensive high mountain pastures from June to mid-September. Although grazing yields were low, semi-natural grasslands provided sufficient feed (120% of standard feed demand DM and SE), due to their large area. Under the conditions of alpine grassland farming the limiting factor for the size of the livestock is the amount of barn feed available (i.e. hay and straw) to maintain livestock during the long winter period. According to my calculations, supply of barn feed was only 80% of demand (at reduced live weight). This indicates that animals were probably losing weight or that stock had to be reduced during winter. A period of low hay yields due to unfavourable climatic conditions must have had a decisive effect on livestock in Großarl, probably resulting in significant reductions of stock.

A significant (but not necessarily predominant) aspect of livestock keeping was the production of meat and milk for human nutrition. In the arable systems of Theyern and Voitsau, net food output was some 40-45 kg/cap*yr of meat (including all edible portions of the carcass) and 420 kg/cap*yr of milk. In Nussdorf – assuming that livestock was adequately fed (see above) - 20 kg of meat and 330 kg of milk were produced per capita per year. It must be noted, however, that a considerable part of the population in Nussdorf was not engaged in agriculture, in contrast to Theyern and Voitsau. If only agricultural population is considered, values for milk production were very similar to those for Theyern and Voitsau.
In the alpine grassland system of Großarl, output of milk was over 800 kg/cap peryr while meat production was rather low, amounting to only 22 kg/cap peryr.
The contribution of animal products to total agricultural production and food supply is discussed in the next section.
Besides food production, livestock provided the draught power necessary for the functioning of the agricultural production system. To analyse the relative significance of draught power provided by livestock, the contribution of the different types of animals to total output of meat and milk (GJ nutritive value) is related to their share of total standard feed demand (measured in SE).
Table 7 indicates the relative energetic cost of draught animals: Horses and oxen were the animals predominantly used for draught purposes. They were a power source for agricultural work, forestry and transportation, being fattened and slaughtered after a certain period of use (typically after 5-10 years – Table 14).

TOTAL CALCULATED STANDARD FEED DEMAND AND FOOD OUTPUT (MEAT AND MILK) BY ANIMAL TYPE.

		Theyern	Voitsau	Großarl	Nussdorf	Austria
Feed demand	(MSE/yr)	105	181	521	245	2,629,000
Horses		8%	0%	6%	13%	13%
Oxen		29%	54%	0%	0%	20%
Cows		30%	24%	66%	54%	42%
Heifers		5%	10%	11%	7%	8%
Sheep		10%	3%	12%	0%	7%
Pigs		18%	9%	1%	26%	8%
Goat		0%	0%	3%	0%	2%
Food output	(GJ_{NV}/yr)	164	212	1,606	515	4,832,000
Horses		0%	0%	0%	1%	1%
Oxen		8%	16%	0%	0%	4%
Cows		63%	69%	82%	85%	75%
Heifers		2%	1%	2%	2%	2%
Sheep		15%	7%	9%	0%	9%
Pigs		11%	7%	0%	12%	4%
Goat		0%	0%	5%	0%	5%

MSE/yr – mega starch equivalent per year, GJ_{NV}/yr – giga Joules (nutritive value) per year
Source: own calculations, see text.

In the arable systems of Theyern and Voitsau, which strongly relied on the draught power provided by animals, horses and oxen together accounted respectively for 37% and 54% of the total feed demand, whereas their contribution to total food output amounted to only 8% and 16% respectively.
In the grassland system of Großarl, draught animals were significantly less important. Cropping, the major labour-demanding activity under pre-industrial conditions, was relatively unimportant. Only some horses (and hardly any oxen) were kept for hauling wood and ploughing the *Egärten*. Together, horses and oxen accounted for only 6% of total feed demand, and contributed very little to food output. In contrast, draught animals in Nussdorf accounted for only 13% of feed demand and 1% of output. Although wine growing is very labour-intensive[8], little of this labour can be carried out by animals. Farmers in Nussdorf kept a limited number of horses for transportation, whereas it must be assumed that cows were also used to provide draught power for ploughing the relatively small amount of arable land per farm. On average, draught animals consumed some 33% of the available feed while contributing 5% to total production of animal food in Austria 1830. In contrast to horses and oxen, cows and pigs are important sources of food energy. Their contribution to total animal food output is significantly larger than their portion of the total feed demand. In Theyern and Voitsau, the feed demand of cows amounted to 20-30% of total feed demand while they provided 60-70% of food output (60% of total feed demand and 80% of food output in Großarl).

The relative importance of the different benefits and the energetic efficiency of livestock can also be assessed by directly relating feed inputs to food outputs (Table 9): The relation of total feed input (MJ_{GCV}) to food output (MJ_{GCV}) refers to the actual conversion rate of feed energy into food: The high value in Voitsau (27.3 MJ of feed produced only 1 MJ of food) indicates that livestock was "expensive" and food production was only a minor reason for keeping animals, while the very low value for Großarl (10 MJ of feed for 1 MJ of food) indicates highly efficient production of animal food. When feed input is calculated in MJ of nutritive value (NV) instead of gross calorific values (GCV) (i.e. only accounting for feed which could also be used for human nutrition, such as grain) and related to food output in NV, this relation provides an indication of whether livestock was a "source" or a "sink" of food: In the arable systems of Theyern and Nussdorf, 2.4 MJ_{NV} of feed were converted into only 1 MJ_{NV} of food – i.e. livestock consumed more food energy than could be obtained in the form of meat and milk. In contrast, livestock in Großarl was a source of food (conversion factor 0.2) because for the most part biomass unsuitable for human nutrition was used as feed.

