Luxembourg's Integrated Nitrogen Budget 2010 and estimation of its Nitrogen saving and recovery potentials

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ABSTRACT

The human use of reactive nitrogen (Nr) in the environment has profound beneficial and adverse effects on human beings.

This research investigates the total nitrogen (N) stocks and fluxes in Luxembourg for all major emitting and receiving media and for all major N-forms by establishing the Luxembourg *National Integrated Nitrogen Budget* (NiNB) for 2010. NiNBs are important for identifying areas at risk of nutrient pollution, for greenhouse gas (GHG) monitoring and for designing measures to prevent detrimental side effects.

As a result, the NiNB finds that Luxembourg is a net N-polluter and a net source of transboundary pollution, contributing to the acidification of the Atlantic Ocean and the Mediterranean Sea. A potential N-surplus of 46 kt N is being rejected into the national and regional environment. This represents about 30 % of the N-volume its national economy and society consumed to prosper in 2010 (N-input of 135 kt N). This also represents a potential personal N-loss of up to 92 kg N/per resident/year.

About 50 kt N of this input are stored in useful products (fertiliser, food, feed). The overall national Nitrogen use efficiency, the ratio between N in useful products and N-input, is therewith 37 %. However the N-excess could substantially be reduced, since the national N-saving potential is estimated to reach 30 kt N/year.

N-losses are highest to the atmosphere because of the intense NO_x emissions from fossil transport. Agriculture is the largest emitter of non-CO_2 GHGs (N_2O) as well as the main contributor to nutrient leaching (NO_3) to groundwater, followed by the wastewater treatment sector. Excess N is responsible for the pollution of drinking water and contributes to climate change.

In order to secure lasting benefits in terms of resource use efficiency, reduction of the pressures on health and the environment, nutrients and food security and sustainability of food production, it is recommended to promote a less polluting mobility, to encourage a reduction of imported chemical fertiliser and of feed, to reduce consumer's high animal protein consumption, and to recover N from human effluents for fertilisation purposes. The latter would necessitate the separation of domestic and industrial waste water streams. It is estimated that a minimum of 38 % of imported synthetic N-fertiliser could be replaced by local non-farm organic N-sources. Within the legal limits (170 kg animal manure/ha/yr), a technical potential of 38 kg/ha/yr of non-farm organic N fertiliser could be made available after having made use of the local animal effluents. Further research is required to validate the uncertain results and to transform the NiNB is an N-pollution mitigation monitoring tool.

Keywords: Nitrogen budget | Nitrogen recovery | Nitrogen use efficiency | Nutrients recovery | Nitrogen scarcity | Fertiliser | Air pollution | Water pollution | Nitrates | Nitrogen oxides | Nitrous oxide | Sustainable food production | Waste water treatment |

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COMPENSATION OF RESEARCH RELATED GREENHOUSE GAS EMISSIONS

The greenhouse gas emissions related to the study (computer use, data storage, journeys to interviews and visits, stationary, …) have been compensated through the plantation (oak, wild cherry tree) on 1 ha of forestland in Luxembourg, Autumn 2012.

ZUSAMMENFASSUNG

Die menschliche Verwendung von reaktiven Stickstoffverbindungen (Nr) in der Umwelt hat tiefgreifende vorteilhafte und nachteilige Auswirkungen auf den Menschen.

Diese Studie erstellt den ersten ***Nationalen integrierten Stickstoffhaushalt*** (*National integrated Nitrogen Budget (NiNB))* für Luxemburg für das Jahr 2010, indem sie die Gesamtmengen von Stickstoffspeichern und Strömen im Land quantifiziert, für alle wichtigen Sektoren, Systeme und N-Formen. *NiNBs* sind wichtig für die Identifizierung von Risikogebieten der Nährstoffansammlung, für die Treibhausgas-Überwachung und für das Ausarbeiten von Minderungsstrategien für Stickstoffemissionen mit schädlichen Nebenwirkungen.

Im Jahr 2010 war Luxemburg demnach ein netto N-Emitter, und eine Netto-Quelle von grenzüberschreitender Umweltverschmutzung. Das Land hat zur Versauerung des Atlantiks und des Mittelmeeres beigetragen.

Ein potenzieller N-Überschuss von 46 kt N wurde in die nationale und regionale Umwelt ausgestoßen. Dies entspricht etwa 30% des N-Volumens der die nationale Wirtschaft und Gesellschaft im Jahr 2010 verbrauchte um zu gedeihen (nationaler N-Gesamteintrag von 135 kt N). Dieser Verlust beläuft sich auf bis zu 92 kg N pro Einwohner und Jahr. Über 50 kt N von diesem Eintrag wurden in nützlichen Produkten (Dünger, Lebensmittel, Futtermittel) gespeichert. Die nationale Gesamtstickstoffnutzungseffizienz, das Verhältnis zwischen N in nützlichen Produkten und dem N-Gesamteintrag, ist damit niedrig mit 37 %. Allerdings könnte der N-Überschuss erheblich reduziert werden, da das nationale jährliche N-Minderungspotenzial auf bis zu 30 kt N geschätzt wurde.

Die höchsten N-Verluste gehen an die Atmosphäre verursacht von den intensiven NO_x-Emissionen aus dem fossilen Verkehr. Wegen seiner Lachgas-Emissionen (N_2O) ist der landwirtschaftliche Sektor der größte Nicht-CO_2-Treibhausgas Emitter und trägt somit zum Klimawandel bei. Er ist auch der wichtigste Beiträger von Nitraten (NO_3) in das Trink u. Grundwasser, gefolgt vom Abwasserbehandlungs-Sektor, der N im häuslichen Abwasser nicht genügend recycliert.

Um dauerhafte Vorteile im Hinblick auf die Effizienz der Ressourcennutzung zu sichern, Gesundheits- und Umweltbelastungen zu mindern, Nährstoff- und Lebensmittelsicherheit zu verbessern, empfiehlt es sich, eine umweltfreundlichere Mobilität zu fördern, die Abhängigkeit der Landwirtschaft von importiertem künstlichem Dünger und von Futtermitteln zu verringern, den hohen individuellen Tierprotein-Verbrauch zu drosseln, und N aus menschlichen Abwässern zu Düngezwecken zurück zu gewinnen. Letzteres würde die Trennung von Haushalts- und Industrieabwasserströmen erfordern.

Es wird geschätzt, dass jährlich mindestens 38 % der importierten synthetischen N-Düngemittel durch lokale nicht-landwirtschaftliche organische N-Quellen ersetzt werden können. Innerhalb der gesetzlichen Vorlagen (170 kg Mist und Gülle/ha/Jahr) könnte ein technisches Potenzial von 38 kg/ha/Jahr an nicht-landwirtschaftlichem organischem N zusätzlich mobilisiert werden.

Weitere Forschung ist notwendig, um die Ergebnisse zu bestätigen und den *NiNb* zu einem nationalen Stickstoff-Minderungs-Instrument zu gestalten.

Stichworte: Stickstoffhaushalt | Nährstoffrückgewinnung | Stickstoffrückgewinnung | Ressourcenknappheit| Stickstoffnutzungseffizienz | Dünger | Luftverschmutzung | Wasserverschmutzung | Stickoxide | Nitrate | Lachgas | Nachhaltige Lebensmittelproduktion | Abwasserbehandlung |

RÉSUMÉ

L'utilisation humaine de l'azote réactif (Nr) dans l'environnement a d'importants effets bénéfiques et néfastes sur les personnes.

La présente étude quantifie l'ensemble des stocks et flux d'azote (N) que connaissait le Luxembourg en 2010, pour tous les grands médias et secteurs et pour les principales formes de N. Il est résulte le ***Budget national intégré d'azote*** *(National integrated Nitrogen Budget (NiNB))* du Luxembourg pour 2010. Les *NiNBs* sont importantes pour identifier les zones à risque de pollution par les nutriments, pour surveiller les émissions de gaz à effet de serre (GES) et pour élaborer des mesures de prévention des effets secondaires néfastes.

Le *NiNB* constate que le Luxembourg est un pollueur net d'azote et une source nette de pollution transfrontalière contribuant à l'acidification de l'océan Atlantique et la mer Méditerranée. Un surplus potentiel de 46 kt N est rejeté dans l'environnement national et régional. Cela représente environ 30 % de l'azote que l'économie et la société luxembourgeoises ont consommé en 2010 pour prospérer (N-input national total de 135 kt N). Cette perte est d'environ 92 kg N/par résident/an.

Environ 50 kt N de cette entrée totale d'azote dans le pays sont stockées dans des produits utiles (engrais, aliments pour hommes et animaux). L'efficience globale nationale de l'utilisation de l'azote, le rapport entre N stockés dans les produits utiles et N total utilisés dans le pays, est bas avec 37 %. Toutefois, l'excès en N pourrait être sensiblement réduit, car le potentiel national d'économie en N pourrait atteindre 30 kt N/an.

Les pertes en N sont les plus élevées vers l'atmosphère en raison des émissions importantes de NO_x liées au secteur du transport fossile. En relâchant du protoxyde d'azote (N_2O), le secteur de l'agriculture est le plus grand émetteur de GES autre que le CO_2, contribuant aux changements climatiques. La pollution de l'eau potable par les nitrates (NO_3) est imputable d'abord au secteur de l'agriculture et à son application excédentaire d'engrais, suivi du secteur du traitement des eaux usées, qui ne recycle pas suffisamment l'azote contenu dans les rejets ménagers.

Afin de garantir des avantages durables en termes d'utilisation efficiente de ressources limitées, de réduction des pressions sur la santé et l'environnement humains, de sécurité alimentaire et nutritive et de continuité de la production alimentaire, il est recommandé de promouvoir une mobilité moins polluante, d'encourager la réduction de l'apport synthétique d'azote et d'alimentation animale importés en agriculture, de réduire la part des protéines animales dans le régime alimentaire des consommateurs, et de récupérer l'azote des effluents humains à des fins de fertilisation pour la production alimentaire. Cette dernière mesure nécessiterait la séparation des flux d'eaux usées domestiques et industrielles.

Il est estimé qu'au moins 38 % de l'engrais azoté importé peuvent être remplacés par des sources d'azote organiques non-agricoles locales. Dans les limites légales (170 kg de fumier/lisier /ha/an), un potentiel technique de 38 kg/ha/an de fertilisant organique non-agricole peut être mobilisé pour l'épandage agricole après avoir fait usage des effluents d'origine animale.

Davantage de recherche est nécessaire pour valider les résultats et pour transformer le *NiNB* en un outil de surveillance de l'atténuation de la pollution en azote.

