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REGIONAL MATERIALS ACCOUNTING OF NITROGEN IN UPPER AUSTRIA

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ABSTRACT

A nitrogen balance for the region of Upper Austria is presented containing a short introduction to the method and materials used and the overall results with emphasis on the N balance for the atmosphere, agriculture and surface waters. It is shown that it was possible to obtain only with existing data an overall balance for nitrogen which takes all important nitrogen fluxes into consideration. Important results are: The biggest input of nitrogen (as NH_X-N or NO_X-N) into the atmosphere comes from agriculture, but also traffic and industrial processes play an important role. The N-losses from agriculture to the environment depend to a high extent on the rate of animal protein production. The N-input to surface waters from nonpoint source discharges is noticeably bigger than from point source discharges. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

KEYWORDS

Diffuse pollution; nitrogen; materials accounting; point source pollution; regional balance; Upper Austria.

INTRODUCTION

In numerous reports it is estimated that the loads in nutrients – among them nitrogen – in river catchments in the developed world are increasing, sometimes even strongly increasing. For the Danube Basin, there are indications that the load of nitrogen in front of the Danube Delta augmented between 1960 and 1990 about tenfold, and the load for phosphorus about threefold (Mee, 1992). Whether these increases are real or due to sampling artefacts, remains open in regard to a non-existing integrated sampling in the 1960s. On the other hand, the change in population – looked upon at first sight as the main driving force for such changes – in the Danube catchment increased by < 20% only. Assuming constant life style over time, thus the population increase alone cannot account for the increase in e.g. the nitrogen load. As a conclusion, the increase must be due to a change in lifestyle as well, in land-water interactions along the drainage network, but also with different "uses" of human excreta over time. Thus, the questions arise: Can we find a plausible method indicative with sufficient evidence what activities are causing the loss of nitrogen to the water environment? Who are the actual and primary players and who are the ones who it seems to be, but in fact are only secondary players? What are the various causes for this increase? What role can regional materials accounting play in pinpointing sources and causes for nutrient loadings? How can we integrate the study of point and non-point source discharges instead of separating them as it is done in some cases?

REGIONAL MATERIALS ACCOUNTING

The problem encountered is one of mass flux, i.e. the reason to be puzzled is that the mass fluxes observed or monitored have increased over time. Despite the fact that the mass conservation principle is well known, in nutrient management it is not widely used yet; common economics is only balancing in monetary terms and is yet not structured towards the accounting of material fluxes. Alas, there is hope in sight, since *Regional Materials Accounting* is now rapidly becoming an established tool. Applying the methodology of *Regional Materials Accounting* systems boundaries have to be established first: They are geographical limits for a region (or a drainage basin) in horizontal terms, in the vertical either including the planetary boundary layer or the atmosphere up to the troposphere, and into the underground such as the 1st groundwater floor within the system. Within these boundaries, *Processes* describe the *Activities* relevant for the mass cycles internal to the system. *A Process is defined as a transport, a transformation or a storage of materials.* The term *Process* does not relate to an individual enterprise, but to all activities of the same type within the system boundaries. The time period for which *Regional Materials Balances are established can vary*; in nutrition, a balance for a year is meaningful and will thus be chosen for nitrogen. Balances can only be established for specified compounds or total elements. The principles and methods of this approach are further demonstrated in Baccini and Brunner (1991). Being as this is, accounting can contribute to showing who is responsible for what, but it has to be supplemented by other tools in order to take the effects into account.

APPLICATION OF "REGIONAL MATERIALS ACCOUNTING OF NITROGEN" TO UPPER AUSTRIA

The *Bundesland* Upper Austria.

Upper Austria is one of the *nine Länder* (states) of Austria. As a preliminary N-balance had been established for Austria (Fleckseder, 1992), interest arose to have one for the next smaller unit, a state. The driving force was that, in 1991 only 62% of the population were linked to centralised sewerage and biological wastewater treatment, the wastewaters of the remaining share being disposed of by trucking to sewage treatment plants and application on land, as well as by leaking into the underground. In order to give some guidance to revised provincial ordinances both for sewage sludge disposal as well as wastewater treatment, it was the idea that we should indicate where the problems are. The preliminary N-balance for Austria had been established without officials from agriculture participating with this work. Thus, when this balance was discussed with colleagues from this side, its numeric validity was questioned. For the balance for Upper Austria, we proposed agriculture to be participating from the beginning, preferably by designating high - ranking delegates. This, by chance, was possible, thus the data obtained are scrutinised also from this side and agriculture will no longer claim that the balance established is wilfully unfair to its side and extremely fair to combustion processes and to waste management.

