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Surplus, Scarcity and Soil Fertility in Pre-Industrial Austrian Agriculture—The Sustainability Costs of Inequality

Michael Gizicki-Neundlinger * and Dino Güldner

Institute of Social Ecology, Alpen-Adria-University, 1070 Vienna, Austria; dinoleon.gueldner@aau.at
* Correspondence: michael.neundlinger@aau.at; Tel.: +43-1-5224000-401

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Abstract: This paper takes a Long-Term Socio-Ecological Research (LTSER) perspective to integrate important aspects of social inequality into Socio-Ecological Metabolism (SEM) research. SEM has dealt with biophysical features of pre-industrial agricultural systems from a largely apolitical perspective, neglecting social relations and conditions of peasant production and reproduction. One of the politically and economically most important manorial systems in Early Modern Austria (Grundherrschaft Grafenegg) serves as a case study to reconstruct the unequal distribution of central resources between ruling landlords and subjected peasants. We show that peasant land use systems generated small surpluses only, whereas landlords enjoyed significant economies of scale. Furthermore, we explore what these conditions of landlord surplus and peasant scarcity implied for their respective agro-ecological sustainability. Finally, we argue that within pre-industrial agrarian systems sustainability costs of inequality were severely limiting margins for agricultural intensification and growth of peasant economies.

Keywords: long-term socio-ecological research; social inequality; land costs of sustainability; material and nutrient flow accounting; pre-industrial agriculture

1. Introduction

In recent years, scholars from different disciplinary backgrounds have studied the sustainability of pre-industrial agricultural systems under the category of "socio-ecological metabolism" (SEM) [1–3]. SEM research starts from the premise that every socio-economic system biophysically reproduces itself via a continuous, socially organized exchange of resources with its natural environment. In today's developing countries—and also in Europe's pre-industrial era—agriculture may be considered one of the core socio-metabolic strategies. Peasants invest labour to make use of land (and other natural resources) and continuously intervene into ecosystem dynamics to warrant steady flows of biomass for societal purposes (i.e., to maintain a certain socio-ecological metabolism). To investigate these metabolic interactions and their changes over time, Long-Term Socio-Ecological Research (LTSER) integrates perspectives from the social and the natural sciences [4,5]. Economic historians, social anthropologists and system ecologists have used indicators and concepts to investigate long-term trends in agrarian resource use at the national [6], regional [7] and local level [8]. Tello et al. [9,10] and Gingrich et al. [11] have intensively debated transitions between different energy regimes (from pre-industrial to fully industrialized agriculture). Tello et al. [12] and Marull et al. [13,14] have used SEM approaches to comprehensively study the evolution of land use changes and effects on local biodiversity. Also, flows of nutrients have been traced through agro-ecosystems to better understand issues of soil fertility [15–18]. Still, a vitally important aspect of (pre-industrial) socio-ecological systems has been widely under-researched. Even though Gonzalez de Molina and Toledo [3] have pointed out that an unequal distribution of materials, energy and nutrients within a specific socio-economic system may cause sustainability problems and lead to overexploitation of the resource base, the socio-economic conditions of peasant production and reproduction have largely been neglected in SEM research. Thus far, only a few authors [19–25] have tried to explicitly address the unequal distribution of resources within pre-industrial agriculture to open their SEM research for political analysis.

Within critical agrarian studies, analysis of social relations and inequalities determining pre-industrial peasant economic activities have a long tradition [26–29]. Some authors even claim that unfavourable property relations on land and labour, the extraction of agrarian surplus by landlord or state authorities and other processes of peasant exploitation and dispossession may be considered the prime determinants of agrarian change and the historical transition from feudalism to capitalism [30–34]. Drawing on Karl Marx' seminal ideas on the dialectics between capitalist agriculture and soil fertility, John Bellamy Foster added important ecological dimensions to the discussion on agrarian change. According to Foster, Marx had already formulated basic premises of the "metabolic rift" between growing industrial centres and their rural hinterlands: the large-scale capitalist agriculture of the 19th century led to a "material estrangement of human beings in capitalist society from the natural conditions of their existence" [35] (p. 383). This delocalization of agriculture and the alienation of the consumers from agricultural production had direct consequences for the "old ecological relations of production. In particular, the nutrient cycling of the old agrarian systems was disrupted" [36] (p. 126). Recently, Wittman [37], and Schneider and McMichael [38] proposed reworking and repairing the historic, capitalist metabolic rift under the auspices of "food sovereignty". Similar ideas of co-benefits between peasant autonomy and agro-ecological sustainability were put forward by several other scholars [39–44]. In the wake of the global land-grabbing processes of past years, critical agrarian studies have studied the disproportionate accumulation of "empty" and "cheap" land in the hands of a few globalized, corporate agro-businesses or national governments at the expenses of peasant communities, mostly in rural hinterlands of the Global South [45–47]. These new dynamics of peasant dispossession and land enclosures not only threaten food security, property relations and income opportunities of indigenous communities, but they also heavily intervene into local land use patterns and agro-ecosystem functions [48]. In a similar vein, scholars have investigated the biophysical burdens of ecologically unequal exchange related to international trade flows in the dominant world system. This concept refers to the externalization of ecological costs of production from the Western core nations to the production systems in the Global South [49–52].

In this paper, we try to integrate questions from critical agrarian studies into SEM research. Following Bernstein [53], we open the socio-ecological reading of our Austrian case study to some important aspects of inequality, explicitly focusing on the unequal distribution of agrarian resources and the extraction of agrarian surplus. Consequently, we present a first approach to use our empirical data on material and nutrient flows to support debates on accumulation, agrarian change and inequality from a biophysical perspective. Of course, the unequal distribution of land, biomass and nutrient resources between different agrarian agents represents a single dimension of social inequality only. Further research would be required to better understand the pivotal role of institutional settings, technological constraints and property relations that helped to establish, shape and maintain social inequality within pre-industrial agriculture. Here, we thus investigate landlord−peasant dialectics in one of the most politically and economically important manorial systems in Early Modern Austria (Grundherrschaft Grafenegg). Empirically, we analyse socio-ecological metabolisms of lords and peasants—in terms of biomass as well as plant nutrient flows—to scrutinize the unequal distribution of land, food and other resources between them and to explore implications of landlord surplus and peasant scarcity for the respective capacities to manage fertility of their soils.