Mots-clés : budget d'azote | récupération de l'azote | récupération de nutriments | rareté de l'azote | efficience de l'utilisation d'azote | engrais | pollution de l'eau | nitrates | pollution de l'air | oxydes d'azote | protoxyde d'azote | traitement des eaux usées | production alimentaire durable |

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ASTA	Administration des services techniques de l'agriculture (Administration for technical services to the agriculture), Ministry of Agriculture, Luxembourg
AWMS	Animal Waste Management System
BNF	Biological Nitrogen fixation
CeDEP	Centre for Development, Environment and Policy, University of London
CLRTAP	Convention on Long-range Transboundary Air Pollution (UNECE)
CONVIS	Cooperative Livestock and Genetics, Luxembourg
CRP	Centre de recherche public, Luxembourg
DM	dry matter
EEA	European Environment Agency
EF	Emission Factor
EIONET	European Environment Information and Observation Network (EEA)
EMEP	European Monitoring and Evaluation Programme
ENA	European Nitrogen Assessment (2011)
E-PRTR	European Pollutant Release and Transfer Register
EPNB	Expert Panel on Nitrogen Budgets
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
kt	kiloton
LULUCF	Land use, land use change and forestry
MSDI	Ministry of Sustainable Development and Infrastructures, Luxembourg
N	Nitrogen
N-to-P	Nitrogen to protein conversion
NB, NNB, NiNB	Nitrogen budget, National Nitrogen budget, National integrated Nitrogen budget
NEB	Nährstoff und Energiebilanzierung (Nutrients-Energy balance CONVIS)
NECD	EU National Emissions Ceilings Directive 2001/81/EC
NIR	National (GHG) Inventory report to the UNFCCC 1990 – 2011 (2013)
NPK	Nitrogen (N), Phosphorus (P), Potassium (K) fertiliser packages
NUE	Nitrogen use efficiency
Nr	Reactive Nitrogen
PE	population equivalent
SER	Service économie rurale (Service for rural economy), Ministry of Agriculture, Luxembourg
SOAS	School of Oriental and African Studies, University of London, UK
STATEC	Institut national de la statistique et des études économiques (National Statistical Office), Luxembourg
UAA (= SAU)	utilised agricultural area = Surface agricole utile (SAU)
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World health organisation
WW, WWTP	Waste water, waste water treatment plant

LIST OF COMMONLY USED ABBREVIATIONS AND CODES FOR NITROGEN AND CARBON DIOXIDE:

CO_{2eq}	Carbon dioxide equivalent
Ncrop	Nitrogen crop uptake
Ndep	Atmospheric deposition of Nitrogen
Nex Nex_{AWMS}	Total Nitrogen excretion by animals in a country Nitrogen excretion per Animal Waste Management System
Nfert = Nsynth	Synthetic fertiliser Nitrogen
Nfix	Biological Nitrogen fixation (also fixation of N_2 for Nfert production via Haber-Bosch)
Nfor	Nitrogen forage uptake
Nleach	Nitrogen input to soils that is lost through leaching and runoff
Nman	Manure Nitrogen applied to soils
Nmin	Mineralised soil Nitrogen (also sometimes used for “mineral N fertiliser”)
Norg	Organic Nitrogen
Nred	Reduced Nitrogen

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Workbook Agriculture

1. INTRODUCTION

Nitrogen (N), together with phosphorus (P) and potassium (K) constitute vital macronutrients for plant growth and global food production. N and to a greater extent P, are finite resources or resources which depend on finite fossil energy for their synthesis. Humankind depends on their efficient use and recycling for ensuring ongoing food production in times of scarcity.

The European Nitrogen Assessment (ENA) (Sutton et al 2011) illustrates the complexity of the N-cycle: High N-inputs to food production and high N-emissions from combustion (industry, energy and transport sectors) negatively impact human health, the environment (biodiversity, soil/air/water quality, …) and the greenhouse gases (GHG) balance.

Generally, farming remains responsible for over 50% of the total N-discharge into surface waters (European Commission Nitrates Directive 2012). Europe's intensive agriculture is characterised by a high synthetic N-input per ha and high N-surpluses. While the European agricultural N-use efficiency (NUE), the ratio between N in useful agricultural products leaving the farm and N-inputs to the farm, has increased during the last 20 years, from 45 % in 1990 to around 60 % in 2010 according to the fertiliser industry (Yara 2012, Fertilisers Europe 2012), it is estimated that there is further scope for improvements (FAO).

From a supply – side perspective, global N-fertiliser production is energy intensive and relies on a finite resource (natural gas). Considering the trend for rising fertiliser prices, linked to rising fossil fuel prices reflecting their scarcity, it can be argued that inefficient management of N-use in agriculture is not sustainable from a financial and economic point of view. This makes the dependency on this input a strategic sustainability issue for food production and resource use policy.

The resource depletion is contrasted by the fact that too much N is wasted as effluents to the soil, air, waters resulting in human exposure to environmental pressures. As pointed out by the *ValuefromUrine* project (CRTE 2013), "urine can provide 18% of the P and 25% of the N currently used for soil fertilisation in the EU." Recirculating urban nutrients such as urine back to arable land presents an opportunity for the future food production and for the mitigation of N-pollution.

As a response to these constraints, more of this wasted N could be used to fertilise the fields. This could be achieved by recycling N contained in human effluents, or by using the by-product of anaerobic digestion of organic wastes and animal effluents (digestate) as an organic fertiliser (Vaneeckhaute et al 2013 a, b).

However, these new organic sources are generally only used in a limited way, due to technical (separating waste streams), political and legal (EU Nitrate Directive, national legislation), economic (cost of recycling N), perception-related reasons (distrust of organic waste derivatives as fertilisers, historic – cultural relationship to mineral fertilisation, …).

Does this general statement apply to Luxembourg? What is its specific situation and what is its national potential for reducing N-losses and recycling N from waste?

The purpose of the present research is to contribute to

- document, synthesize and map the major N-flows and stocks in Luxembourg, visualize and communicate the complexity of the problem, supplement national N-data and monitoring;
- identify potential important sources for N-recovery from human waste and for potential N-loss reductions linked to consumer behaviour; if so, make the case for substitution of imported mineral by local organic N-fertiliser.

The research proceeded in 2 steps:

1) Quantification of the N-demand, supply and losses by carrying out a national integrated N-Budget (NiNB) for the year 2010
2) Appraisal of the substitution/reduction potential, with the help of expert knowledge accessed via interviews

The research angle taken here is one of a combination of all sources, sectors and media concerned by N into one integrated illustrated N-Budget. Special attention went to the vital food production and security questions and to the individual consumer responsibility for the societal and environmental impacts of N-pollution.

Overall the research aims to contribute to demonstrating the inevitability of human effluent N-recovery and loss reduction for securing lasting food production and preserving human health and the environment, in a cost-efficient manner.

The decisive question the author attempted to answer is **"Is a win - win situation possible?",** a scenario of sustainable local fertiliser production, of reduced pressure on primary resources, on health and on the national, regional and global environment, while at the same time closing the organic matter cycle between food production and consumption and bridging the urban/rural, agricultural/societal divide.

The research questions are as follows:

- Question 1: What is the national bio-physico-chemical N-situation?
- Question 2: What conclusions can be drawn from the quantification exercise above as to the theoretical potential for improving the overall national NUE?

1.1. State of the Art in N-inventory data for Luxembourg

A preliminary rough Luxembourg national N-Budget exists for the year 2000, calculated by the Integrator model (Sutton et al., 2011) (Table 1).

Table 1 - Luxembourg N-Budget as calculated with the Integrator model for the year 2000 (kt N/yr)

Nman	Nfert	Ndep	Nfix	Nmin	Ncrop	Nfor	NH_3	N_2O	NO_x	N_2	Nleach	Nleach
Excre-tion	Ferti-lizer	Atmos-pheric Depo-sition	Biolo-gical Fixa-tion	Mine risa-tion	Crop uptake	Forage uptake	NH_3 Emis-sion	N_2O Emis-sion	NO_x Emis-sion	N_2 Emis-sion	Leach-ing to Ground-water	Leach-ing to Surface-water
12.57	13.95	2.86	0.74	-0.03	10.69	6.21	3.25	0.56	0.37	6.18	2.23	0.17

Source: Courtesy Wim de Vries, Hans Kros (email exchanges May 2013)

The objective of this research is to update, verify and complete this data compiled by De Vries and Kros (2000) mainly for the agricultural sector and to illustrate the dynamics and linkages of the different N-flows in an illustrated integrated N-Budget for 2010.

1.2. Relevant Nitrogen forms to be budgeted

Reactive nitrogen (Nr) is any form of nitrogen that is available to living organisms via biochemical processes (terminology : see Annex 2). Following Galloway (2003) and Erisman and Hertel (ENA, 2011), for building the N-Budget, the following Nr compounds are made an inventory of:

- reduced nitrogen: ammonia NH_3 and ammonium NH_4^+;
- oxidised nitrogen: nitrogen oxides (NO_x) such as nitrogen oxide (NO), nitrogen dioxide (NO_2), nitrate (NO_3) and nitrous oxide (N_2O);
- organic nitrogen compounds (e.g. urea, proteins, amines).

Nr can pose a risk to the environment. NH_3 and NO_x are pollutants which contribute to causing respiratory problems, cancer and cardiac diseases in humans (Galloway 2003), acidification of soil and surface water, damages to vegetation. NH_3 emissions derive almost entirely from animal excrement. NO_x is a precursor of ozone, which causes damage to crops and other vegetation. Of this list, N_2O is an important greenhouse gas (GHG) with a global warming potential of 310 times that of CO_2 (IPCC 1996). N_2O is usually assumed to be emitted by terrestrial surfaces (Hertel O et al, ENA 2011): "N_2O plays a major role in the destruction of stratospheric ozone. Soil processes are the largest contributor to the atmospheric N_2O, with agriculture as the largest anthropogenic source, accounting for 65% to 80% of total emissions".

In addition to the list of reactive N-forms, we consider dinitrogen (N_2), an inactive form of nitrogen that exists abundantly in the atmosphere, unsuitable for plant, animal, human, soil uptake. N_2 does not pose a risk to the environment.

1.3. Relevant Country Context

A description of the country context (land use surfaces, meteorology, economy, population, ...) is given in Annex 3. Hereafter the national nitrogen pollution situation will be described for the atmosphere and the water systems. No information could be found on the local effects of this pollution on soil quality and biodiversity.

1.3.1. National nitrogen pollution

a. Air

According to the EEA (2010), in 2010, the concentrations of NO_x in the Luxembourg urban ambient air exceeded, with an average of 59 µg/m^3 the EU threshold (protection of the human health) of 40 µg NO_x/m^3 as annual average. The main cause is the ever-increasing volume of road traffic. In rural areas, the limit of 30 µg NO_x/m^3 (annual average) for the protection of ecosystems has been respected.

b. Water

Water pollution by Nr causes eutrophication and acidification in fresh waters whereas high nitrate concentrations may cause cancer. The entire country is classified as a sensitive area under the EU Urban Waste Water Treatment Directive (91/271/EEC). In 2009, the ecological status of the rivers was moderate for 52% and poor for 26% of the rivers (Fig. 1).

Ecological status	in %	2009
good		7
moderate		52
poor		26
bad		16

Fig. 1 – Organic pollution of the Luxembourg rivers (2009)
Source: STATEC 2012a

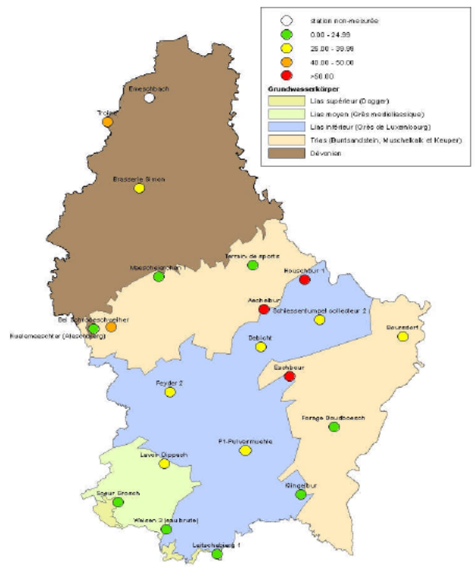

Fig. 2 – Average concentrations of nitrates in groundwater, Luxembourg 2008-2011 (mg/l)
Source: Water Administration (2012) p. 24

Concerning nitrate (NO_3) pollution of surface waters, the Nitrates Report of the Water Administration (2012) informs that, for the period 2008-2011, the average concentration of nitrates in surface water was 20 mg NO_3/l (Fig. 2). In groundwater, the average nitrates concentration for the period 2008-2011 was 32 mg NO_3/l, whereas 11 % of the measurements had a concentration exceeding the EU Nitrates Directives (91/676/EEC) threshold value of 50 mg/l for drinking water (Nitrate report 2012 p. 23). An average 60 % of the groundwater stations and 30% of the surface water exceeded the 25 mg/l limit between 2008 - 20011 (European Commission 2013). Groundwater reserves procure most of Luxembourg's drinking water.