Farmers in villages dominated by arable land kept a large number of animals because they relied on the draught power provided by animals and required animals for fertilizer management. To obtain this service, they had to invest even biomass suitable for human nutrition in feeding their animals. In arable systems, livestock can be considered to have been a sink of food energy, consuming more food energy than could be obtained in the form of meat and milk. Under alpine conditions, however, animals (predominantly ruminants) were kept to facilitate the use of land not suitable for cropland and to convert biomass not suitable for human nutrition into human food. Draft power is of less importance under these conditions, and animals can be regarded as sources of food.

4.5 Food production and human nutrition

Food production and net output of food are very important parameters for the classification and evaluation of agricultural production systems. With respect to the model presented in Figure 1, food production links the agro-ecosystem with the population system, since food is the energy source for the human population, which in return has to invest work energy to maintain the land-use system[36,49]. Food production compared with the physiological requirement of food provides information on the degree of self-sufficiency, and allows some conclusions to be drawn regarding the nature of the production system and its position in relation to subsistence and market participation[8,68].

TABLE 8

FOOD PRODUCTION, RELATIVE CONTRIBUTION OF DIFFERENT FOOD TYPES TO OUTPUT AND FOOD DEMAND VERSUS SUPPLY

		Theyern	Voitsau	Großarl	Nussdorf	Austria
Total food supply	(MJ_{NV}/cap/yr)	5,586	5,374	2,971	2,714	3,904
Grain (flour)		50%	64%	16%	27%	58%
Other vegetable food		11%	4%	1%	9%	2%
Wine, fruits		9%	1%	0%	22%	4%
Total vegetable food		70%	69%	17%	58%	65%
Meat		8%	9%	6%	8%	5%
Milk		22%	22%	77%	35%	30%

Total animal food		30%	31%	83%	42%	35%
Calculated food demand	(MJ_{NV}/cap/yr)	3,285	3,285	3,285	3,285	3,285
Supply on demand		170%	164%	90%	83%	119%
Surplus (+)/deficit(-)	(MJ_{NV}/cap/yr)	2,301	2,089	-314	-571	619

MJ_{NV} /cap/yr - mega Joules (nutritive value) per capita per year
Source: own calculations, see text.

Table 8 gives an overview of total net food output of agriculture (MJ_{NV} per cap*yr) in the different villages and relates it to the calculated amount of food required to maintain the population. Relative food production is highest (and significantly above Austrian average) in the arable systems. It amounts to 5.5 GJ_{NV}/cap/yr in Theyern and to 5.3 GJ_{NV}/cap/yr in Voitsau, exceeding the average local food demand by 60-70%. In the alpine grassland system of Großarl food production is significantly smaller and amounts to slightly below 3 GJ_{NV}/cap/yr, hardly matching demand (90%).
In Nussdorf total food output is lowest, and with just 2.7 GJ_{NV}/cap/yr it is significantly (17%) below demand. However, it has to be considered that, on the one hand as a wine growing community, Nussdorf was probably to a much larger extent integrated in market economy than all other villages, and on the other hand only 80% of the households of Nussdorf were considered to be engaged in agriculture[8]. If food output is related only to the agricultural population the value increases to 3.3 GJ_{NV}/cap/yr.
Furthermore, it has to be noted that the values for standard food requirement that have been used to calculate average per-capita food demand refer to present day individuals of standard size, weight and moderate activity (see section methods). However, basic metabolic rate (i.e., the minimal rate of energy expenditure compatible with life) which typically accounts for 60-70% of total energy expenditure (i.e., the calculated demand) is dependent on body weight and body composition and can vary considerably[92]. Considering the possibility that people were generally smaller and lighter in the early nineteenth century, the values used as estimates average food demand may overestimate actual demand, while considering the argument that average work activity was presumably higher in the early nineteenth century, food demand might also have been underestimated.

In the arable systems of Theyern and Voitsau, grain (flour) was the quantitatively most important food product, accounting for half of total output in Theyern and for almost two-thirds in Voitsau. All in all, vegetable products contributed some 70% to total output, while milk accounted for 22% and meat for less than 10%. This matches well with the Austrian average, where vegetable products accounted for 65% and meat and milk accounted for 35%. In contrast, the food output of Großarl was dominated by milk (77%) and plant products accounted for only 17%. Interestingly, meat was of comparatively little importance (only 6%) in Großarl. In Nussdorf, besides grain (27%) and milk (35%), wine was of significant importance, accounting for 22% of total food production.

4.6 Agricultural productivity

The productivity of agriculture is an essential parameter for the characterisation of agricultural systems[6,91,93]. However, the notion of productivity can be conceived differently and measured in various ways. In the following section, some productivity measures indicating area productivity, labour productivity and economic productivity are discussed.

Data presented in Table 9 relate food output in nutritive value and calorific value to various parameters such as population, agricultural area or monetary value. Nussdorf is not considered in the comparative analysis, except concerning economic productivity according to the FC.

TABLE 9
AGRICULTURAL PRODUCTIVITY: AREA PRODUCTIVITY, LABOUR PRODUCTIVITY AND ECONOMIC PRODUCTIVITY. EFFICIENCY OF LIVESTOCK PRODUCTION (FEED INPUT VERSUS FOOD OUTPUT).