Upper Austria (see Fig. 1) is 11,980 km^2 in size, Linz – the biggest industrial centre in Austria – being its capital, and in 1991 (the reference year selected) Upper Austria had ~ 1.3 Mil. inhabitants. The only nitrogen fertiliser factory existing in Austria is located at Linz. Large rivers bordering are the Enns, the Inn and the Salzach, and the large river entering and leaving is the Danube. There are rivers within Upper Austria reaching the Danube, e.g. the Traun. Dissolved oxygen conditions both in the lakes and rivers in Upper Austria are generally good, thus denitrification in surface waters has – at first sight! – not been selected as a process of importance to be numerically taken into account.

A Systems Analysis for Regional Materials Accounting of Nitrogen in Upper Austria.

In 1992 Zessner *et al.* (1992) studied the management of nitrogen in the State of Upper Austria. Within the boundary of Upper Austria, the vertical limit was set by the planetary boundary layer, and the lower limit with the 1st groundwater floor within the system. The following Processes were selected as important for the overall nitrogen balance: Atmosphere, Households (incl. consumption and disposal of goods and wastes), Combustion (incl. heating, industrial process heat and traffic) , Industry and Trade (incl. chem. industry, trade, other industry and processing of food and forest products), Waste Management (Wastewater treatment and solid wastes management), Forests incl. Soils, Agriculture incl. Soils (incl. agric. soil, agric. vegetation, farm and feed stock), Other Soils, Subsoil, Groundwater and Surface Water.

The first task was to establish the fluxes of goods (containing nitrogen) between these Processes, to transform the fluxes of goods into fluxes of total nitrogen, and to balance these fluxes between the various Processes. The dominant Processes of 1st order selected were subdivided into Processes of 2nd order as indicated, e.g. Agriculture incl. Soils into Agricultural Soils, Agricultural Vegetation, Farm and Feed Stock. It was also possible from the beginning to predict that local groundwater problems can be investigated with this tool only if the systems boundary is much smaller, i.e. the horizontal extension describes the individual groundwater catchment area.

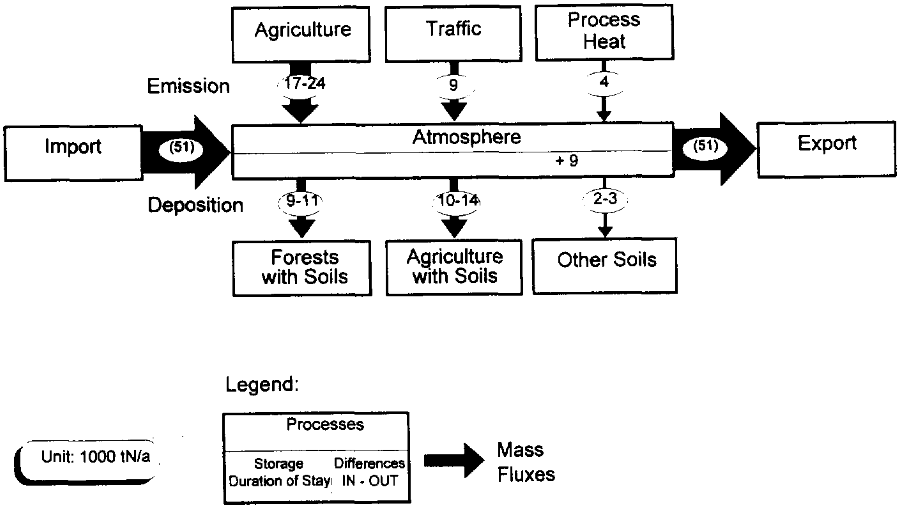

Figure 1. Some Characteristics of Upper Austria.

All work was based on existing data, with the view that the procedure should be improved in a smaller region (Krems Valley; ~ 500 km^2, ~ 50.000 inhabitants; Kaas *et al.*.1994) in order to see how data can be obtained at such a level and what links there are to the processes selected. For all fluxes of nitrogen, lower and upper bounds were established. The reference year was 1991, but if no other data were available, values from neighbouring years were chosen. There were data with quite good accuracy, e.g. the ones from the urea plant and subsequent processing, and other data, where the fluxes were obtainable only after a certain amount of transformations (goods from statistics with nitrogen contents from statistics transformed into yearly nitrogen fluxes). Balancing thus is impacted by the inaccuracy of the data sets; how to overcome that by statistical methods was a task assigned to the follow-up project, budgeting of the Krems Valley Region. Values indicating change in storage of a process thus are showing either real storage taking place or they are indicative of data inaccuracy.