According to the EU Commission and EEA (2013), Luxembourg's groundwater control stations network is of low density and the country fares very poorly in the EU-27 comparison of water quality, be it groundwater, freshwater or rivers, as can be seen in the graphics presented in Annex 4.

2. LITERATURE REVIEW

2.1. Global nitrogen literature review

The economic value of N-benefits to the European society is very substantial (ENA 2011 p. 32). Since the industrial exploitation of the *Haber-Bosch* process for synthetic N-fertiliser production at the beginning of the XXth century, an impressive gain in agricultural productivity has been achieved. Energy efficiency of the process was considerably improved and food production indeed exploded. Today it is acknowledged (Fig. 3) that the Haber-Bosch process of N-manufacture supports half of the world population.

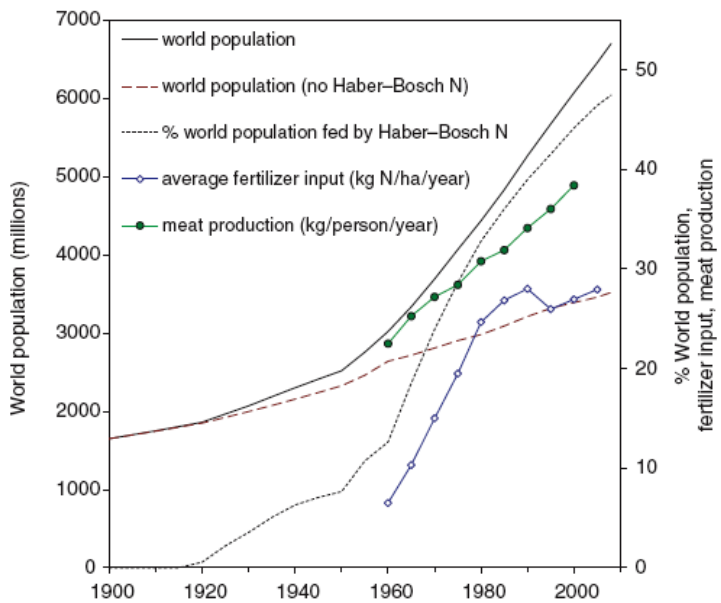

Fig. 3 - Correlation between the Haber-Bosch process and the increases of the world population, of synthetic fertiliser use and of meat consumption.
Source: Sutton et al., ENA 2011

With a growing dependency on mineral N and a growing population, the detrimental effects of excess N in the terrestrial, water and atmospheric systems come to the forefront and scientific enquiry into the health related, environmental and societal damages linked to the reliance on inorganic commercial N for global food production intensified.

So did the development of multilateral environmental agreements to reduce pressure on human health and the environment from excess N (International Gothenburg Protocol to abate Acidification, Eutrophication and Ground-level Ozone 1999; Edinburgh Declaration on Reactive Nitrogen 2011).

In a European context, the European Union Sludge Directive (1986), Nitrates Directive (1991), Water Directive (2000) all deal with the threats to human wellbeing and to the environment from N accumulated in the soil, air or water. The EU Nitrates Directive aims in its Article 1 at “reducing water pollution caused or induced by nitrates from agricultural sources and prevent further pollution”.

In 2011, the European Nitrogen Assessment (ENA) (Sutton et al 2011) undertakes to summarise and synthesise scientific knowledge on the benefits of fixed N to society as well as the negative effects of high societal N-use in the environment. The threat to biodiversity is illustrated by plants favouring high Nr supply out-competing other sensitive species or by losses of soil biodiversity as a result of soil acidification. The book also helps to make apparent the linkages between animal and human consumption, food production, sanitation and waste treatment. Fig. 4 illustrated the N-cascade in the environment:

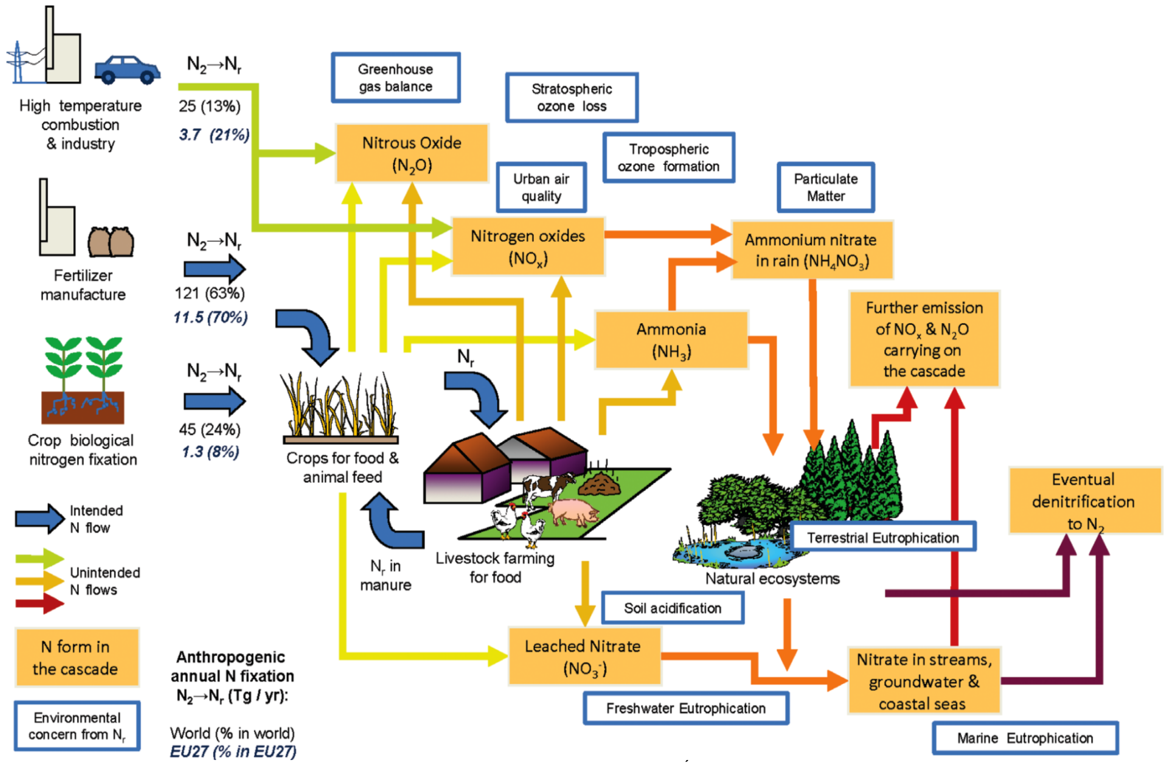

Fig. 4 - Simplified view of the N-Cascade
Source: Sutton et al., ENA 2011

However the prospect of a potential mid-term shortage of manufactured N-fertiliser in agriculture, due to vanishing or insecure gas reserves and increasing energy costs, is not clearly spell out in the ENA. The scientific community generally continues to assume that as long as energy is available Nr can continue to be synthesised.

In 2012, Malingreau et al. produced a foresight study entitled “NPK: Will there be enough plant nutrients to feed a world of 9 billion in 2050?” The scarcity and substitution issues come to the forefront with the spectacular increase in fertiliser prices linked to the respective recent increase in oil and energy prices.

Following the age of *insouciance* in an apparently abundant world, the growing concern for the environmental consequences and the *Limits-to-Growth* debate of the 1980s resulted in a number of publications exploring ways to improve N (and P) use efficiencies and management. Recycling N from human effluents for agricultural purposes and closing-the-loop food systems become primary concerns in a resource limited world.

Rockström et al. (2009) defined nine planetary boundaries within which humanity can operate safely and roughly quantified them. The study estimates that humanity has already transgressed the *nitrogen cycle* boundary (Fig. 5). The sustainable personal world citizen N planetary boundary for industrial fertiliser is set at 5 kg N/per capita/yr, which translates in territorial terms, into an allowance of 2.5 kt Nfert/yr for Luxembourg (Swedish Environmental Protection Agency 2013).

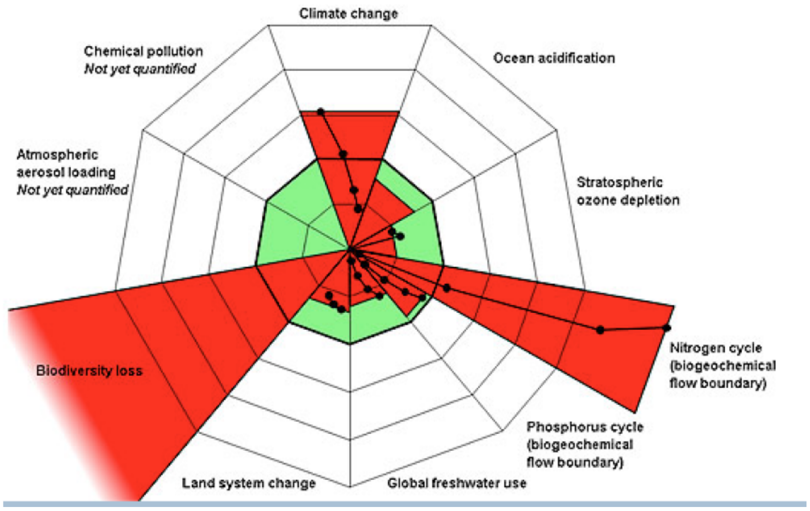

Fig. 5 - Estimate of quantitative evolution of control variables for seven planetary boundaries from pre-industrial levels to present.

Legend: The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle) have already been exceeded

Source: Rockström et al. 2009

Various methods and models exist to monitor N-fluxes (OECD, Eurostat, …). Among these, the European Commission's Joint Research Center - Monitoring Agricultural Resources Unit, developed a tool which compiles national N-emissions data into a map composed of boxes the sizes of which are proportional to the weight of the different sourcesand stocks, and of arrows representing the flows between boxes and N-forms. All sectors are concerned, hence its name "National integrated Nitrogen Budget" (NiNB). ENA (2011) dedicates chapter 15 to NiNBs. This NiNB approach is retained for the present research work.

2.2. Luxembourg literature and secondary data review

Luxembourg does not produce chemical fertilisers (a small factory – Fabriques d'engrais Baden Max – existed in the late 19th century). The country covers the entirety of its synthetic fertiliser needs by importation. National data on fertiliser import, consumption and nutrient balance used to be patchy and inconsistent.

This situation improved with the extensive collective data generation, collection and monitoring efforts undertaken by the Luxembourg administration in the light of the 5th National Greenhouse Gases Inventory, finalised mid-2012 in the framework of the UNFCCC review of Luxembourg's Kyoto Protocol Commitments. This led, in May 2013, to the comprehensive National (GHG) Inventory Report 1990 – 2011 (NIR 2013) (Annex 3).

Other publications of national relevance completed the country's normative picture of resources consumption and rejection (Annex 3):

- Farm Nutrients and Energy Balances (NEB) Report (CONVIS 2008);
- The Ecological Footprint of Luxembourg (CRTE 2010);
- The Dairyman Report (2010);
- The Nitrates Report 2008 – 2011 (Water Administration 2012).

A detailed national agricultural N-balance is being developed, under the direction of the Service for rural economy (SER) and the Administration for technical services to the agriculture (ASTA), both divisions of the Ministry of Agriculture. This national agricultural N-balance would be an important means for increasing the reliability of the NiNB prepared by the present research.

Deriving from the above-mentioned research and monitoring works, the current knowledge on the N-situation in Luxembourg can be summarised as follows:

- The emissions from the agricultural and from the waste management sectors are on a downwards trend ;
- Human food consumption patterns remain very protein intensive;
- Luxembourg is not on track to fulfil its Kyoto protocol GHG reductions targets and more efforts need to be undertaken to reduce the national GHG emissions (UNFCCC 2012). The transport and energy sectors are the major contributors to national GHG emissions;
- A national legal and regulatory framework ruling N-management is in place. It primarily concerns the agriculture, water and transport sectors;
- There is a general awareness of the non-sustainable development of Luxembourg's economy and society (publications see Annex 3);
- No assessment of the N-abatement potential exists for the agriculture, consumption and waste compartments (UNFCCC 2012).