		Theyern	Voitsau	Großarl	Nussdorf	Austria
Gross area productivity of agriculture	(GJ_{GCV}/ha_{AGR})	37	30	10		32
Net area productivity of agriculture	(GJ_{NV}/ha_{AGR})	4.00	2.23	1.15		3.00
Gross/net area productivity	MJ_{NV}/MJ_{GCV}	9	13	9		11
Monetary value of agric. output/area	(Kronen/ha_{AGR})	133	65	42		95
Monetary net gain/agric. area	(Gulden/ha_{AGR})	8.0	5.5	1.3	24.5	-
Monetary gross gain/agric. area	(Gulden/ha_{AGR})	17.9	11.4	2.4	48.0	-
Food output/total pop.	(GJ_{NV}/cap)	5.59	5.37	2.97	2.71	3.90
Food output/agricultural pop.	(GJ_{NV}/cap)	5.59	5.37	2.97	3.37	5.21
Monetary value of food output	(Kronen/cap_{AGR})	186	158	108		164
Monetary net gain of food output	(Gulden/cap_{AGR})	11	13	3	9	
Monetary gross gain of food output	(Gulden/cap_{AGR})	25	27	6	18	
Maintainable persons	(cap/ha_{AGR})	1.22	0.68	0.35		0.09
Maintainable persons	(cap/cap_{AGR})	1.70	1.64	0.90		1.58
Livestock efficiency						
Feed input versus food output (NV)	(J_{NV}/J_{NV})	2.4	2.5	0.2		1.7
Feed input versus food output (GCV)	(J_{GCV}/J_{GCV})	19.6	27.3	10.2		20.4

GJ_{GCV}/ha_{AGR} – giga Joules (gross calorific value) per hectare (of agricultural area), GJ_{NV}/ha_{AGR} - giga Joules (nutritive value) per hectare (of agricultural area), MJ_{NV}/MJ_{GCV} – mega Joules of food output (nutritive value) per mega Joules of biomass input (gross calorific value), Kronen/ha_{AGR} – Kronen per ha agricultural area, Gulden/ha_{AGR} – Gulden per ha agricultural area, GJ_{NV}/cap – giga Joules (nutritive value) per capita, Kronen/cap_{AGR} – Kronen per capita agricultural population, Gulden/cap_{AGR} - Gulden per capita agricultural population, cap/ha_{AGR} – persons per ha agricultural area, cap/cap_{AGR} – persons per capita agricultural population, J_{NV}/J_{NV} – Feed input in Joules (gross calorific value) per food output in Joules (gross calorific value), J_{GCV}/J_{GCV} – feed input in Joules (gross calorific value) per food output in Joules (gross calorific value)

biomassMJ_{NV} – mega Joules (nutritive value), cap_{AGR} – capita (of agricultural population)
Source: own calculations, see text.

Total gross agricultural area productivity - i.e. biomass harvest (DE) from arable land, permanent cultures and all types of grassland per ha of agricultural area (ha_{AGR}) - is a measure for physical productivity of agriculture, aggregating the local structure of land use and yield level. It was highest in climatically favoured regions and amounted to 37 GJ_{GCV}/ha_{AGR} in Theyern and 35 GJ_{GCV}/ha_{AGR} in Nussdorf, followed by Voitsau (30 GJ_{GCV}/ha_{AGR}), being

significantly lower in Großarl (only 10 GJ_{GCV}/ha_{AGR}). Net agricultural area productivity - i.e. total net food production (total of vegetable and animal food in GJ_{NV}) per ha of agricultural area (arable land, permanent cultures, all types of grassland) - attained by far the highest value in Theyern (4 GJ_{NV}/ha_{AGR}), followed by Voitsau (2.2 GJ_{NV}/ha_{AGR}) and was lowest in Großarl (1.2 GJ_{NV}/ha_{AGR}). Expressed differently, 1 ha of agricultural land provided sufficient nutrition for 1.22 persons in Theyern, 0.6 persons in Voitsau and 0.35 persons in Großarl (Austrian average, 0.92 persons).
Relating gross and net agricultural production (i.e. total biomass input and net food output) indicates the rate of biomass conversion achieved by different production systems. It is quite remarkably that in all systems studied, gross agricultural harvest was transformed into food with a factor of roughly 1:10. In other words, the production of 1 MJ_{NV} of food required 10 MJ_{GCV} of agricultural biomass, regardless of the internal structure of the production system.
As a rough indication for the amount of gross monetary output per unit area, we can value the physical output (grain, meat, milk, wine) according to average product prices (see section methods). Monetary output per ha agricultural land amounted to 133 Kronen/ha_{AGR} in Theyern, to less than half of this value in Voitsau, and less then one-third of this value in Großarl (Austrian average, 95 Kronen/ha_{AGR})
Monetary net and gross gain according to the tax estimations of the Franziscean Cadastre (see section methods) suggest that gross and net gain/ha_{AGR} were largest in Nussdorf, where net gain was as high as 48 Gulden/ha due to the large number of vineyards. Theyern produced a net gain of 17.9 Gulden/ha, Voitsau was estimated considerably lower at 11.4 Gulden/ha, while the land-intensive production system of Großarl yielded only 2.4 Gulden/ha according to the FC data.