To this end, first, we explain two central conditions of pre-industrial agriculture: the land costs of sustainability and the manorial regime. Second, we briefly introduce our case study region and the historical sources. Third, we reconstruct the unequal distribution of resources between lords and peasants and how it affected the sustainability of the respective agro-ecosystems. Finally, we show

how the maldistribution of socio-ecological capital limited margins for agricultural intensification and growth of the peasant economies. This is what we call the "sustainability costs of inequality".

2. Conditions of Pre-Industrial Agriculture in Central Europe

Agrarian sustainability is fundamentally linked to the maintenance soil fertility in the long run [54]. Soil fertility is determined by numerous biological (e.g., diversity of micro-organisms) or physical parameters (e.g., temperature, water and clay content of the soil), but primarily by the availability of the important macro-nutrients nitrogen (N), phosphorous (P), and potassium (K) in the agriculturally used soils [55]. In what follows, we focus on the availability of N exclusively; more data would be needed to reconstruct P and K dynamics in our case study. In fertile soils, the amount of nutrients extracted (via biomass harvest or grazing) or lost (via leaching and erosion) does not exceed the amount of nutrients replenished in the course of an agricultural year or rotation cycle. This holds true not only for pre-industrial agro-ecosystems as in our case study, but also in contemporary organic or industrial agricultural systems. An equilibrium state of nutrients is an important prerequisite to maintain ecosystem productivity and—therefore—a significant determinant of agricultural yields. Consequently, peasants have to ensure that sufficient quantities of nutrients are recovered each year in order to sustain food provision and security [56]. Nutrient replenishment in the soil is determined by various natural conditions, as well as through cultivation and management measures [15]. N deposition via rainfall is an important natural input into soil ecosystems. In Austria, annual precipitation ranges from 550 L/m^2 (lowland) to 1500 L/m^2 (pre-Alpine), adding up to 40% of the total N replenishment [57]. In regions with lower rainfall, other natural N inputs are of greater quantitative importance. For example, in the province of Lower Austria, non-symbiotic fixation (i.e., fixation of atmospheric N via free-living micro-bacteria) accounted for up to 35% of the annual nutrient inputs (see below).

In addition to these natural nutrient dynamics, peasants actively manage some socio-economic nutrient flows. Under the conditions of pre-industrial agriculture, chemically synthesized fertilizers were not available to replenish nutrients extracted or lost. Also, transportation opportunities were severely restricted, rendering the transfer of nutrients from remote agro-ecosystems relatively costly and inefficient [1]. Thus, for pre-industrial Central European agricultural systems—as well as for most agricultural systems in the Global South today—cultivation of leguminous crops, complex multi-annual rotation systems, irrigation measures or the application of manure may be considered the most important, local nutrient management strategy [58]. In quantitative terms, though, animal manure made up for the most significant nutrient input to the soil systems. Depending on the livestock density and the efficiency of the manure management, 30%–90% of the total extracted nutrients could be replenished [17,59]. One way of efficiently managing nutrients is livestock keeping and feeding. In Catalonia, for instance, the on-field burying of biomass constitutes another major N backflow into the soils [60]; however, this practice was not common in Austria. Livestock is able to convert biomass that is not suitable for human consumption (grass vegetation, bushes, stubble fields) into food products (and draught power) and it concentrates nutrients in a plant-available form—manure, which can be collected and applied on fields. Therefore, livestock keeping may be used to mobilize nutrients throughout the whole agricultural landscape, integrating different types of land uses at the local level and providing for a very important socio-economic nutrient backflow. In Austria—but also in other Central European regions—livestock was used to transfer nutrients from grassland or forests to more intensively used land, such as arable land, kitchen gardens or vineyards.

The necessity to support favourable livestock densities, however, did not come without costs. Sufficient land area was needed to feed animals either directly (from grazing areas) or indirectly with forage crops from arable land. In addition, livestock was regularly fed on cereal crops and their residues (mostly straw or bran). These "land costs of sustainability" may be considered an important condition of pre-industrial agriculture in Central Europe [1] and also in the Mediterranean [61,62]. High land costs may even push agro-ecosystems towards ecological disequilibrium. Feedstuff grown on cropland may directly compete with crops produced for human consumption. Also, nutrient depletion of grassland and forest due to intensive grazing may significantly reduce productivity of these ecosystems. Here, nutrient replenishment is mostly limited by natural processes (e.g., rainfall, fixation, formation of new soil), as peasant cultivation measures would entail relatively high labor requirements. And again, active nutrient replenishment in grassland and forest ecosystems would limit the availability of nutrients that can be transferred to intensively used croplands.