Overall Results regarding *Imports* and *Exports* across the system boundaries

The overall results are shown in Fig. 2, and have in principle been confirmed by the Krems Valley study. They are expressed in kt of N per year. There are three main imports into the system: ***Atmospheric nitrogen (incl. depositable compounds), nitrogen compounds in surface water and nitrogen in fertilizers, fodder and food,*** as well as three main ***exports*** from the system corresponding to ***atmospheric nitrogen, nitrogen compounds in surface water*** and ***nitrogen compounds in marketable goods.*** The export of nitrogen in marktable goods in Upper Austria is dominated by the nitrogen in the products of the fertiliser factory located at Linz. Neglecting this nitogen as a special situation in Upper Austria and assuming that Upper Austria is neither net importer nor net exporter of atmospheric nitrogen, as shown later on as a possible assumption, the important outcome - corresponding to previous as well as other work - is that nitrogen ***imported*** to Upper Austria ***leaves it to a high amount by the water route,*** i.e. our flowing waters are the main ***export tracks*** of nitrogen, see Bundi, 1993, Fleckseder, 1992, Isermann, 1992, 1993, and Van der Voet *et al.*, 1994. This statement is also valid for regions not impacted at all by an excessive use of market fertilisers containing nitrogen.

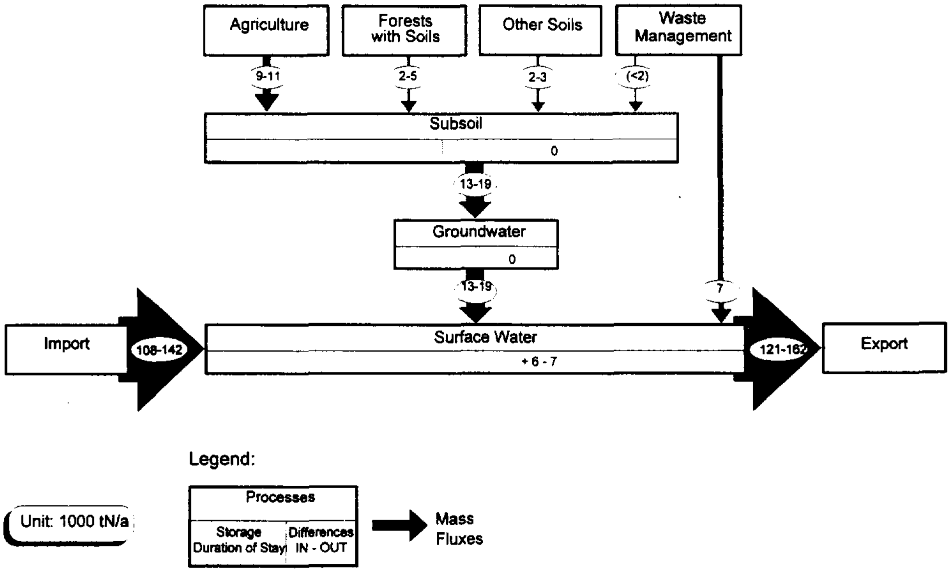

Figure 2. The Overall Nitrogen Balance for Upper Austria for the year 1991.

Overall results regarding the most important internal processes and fluxes.

Atmosphere. In the balance shown in Fig. 3 aerial nitrogen (N2) is ignored, and only the nitirc oxide (NO_X-N) and Ammonia (NH_X-N) compoundes are taken into consideration. It is shown that especialy traffic but also industrial processes play an important role for the nitrogen emissions into the atmosphere in the form of nitric oxide. But the biggest input of nitrogen into the athmosphere in Upper Austria comes from agriculture (17 – 24 kt a^{-1}), especially from the ammonia losses from the lifestock. This is primarily due to the fact that agriculture in Upper Austria is a net exporter of meat and dairy products to other parts of Austria (and outside of Austria).