Agricultural output related to agricultural population (cap_{AGR}) can serve as an indication of labour productivity in the systems studied: While output per area was clearly highest in Theyern, output per capita of agricultural population followed a different pattern. Total food output/cap_{AGR} was rather similar in Theyern and Voitsau, being slightly above the Austrian average of 5.2 GJ_{NV}/cap_{AGR}/yr and amounting to 5.4-5.6 GJ_{NV}/cap_{AGR}/yr whereas in Großarl it amounted to only half of this value. To put it another way, one person engaged in agriculture (referring to agricultural population as a whole, i.e. including young and old individuals) produces enough food to fulfil the nutritive requirements of 1.6 to 1.7 persons in Theyern and Voitsau. In Großarl, one person is only able to maintain 0.9 persons – i.e. is hardly able to support themself. Results concerning the per capita-productivity of agriculture indicate that regions dominated by arable land were able to support a larger population density and a considerable amount of non-agricultural population, in contrast to alpine grassland systems.
The monetary value of agricultural output in Kronen per capita of agricultural population was highest in Theyern (186 Kronen/cap_{AGR}), followed by Nussdorf (162 Kronen/cap_{AGR}) and Voitsau (158 Kronen/cap_{AGR}) and was lowest in Großarl (108 Kronen/cap_{AGR}). Interestingly, the data on net output according to the tax estimations produce a different ranking: According to these data, Voitsau had a slightly higher net gain per capita than Theyern, while Großarl would bes classified at one-quarter of the value for Voitsau.

4.7 Woodland: wood, litter and grazing

The share of woodland of the total land area varied broadly (Table 10) in the communities studied: In arable systems, woodland was usually restricted to areas not suitable for cultivation, while covering large areas in the alpine regions (Austrian average 38%, 0.92 ha/cap). While woodland accounted for 58% of the area of Nussdorf (0.45 ha/cap), 35% of the area of Theyern (0.77 ha/cap) and 27% of Großarl (1.22 ha/cap), the territory belonging to Voitsau was almost entirely lacking in forest cover (0.03 ha/cap). However, as noted before, the farmers of Voitsau had the right to use external wooded commons.

TABLE 10

USE OF WOODLANDS: AREA, BIOMASS EXTRACTION BY TYPE; CONTRIBUTION OF WOOD LITTER AND GRAZING TO TOTAL DEMAND; EXTRACTION OF NITROGEN BY TYPE; WOOD SUPPLY.

		Theyern	Voitsau	Großarl	Nussdorf	Austria
Woodland as % of total area	(% of total area)	35%		27%	58%	38%
Woodland per capita	(ha/cap)	0.77	0.03	1.22	0.45	0.92
Biomass harvest	(GJ_{GCV}/ha/yr)	34	44	43	38	52
Wood	(% of total)	72%	74%	80%	61%	89%
Grazing	(% of total)	5%	0%	6%	7%	3%
Litter	(% of total)	23%	26%	14%	32%	9%
Wood grazing as % of total grazing	(% of total)	20%	0%	17%	68%	12%
Wood litter as % of total litter	(% of total)	59%	38%	100%	94%	54%
Nitrogen extraction	(kg N/ha/yr)	7	8	8	11	6
Wood	(% of total)	10%	16%	18%	6%	24%
Grazing	(% of total)	30%	1%	39%	32%	31%
Litter	(% of total)	60%	83%	43%	62%	45%
Wood supply per household	(scm/yr)	10	0.2	27	6	24
Wood supply per household	(GJ_{GCV}/yr)	98	2	225	64	232

ha/cap – hectares per capita, GJGCV/ha/yr – giga Joules (gross calorific value) per hectare per year, kg N/ha/yr – kilograms of Nitrogen per hectare per year, scm/yr – solid cubic metres per year
Source: own calculations, see text.

Woodland provided for firewood, which represented the prime source of technical energy in the early nineteenth century. But as we have seen before, woodland was also grazed to a considerable extent, providing a significant share of total grazed biomass, and being vital for meeting the necessary litter demand[85,94,95]. The regional structure of the use of forest resources, and the effect of forest use on the productivity as well as the character of woodland is a much-discussed topic in environmental history[85,94,96-98].
Table 10 gives an overview of the biomass extraction from woodland in GJ_{GCV}/ha: Quantitatively, wood represents the largest share of extracted biomass, accounting for 60-90% of total extraction, litter accounts for roughly 25% in the arable systems, while grazing accounts for between 3% and 7%. In the villages studied, forests provided for 40-100% of the total demand for litter and for 12-68% of grazed biomass.
As both grazed biomass and litter have a high nutrient content in comparison to wood, grazing and litter extraction are responsible for a considerable transfer of plant nutrients from woodland to cultivated land, which is likely to have had a significant ecological impact. According to my calculations, litter extraction is responsible for 45-90% of the nitrogen removal from woodland (see also the section on the nitrogen cycle below). The intensive use

of woodlands for various purposes and its rather extractive character must be seen as a cause for the comparably low growth rates and the low wood yields: The cadastre reports average wood yields (sustainable growth rates) of 2-3 scm/ha while currently average wood yields of 6-9 scm/ha are reported for Austrian forests[99].