3. METHODOLOGY FOR THE LUXEMBOURG N-BUDGET CALCULATION

3.1. Research design and data collection methods

For this research, a case study design was applied for the year 2010 to the territory of Luxembourg.

The main data collection methods were :

- Analysis of primary quantitative data (SER, ASTA, Water Administration, NIR 2013, Statec, …)
- Analysis of secondary quantitative data (UNFCCC, OECD, Eurostat, EEA, FAOSTAT, …). Modelling of the data via the N-budget (Fig. 7).
- Informal and semi-structured interviews with key stakeholders from the following groups:
    - Ministry of Agriculture, Environment, Sustainable Development, Water
    - Farmers organisations
    - Actors of the waste management sector (Waste treatment plants, Soil concept, …)
- Field visits to farms and waste treatment facilities;
- Literature review, both scientific and grey literature;
- Documentary analysis of working documents, official reports, policies available online or handed over.

Apart from the interview data, no specific primary data was generated or measured. Missing national data was completed by model data as reported in the ENA 2011 (p. 321). Aggregation and synthesis of primary data were done by the author (National data description: see Annex 3 and Technical Annex 4).

3.2. N-Budget definition

The *Draft Guidance Document on Nitrogen Budgets* (UNECE 2012) is the basis for the present N-Budget compilation work (see Annex 2). The definition applied in this research for an N-Budget (which diverge between sources) is as follows:

> "A Nitrogen budget (NB) consists in the quantification of all major N flows across all sectors and media within given boundaries, and flows across these boundaries, in a given time frame (typically one year), as well as the changes of N stocks within the respective sectors and media. NBs can be constructed for any geographic entity, for example at supranational level (e.g., Europe), sub-national level (regions, districts), for watersheds or even individual households or for economic entities (such as farms). National NBs (NNBs) use the borders of a country including its coastal waters as system boundaries, such that the atmosphere above and the soil below this country are also included".¶
> Extract from Draft Guidance Document on Nitrogen Budgets, prepared by the Expert Panel on Nitrogen Budgets (EPNB) (UNECE 2012) ¶

3.3. N-Budget data sources

3.3.1. N-Greenhouse gas (N_2O)

The only known direct N-GHG is nitrous oxide (N_2O). The major data source for N_2O was the NIR 2013 (Environment Adm., 2013). The references for accessing the NIR 2013 report and it's primary excel data sheets are detailed in Annex 3.

As stated in the NIR 2013, data quality faces limitations, particularly for CH_4 and N_2O emissions (especially from soils). They remain understudied and uncertain, a feature Luxembourg shares with the other reporting EU member states (NIR 2013 p. 85).

The Luxembourg NIR 2013 mostly relies on the default emission factors (EFs) as documented in the IPCC 2006 Guidelines, uses few measurement data and subsequently produces uncertain estimates. These uncertainties are discussed in Annex 3.

3.3.2. N-non-greenhouse gases

N-non-GHG comprise NH_3, and NO_x, with the exception of N_2O. The main external sources for national Nr-emissions which are non-GHG are:

- UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) data base (NO_x and NH_3);
- European Monitoring and Evaluation Programme (EMEP), under the CLRTAP (NO_x, NH_3, Ozone);
- National Emissions Ceilings directive (NECD) (2001), monitored by the European Environment Agency (EEA) (NO_x and NH_3);
- European Pollutant Release and Transfer Register (E-PRTR) (NO_x, NH_3 and N_2O).

For both gas-families, GHG and non-GHG, the data reported under the country's international obligations derive from national statistics and data sets. The main data providers for the present research are the relevant national administrations and their registries (annual reports and shared excel datasets) and the National Official Statistical Office (Statec) for import/export data.

3.3.3. Nitrate NO_3

Nitrate is a solid salt that leaches mainly from fertilisation into the soil and waters. The main source for NO_3 data was the Water Administration's Nitrates report (2012).

3.4. N-Budget data handling - Assumptions

The different assumptions, definitions and simplification options taken to adjust national data to the N-Budget nomenclature are as follows:

The system boundaries start with the crude production and end with the disposal of the products, while integrating the net trade volumes (quantities imported minus quantities exported) staying in the country. Domestic transformation of primary products is not considered.

Within the system we distinguish between different pools (containers, such as industry, energy, transport, agriculture and terrestrial systems, waste, consumers, trade, water, atmosphere), where the very mobile and diffuse N is stored, transits or converts to a different N-forms.

N-conversion: Food items were converted into proteins and N on an edible portion basis, since this is what the statistics report. Feed items were converted in proteins and N, after having been converted in their dry matter (DM) equivalent. For both feed and food, proteins were converted into N using the Jones' N-to-P default conversion factor of 6.25% (IPCC 2006 Guidelines, EIONET 2010). No distinction is made between the plant or animal origin of proteins.

Reference period: The assessment was done for the calendar year 2010, the most recent year for which most of the consulted datasets are complete. Missing national data for 2010 is derived from model calculations for the year 2000, as reproduced in ENA (p. 327).

The functional unit is in principle the kiloton (kt). Per capita values are expressed in kg.

Geographic boundaries: All major N-containing products, commodities, waste flows were assessed as long as they concerned the national territory.

The population under investigation: Because of the high proportion of commuters working in Luxembourg (151 900) compared to the residents (502 100) (Statec 2013), daily commuters were accounted for 0.5 residents (75 950 units). Thus a total of 578 050 equivalent inhabitants were considered at the start of the year 2010 (Fig. 6). As commuters only spend their working hours in the country, their impact is commonly evaluated to represent that of half a resident. This approach is consistent with the approach adopted by the national administrations when reporting to UNFCCC, and with the method adopted for calculating the Luxembourg ecological footprint (CRTE 2010).

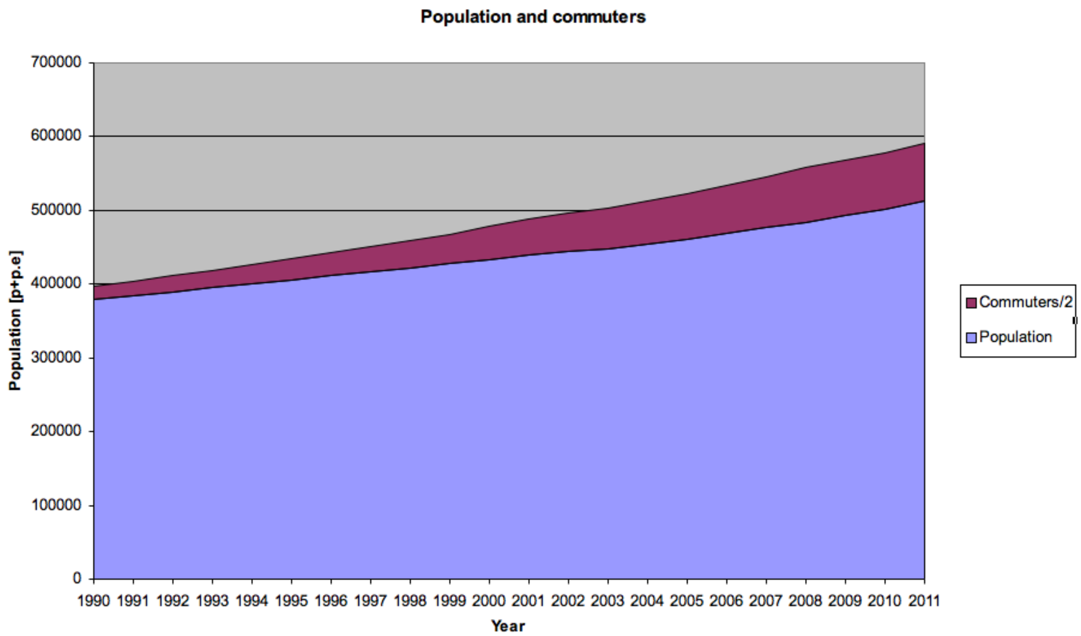

Fig. 6 - Progression over time of the resident over the non-resident commuter populations, Luxembourg, 1990 - 2011

Source: Water Administration (2012) based on Statec population data

3.5. N-Budget methodology

The overall applied methodology can roughly be subdivided in 3 steps, developed extensively in the Technical Annex 4:

STEP 1: Calculate N-Budget data per pool and N-form

The N-inventory was established per pool and subpool, per Nr-form and for molecular N_2, where available, as per EPNB methodology. Model data was completed by national data, communicated by national administrations. Often the N-quantity was not readily available but had to be calculated (e.g. N in organic solid waste, N deposited through the atmosphere). Sometimes the N-content value could not be found (N in wood?). Sometimes the values were contested (NO_3 in waters). Each time conflicting data from different origins and methodologies were available, an end-column presenting the possible maximum values of all values found, was presented and in principle retained. The details of this lengthy exercise, including all intermediary tables produced and graphics used can be consulted in Annex 4.

STEP 2: Estimate N-amount in food and feed

The N-amount in food and feed available in the country in 2010 was calculated. This way-of-doing goes beyond the EPNB methodology. The aim was to obtain the total quantities of N consumed by humans via food, and by livestock via feed, necessary for completing the N-Budget.

The pools “human food consumption” and “domestic waste water” were treated together on the assumption that N contained in food consumed is equal to N contained in human effluents, or in other words, that the quantity of N taken in is considered equal the quantity of N excreted.

For estimating the N-quantity in the consumed food and ending up in the wastewater, three calculation methods were developed and applied in order to corroborate results:

a) **Protein-to-N method:** Conversion of the average national protein intake via food into N consumed and, by extension, into N in domestic wastewater. Protein data originates from FAO data online, and the Water Adm. xls 2012 (Annex 3);

b) **Water-to-N method:** Conversion of population equivalents of waste water effluents into N. Data was sourced from the Water Adm .xls 2012 (Annex 3);

c) **Food-to-N method:** Conversion of the quantity of food consumed into N consumed and discharged into domestic wastewater. Data was sourced from SER and Statec (Annex 3).

This original exercise proved valuable since the results of the three methods effectively converge.

The import/export data communicated by Statec for the selected food groups was combined with SER national food production data, to arrive at the estimated net quantity of protein/N available for human consumption in Luxembourg in 2010.

For the needs of the NiNB, the SER crop list had to be separated into human food and animal feed. The production information was then completed with the net trade data (balance between import-export of food) to derive the total amount of N available for domestic consumption. Food waste (estimated to 30-50% of food, FAO 2011) is not accounted for, since it is considered that the food which is not eaten finishes in the organic waste recycling chain and is not lost for the N-Budget.

STEP 3: Derive "per capita" values

The resulting overall absolute NiNB values were transformed into relative per capita values. Considering the specific demographic situation and "capital metropolitan region" characteristics of Luxembourg (Annex 3), absolute values are not necessarily meaningful. Per capita estimates were calculated to permit to compare Luxembourg's consumption and emission patterns with those of other countries.

After having accomplished these steps, results in the form of the Luxembourg NiNB 2010 are subsequently presented and compared to the partial static N-Budget of 2000 (chapter 4), analysed, discussed (chapter 5) and conclusions established (chapter 6).

4. RESULTS: LUXEMBOURG'S NATIONAL INTEGRATED N-BUDGET FOR 2010

4.1. Luxembourg NiNB 2010 general results

The integration of N-fluxes from all economic sectors, social segments and media allows an overall coverage of the environmental problems related to N in the environment, highlights the major N-fluxes, depletions and accumulations, indicates synergies and antagonisms and prepares the way for identifying the most efficient strategies for mitigating N problems (Table 8 below) at the national scale.