Industry and Trade. When subtracting the export of nitrogen from Upper Austria from that amount 'abstracted' from the atmosphere by the urea plant, there is an overall non-elemental *input* into this process of ~ 97~105 kt a^{-1}, including ~10 kt a^{-1} in coal abstracted from Subsoil, and out of that 59~62 kt a^{-1} are the overall input to Agriculture incl. Soils. In Industry and Trade, their should be only a very minor increase in storage, and this is relative to the input also the case.

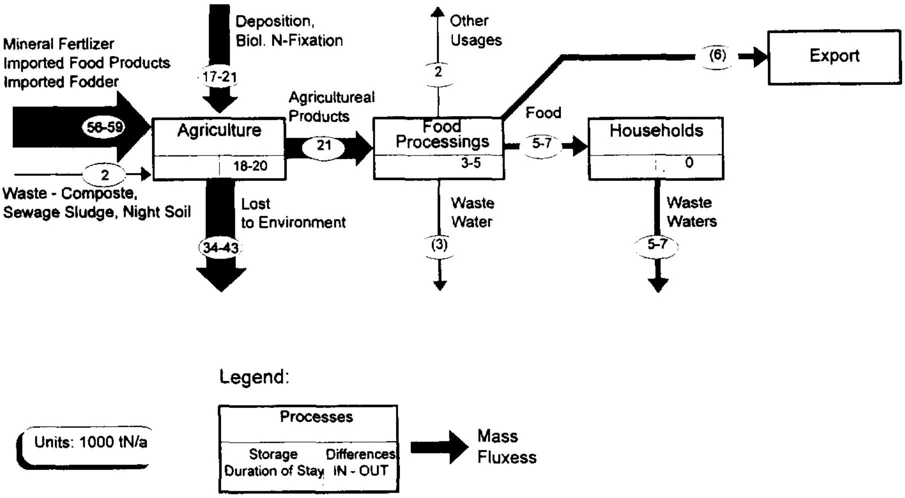

Figure 3. Balance of nitrogen for the Atmosphere of Upper Austria.

Waste Management. In contrast to this, the increase in storage in this process is, relative to the total input, much bigger. This is due to the fact that with our present disposal methods, we are creating also some nitrogen build-up in disposal sites, but also to the fact that our present-day knowledge about the quantification of both input and output to this process is not very precise at all. From the input of 15 ~ 16 kt a^{-1}, 7 kt a^{-1} are assignable in Upper Austria to Households (5 kt a^{-1} going to Wastewater Treatment and 2 kt a^{-1} to Waste Management). The 2 kt a^{-1} passing on to Agriculture incl. Soils account for sewage sludge as well as for compost.

Combustion. Despite the fact that 40 kt a^{-1} are the input in the form of non-elemental N, 13 kt a^{-1} is the present estimate as NO_X-N emitted to the atmosphere. A much bigger flux of elemental nitrogen is cycled between this process and the atmosphere.

Households. They are receiving 9~12 kt a^{-1} and are discharging 7 kt a^{-1} to Waste Management. The difference of 2~5 kt a^{-1} has again to account both for actual storage in materials as well as data inconsistencies.

Agriculture incl. Soils. In regard to the processes having relation to soils, this is the most important one. The inputs are: 'wanted' in fertilisers and fodder 59~62 kt a^{-1}, from Waste Management 2 kt a^{-1} and in deposition as NO_X-N as well as NH_X-N from the atmosphere and including also biological fixation 17~21 kt a^{-1}, yielding a total input of 78~85 kt a^{-1}. The outputs are: 25~32 kt a^{-1} in the form of NH_3-N passing on to Atmosphere, 23 kt a^{-1} (incl. slaughterhouse waste recycled as fodder) to Processing of Agricultural Products, and 9~11 kt a^{-1} via Subsoil and Groundwater to Surface Water. Denitrification of nitrogen applied with fertiliser and manure is included with an estimate of ~ 8 kt a^{-1}. So about 30 % of the total N input into agriculture leaves it in the nutritional products. That the losses in conversion from primary protein to animal protein are so much bigger than they are for the production of primary protein alone, even under best agricultural practice, is – as we are assuming at present – the reason for this context. The increase in stock in Agriculture and here especialy in the soils is for sure existing, but the difference between input and output as shown in Figs. 2 and 4 has also to be explained by inconclusive data.