According to literature values for wood consumption (firewood and timber for construction and agriculture) in Austrian households in the early nineteenth century typically range from 20-30 scm/year (see section methods and data). The available amount of wood in the villages studied according to the FC is significantly lower than these averages in most villages (Table 10): Wood availability per household amounts to 10 scm (98 GJ_{GCV}/hh/yr) in Theyern, 0.2 scm (2 GJ_{GCV}/hh/yr) in Voitsau (excluding the use of commons) and 6 scm or 64 GJ_{GCV}/hh/yr) in Nussdorf. Only in Großarl are the values significantly higher (27 scm (225 GJ_{GCV}/hh/yr)). An average of 24 scm (232 GJ_{GCV}/hh/yr) of wood are available per household according to the Austrian average in 1830. On the one hand it may be assumed that the FC underestimates average growth rates for wood and average timber yields[20], but on the other hand it should be considered that there is in fact a very wide range of values for wood demand, and that, due to the high transportation costs, local consumption of wood was likely to be closely related to local wood availability. Because of this and due to the lack of better data, it was assumed that wood demand ranged between 10 and 20 scm/household per year. According to these assumptions, wood supply more or less matched local demand in Theyern. In the case of Voitsau, it was assumed that 7-10 scm of wood per household could have been obtained from rights of use of the large commons at Voitsauer Heide and Kottinger Heide. In contrast, wood supply in Großarl was more than sufficient to satisfy local demand. Assuming that there was an average wood consumption per household of 20 scm, the supply allowed for a considerable export of wood (respectively charcoal) to the market (e.g. industrial sites in the vicinity), which is also noted in the CE of Großarl[49].

4.8 Socio-economic energy flows

The calculations and data discussed in the previous sections allow socio-economic energy flows for Theyern, Voitsau, Großarl and Austria to be quantified. Aggregate results of energy flows according to the model presented in Figure 1 are compiled in Table 11:

TABLE 11

SOCIO-ECONOMIC ENERGY FLOWS: DOMESTIC EXTRACTION (DE), DIRECT INPUT (DI) AND DOMESTIC CONSUMPTION (DC). FLOWS OF DOMESTIC CONSUMPTION WITHIN THE SOCIO-ECONOMIC SYSTEM ACCORDING TO THE ENERGY FLOW MODEL (FIGURE 1).

	Theyern (GJ_{GCV}/cap/yr)	Voitsau (GJ_{GCV}/cap/yr)	Großarl (GJ_{GCV}/cap/yr)	Austria (GJ_{GCV}/cap/yr)
Domestic Extraction (DE)	78	91	80	89
Import	-	-	0	
Direct Input (DI)	78	91	80	89
Export	2	2	10	
Domestic Consumption (DC)	75	89	70	89
Processing	6	6	4	5

Livestock	50	66	37	15
Material use	3	3	3	1
Energetic use	17	15	29	10
Food	4	4	4	3
Seeds	2	3	0	0
Dunghill	19	23	14	10
Waste	3	5	9	1
Heat	26	36	11	3

GJ_{GCV}/cap/yr – giga Joules (gross calorific value) per capita per year
Source: own calculations, see text.

Figures for domestic extraction are rather similar for Theyern, Voitsau (including DE from commons), Großarl and Austria, ranging between 78 GJ_{GCV}/cap/yr in Theyern and 91 GJ_{GCV}/cap/yr in Voitsau. (Net) import of biomass was quantitatively not of significance, while (net) exports ranged from 2-3% of DE in Theyern and Voitsau (exports of food to market or seigniory) and up to 12% in Großarl (export of wood or charcoal). For Austria, no data on imports and exports are available, but it may be assumed that they were small compared to DE and generally balanced[37]. Domestic consumption, respectively, ranged from 70-90 GJ_{GCV}/cap/yr.

Between 37 and 66 GJ_{GCV}/cap/yr of biomass passed through the livestock compartment, while 4-6 GJ_{GCV}/cap/yr were transformed within the processing compartment.
Only 5-6% of the DC were finally used for human nutrition, while up to 3% of DC left the socio-economic system as seeds for the land-use system. A large share of DC was finally used as raw material or for the provision of technical energy (20-46%), while 48-72% left the system from processing and livestock compartment and re-entered the natural system in the form of manure, wastes, emissions and heat.

4.9 The nitrogen cycle

One of the crucial questions for understanding the functioning and productivity of pre-industrial agricultural production systems concerns how soil fertility could be maintained[100-102]. While currently agricultural productivity and soil fertility rely on the massive input of plant nutrients from external sources (artificial fertilizers), nineteenth-century agriculture had to rely on natural and internal flows of nutrients. The necessity of keeping local and regional cycles more or less closed may be regarded as one of the central factors limiting growth under pre-industrial conditions. The issue of soil fertility and nitrogen (one of the most important plant nutrients) is extensively discussed – however, only few quantitative estimations for nitrogen flows in pre-industrial agriculture have been published[74-76,83,103,104]. Some aspects concerning soil fertility and nitrogen flows in the Austrian villages will be discussed in the next section.
Table 12 gives an overview of socio-economic outputs and socio-economic and natural inputs of nitrogen into the agro-ecosystem of the systems studied.

TABLE 12

NITROGEN FLOWS: NITROGEN OUTPUTS DUE TO BIOMASS HARVEST; SOCIO-ECONOMIC INPUTS OF NITROGEN DUE TO SEED, LEGUMINOUS CROPS AND MANURING; NATURAL INPUTS DUE TO ATMOSPHERIC DEPOSITION AND NATURAL N FIXATION; SOCIO-ECONOMIC RETURN OF NITROGEN.