In order to navigate between favourable food production and overexploitation of soil nutrient resources, land costs needed to be actively managed. Evidently, this land management was embedded in distinct socio-economic contexts, unequal power relations and specific technological constraints. In what is Austria today, the "manorial regime" was a prime determinant of peasant livelihoods and land use practices from the early Middle Ages until the Liberal Reforms of 1848. The stark contrast between ruling landlords and subjected peasants was one of the most important structural elements of this historical era—not only in Austria, but all over Europe [63]. Under the conditions of the manorial regime, landlords formally owned the land and leased small, fragmented plots to their subjects ("rustic" lands). Rigorous land tenure excluded most of the population from large parts of the farmland. It should be noted that, within pre-industrial agriculture, the manorial regime represents one of the most important property systems on land. However, past tenurial relations and property rights were situated in specific socio-economic and historically contingent contexts. As Congost [64] has pointed out, many of the manorial rights were far from perfect. Also, dynamic Early Modern land markets may have created opportunities for peasants to increase their farm sizes [65]. Finally, common land resources without any formal property rights were a constitutive—and conflictive—element all over pre-industrial Europe [66]. To illustrate with an example, in one of our sample villages (Kamp), peasants had access to only 60% of the agriculturally productive land, whereas landlords controlled the remaining 40%. On average, small peasant families cultivated farms no larger than one hectare of cropland or small kitchen gardens, lacking the resources to keep more than a few heads of livestock. Also, peasant fields were situated in a complex amalgam of dispersed land tenure relations. On the contrary, landlord fields were geographically integrated to perform uninterrupted and efficient agricultural rotations [23]. In return for the land tenure, peasants were obliged to perform certain manorial services. On the one hand, they had to deliver some fractions of their surplus harvest as tithes or other forms of taxes. On the other hand, they were bound to perform corvée labour within their lord's domestic ("demesne") economy—bringing in the lord's harvest, working in the manorial manufacture, threshing corn, etc. Alternatively, peasants could compensate for their manorial obligations in money.

3. Lord and Peasant Agriculture in Grundherrschaft Grafenegg

In the first half of the nineteenth century, Lower Austria—one of the core provinces of the Austro-Hungarian Empire—was characterized by relatively strong manorial regimes [67]. The manor of Grafenegg in the central part of the province serves as our case study. Under the reign of the Breuner family (1730–1848), it became one of the most economically [68] and politically [69] influential manorial systems in Early Modern Austria. The manor comprised two demesne estates—Gut Grafenegg and Gut Neuaigen—which were located within the geographical boundaries of different peasant villages. In the nineteenth century, peasants were regularly embedded in broader, more complex networks of manorial obligations (from other manorial or ecclesial systems or the emerging state authorities). These other socio-economic systems, however, are beyond the scope of our study. Here, we assume that all villages containing Breuner demesne lands formally belonged to the manor of Grafenegg. In the historical sources, those villages were grouped together into two administrative regions—Augegend (Floodplain District) and Waldgegend (Forest District). Augegend data contains information on 9 out of 13 villages; Waldgegend data refers to 17 out of 30 villages. Information on the other villages was not available in the archives. Seven sample villages contained in the two regions were also investigated to represent different socio-economic and agro-ecological conditions of peasant agriculture in the manor, e.g., in the village of Kamp (Ka) we found a strong polarization between many smallholder families—with ploughing fields no larger than one hectare—and major demesne arable lands. In contrast, Untersebarn (U) hosted relatively large peasant holdings, and in Haitzendorf (H), land access was distributed very equally between the different village residents. In Etsdorf (E), we found many economically important peasant vineyards, whereas in Straß (St), almost all of the demesne wine production took place. Table 1 shows the main agrarian features of the two demesnes, the two districts and the seven villages. We can see the pronounced differences between lord and peasant economies—in terms of land use, population structure and livestock composition.

Table 1. Agrarian structure of the two demesne estates Gut Grafenegg (GG) and Gut Neuaigen (GN), of the two administrative regions Augegend (AG), Waldgegend (WG) and the seven sample villages of Kamp (Ka), Untersebarn (U), Grafenwörth (G), Haizendorf (H), Etsdorf (E), Sittendorf (Si) and Straß (St) in the first half of the nineteenth century.

	GG	GN	AG	WG	Ka	U	G	H	E	Si	St
Area (km^2)	37	10	44	63	2.4	7.6	11.6	2.8	5.4	3.2	11.5
Cropland (%)	15	11	52	46	79	72	43	45	72	72	28
Grassland (%)	1	9	19	2	5	4	24	26	0	5	0
Gardens (%)	0	0	5	6	3	7	4	3	3	3	3
Vineyards (%)	-	4	1	29	6	2	1	1	22	18	40
Forest (%)	83	77	23	17	6	15	29	24	3	2	29
Cereal Yields (kg·DM/ha × year)	1004	1315	815	960	792	766	719	798	621	827	975
Population (cap)	138	n. d.	3124	7750	342	368	782	291	586	393	1072
Density (cap/km^2)	3	n. d.	71	123	147	48	68	103	108	122	93
No. Farms	2	2	467	1099	42	54	123	41	76	55	158
Farm Size (ha cropland)	278	55	3	3	2	7	3	2	3	4	1
Livestock (LU500)	39	13	212	350	14	20	52	16	29	19	45
Horses (%)	16	6	22	16	14	10	20	15	21	9	10
Bull (%)	—	—	1	1	—	—	1	—	—	1	1
Oxen (%)	3	—	5	9	18	10	-	21	3	4	—
Cows (%)	7	—	54	55	47	57	59	54	53	64	78
Heifers (%)	—	—	3	1	—	3	2	—	—	2	—
Pigs (%)	1	—	7	6	10	4	11	—	8	—	—
Sheep (%)	63	91	8	12	11	5	7	9	15	19	11
Poultry (%)	10	3	0	1	1	0	0	0	0	1	1
Density (LU500/km^2)	6	15	5	6	6	3	5	6	5	6	4

DM = dry matter; LU500 = livestock unit of 500 kg live weight; livestock density refers to manured land; n. d. = no data available; GG data refers to 1836, GN data refers to 1837 and village data refers to 1829–1830.

In terms of land use, the Breuner demesnes occupied almost 50 km^2, which was larger than the total land area of Augegend and almost as large as Waldgegend. These vast land areas enabled Breuner landlords to enjoy significant economies of scale. They primarily exploited forest resources—not only for timber exports, but also to fuel their brick manufacture. Even though soil conditions were generally favourable for intensive agriculture (chernozem and other humid black soils prevailed in the entire region), the respective share of cropland of the total demesne land was significantly lower compared to village arable land. Strikingly, cereal yields in the two demesne estates were higher than on the peasant fields and above the Austrian average of approximately 920 kg·DM/ha × year [59]. In the entire region, grazing opportunities were severely limited, except for some wet meadows next to the Danube River (in the southern part of the manor), and for a large communal pasture located in the village of Grafenwörth (G). Additionally, some parts of the wooded land provided another opportunity for communal grazing. In the northern hilly zones with favourable podzol loam soils, orchards and—the economically important—vineyards added to the land use portfolio of both lords and peasants.