As a result of applying the above presented methodology, the NiNB 2010 prepared for Luxembourg (Fig. 7) is closed in the sense that it was possible to illustrate and explain most of the N-flows, but is biogeochemically not balanced in the sense that more N is rejected than is absorbed:

- Air: 67 kt N are emitted by Luxembourg to the atmosphere, whereas 33 kt N are extracted from the atmosphere, leaving a surplus of 34 kt N in the air, which accumulates in the atmosphere;

- Waters: 13 kt N enter the national hydrosphere, 5 kt N leave the Luxembourg hydrosphere by way of denitrification back to the atmosphere, leaving a surplus of 8 kt N, which is stored and disperses in the hydrosphere;

- Soils: Minimum 8.4 kt of excess agricultural N transit through the terrestrial ecosystems to end up in the hydrosphere. Another 4 kt NH_3 and 5 kt N_2 are emitted by agriculture to the atmosphere.

A cumulated N-surplus of 46 kt N ends up in the environment, without serving the purpose for which it was created.

NiNB are difficult to compile because they use a large range of data sources of varying quality and are based on a complex system of interconnected flows and stocks. By its integrative nature, the NiNB arrives at higher N-flows and stocks figures than previously documented (NIR 2013, Convis 2008, SER 2013, Water Administration 2012, Environment Administration 2011, 2012 etc.). Bearing in mind that the national figures are considered underestimated and uncertain (NIR 2013 and interview with the national compiler of GHG April 19, 2013 (see Annex 5)), and that it was not possible to quantify all movements and stocks, it can be said that the derived NiNB is a conservative estimate.

The resulting NiNB, although not complete, shows a high degree of detail when compared with other country NiNB (Leip et al. in ENA 2011 p. 362-369). Except for the hydrosphere and the marine waters (Luxembourg is land-locked), all major pools have been accounted for. The degree of detail of the information aggregated in the Luxembourg NiNB 2010 approaches that of the EU integrated N-Budget for 2000 (ENA 2011 p. 369). Notwithstanding the data uncertainties, the Luxembourg NiNB 2010 seems therewith to be the most recent and most comprehensive national integrated N-Budget available.

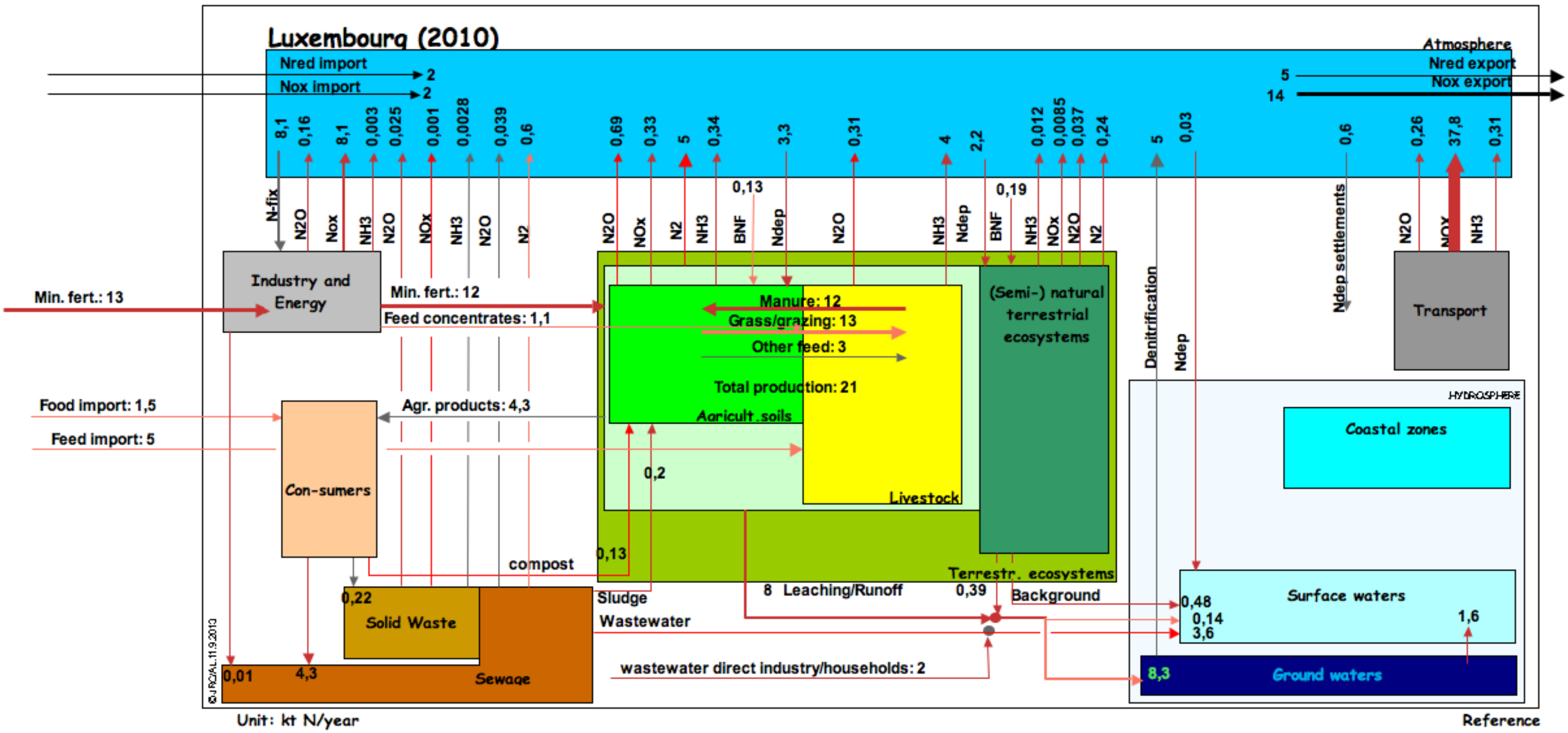

Fig. 7 – Map of the National integrated N-Budget (NiNB), Luxembourg, 2010 (kt N)

Source: Own calculations. © JRC/AL

4.2. Luxembourg NiNB 2010 results per pool

The NiNB model also produces a table organising the information illustrated in the map (fig.7) into a total Nr-input, Nr-output, Nr-stock and Nr-balance per pool or system (Table 2).

Table 2 – Luxembourg NiNB 2010 – Balance between N-input and N-output per pool (kt N yr)

Luxembourg (2010) N-input, N-output, N-balance per pool [kt N/year]						Comment
Pools/System	Input	New Nr	Output	Stock change	Balance	
Atmosphere	54		25		29	Quantified N2-fluxes: 6 kt N/year. Denitrification: 5 ktN/yr. Total 11 kt N2/year
Industry + Energy	13	8	21		0	Nfix/Nox for fertiliser neutral.
Transport	0		38		-38	
Consumers	6		5		1	
Agriculture	22		23		-1	Internal cycling excl.
Forests	2		1		1	
Waste	5		4		0	
Freshwater	13		0		13	Water excl. denitrification
Marine water	n.d.	n.d.	n.d.	n.d.	n.d.	
Atmosphere incl. N2, N2O, Nfix, denitrification	67		33	0	34	attention: correction for deposition

Source: Adapted calculations produced by the NiNB model, in addition to the NiNB map (Fig. 7). N.d. = not determined.

Table 2 shows the sum of all N-inputs into each pool (illustrated in the NiNB map (Fig. 7) with an arrow towards the pool), as well as the sum of all the N-outputs out of each pool (illustrated in the NiNB map (Fig. 7) with an arrow leaving the pool). An input in one pool/system is an output from another pool/system. However system boundaries are not always as clear as the NiNB map suggests. F.i. losses of N to the hydrosphere is a flux of N across soil and livestock system boundaries.

Some components of an ecosystem also show internal cycling of Nr, such as the Nman input from livestock to agricultural soils and grasslands, where it is temporarily stored in crops or cycled back to livestock as fodder. Table 2 sums reactive N, inert N_2 returning to the air is mentioned for information only. Stock changes in terrestrial ecosystems (soil stock changes or standing biomass in forests) and aquatic systems (sedimentation in lakes and rivers) are not reported.

As described by Galloway (2003), the circulation of anthropogenic Nr in the atmosphere, hydrosphere and biosphere has a wide variety of consequences, which change over time as Nr moves along its biogeochemical pathways. Nr does not cascade at the same rate through all environmental pools. Some systems have the ability to accumulate Nr, slowing the cascade. This accumulation in Nr reservoirs can in turn enhance the negative effects of Nr on that environment. JN Galloway coined the expression “nitrogen cascade” (Fig. 4) to describe these changes in Nr form and state over time and space as Nr passes through the environment and the resulting sequence of effects on the health of people and ecosystems.

Atmosphere N-Budget

An N-input into the atmosphere is a gaseous emission. The atmosphere budget exceeds all other pool budgets: the air receives the highest quantity of N with NO_x from the transport pool coming first (37.8 kt N). Luxembourg does not produce fertiliser but imports them. For this reason, the NO_x emissions by the industry for the fixation of atmospheric N_2 for artificial fertiliser production, reported according to the model as a flow between the atmosphere and industry pools, are neutralised in the Luxembourg N-Budget by an identical Nfix quantity leaving the air for the industry pool.

In total, Luxembourg releases 67 kt N (N-input) into the atmosphere through the sum of all Nr emissions, including NO_x from transport, denitrification, oxidized and reduced N-imports and NO_x emissions generated in the Haber-Bosch process. Luxembourg extracts 33 kt N (N-output) from the atmosphere through atmospheric deposition, BNF through leguminous plants, oxidized and reduced N-exports.

The atmospheric budget is explained but not balanced. There exists an N-surplus of 34 kt in the atmosphere, which accumulates and disperses into the wider surroundings. Luxembourg is therewith a net source of transboundary pollution.

Industry and Energy N-Budget

The N-input into these 2 sectors presented together is 13 kt N, composed of inorganic fertiliser imports. New Nr is added to the Luxembourg industry sector in the form of 8.1 kt Nfix for the Haber-Bosch fertiliser manufacturing process happening elsewhere. The N-output amounts to 21 kt composed of mineral fertiliser and domestic feed provision to agriculture, and 8.1 kt NO_x emissions from the Haber-Bosch process. The model neutralises the N-flow linked to manufacturing fertiliser. Luxembourg does not produce synthetic N-fertiliser but the model was built to encompass such possibility.

Nr in non-fertiliser products and substances is not quantified. The N stored by the industry and energy compartments in useful products is thus limited to 14.1 kt N (fertiliser, feed).

Transport N-Budget

Transport has a marked net N-emission of 38 kt NO_x to the air. The transport budget, second largest budget after the atmosphere, is explained but grossly in deficit.

Consumer N-Budget

A positive N-balance is found for consumption: Consumers eat and drink 5.8 kt N, thereof 4.3 kt from national sources (see Annex 4, Table VIII). The quantity of national food consumed in Luxembourg equals the N-output to sewage from consumers. It can be assumed that the 1.5 kt N from food not ending up in the national sewage system finishes in neighbouring countries' sewage systems (commuter impact). Non-food Nr, stored in consumed products, is not quantified. Consumers are central for NiNBs since high consumption behaviour and individual resource-intensive lifestyles steer all other production and waste absorption machineries.

Agricultural N-Budget

Without considering internal recycling of organic matter, the N-input is 22 kt N composed of feed concentrates, feed imports, mineral fertilisers, atmospheric deposition on agricultural land, compost and sludge applications. The N-output is 23 kt N composed of all Nr and of 5 kt N_2 emissions, agricultural products, N-leaching and running off. Estimates for N_2 and NH_3 are uncertain. Data is missing for N stored in soils. The total domestic agricultural production amounts to 21 kt N in 2010 (food crops 1.63 kt N, animal products 2.65 kt N, feed and forage 17 kt N, see Annex 4, Table X).