		Theyern	Voitsau	Großarl	Nussdorf	Austria
Nitrogen contained in harvest						
Arable land/garden	(kg_N/ha)	25	21	33	22	31
Grassland	(kg_N/ha)	37	23	11	15	31
Woodland	(kg_N/ha)	7	8	8	11	6
Total	(kg_N/ha)	19	20	11	15	21
Nitrogen inputs to arable land						
Socio-economic inputs:						
Seed	(kg_N/ha)	2	2	1	1	2
Leguminous crops	(kg_N/ha)	8	-	-	4	6
Manure (60% losses)	(kg_N/ha)	6	8	28	13	14
Manure (45% losses)	(kg_N/ha)	8	10	38	18	19
Socioeconomic return of N (minimum)		63%	45%	89%	83%	71%
Socioeconomic return of N (maximum)		72%	59%	120%	105%	87%
Natural Inputs (deposition/natural fixation) :	(kg_N/ha)	6	7	6	6	8
Total input to arable land*	(kg_N/ha)	24	19	45	29	35
Nitrogen inputs to grassland/wood						
Natural inputs to grassland	(kg_N/ha)	9	8	8	8	0
Natural inputs to woodland	(kg_N/ha)	5	5	5	6	0

kg_N/ha – kilograms of Nitrogen per hectare
*assuming 45% losses of manure
Source: own calculations, see text.

Total nitrogen extraction due to the harvest of biomass ranged from 11 kg/ha in Großarl to 20 kg/ha in Voitsau. With the exception of the small area of high-yielding meadows in Theyern where 37 kg/ha were extracted, average nitrogen extraction was highest from arable land and amounted to 25 kg/ha in Theyern, 21 kg/ha in Voitsau and 33 kg/ha in Großarl. N extraction from woodlands ranged from 7 to 8 kg/ha, with litter extraction contributing the largest share. However, socio-economic exports of nitrogen out of the system due to the export of agricultural products (e.g. sold grain) were very small. The estimated exports of food in Theyern and Voitsau amounted to only 4-7% of the total amount of N extracted, while only 1% of the total N extraction was exported with wood in Großarl.

The CE provides some qualitative information on manuring practice in the villages. According to this information, in general only the best plots of arable land, permanent cultures and back gardens received manure at regular intervals (i.e. generally at intervals of 2-

4 years) while arable land of category 2 and 3 only irregularly received manure treatment. Grassland and woodland received no manure at all[8,19].
Socio-economic inputs to arable land (including permanent cultures and gardens) were due to seeding, to symbiotic fixation of leguminous crops (clover), and to manure treatment.
According to my calculations, seeding contributed 1-2 kg of N per ha. N inputs due to leguminous crops were of significant importance only in Theyern (no clover was planted in Voitsau and Großarl), where they provided an input of 8 kg/ha. Socio-economic N input due to manure treatment was comparably low in the arable systems and amounted to 6-8 kg/ha in Theyern, 8-10 kg/ha in Voitsau and 13-18kg/ha in Nussdorf, depending on the losses of nitrogen during storage and application (60-45% of total N contained in manure were lost). My calculations indicate that manuring probably replaced 25-50% of the N output through biomass harvest on arable land in regions dominated by arable land. Interestingly, in Theyern (though only 13% of fallow land was planted with clover), nitrogen input due to leguminous nitrogen fixation was of a similar extent as total N input due to manure treatment. This high contribution of leguminous crops to socio-economic N inputs in Theyern indicates the significance leguminous crops for soil fertility in pre-industrial agro-ecosystems and agricultural modernisation. In Großarl, characterized by a large livestock and comparatively little arable land, this fraction was significantly larger: 28-38 kg of N contained in manure replaced 85-120% of the extracted N from arable land (*Egärten*).

All in all, socio-economic inputs replaced roughly 45-60% of the harvested N from arable land, gardens and permanent cultures in Voitsau, 63-72% in Theyern and 90-120% in Großarl. It is interesting to compare these values to the possible contribution of some natural N inputs (atmospheric deposition and N fixation of free living organisms): These natural processes provide an input of 6-7 kg Nitrogen/ha, which is roughly the same amount as manuring provided in Theyern.
Grassland and woodland did not receive any socio-economic return at all – their N balance was completely dependent on natural processes. According to a very rough estimation, deposition and fixation of free living organisms may have returned about 8-9 kg/ha on grassland and 6 kg/ha in woodlands. No estimation is available for N inputs due to the decay of soils.

5. Conclusions

The presented material allows for conclusions to be made at various levels: The methodology proposed in this paper and the results obtained allow for a certain validation of the plausibility of the data contained in the Franziscean Cadastre. The good match of calculations on supply and demand of food and feed generally indicates the good reliability of data on land use, physical yields, livestock and population provided by the different sources of the FC. My results also suggest, however, that the significance of certain aspects such as rough grazing might be underestimated in the CE, and that the assumptions on growth rates and sustainable wood yields given in the cadastre require further analysis. It is not yet clear whether the low wood yields given in the cadastre correspond with actual conditions (i.e. low wood yields due to the intensive use of woodlands for grazing and litter extraction) or whether actual yields are underestimated. My results also emphasise the significance of an analysis of external land use (*Überlandgründe*), which may account for 10-20% of total land use and biomass harvest. However, data on external land use are not readily available from the CE, but can be quantified by in-depth evaluations of parcel protocols [8,18].