The large demesne lands only hosted a few permanent residents, who were normally not directly involved in the agricultural cultivation (e.g., the nobility, their stewards, brewers, millers). The main agricultural workforce was recruited from the population of the subject villages, either within corvée or wage-labour relations. As shown in [23], small rustic land plots required less labour input than the large landlord economies. In some of the villages, smallholders accessed so little land that they only needed around half of their available labour time to cultivate it. Most of the population thus worked in service of the Breuner economy, generating some additional family income. Competition on the local labour market was probably high, as labour force was available in abundance. Landlords benefitted from this labour surplus situation, keeping wages at relatively low levels. On both landlord and peasant land, livestock was relatively scarce. Except for the estate Gut Neuaigen, livestock density was far below the Austrian average of 17 LU500/km^2 and was also lower than in other cropland regions in the province of Lower Austria, such as in the village of Theyern (about 16 km south of Grundherrschaft Grafenegg) where livestock density reached 24 LU500/km^2 [8]. The demesne livestock economy was dominated by large sheep herds reared for wool production for textile manufacturing. Peasants integrated a few larger ruminants (mostly oxen and cows) into their agricultural production system. In contrast to mono-functional sheep, cattle were held to serve multiple purposes. They provided draught power to pull agricultural machinery, produced livestock products (mostly meat and milk) and supplied heavily needed manure in greater quantities than sheep.

4. Historical Sources and Their Socio-Metabolic Reading

To efficiently organize their huge farming enterprises, Breuner landlords kept a complex administrative body. During the agricultural year, manorial bookkeepers meticulously compiled quantitative data on earnings and expenses, not only in monetary but also in physical terms. These accounting books comprise all relevant inputs and outputs to and from the manorial farmsteads and cover the most important agricultural activities in the demesne economy: production of cereals and legumes, production of hay and wine, harvest of fodder crops, livestock products, seeds applied, commodities exported, the collection of tithes and other taxes, imported goods such as salt, tools and candles, etc. [23]. Today, we can use the rich information contained in the accounting documents to reconstruct a fine-grained, biophysical picture of agricultural life on the Breuner demesnes. It should be pointed out that data generation from historical sources is a very sensitive, context-driven process. Gizicki-Neundlinger et al. [23], Gingrich et al. [57], and Krausmann [59] provide details on how to process historical data for socio-ecological analyses of 19th-century rural communities in Austria. Also, it is important to keep in mind to be aware of possible data uncertainty and keep a critical view on the sources. Historical sources are potentially biased and selective against their specific socio-economic background: “In the historical archives, accountancy records listing all the inputs and outputs involved in the agrarian cycle are never found” [70] (p. 174). For example, manorial accounting books do not contain any information on land ownership and tenure, on the occupational structure of the economy or on population and household composition. To close data gaps, we used as much site-specific information as possible, such as documents listing every single land parcel under direct Breuner cultivation [71]. For some of the more specific questions on ecological aspects of the demesne land use system, we had to rely on modelling assumptions derived from agro-ecology and socio-metabolic modelling (Güldner et al. [17], Krausmann [59], and Guzmán Casado et al. [72] give detailed descriptions of relevant conversion factors and modelling assumptions). Livestock grazing, for instance, is not reported within the accounting books. We used information on feed requirements of 19th-century farm animals, some quantitative data on feedstuff and local or regional feeding practices to estimate the share of grazed biomass within the animal diet. In other instances, the accounting books report seeds of certain fodder crops that were sown, but do not list any harvest of these crops. Here we considered that the crops were directly consumed by livestock as green fodder (e.g., millet and buckwheat).

To reconstruct peasant economies in the seven villages, we used one of the most important sources for Austrian agrarian and environmental history—the Franciscan cadaster [1,73,74]. From 1817 to 1856, expert commissions roamed the Habsburg Monarchy to undertake a comprehensive land tax survey of the whole country (530,000 km^2 in total). Numerous topographic maps and detailed descriptions of the land system were created, providing important information on peasant agricultural life.

The documents contain data on agricultural yields, livestock numbers, the demographic and occupational structure of the village, peasant diets, feeding practices, land tenure and ownership, etc. Overall, data from these records is considered very accurate [75]. Yields assembled within the cadaster refer to long-term averages and are therefore not biased by single-year anomalies [59]. Here, too, we used agro-ecological and socio-metabolic models to reconstruct important missing biomass flows, e.g., grazing, manure availability, etc. To close data gaps and to minimize data uncertainty in our study, we integrated and cross-checked information from the accounting books and the Franciscan cadaster. We found, for example, very high values for hay production for the villages on the alluvial floodplains. In light of the low livestock densities and the figures on landlord hay production, we assumed that the cadastral commission copied data from another region or year, and have corrected figures accordingly (Sandgruber [73] found similar practices in the province of Upper Austria). To clearly delineate landlord and peasant land use systems and to avoid double counting of land, we subtracted demesne plots found in the historical data of Gutsverwaltung Grafenegg [71] from the total village area provided in the cadaster. Yields were corrected correspondingly.