We find a good system-internal recycling of Nr between grass and crop production and manure excretion. The livestock sector receives 16 kt Nr in the form of domestically produced grass and other feed, whereas it delivers 13 kt Nr as manure to the agricultural soils. Table 2 does not account for this internal cycling.

The picture of the agricultural budget changes when singling out the subpools "agricultural soils" and "livestock", as well as the release of N_2 and NO_3, and when adding the agricultural internal cycling, as illustrated in Table 3 below.

Table 3 – Luxembourg NiNB 2010 – Balance N-input and N-output per agricultural subpool (kt N yr)

	N-Input	N-output	N-Balance
Subpool Agricultural soils	28	19	9
Subpool Livestock	22	19	3
N2 and Nleach from Soils and Livestock		13	-13
Total agricultural pool	50	51	-1

Source: Own calculations on the basis of the NiNB data (Fig. 7)

The N-flow then becomes almost as intense as for the atmosphere pool, making agriculture the second largest national N-budget before transport.

For supplying the protein requirements of Luxembourg consumers, about 20 kt N of fertiliser, food and feed are imported. The overall N-input into the national agricultural system (50 kt N) is more than 10 times higher than the N actually stored in food produced by this agricultural system for local consumption (4.3 kt N). As pointed out by ENA (2001, p. 372): "A large part of [the European agricultural] resources is invested to feed the livestock, which consume three times the nitrogen that humans consume but deliver only about 50 % of the proteins in human's diet in the EU-27". Smil (2002) reckons that of the total Nr added to global crop agro-ecosystems in 1995, only about 12 % entered human mouths.

The total agricultural food and feed production releases minimum 8 kt N from fertilisation to the surface and groundwaters, illustrating the Nitrate report's conclusion that agriculture is the main contributor to the high N-concentrations in water, before waste water. This quantity of agricultural Nleach (8 kt N) is however a conservative estimate and highly sensitive to :

- the agricultural N-input and N-output definitions and reported quantities used (Annex 4, Table III);
- the Nitrogen use efficiency (NUE) calculation methodologies applied (Annex 4, Table III).

It was shown (Annex 4, Table VII) that the real quantity of NO_3 leaching into the soil and waters could actually be as high as 14.5 kt.

The fact that the agricultural N-Budget is explained and balanced should not distract from the low agricultural N-use efficiency and high agricultural contribution to N-pollution.

Terrestrial ecosystems N-Budget

Terrestrial ecosystems comprise natural and semi-natural land, including forests. The N-input into forest is 2.2 kt from atmospheric deposition and BNF. The N-output consists of 1 kt Nr-emissions and N-leaching. Most data is model derived from the year 2000 (ENA 2011). N_2 and N_2O emissions from soils and forests are highly uncertain. No updated national reference could be found for N stored in forest biomass. Wood use and trade related N-fluxes have not been estimated. No conclusion can be drawn on whether or not the terrestrial ecosystems N-Budget is balanced.

Waste N-Budget

The N-input to the waste sector (6 kt) derives from solid waste and treated and untreated effluents from humans and industry. The N-output (4 kt) consists of N from WW and sludge and in Nr-emissions including discharges of NO_3 to surface water. There is little information on sewage sludge applied to agricultural fields. Non-edible products and food waste are included in solid waste. The waste N-Budget is positive.

Freshwater N-Budget

The ground and surface water system is a net receiver of N, with an N-surplus of minimum 13 kt (Table 5 below). This surplus derives mainly from agriculture (8 kt) and wastewater, which is with minimum 3.6 kt N-output a non-negligible source of nitrate discharges (Annex 4, Table VII). Other minor sources are natural land and forests (0.4 kt), urban and erosive losses from terrestrial systems (diffuse background N-inputs of 0.48kt) and atmospheric deposition (est. 0.03 kt Ndep). Atmospheric Nr deposition has been estimated on an area-fraction basis. Leaching from agriculture is without contest the primary anthropogenic Nr source for groundwater. Nitrate is the most common Nr species.

The knowledge gap is high for budgeting the N fluxes in the aquatic systems. Hydrosphere N_2O emissions, inland fishery, river imports and exports, leaching from settlements, N in septic tanks, subsurface Nleach, direct Ndep into aquatic systems or via WWTPs could not be quantified. No data was found for the transfer of N from surface water to groundwater.

The NiNB map (fig. 7) illustrates the estimated denitrification flows linked to the conversion of Nr to N_2 (see Annex 4, p 71). However Table 2 and Table 3 produced by the NiNB model consider the denitrification process apart. The quantities of N_2 and N_2O escaping from wastewater in WWTP are in fact difficult to establish. The German NiNBs (Umweltbundesamt 2009, ENA 2011 p. 363) uses a total dinitrification rate of 60 %. The integrated N-Budget for EU (Leip et al, 2011 and Annex 2) applies roughly a factor of 50 %. Applying the German rate to Luxembourgin 2010 would yield approximately 5 kt N_2 emissions from ground waters by way of denitrification. This N_2 quantity is shown as an emission from the freshwater pool into the air in fig. 7. This N-rich resource could potentially be recovered as N-fertiliser before being denitrified back to N_2.

Whatever the way of dealing with denitrification, and although uncertain and incomplete, the freshwater N-budget shows a strong imbalance, which reflects in the high N-water pollution levels.

Table 4 below summarises the findings for Luxembourg in 2010. The sum of the N-inputs to the air, soil and waters is double (104 kt N) that of the sum of the N-outputs from these ecosystems (58 kt N), leaving an N-surplus of 46 kt in these systems. The fate of the N-surplus is not clear and the extent of the loss is not known. This N-surplus can be partially recycled into the food production system (compost, sludge, feed …) or it can accumulate in environmental reservoirs or disperse to the wider surroundings, without serving the purpose for which it was created. The literature therefore refers to the notion of *potential* N-loss. The N stored in useful products (fertilisers, feed, food) amounts to 50 kt. Under this configuration, the national NUE would be 37 % (50 kt N in useful products relative to 135 kt N-inputs).

Table 4 – Luxembourg NiNB 2010 – Summary of N-flows and stock findings and destinations (kt N yr)

A) Ecosystems Air-Water-Soil	Total Ninput	104		
	Total Noutput		58	
	Total Nbalance			46
B) Non-Ecosystems (Industry, Energy, Transport, Consumers, Waste)	Total Ninput	31		
	Total Noutput		69	
	Total Nbalance			-38
All systems (A+B)	Total Ninputs	135		
	Total Noutputs		127	
	Total Nbalance			8
	Total N in useful products (food, feed, fert)		50	

Source: Own calculations from the NiNB (Fig. 7)

4.3. Luxembourg NiNB 2010 results per N-form

The NiNB also quantifies and sums the unwanted harmful by-products of N-use in Luxembourg in 2010. Table 5 shows the synthesis and ranking of adverse annual emissions and discharges to the ecosystems, per dominant Nr-form and per compartment. In 2010, the air received in total 63 kt N composed of 52 kt Nr (NO_x, NH_3, N_2O) and 11 kt N_2. The waters received a total of 13 kt Nr (NO_3).

Table 5 – Luxembourg NiNB 2010 – Ranking of discharges per dominant Nr-form and per pool (kt N and %)

Luxembourg (2010) N-input per pool and per N-form [kt N/year]						Comment
Pools/System	Air	%NOX	%NH3	%N2O	Water	internal cycling excl.
Industry + Energy	8	98%	0%	2%	2	Air without N_2. Quantified N_2-fluxes: 6 kt N/year. Denitrification: 5 ktN/yr. Total 11 kt N_2/year
Transport	38	99%	1%	1%	-	
Consumer	0	n.d.		n.d.	-	
Agriculture	6	6%	77%	18%	8	Air without N_2
Forests	0	15%	21%	64%	1	Air without N_2
Waste	0	2%	4%	94%	2	Air without N_2
Aquatic	0	n.d.	n.d.		-	Air without N_2, no river import!
Total Air in %	100%	88%	9%	3%		
Total Air [kt N/year]	52	46	5	2		NOx incl. Nfix
Total Air [kt N/year] incl N_2 and dinitrification	63					
Total Water [kt N/year]					13	

Source: Calculations produced by the NiNB model, in addition to the NiNB map (Fig. 7).

Nitrogen oxides gases (NO_x as nitrogen dioxide NO_2)

The most intense emission of any form of N in Luxembourg is that of NO_x emitted from the transport sector, with 37.8 kt entering the atmosphere in 2010 (Table 6). The road transport sector is also the highest contributor to GHG emissions in Luxembourg with 56 % of CO_{2eq} in 2010 (on a “fuel sold” basis (NIR 2013).

For all combustion sectors, Luxembourg emitted, according to EEA, in 2010 41.1 kg NO_x/cap and ranks first per capita NO_x emitter among the EU27, on a “fuel used” basis. Multiplied by the number of residents, this would amount to a total national emission of 21 kt NO_x in 2010 (Table 6). The picture is however grimmer when looking at the NiNB and referring to CLRTAP: for all combustion sectors, 47.9 kt NO_x have been emitted by Luxembourg in 2010, on a “fuel sold” basis. Divided by the number of residents, this results in a per capita NO_x emission of 96 kg/yr, confirming Luxembourg’s undisputed rank 1 out of 27 EU Member States for national per capita NO_x emissions. The NO_x emissions have been stable since the year 2000 (EMEP 2012).

NO_x emitted from the agricultural sector amount to 0.33 kt and consists of soil emissions from volatilised NO_x resulting from synthetic fertiliser and manure applications.

Reduced Nitrogen – Ammonia (NH_3)

NH_3 emissions are dominated by manure application, housing and storage emissions. According to EMEP (2012), Luxembourg emitted 5 kt NH_3 in 2010 (Table 6). EEA estimates per capita emission to be 8 kg NH_3/cap in 2010, totalling 4 kt NH_3/yr, on a “residents-only” basis. This NH_3 emission level would place Luxembourg on the 6st rank for per capita emission of NH_3 among the 27 EU member states.

Under the NECD, the Luxembourg national emission ceilings for 2010 were 11 kt for NO_X and 7 kt for NH_3. Whereas Luxembourg is below the national ceiling for NH_3 with 5 kt emissions in 2010, the country surpassed the national ceiling for NO_x by 87%, on a basis of 21 kt NO_x attributed to Luxembourg in 2010 (Fig. 8). However, Table 5 below shows that the 21 kt NO_x basis used under the Directive is likely to be too low, since according to other sources the emissions may amount to 52 kt NO_x in 2010.

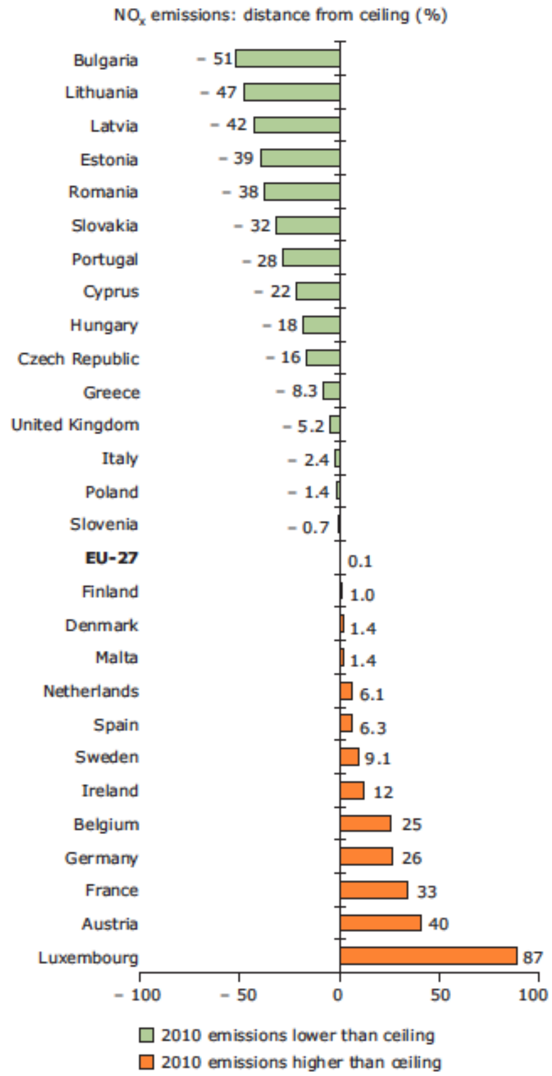

Fig. 8 – Distance to ceiling (%) for NO_x emissions in 2010
Source: EU NEC Directive Status report 2012

Note: The reported national totals of Austria, Belgium, Bulgaria, Ireland, Luxembourg, the Netherlands and the United Kingdom are based on fuel used. All other Member States reported a national total based on fuel sold. The aggregated EU-27 emission total is a mix of data based on fuel used and fuel sold.