Above all, the results presented here throw light on a series of aspects concerning the functioning of the production system in the specific cases mentioned, and they contribute to answering crucial questions at a more general level. My calculations give some empirical and quantitative information for much-discussed topics of environmental history. The role of livestock in different types of agricultural systems, feeding sufficiency, nitrogen management, soil fertility, and exploitation of woodlands are intimately related – however, they are commonly analysed separately with reference to different sources and separate cases and without much quantitative biophysical information. The systemic and model-based approach presented in this paper allows these questions to be discussed in a highly consistent way and focuses on the mutual interrelation of these aspects.

My calculations emphasise that livestock played a central and integrative role in pre-industrial systems – it was absolutely necessary in every type of production system for draught power, nutrient management and fertilization and to a varying extent for human nutrition. More than 85% of the total agricultural biomass harvest passed through the livestock system as feed or litter, regardless of the specific type of production system. In biophysical terms, the animals were rather “expensive”: Horses and oxen, predominantly used to provide draught power especially in the regions dominated by arable farming, required 40-50% of the total feed supply. In arable systems, livestock can be regarded as a sink of human food, i.e. livestock consumed more biomass suitable for human consumption than was provided as meat and milk. Nevertheless, animals were essential for the functioning of the system with respect to cultivation of soil and the management of soil fertility. Animals allowed for the transfer of plant nutrients from grassland and woodland to arable land, where manure replaced 50-75% of nitrogen extracted by harvest. Livestock keeping represented one of the few possibilities for pre-industrial farmers to actively control and manage soil fertility.

Under alpine conditions, things were very different. Only ruminants allowed for the use of land by humans under pre-industrial conditions. They “converted” land not suitable for the production of vegetable food and biomass not suitable for human nutrition into food, predominantly milk. Draught power was of minor importance, while the concentration of large quantities of animal manure allowed for considerable yields on the few plots of arable land even at high altitudes. Nevertheless, food output was low in alpine regions, leaving it up to the lowland farmers to provide a significant non-agricultural population with food.

In all systems, the amount of livestock was near the upper limit set by feed availability, that is, feed was generally a scarce resource. Rough grazing on virtually every type of land for certain periods of the year was essential for feeding the livestock during the summer, while during the stable period, straw was an essential feed-stuff (providing up to 40% of feed supply in the lowlands). In general, the biological resources were probably used to their very limits in all systems. In the arable systems in particular, land was used very intensively and every plot was used, at least for grazing. Woodlands had to serve as grazing land for the livestock and as a source for litter and they were the one and only source of primary energy for room heating and process heat. All of these functions were essential for the functioning of the production system, although the amount of woodland was basically reduced to areas not suitable for arable farming or grassland at low altitudes. Correspondingly, the condition of large parts of the woodlands may have been rather poor.

This paper demonstrates that the Franciscean Cadastre can be regarded as an extremely valuable and rich source for environmental history and human ecology. The data provided by the FC allow a wide variety of aspects concerning the socio-economic metabolism of agricultural production systems to be analysed. The proposed methodology was applied to model material and energy flows of small-scale villages, but it is applicable as well at the level of individual farms or regional land-use systems. The quantitative biophysical approach provides a useful supplement to more conventional methods in environmental and agricultural history and contributes to the understanding of the functioning of agricultural production systems and their development. It allows us to compare and analyse regional types of production systems, their structure and functioning and to address significant parameters with respect to agricultural modernisation. The proposed model is a powerful tool for further research, as it can be used for many purposes, e.g. to simulate the effect of specific aspects of agricultural modernisation on the functioning and productivity of the systems studied. It allows us to analyse the effect of an increasing cultivation of the fallow fields by leguminous crops and potatoes on feed supply, stable feeding, food supply and soil fertility, or to test the vulnerability of the production system by simulating crop failures and their effect on food and feed supply.

However, to take full advantage of the proposed approach it should be related to or combined with the socio-economic, demographic and historical analysis of agricultural systems. This should include the analysis of socio-economic distribution of resources and the labour force, social stratification, land tenure, ownership and property rights as well as the significance of external institutions or market integration, etc.[4,11,36]. Concerning the villages studied, a variety of aspects would appear to be fruitful for further analysis: The structure and expenditure of human and animal labour over time during the course of a year, the evaluation of data concerning market integration and the significance of seigniorial tithes and taxes and an evaluation of data at the farm level to gain information on social stratification. A comparative analysis of the changes in the functioning and structure of the agricultural production system and the socio-economic energy system over the last 170 years in the four villages mentioned here is in preparation.

5.1 Acknowledgements

The research presented in this article was funded by the Austrian Federal Ministry of Education in the research programme *Kulturlandschaftsforschung* (Cultural Landscape Research). The study upon which this paper is based is part of the LUCC-endorsed project #33: *Land-use change and socio-economic metabolism: a long term perspective*.

This study would not have been possible without the experience and the data provided by Projektgruppe Umweltgeschichte, above all Klaus Ecker, Christoph Sonnlechner, Harald Wilfing and Verena Winiwarter who have studied this villages for years. Furthermore I want to thank Helmut Haberl for his valuable contributions, my colleagues Elke Hanser, Ortrun Veichtlbauer and Sibylle Wentker for their cooperation and support and two anonymous reviewers for their comments.

Table 13: Plant production: Conversion factors and model assumptions.