Based on the database established on the grounds of these sources, we derived a set of socio-metabolic indicators to investigate (1) the unequal distribution of crucial agrarian resources within the Breuner manorial regime and (2) the consequences for the sustainability of the associated agro-ecosystems. To compare the production of the lord and peasant economies at the level of the demesne estates and the two different regions, we calculated the respective amount of total biomass extraction per agricultural year (in metric tonnes of dry matter). This indicator comprises all agricultural products related to the production of food (crops, fruits, vegetables and wine), feed (straw, hay and grazed biomass) and wood. To compare the productivities of the landlord and peasant systems we related total biomass extraction to units of land area. At the intermediate level of manorial distribution, we estimated total biomass transferred (1) between lords and peasant land use systems and (2) on to local or regional markets, again at the level of the two estates and regions. This indicator comprises all the surplus extracted via tithes and taxes, backflows from lords to peasants (as rent in kind for specific manorial services) and trade relations—again in metric tonnes of dry matter per year and land unit. To assess the final biomass availability in each of the two systems, we related the biomass transfers to total biomass extracted. For the demesne economies, we added tithes and taxes as well as imports to the extraction, and subtracted rents in kind, exports and seeds. Final biomass availability for the peasant regions was estimated by reversing the calculations.

To elaborate on the aspect of food provision for both lords and peasants, we estimated the supply of plant- and animal-based food in terms of nutritional energy. Knowing the amount of food available for consumption—i.e., after all biomass transfers (and seed output as well as processing losses) have been deducted, expressed in gigajoule nutritional value per capita and year—allows exploring aspects of food provision under the conditions of manorial regimes. Using an average value of 3.4 GJ per capita and year as the minimum amount of energy required to sustain an individual metabolism [76,77], we can estimate nutritional surpluses and deficits in our case study. This is an average figure and probably on the higher end of actual average intake. The minimum metabolic requirement may vary substantially according to age, weight and occupation. To add an important economic dimension, we estimated the monetary value of the potentially marketable food. We assessed the amount of Kronen (Austrian currency of the time) to be gained by selling all available surplus food at the local markets—average contemporary prices for main agricultural products were taken from [78]. We compare these peasant income opportunities with the monetary obligations issued by the Breuner family—i.e., compensations for tithes and labour services found in the historical data of Gutsverwaltung Grafenegg [79,80].

Finally, to assess the complex issues of agrarian sustainability and soil fertility of the local agro-ecosystems, we calculated nitrogen (N) budgets for the two demesne estates, the two peasant regions Augegend and Waldgegend and for the seven sample villages. We reconstructed nutrient balances at the soil-surface scale, i.e., we assessed the total amount of annual natural and socio-economic N inputs and outputs to and from agriculturally used soils [81]. Positive budgets indicate that N is accumulating in the soil, whereas negative nutrient budgets indicate soil N depletion, pushing the land use system towards agro-ecological disequilibrium. Natural inputs (e.g., N deposited via rainfall or non-symbiotic fixation) and outputs (e.g., N losses due to denitrification, leaching and erosion) were quantified following [15,17], albeit translated into site-specific information for the province of Lower Austria. Landlord and peasant management of N fluxes was estimated according to land use information available in historical sources. We had to rely on assumptions from agro-ecology and socio-metabolic models to estimate some of the information required to perform the N balances. For instance, we followed Güldner, Krausmann, and Winiwarter [17] and used information on local feeding practices, the average number of days that animals were kept in stables, species-specific physiology and demographic change of the respective livestock species to estimate the amount of N retained in the livestock. After calculating N retention (and other losses) we arrived at the net amount of N available in manure, which we allocated to different types of land (mostly to cropland). As livestock density was comparably low in our case study region, we assumed that also human excreta were used to fertilize fields, at least next to the peasant houses. Therefore, we included an estimation of N contained in human excreta into our budgets. We modelled N content of human faeces and urine according to [82,83] and cross-checked our findings with rough estimates of N contained in the specific food intake. Here, we assumed large losses due to storage and transportation according to [84], arriving at similar values of net N availability in human excreta as [85,86].

5. Lord and Peasant Resource Use and Implications for Sustainability

Table 2 shows total biomass extraction, biomass transferred and final availability of biomass for the two Breuner demesnes Gut Grafenegg and Gut Neuaigen and for the two administrative districts Augegend and Waldgegend within one agricultural year. Comparing the biomass extracted per unit area, we see that the peasants used their resources more intensively than the landlords. In Waldgegend, biomass extraction per unit of land was greater than the demesne extraction by a factor of two and in Augegend by a factor of three. Also in the sample villages, where biomass extraction ranged between 1224 kg DM/ha × year in Sittendorf and 2563 kg DM/ha × year in Grafenwörth, peasant productivity greatly exceeded that of the landlord values. The same holds true if we compare demesne extraction to other case studies in early 19th-century Austria [57,59]. Looking at the composition of biomass extraction, we find that crop (and straw) production was important in the entire region, except for Gut Neuaigen. Viticulture seems unimportant in terms of physical (dry matter) extraction, but in the peasant districts, it provided an important source of monetary income. Grazed biomass represented higher shares of total biomass extraction in Gut Neuaigen—where the large manorial sheep herd was held—and in Waldgegend. Harvesting of hay was negligible in all the systems. Forestry played a dominant role in the demesne economy and in Augegend, where large alluvial floodplains were exploited by the peasant residents. Interestingly, in Waldgegend—the "forest district"—wood extraction was of least importance.

Comparing the amount of biomass transferred per unit area, we find that a relatively higher share of biomass was transferred within the manorial system. Here, between 145 and 290 kg DM/ha × year were mobilized as either inputs (tithes, taxes and imports) to or outputs (rent in kind and exports) from the demesne economy, accounting for approximately 25% and 65% of the annual demesne biomass extraction. In both Gut Grafenegg and Gut Neuaigen, exports for the local or regional markets constituted the most important output. Gut Grafenegg's tithes and Gut Neuaigen's imports of marketable goods accounted for the greatest inputs. Interestingly, the biomass flow from the landlords to the peasants (rent in kind) drastically exceeded their tithing obligations in Gut Neuaigen. Here, many peasant families worked in service of the Breuner economy, receiving agricultural goods in return. On the regional level, tithe and tax obligations made up for only 5% to 6% of the total physical produce. On the village level, manorial surplus extraction reached higher levels, e.g., in Kamp, Sittendorf or Haitzendorf [23]. In all cases, the biomass composition of tithe and rent flows was relatively similar.