Agriculture is, with 4.34 kt released in 2010, the major source of NH_3 emitted in the country (Tables 5 and 6). This flux consists of volatilised NH_3 emissions from synthetic fertiliser and manure applications. According to the ASTA expert, agricultural NH_3 reported by Luxembourg to UNFCCC could however be overestimated (Marx S, interview 22.1.13, Annex 5). Findings for NO_x and NH_3 are summarised in Table 6 below.

Table 6 – Total NO_x and NH_3 emissions according to different sources and methods, Luxembourg, 2010 (kt)

	EMEP (2010) a)	EPRTR (2010) b)	CLRTAP (2011) c)	EEA. NECD Status report (2012) d)	NIR (2013) e)	*Calculated possible maximum from the columns a) – e)/*
NO_x (as NO_2)						
agriculture	0.33		0.30			*0.3*
energy	1.83					*1.8*
institutional+residential combustion	1.72					*1.7*
industry	4.57	4.82	9.67			*10*
transport	37.80		37.90			*38*
total NO_x (as NO2)	**46.25**		**47.87**	**(18) 21**	**46.24**	***52***
NH_3						
agriculture	4.49		4.35			*4.5*
institutional+residential combustion						
transport	0.29		0.31			*0.3*
total NH_3	**4.78**		**4.67**	**4.02**	**4.07**	***5***

Source: Aggregation from sources listed in the head column. For more details and explanations, see Table IV, Annex 4.

Nitrogen oxides – Nitrous oxide (N_2O) (Laughing gas)

The NiNB (Fig. 7 and Table 7) shows a total national emission of 1.5 kt N_2O in 2010, of which the majority, roughly 1 kt is attributable to the agricultural sector. Agricultural N_2O emissions are dominated by grazing emissions, chemical fertiliser and indirect emissions from agricultural soils. Convis (2008) reports 10 kg N_2O/ha as an annual average N_2O emission for 2002 – 2005. Multiplying this hectare emission by the number of hectares of UAA, an annual total of 1.3 kt N_2O is calculated, which is in the range of the 1 kt of the NiNB 2010. The difference between the NiNB and the Convis findings can be explained by the facts that emissions from the agricultural sector have continued their downward trend since 2005 and that the Convis milkfarms are in average more energy and protein intense than the national average consisting of milk and cereal farms (Convis 2008 p. 72).

The distribution of agricultural N_2O emissions between subpools is also consistent between sources with fertiliser applications (mineral and organic) being the first direct emitters (44 % direct N_2O emissions from soils), followed by indirect emissions from agricultural soils. These indirect emissions are due to atmospheric deposition from volatised N from fertilisers and animal manure and due to N-leaching and runoff, also from fertilisers and animal manure. Roughly 40 % (0.38 kt) are indirect N_2O emissions from agricultural soils according to NIR 2013. For Convis (2008) the first emitting source is the mineral fertiliser application with 4.4 kg N_2O/ha, followed by manure handling with 3,2 kg N_2O/ha, and agricultural soils (2.4 kg N_2O/ha). However, actual measurement data of N_2O emissions from agricultural soils, terrestrial ecosystems, manure storage or WW handling could not be found.

In any event, fertilisation is the major cause of N_2O emissions from agriculture, and in relation with the decrease in quantities of mineral fertilisers applied and the reduction in livestock numbers, agricultural N_2O emissions also declined since the 1990s (Dairyman 2010). However N_2O being an important GHG, there is further potential to reduce the GHG balance of Luxembourg by reducing the N-losses due to fertilisation. Digestate application as a means to reduce N-emissions from fertilisation could be studied further.

According to the NIR (2013), for the 1990-2011 period, N_2O was, with about 3.83 % of the total emissions (excluding the IPCC category *Land use, Land use change and Forestry (LULUCF)*), the second source of Luxembourg's GHG after CO_2 (92 %). These N_2O emissions decreased by about 3.3 % over the 1990 – 2011 period.

Nitrogen oxides salts – Nitrate (NO_3)

Fertilisation is also at the origin of the remarkable quantity of 8.3 kt N-leaching and running off into the groundwater in 2010. As discussed in the *Agricultural N-Budget* section above, this quantity has to be considered as a minimum. When crossing sources and methods, it can be seen that the quantity of nitrates agriculture releases in the waters is more likely in the range of 11 kt NO_3 (Table VII of Annex 4).

In addition, 3.6 kt of NO_3 are discharged with waste water into rivers and surface waters. This is confirmed by different sources and methods (Table VII in Annex 4). Surface waters receive 1.6 kt N from ground waters. Excess NO_3 concentrations in water are explained by a suboptimal urban waste water treatment (Nitrates Report 2011). The Nitrate concentrations in surface water is mainly related to the suboptimal functioning of WWT.

Whereas the Nitrate excess in groundwater is mainly of agricultural origin, WW plays thus a significant second role in NO_3 pollution of fresh waters.

Dinitrogen (N_2)

N_2 discharge to the air through dinitrification have been cautiously estimated for agriculture (5 kt), for terrestrial ecosystems (0.24 kt N_2), for ground waters (5 kt N_2) and for sewage (0.6 kt N_2). In total, 11 kt N_2 are cyled back to the atmosphere.

4.4. Synthesis of the Luxembourg NiNB 2010 results

The simplified, static N-Budget for the year 2000, presented in Table 1, can now be compared with the updated and comprehensive NiNB 2010 results (Table 7).

Table 7 – Comparison Luxembourg N-Budget 2000 and Luxembourg NiNB 2010 (kt N/yr)

Nman	Nfert	Ndep	Nfix	Nmin	Ncrop	Nfor	NH_3	N_2O	NO_x	N_2	Nleach	Nleach
Excre-tion	Ferti-lizer	Atmos-pheric Depo-sition	Biolo-gical Fixa-tion	Mine risa-tion	Crop uptake	Forage uptake	NH_3 Emis-sion	N_2O Emis-sion	NO_x Emis-sion	N_2 Emis-sion	Leach-ing to Ground -water	Leach-ing to Surface -water
2010												
12	13	5.5	0.32	?	1.63	16	4.8	1.5	46.24	10.84	8.3	5.82
2000												
12.57	13.95	2.86	0.74	-0.03	10.69	6.21	3.25	0.56	0.37	6.18	2.23	0.17

Source: Own calculations based on NIR 2013, SER, STATEC, Water Administration (2012), ENA, UNFCCC, CLTRAP, EMEP, EEA. The light blue-shaded fields mark the agricultural N-inputs. The gray-shaded fields mark the N in useful agricultural products (N-outputs). The orange-shaded fields are commonly considered N-surplus.

Over 10 years, slightly lower quantities of fertiliser inputs and significantly higher quantities of atmospheric deposition, of NO_x emissions and of N-leaching and runoff are observed. The already insignificant quantity of BNF decreased further between 2000 and 2010.

It rather seems that the 2000 data are incomplete, rather than that the emissions and discharges increased so much in 10 years or that fertiliser import decreased so little since 2000. In fact Nfert amounted to 18 kt in 2000 (Table II, Annex 4) instead of the reported 14 kt. It is also known that N_2O emissions from agricultural soils decreased since the early 1990s (OECD, UNFCCC 2011), in the sense that the 2000 figures cannot be lower than the 2010 figures.

NO_x emissions are grossly under-evaluated in 2000, since CLRTAP confirms they reached that year 48 kt. Gaseous N_2 emissions in 2000 are model derived. N_2 emissions for 2010 are derived from a model for agriculture (ENA 2011) and from literature for water (Umweltbundesamt 2009).

The big differences in crop and forage values is probably due to a divergence in defining of Ncrop and Nfor: whereas the 2010 values strictly separate crops and forage between their human and animal consumption uses, the 2000-values seem to add all cereal crops into the Ncrop category, limiting the Nfor category to grass, without distinguishing the end users. However, the majority of crops produced in Luxembourg is used as feed rather than food (Tables VIII - N in Food and X - N in feed, Annex 4). In the national agricultural vegetal production, the fodder part for animals is actually three times higher than the cereal part for humans (SER 2012).

It seems also that the volume of the 2000 Ncrop and Nfor values are underestimated, since total grass production was higher in 2000 than in 2010, thus contained more N in 2000 than in 2010. Total national crop production increased slightly between 2000 and 2010 (from 153 kt to 166 kt) (Fig. 9 and 10).

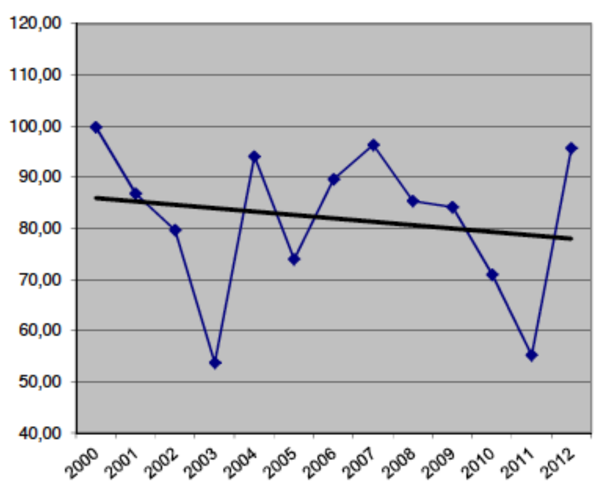

Fig. 9 - Total temporary grass, perm. pasture and meadows cuts per ha Luxembourg, 1995 - 2012 (100 kg/ha)

Source SER 2012

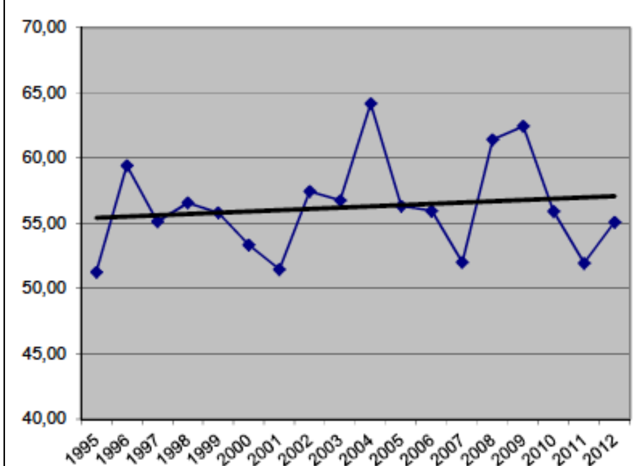

Fig. 10 - Total cereal production per ha, Luxembourg, 1995 - 2012, (100 kg/ha)

Source SER 2012

Overall, the comparison between 2000 and 2010 leads to the conclusion that the 2010 NiNB is more complete and realistic than the N-Budget 2000.

4.5. Data limitations and implications for the quality of the Luxembourg NiNB 2010

N-compounds are highly mobile and undergo chemical reactions resulting in different effects at different places over different time spans. Due to this intrinsic nature of the N-cycle and due to the fact that data was compiled from different origins and quality, inconsistencies are unavoidable. Details on the quality and reliability of the data used can be found in Annex 3.