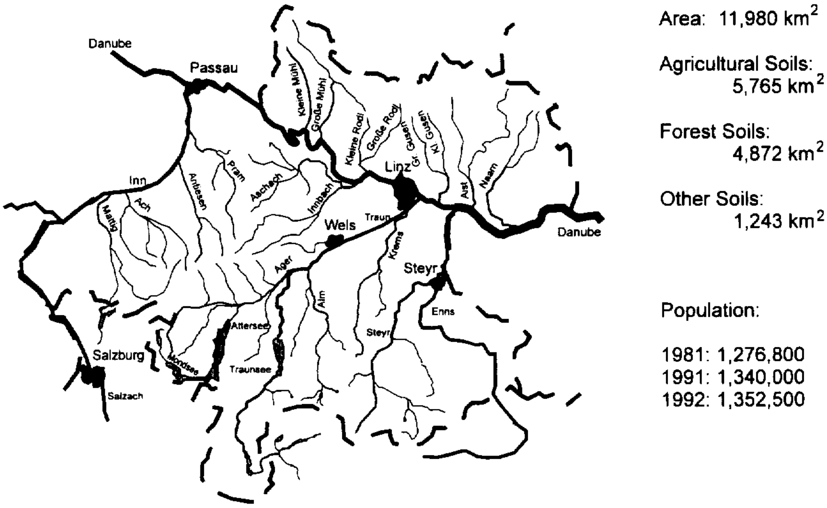

Figure 4. Balance of nitrogen in nutritional products for Upper Austria.

Forests incl. Soils. Fertilizing forests is in Austria forbidden by law. Our forests are nevertheless receiving both NO_X-N as well as NH_X-N by deposition. Output from this process to Subsoil was estimated with 2~5 kt a^{-1}, and in the wood harvested – the big variation being due to inconsistent data about the nitrogen content of wood in literature – 1~5 kt a^{-1} go to Industry and Trade, yielding a difference of 1~6 kt a^{-1}. Part of this may go to an increase in stock.

Other Soils. i.e. in general uncultivated land situated in mountains as well as some land in human settlements etc. These are estimated to receive a deposition of 2~3 kt a^{-1} which is assumed to pass on to Subsoil and from there consequently via Groundwater to Surface Water.

Underground. The withdrawal of nitrogen in coal had to be set, otherwise it was assumed that no increase in stock – based on the time scale selected – is taking place, and thus the inputs are passed on to Groundwater and from there to Surface Water.

Surface and groundwater. Comparing the fluxes from Waste Management, *i.e. point source discharges* with only a "partial" removal of nitrogen in wastewater treatment, with the ones via Subsoil and Groundwater, i.e. *nonpoint-source discharges,* one can realise that also in this 'Land' the bigger weight of input to Surface Waters is not on the point-source, but on the nonpointsource-side (Fig. 5). Up to after the year 2,000, an expansion of wastewater treatment plants bigger than 5,000 p.e. to include denitrification in Austria will allow for a further reduction of the point source discharge.

From this overall view, one could conclude that the *comparatively **biggest player** in regard to **nitrogen in the environment***, and thus also to Surface Water, is the **Agricultural Sector** and that we should now, since we are implementing denitrification in wastewater treatment, also urge agriculture to undertake its share to decrease nitrogen emissions. Such a view is to a certain extent possible, as not all measures indicating *best agricultural practice* are implemented yet in Upper Austria (as well as in other parts of Austria). However, in comparison to other Western European regions, the amount of nitrogen in fertilisers applied in Austria is not very high in area specific terms. The same is true for animal feed. Thus the question arises in what context nitrogen has to be put in the *balance of nutritional products* for Upper Austria. For this, see Fleckseder, (1994).