Table 2. Total biomass extraction, transfers and availability in Gut Grafenegg (GG), Gut Neuaigen (GN), Augegend (AG) and Waldgegend (WG).

	GG	GN	AG	WG
Total Biomass Extraction (t·DM/year)	1631	514	8898	7513
Biomass Extraction per land unit kg DM/ha × year	440	521	1704	1059
Crops (%)	16	6	15	23
Fruits & Vegetables (%)	0.3	0.05	2	1
Wine (%)	0.1	—	0.03	2
Straw (%)	26	11	25	27
Hay (%)	5	—	3	1
Grazed Biomass (%)	22	34	15	31
Wood (%)	31	50	40	15
Total Biomass Transferred (t·DM/year)	1075	143	280	40
Biomass Transferred per land unit (kg DM/ha × year)	290	145	54	6
Tithe and Taxes (%)	18	1	72	4
Rent in Kind (%)	7	35	28	96
Import (%)	8	16	n. d.	n. d.
Export (%)	67	48	n. d.	n. d.
Total Biomass Available (t·DM/year)	1078	412	8533	7230
Biomass Available per land unit (kg DM/ha × year)	291	418	1634	1019
Food Available (GJ·nv/cap × year)	17	n. d.	5.7	3.6
Crops (%)	73	n. d.	56	47
Fruits & Vegetables (%)	3	n. d.	11	3
Wine (%)	0.3	n. d.	0.4	11
Livestock Products (%)	24	n. d.	33	38
Food needed for local demand (%)	20	n. d.	62	97
Marketable Food Potential (Kronen/cap × year)	244	n. d.	60.7	2.9
Taxes levied from Breuner (Kronen/cap × year)	—	n. d.	1.4	3.4
Tithes (%)	—	n. d.	75	91
Corvée (%)	—	n. d.	25	9
Balance (Kronen/cap × year)	244	n. d.	59.3	−0.5

DM = dry matter; GJ nv = Gigajoule nutritional value; Kronen = Austrian historical currency; n. d. = no data available; Gut Grafenegg (GG; 1837), Gut Neuaigen (GN; 1838), Augegend (AG; 1830) and Waldgegend (WG; 1829).

Food output per person greatly exceeded local demand in the landlord economy (at least for Gut Grafenegg; unfortunately, no population data was available for Gut Neuaigen). Surplus food was transported downstream the adjacent Danube River towards the capital city of Vienna, where it was profitably sold to feed a growing urban population [87]. In contrast, we find an almost negligible food surplus of 0.2 GJ per capita and year in the densely populated Waldgegend—pushing the peasant population towards the edge of agricultural subsistence—and a higher food surplus of 2.3 GJ per capita and year in the more intensively ploughed Augegend. Augegend peasants may have used their surplus food to participate in the local or regional markets, generating some modest monetary income of ca. 60 Kronen per capita. Sandgruber [88] found similar values for average smallholder families in the first half of the nineteenth century. If we compare the monetary value of the potential food surplus to tithing obligations issued by the Breuner family, we see that tax obligations were comparably small in Augegend. In Waldgegend, however, monetary obligations further aggravated subsistence pressure. Also, we have to bear in mind that under the conditions of the manorial regime, peasants were regularly embedded in a broader, more complex network of tithes and taxes (from other manorial or ecclesial systems or the emerging state authorities). Total tax burdens may have been substantially larger on the individual households than our figures suggest [89].

Therefore, within our case study region, peasant food provision may be considered very precarious (Waldgegend) or modest (Augegend), whereas the demesne economy regularly produced large surpluses of food and other resources (wood, wool, etc.). Under these conditions of relative subsistence pressure and local market incentives, the peasants used their land more intensively than the landlords did—as two indicators on output-related land use intensity suggest: Table 2 shows the estimates of biomass extraction per land unit in mass (kg·DM/ha), Table 3 shows plant nutrient extraction per land unit (kg N/ha). However, the production of more resources on the same land area may have created severe consequences for the agro-ecosystems, as agricultural intensification often comes at the cost of a long-term decrease in soil fertility [3,90]. Table 3 shows the total N budgets for the two demesne estates and the two peasant regions to empirically assess feedbacks between demesne surplus produce, peasant resource scarcity and the respective soil fertility.

Table 3. Nitrogen (N) balances for Gut Grafenegg (GG; 1837), Gut Neuaigen (GN; 1838), Augegend (AG; 1830) and Waldgegend (WG; 1829).

	GG	GN	AG	WG
N Inputs (kg DM/ha × year)	14.3	13.7	19.2	20.5
Rainfall (%)	27	28	20	19
Non-symbiotic fixation (%)	33	35	21	18
Symbiotic fixation (%)	12	0.3	2	0.5
Animal manure (%)	25	35	36	37
Human excreta (%)	0	0	12	19
Harvest Residues (%)	1	1	3	2
Seeds (%)	2	1	6	5
N Outputs (kg DM/ha × year)	9.1	10.3	20.9	17.6/19.8 *
Harvest and grazing (%)	48	45	71	62
Denitrification (%)	26	27	15	21
Ammonia volatilization (%)	25	27	13	18
Balance (kg DM/ha × year)	5.2	3.4	−1.7	2.9/0.7 *

* Without access to forest grazing.