	Yield range (kg_{FW}/ha)	Seed (kg_{FW}/ha)	Volume weight (kg_{FW}/hl)	Harvest Index	Water content (%)	Gross Calorific Value (MJ_{GCV}/kg_{FW})	Nutritive value (MJ_{NV}/kg_{FW})	Nitrogen content (% of FW)	Feeding value (SE/kg_{DM})
Rye	820-1,180	175	700	0.28	14%	15.9	11.0	1.76%	836
Rye flour	79%				13%	16.0	13.0	1.76%	780
Oat	650-760	176	440	0.28	14%	16.1	15.0	1.92%	730
Barley	660-1,170	186	620	0.25	14%	15.5	13.2	1.60%	810
Wheat	780-980	160	750	0.31	14%	15.7	12.7	2.05%	863
Wheat flour	80%				12%	16.0	14.0	2.05%	700
Mixed corn (*Linsgetreide*)	780-860	186	630	0.25	14%	15.5	13.2	1.60%	820
Straw of rye	2,100-3,030		40		14%	15.8		0.40%	290
Straw of oat	1,660-1,940		44		14%	15.5		0.56%	327
Straw of barley	1,990-3,510		40		14%	15.6		0.64%	302
Straw of wheat	2,170-3,390		38		14%	15.3			260
Straw of mixed corn	2,330-2,580		40		14%	15.6		0.64%	290
Vegetabiles (back garden)	7,000-14,000	10%			86%	1.5	1.0	0.30%	656
Fruits (apples/pears)	2,500				85%	3.0	2.0	0.06%	656
Grapes	2,125-3,200				83%	3.0	3.0	0.17%	
Marc					54%	6.0		0.66%	360
Wine	75%				85%		3.3		
Wine leaves, etc.	833				16%	16.0		1.09%	480
Potato	7,200-7,400	1,500	77	0.51	78%	3.7	3.0	0.34%	762
Cabbage	4,900				92%	1.5	1.0	0.54%	
Fodder beet	9,000-11,000	35	64	0.59	88%	1.9	0.7	0.21%	690
Clover	1,750-3,800	25			14%	15.9		2.00%	450
Beet top					87%	2.3		0.34%	656
Hay	1,460-2,200				14%	15.4		2.00%	450
Grazed biomass	200-600				14%	15,4		2.00%	600
Wood	1.38-4.77 [scm]		573-713 [kg/scm]		25%	19.7		0.06%	
Litter	2,150-2,500				14%	16.0		0.8-0,9%	

kgFW/ha – kilograms (fresh weight) per hectare, kgFW/hl – kilograms (fresh weight) per hektoliter, MJGCV/kgFW – mega Joules (gross calorific value) per kilogram (fresh weight), MJNV/kgFW - mega Joules (nutritive value) per kilogram (fresh weight), % of FW - % of fresh weight, SE/kgDM - starch equivalent per kilogram (dry weight), scm – solid cubic metre
Sources: See text.

Table 14: Livestock production: Conversion factors and model assumptions livestock production.

		Horses	Oxen	Cows	Young cows	Calves	Pigs	Sheep	Goats	Poultry	Cows milk	Eggs	Wool
Live weight	(kg)	380-450	330-390	230-270	105-125	30-35	60	35	45	2			
Slaughter weight	(% of live weight)	50%	55%	46%	60%	55%	75%	45%	45%	50%			
Slaughter rate	(%)	10%	25%	12%	5%	75%	70%	35%	15%	20%			
Water content	(% of live weight)	50%	55%	55%	50%	50%	45%	60%	60%	60%	87%	66%	10%
Gross calorific value carcass	(MJ_{GCV}/kg_{FW})	11	11.5	11.5	11	11	17	10	10	10	3.1	7	
Nutritional value edible portion	(MJ_{NV}/kg_{FW})	6	9.8	8.6	7.8	7.8	13.5	9	9	9	2.8	6.6	
Nitrogen content carcass	(% of FW)	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5	3.5%	0.5%	2.0%	
Feed demand min SE	(SE/kg live weight/day)	5.5	6.0	7.0	9.5	10.0	8.0	8.0	7				
Feed demand standard SE	(SE/kg live weight/day)	10.0	9.0	10.0	12.0	15.0	20.0	11.0	10				
Feed demand min DM	(kg_{DM}/1000 kg live weight/day)	14.0	15.0	17.0	20.0	25.0	22.0	18.0	18	-			
Feed demand standard SE	(kg_{DM}/1000 kg live weight/day)	20.0	21.0	22.0	25.0	30.0	35.0	24.0	24	-			
Milk/egg yield	(kg/year)	-	-	1.300	-	-	-	88	300	8			
Grazing period	(days per year)	100-185	100-185	100-215	100-225	100-225	-	100-225	100-225	-			
Stable period	(days per year)	180-265	180-265	150-265	140-265	140-265	180-365	140-265	140-265				
Litter demand	(kg/day stable period)	1.7-3.3	2.1-3.0	2.1-2.4	1.1-1.2	0.2-1.0	0.7-1.0	0.2		-			

MJGCV/kgFW – mega Joules (gross calorific value) per kilogram (fresh weight), MJNV/kgFW - mega Joules (nutritive value) per kilogram (fresh weight), % of FW - % of fresh weight, SE/kg live weight/day - starch equivalent per kilogram live weight per day, kgDM/1000 kg live weight/day – kilograms dry matter per 1000 kg live weight per day

Sources: See text.

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