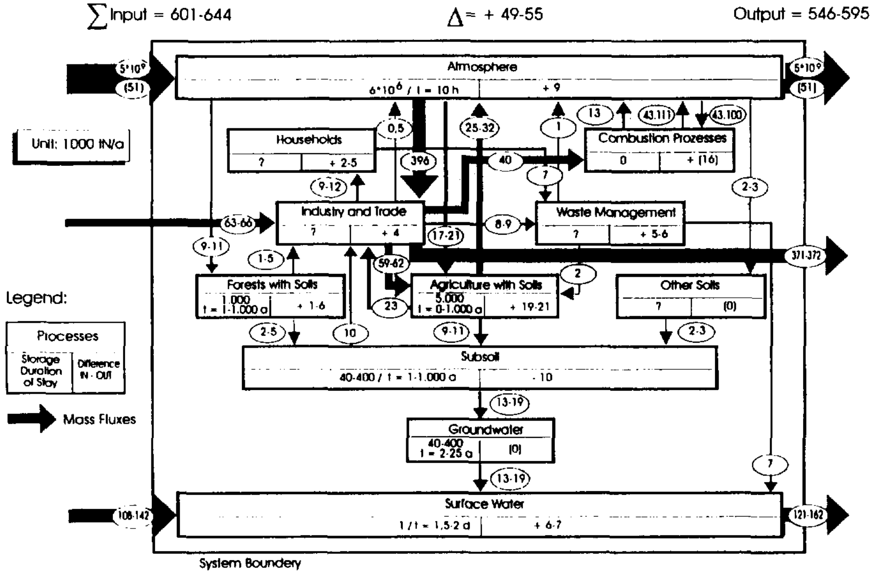

Figure 5. Balance of nitrogen explaining the input to groundwater and surface water.

DISCUSSION OF THE N-BALANCE FOR UPPER AUSTRIA.

Having shown the appropriate accuracy and precision obtainable at present with this approach (based only on existing data), the weight of the individual players shown may vary somewhat, but in the end, will stay within the proportions indicated. Within Upper Austria, there are **two main players**, Agriculture and Combustion (vehicles and industries), the other ones – like Waste Management – being minor ones.

Thus, there are **three decisive** ***activities*** **dominating the flux of nitrogen to the environment**, and these are ***to nourish, to transport***, and **to reside. To nourish** has, at least in Upper Austria, a markedly bigger impact than ***all other activities***. The second additional point of importance, is that despite the fact that Agriculture plays such an important part, **it is only a secondary player**. The **primary players** are the **individual decision makers**, i.e. ***in practice modern women and men and our lifestyles,*** in this case the average personal lifestyle at around 1991 in Upper Austria and Central Europe. If we can influence these lifestyles, a lowering of the *exports* should be possible.

In discussing the activity ***to nourish***, without skipping the others, but for space reasons the results are not shown in detail, let us mention that the consumption of meat in Austria evolved along the route shown in Table 1.

Experts in human nutrition – and not those who are extremists regarding vegetarianism – are indicating that 0.85 g of protein per kg of body weight and day are what we should consume, but on average, the value is 30% bigger (Billen-GirmscheidandSchmitz, 1986; Holtmeier, 1986). Thus, by **eating less, without a change in protein composition and the technology how this protein is being produced, savings should be possible**. In addition, **the advice by the experts on nutrition mentioned is that 1/3 of the protein in human nutrition should be of animal origin, the remainder of primary origin**. Let us define the ***average Central European*** - child to elderly people, male as well as female – as having 60 kg of weight and let us select 18% to be the share of protein in meat (wet weight). From these assumptions one can conclude that an ***average Central European*** should consume a maximum of ~ 35 kg of meat per year on the plate, equivalent to ~ 50 kg per year at slaughter time, and doing that he should skip eggs or dairy products completely! Thus, by reducing the quantity of meat or other animal protein produced and consumed to this level, the flux of nitrogen to the environment could be reduced, based on Fig. 2 and 4, as this is valid for a point in time when the average meat consumption was ~ 90 kg/pe^{-1} a^{-1}.

In discussing the activity to ***burn*** (transport and reside) the process Combustion is to us the second ***secondary player***. This process is dominated by the sub-process Traffic (9 kt a^{-1}), with Process Heat mainly from industries with 4 kt a-1 on the second position. Also in this case, the actual decision-makers are we with our lifestyles. In this case, too, the evolution of energy consumption over time is of interest, and data in regard to this are assembled in Table 2 for Austria.

Table 1. Per capita consumption of meat over time in Austria (various sources; animal weight at time of slaughtering)

	1930s	1940/44	1961	1985	1991
kg pe^{-1}.a^{-1}	~ 45	~ 20	~ 65	~ 95	~ 90

Table 2. Per capita consumption of energy over time in Austria (various sources)

	1950	1960	1970	1980	1990
kg oil units pe^{-1}.a^{-1}	~ 1,200	~ 1,700	~ 2,500	~ 2,900	~ 3,400

A final conclusion from the regional materials accounting of nitrogen is:
Unreflected decisions of an affluent lifestyle – e.g. too big an animal protein consumption or too big a consumption of fossil carbon - can be looked upon as a mental pollution which is causing materials pollution in mass flux terms.

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