N balances indicate differences between the fertility of the demesne and rustic land. The two demesne economies and Waldgegend show positive N balances. In Augegend, slightly more N was extracted and lost than replenished during the entire agricultural year. Natural N dynamics (deposition via rainfall, non-symbiotic fixation, denitrification and volatilization) have to be considered when addressing any societal intervention. If we look into the N management practices of lords and peasants, however, we may find reasons for the differences in soil fertility. In our case study, landlords applied some of the decisive agrarian innovations of the time. On Gut Grafenegg, for instance, the cultivation of leguminous crops (beans, lentils, clover) played an integral role in soil fertility. Through symbiosis with rhizobium micro-bacteria, legumes are able to fix atmospheric N in the agricultural soil. Also, landlords integrated new fodder crops into their annual rotations. Former uncultivated fallow fields were now planted with roots and tubers (mostly potatoes and turnips in our case study). As a consequence, fodder availability was significantly raised within the demesne agricultural system. Abundant animal feedstuff—in combination with access to scarce grazing areas—was used to support large sheep herds and some larger ruminants, which supplied meat, milk and wool and considerable quantities of manure at the same time—either as on-field droppings or as manure collected in the stables. With these innovations, the relative ecological sustainability of the demesne agro-ecosystems was ensured and possible margins for agricultural intensification were created.

In the peasant regions, agrarian innovations were adopted more slowly. For example, clover was still very uncommon in the Lower Austrian peasant economies of the 19th century [88]. The low livestock density—compared to the Austrian average of 17 LU500/km^2, or to Gut Neuaigen—led to a relative scarcity of animal manure. We can thus assume that human excreta were also applied on intensively used land (orchards, vineyards and to a lesser extent, cropland) to substitute for manure of animal origin. In the 19th century, efficient management and application of human excreta was heavily debated among agronomists of the time [84]. Our reconstructions suggest that the application of human excreta may have considerably contributed to soil fertility of rustic lands—even though we do not find any explicit confirmation of this practice in the historical sources. According to our calculations, human excreta may have accounted for up to 20% of the total annual N replenishment. Still, in Augegend, the negative N balance indicates that N stocks in agricultural soils were slowly diminished. Here, market integration seems to be higher than in the other peasant regions. Accordingly, Augegend provides a vivid example of how metabolic rift processes may lead to N deficits, threatening the agro-ecological stability and food security in peasant land use systems. In Waldgegend, cultivation of common pool resources may be considered an important strategy to alleviate N scarcity. Here, communal forest grazing was the prime determinant of manure availability. But as Breuner landlords exerted strong, exclusive manorial rights to woodland areas, access to this vitally important N source may be considered extremely fragile and open to constant dispute [89]. If we consider that no forest grazing took place in Waldgegend, the total N balance drops to 0.7 kg·N/ha × year.

If we analyse the seven sample villages according to different land use types, we find a very similar picture of declining or stagnant levels of soil fertility for most peasant agro-ecosystems (see Figure 1). We find possible soil mining in four of them, whereas three villages show N balances around zero. In most of the cases, all land use types open to animal grazing (meadows, pastures and forests) and/or fodder production (cropland) show negative N balances. In addition, we can see that common pool resources may only restore soil fertility up to a certain threshold, as the case of Grafenwörth shows. Of the total grassland areas of the region, 30% was located in this village, and it shows a strongly negative N balance. The peasant livestock of all the neighbouring villages were regularly led to graze in Grafenwörth, transferring considerable amounts of N to their small plots of cropland. This drew on the fertility of the grazing areas (−5 kg·N/ha × year on meadows, −0.8 kg·N/ha × year on pasture and −1.1 kg·N/ha × year in the forests). Also, the amount of N removed via fallow grazing contributed to a highly negative balance on the cropland (−5.1 kg·N/ha × year) and village level (−3.6 kg·N/ha × year). The scarcity of fertile agricultural soils drove the peasant population of Grafenwörth towards forestry or the secondary sector, mostly artisanry and proto-manufacture. In Sittendorf, high levels of manorial surplus extraction led to a significantly negative N balance. Only in Haitzendorf and Straß was N successfully transferred from extensively used land (meadows, pasture and forests) towards intensively used land (cropland, vineyards and orchards), allowing for stable N balances of around 0.1 to 0.3 kg·N/ha × year at the village level.

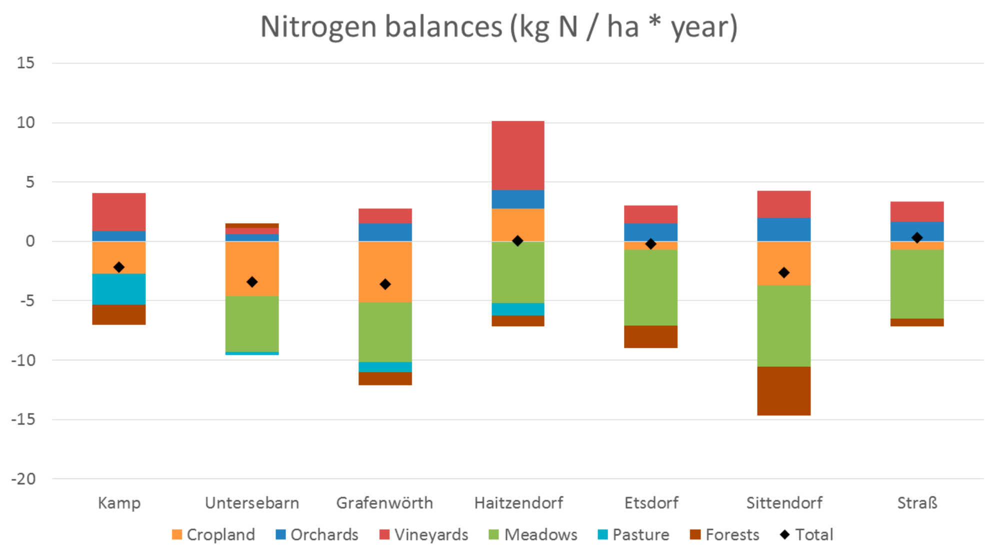

Figure 1. Nitrogen balances for the seven sample villages (1829–1830).

6. The Sustainability Costs of Inequality

Our empirical findings suggest that under the conditions of the manorial regime—characterized by surplus extraction via tithes and taxes, increased market integration and drastic scarcity of rustic land—a significant fraction of the peasant population was not able to cover the land costs of agrarian sustainability. Peasants could not maintain N transfers from extensively used grazing areas on to their small plots of cropland, as they were excluded from additional land and livestock resources. Rather, the accumulation of agrarian capital within the landlord economies—at the expenses of their subjects—led to a significant loss of sustainability of the peasant land use systems. In his seminal contribution from 1987, Marxist historian Robert Brenner already formulated the basic idea of what we call the sustainability costs of inequality.

> [B]ecause of lack of funds—due to landlords' extraction of rent and the extreme maldistribution of both land and capital, especially livestock—the peasantry was by and large unable to use the land they held in a free and rational manner. They could not, so to speak, put back what they took out of it. Thus the surplus-extraction relations of serfdom tended to lead to the exhaustion of peasant production per se; in particular, the inability to invest in animals for ploughing and as a source of manure led to deterioration of the soil, which in turn led to the extension of cultivation to land formerly reserved for the support of animals. This meant the cultivation of worse soils and at the same time fewer animals—and thus in the end of a vicious cycle of the destruction of the peasants' means of support [32] (p. 33).

This assumption is strongly corroborated by the results for our case study. The maldistribution of both land and capital in pre-industrial agriculture drove the peasant economies towards relatively unsustainable paths. Peasants were not only excluded from land and livestock, but also from vitally important nutrients, strongly limiting peasant capacities to cover the land costs of agricultural production. Small farm sizes—and the lack of grazing opportunities that came with it—led to comparably low agricultural yields within the peasant land use systems, which resulted in a precarious or relatively modest provision of food and also animal feedstuff. Again, the lack of feed resulted in low livestock densities and—therefore—manure scarcity, drastically limiting the amount of nutrients available to replenish annual N extraction and losses—even if we consider that human excrement was regularly applied on intensively used land. In turn, these nutrient deficits severely limited possibilities to intensify agricultural production. Figure 2 illustrates this "vicious cycle" of the sustainability costs of inequality.

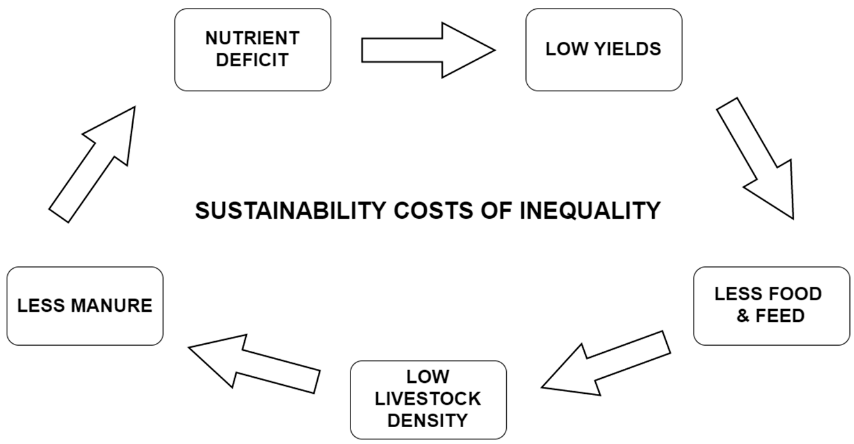

Figure 2. The vicious cycle limiting growth of peasant economies.

Only beneficial N transfers from extensively used land to more intensively used land may have expanded the sustainability frontiers of peasant agriculture, i.e., providing food security while sustaining the agrarian resource base in the long run. In contrast, landlords were endowed with enough socio-ecological capital (land, food, livestock, revenues) and agrarian innovations (e.g., clover, potatoes) to compensate for the land costs of their demesne economies. In doing so, Breuner represents a typical "advanced organic economy" [91] of the 19th century, combining significant, market-oriented economies of scale with sound, sustainable resource management.

7. Conclusions

This paper shows how SEM research may benefit from critical questions on the socio-economic conditions of peasant production and reproduction and—alternatively—how debates on accumulation and inequality may benefit from biophysical approaches. In our case study on the Breuner demesne, we found that the huge sustainability costs of inequality drove peasants towards a struggle to meet their subsistence needs and to maintain fertility of their soils at the same time. Our reconstructions suggest that peasants used their resources more intensively (in terms of resource extraction per land unit) than their landlord counterparts. Ester Boserup described an increase in land use intensity as a common strategy to improve nutrient availability and agricultural yields under the conditions of population growth and land precariousness [92]. In the seven sample villages, sufficient labour time was available [23] to intensify land use on the small peasant plots and/or to include some land-saving strategies, e.g., cultivation of crops with higher nutritional values such as maize or potatoes [93]. Still, agricultural intensification seemed to be the exception rather than the norm, as the agro-ecological conditions of soil fertility did not allow for significant agrarian accumulation. Without structural solutions to cover the land costs—e.g., access to sufficient (common pool) grazing areas and the necessary livestock numbers, imports of feed and/or manure—peasants tended to slowly erode their soil resources. A second option to cope with the sustainability costs of inequality was to substitute subsistence crops for cash crops. Badia-Miro and Tello [21] and Parcerisas [22] have shown that, in Catalonia, vineyard specialization helped to alleviate subsistence pressure under pre-industrial conditions. In the seven sample villages, however, opportunities to shift to more intensive wine-growing seemed to be rather limited, as the historical sources indicate that significant amounts of manure were applied to vineyards already [94].

On the contrary, Breuner landlords created possible margins for agricultural intensification and economic growth while maintaining agro-ecological sustainability. In light of the relative fertility of their land, they could increase demesne production and further exacerbate accumulation of agrarian surplus. Therefore, the Breuner case shows how a systemic view at the intersection of SEM research and critical agrarian studies may help to better understand the maldistribution of agrarian capital and social inequalities at the onset of industrial transformation. Also, our LTSER case study shows how land-grabbing dynamics of today may intervene with fragile land use (and nutrient) equilibria of Global South production systems. New land enclosures and other processes of peasant dispossession may not only threaten property rights on land and food security of peasant communities, but also the agro-ecological sustainability of local agriculture.

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