Although the NiNB 2010 shows higher quantities of N used and consumed than the current knowledge on N-use and consumption in Luxembourg, the NiNB 2010 is itself not complete and does not capture all flows and stocks. Due to data insufficiencies, it was not possible to consider or quantify the following N-loss or N-gain elements:

- Soil N-stock changes linked to changes in soil organic matter content;
- N in crop residues;
- Import and export of manure, organic waste (sludge, …), biomass (wood …);
- Agricultural land cultivated outside the borders;
- Inconsistent estimation of UAA and other land use data (substantial differences for cropland and grassland;
- Conversion of agricultural or forested land into settlements;
- Residential fertiliser use, undocumented private trade in feed and fertiliser, self-produced garden fertiliser;
- Home garden food production and farm self-consumption;
- Food waste;
- Imported compound feed waste (est. 18 kt);
- Seed and planting materials;
- Agricultural non-food (=energy plants) production;
- Non-agricultural fertiliser use (city parks, golf courses etc.);
- Obsolete sewage systems leaks, water losses, … ;
- Septic tanks releases;
- N stored in materials, goods, substances, wood;
- Non-agricultural animals (pets) feed;
- N emissions from waste incineration and landfilling;
- “Fuel-sold” versus “Fuel-used” divide NO_x emission;
- Aviation in the cruise cycle;
- Visiting consumers (tourism, business, cultural-sports-political events …);
- Mineralisation of N in soils;
- Other unquantified compartments: fisheries, lightning, river imports/exports, coastal zones, leaching from settlements, subsurface leaching, direct Ndep into aquatic systems or WWTPs, dinitrification through sedimentation;
- Imprecise and controversial accounting rule consisting counting “one commuter for half a resident”;
- Knowledge gap on the cumulative effects of the different N-inputs and on the local effect of climate change onto the N cascade;
- Overlapping waste compartments, imprecise system boundaries, unclear origin, destination and quantities of wastes

Neglecting soil stock changes can lead to problematic results if the data are used to derive efficiency indicators. Primary data is often estimated based on a high number of assumptions, or extracted from the literature rather than measured. Whereas raw national production and emissions data are generally consistent between national sources, they are not for food and feed trade data.

Protein content values per feed/food item are often diverging between sources. Import/export data, notably for feed, are often incomplete or implausible. As a consequence, the food (Annex 4, Table VIII) and feed N-Budgets (Annex 4, Table X), as derived from official production and import/export data, are likely to be underestimated.

Using an FAO default protein intake figure for Luxembourg is maybe not precise enough since it is uncertain whether FAO considers the commuter impact. In reality, the NiNB 2010 showed that the N in food and waste is higher than this default assumption. Replacing some default parameters, coefficients and emission factors by national measurements and values, especially for agricultural soils and crops nutrient content, would be useful.

The NiNB model proposes a ranking of the data on a confidence scale from 1 (very low) to 5 (very high) (Annex 2), according to the IPCC methodology AR4. The magnitude of the confidence level has been prudently estimated to be on average 3 – medium (5 out of 10 chances of being correct).

For all these reasons, the resulting Luxembourg NiNB 2010 is considered a conservative estimation.

5. ANALYSIS OF THE LUXEMBOURG NATIONAL INTEGRATED N-BUDGET 2010

5.1. Main characteristics of the Luxembourg NiNB 2010 and policy implications

Luxembourg's NiNB is tiny in absolute quantity in comparison with other national or the EU 27 budgets (ENA 2011). The kt unit has been maintained for the sake of comparison with other existing national N-Budgets, but it is perhaps not justified for Luxembourg alone. The appropriate unit for the Luxembourg NiNB would be tons.

The year 2010 under study is already a year on the downwards curve for N-emissions (except for Luxembourg's NO_x from transport), observed throughout Europe. This decrease in emissions is attributed to the economic crisis and the slowing down of industrial and commercial activities (NIR 2013).

Considering this conjuncture, the main characteristics of the Luxembourg NiNB 2010 can be summarised as follows:

- **Luxembourg has an overall NUE of roughly 37 %.** The N-excess in the ecosystems in Luxembourg is considerable, with 46 kt N that are potentially lost. With a rising population, consumption, trade and traffic, with increased milk and meat productivity, the risks of adverse health and environmental effects of this N-surplus increase year by year;
- **Luxembourg is a net source of transboundary N-pollution** (mainly NO_x). N-pollution in Luxembourg is predominately caused by road transport (NO_x emissions), followed by agriculture (NO_3 and NH_3) and waste water (NO_3);
- **Luxembourg is not food N self-sufficient.** Luxembourg's national food N production (4.3 kt N) covers maximum 74 % of the national food N needs (min 5.8 kt N) (Annex 4, Table VIII). The country depends on trade for covering its food protein/N needs;
- **Food trade outweighs food production.** Food trade is very intense compared to the food quantities produced and consumed domestically. The volumes of food imports (8.5 kt N) and of food exports (7 kt N) are each almost double the volume of the national food production (4.3 kt N), leaving a food trade surplus of 1.5 kt N in the country (Annex 4, Table VIII);
- **Milk is the first agricultural product**. Agricultural N is mainly absorbed to produce meat and milk. Milk is, with 300 kt produced in 2010, by far the first national agricultural product, before cereals (50 kt) and meat (30 kt). Of the 300 kt milk produced, 200 kt are exported (Annex 4, Table VIII);
- **Meat is the first protein source.** Since milk is massively produced for the export market, it does not constitute the first food protein and nitrogen provider in the national diet. This function is, after trade, attributed to meat, followed by cereals.
- **Nitrate pollution is mainly explained by high N-losses to waters from the agriculture and waste water sectors**. Whereas food production is generally pointed out as the main, and sometimes also as the sole water N-polluter, the NiNB shows that the contribution from WW is almost half as high (minimum 3.6 kt N) as that from agriculture and livestock (minimum 8 kt NO_3). The mitigation of water N-pollution has thus to look at both the sectors. It seems that N can be recovered more readily at the point-source WWTPs, than in the diffuse agricultural sector. In the Luxembourg case, there is a potential to recover the significant amount of minimum 3.6 kt N on site at the WWTPs;
- **Crop and grass NUE** can, according to the ENA method described below, carefully be estimated to be in the range 66 %, which is slightly above the European average of about 60 % calculated by the ENA (2011) Domestic grain production serves primarily animal consumption (70 %) before human consumption (30 %), which reflects the meat intensive diet of the consumers. Imported feed N serves the production of export animal products;
- **Animal products NUE** can, according to the ENA method described below, carefully be estimated to be very low with 11 %, which is in the low range of the national livestock NUE calculated for the EU 15 (ENA 2011, p. 51)

Both Luxembourg agricultural NUEs calculated above are subject to a high uncertainty.

Resource efficiency is generally defined as the relationship of resource inputs and output of a system for a given timeframe (EEA). NUE can be expressed in a number of ways (ENA 2011 p. 37, 50) depending on the definitions of input and output (manure and grass?, Nleach?) and on the system boundaries. NUE can be calculated for a country, a system, a pool, a product. We try to focus here on the agricultural (vegetal and animal) and food NUEs (See also Annex 4, Table III).

From a commercial point of view, NUE is simply defined as the fraction of synthetic fertiliser removed from the field with the crop harvest (Yara 2012). A broader definition of agricultural crop NUE consists in calculating the ratio of N input through fertilisation (organic and inorganic) and N removal with harvest. Both methods result in a favourable NUE since other N-gains (BNF, atmospheric deposition) and N-externalities such as volatisation (NH_3), dinitrification (N_2) or leaching (NO_3) are not accounted for.

When atmospheric deposition and BNF are considered, the European agricultural NUE for cultivation on soils is about 60 % (Leip A, ENA 2011 p. 370). Under this method, the Luxembourg agricultural crop and permanent grass NUE would be about 66 % (1.65 N cereals + 17 kt N grains and grass produced from 13 kt Nfert, 12 kt Nman, 0.13 kt BNF, 3.3 kt Ndep).

Livestock NUE can defined as the ratio of N-intake by animals via feed (concentrates, ensiled grass, fodder) and N in animal products (milk and meat) (ENA 2011 p. 51). In Europe the livestock NUE evolves around 10 – 30 %. Under this method, the Luxembourg animal NUE would approximate 11 % (2.65 kt N in meat, milk and eggs produced from 5 kt N in imported feed, 17 kt N in grass and grains, 1.1 kt N from concentrates).

According to the whole-farm NUE approach presented by Nevens et al (2006), the Luxembourg agricultural NUE would be 32 % in 2010.

In an integrated, externalities-inclusive approach to agricultural NUE, all damaging N-excesses would be incorporated into the calculation. For producing 4.3 kt agricultural endproducts on Luxembourg farmland in 2010, a total input of 50 kt N was required (Table 3 above). The integral agricultural NUE would therewith decrease to 8.6 %.

A discussion of the potential Luxembourg agricultural NUE can be consulted in Annex 4 (Table III). It was not possible within the framework of the present research to come to a satisfying consensual conclusion concerning the Luxembourg agricultural NUE in 2010.

The NiNB estimates the potential quantities of N-excess. The actual effects of these flows depend however on many factors like time, meteorological conditions, soil characteristics, farmer management practices etc. The actual risks of N-discharges to air, soil, water and human health are better apprehended in combination with other environmental indicators such as “Ammonia emissions”, “GHG emissions”, ”Water quality (Nitrate pollution)” or “Nutrients in freshwater”.

On the whole, the NiNB is not complete because of missing information, or information of different origin and quality. The magnitude of the confidence level of the NiNB has been estimated to be in a “medium” uncertainty range (Annex 2).

Possible ways to reduce Luxembourg’s N-footprint and enhance Luxembourg N-self-sufficiency can be broken down in policy measures, in quantified saving potentials and in indicative costs and benefits for society (Table 8). Table 8 shows that the 46 kt national potential N-loss to the ecosystems could largely be reduced by a national N-savings and reduction potential of up to 30 kt N.

Table 8 – Nitrogen reduction measures, their estimated N saving/recovery potentials and their indicative cost-benefits for Luxembourg (kt/yr)

Area for potential N savings /recovery	Possible mitigation measures	Potential in tons (est.)*	Cost items	Benefit Items
Fuel Combustion	▪ Tax incentives to reduce NO_x emissions from road traffic, to reduce traffic altogether ▪ No further extension of road network ▪ Disincentives to fly-for-fun ▪ Support less-polluting mobility (walking, cycling, public transport, car sharing etc.) (plan directeur Transport (2008)) ▪ Reduce the fuel price difference with neighbouring countries (EEA online) ▪ Low – NO_x burners, esp. glass furnaces ▪ Energy saving measures ▪ Tighter regulations, controls and sanctions for exceedance of NO_x ceilings, speed limits, …	10 kt	▪ Clean mobility infrastructures ▪ Clean combustion technology (See marginal abatement cost curve, NO_x) ▪ Reduced tax income ▪ Incentives costs ▪ Control costs	▪ Avoided health, infrastructure traffic accidents cost ▪ Avoided environmental damage (ozone depletion, indirect climate change impact, habitat fragmentation by roads, forest degradation, …) ▪ Reduced emissions

Agriculture	▪ Improve NUE
	    o Fert NUE: dosage, timing, storage, Prior soil nutrient content laboratory testing, favour bio-based, local, farm fertilisers
	    o Feed NUE: N-reduced feeding regime, pastures & extensive grazing instead of stable silage feed, reduce reliance on soymeal imports
	▪ Tighter regulation for or a charge on N surplus, N leach/runoff
	▪ No transformation of permanent pastures into arable land (Water Adm 2012)
	▪ Upscaling of agri-environmental and biodiversity measures
	▪ Subsidise energy and protein efficient farms
	▪ Extension of advisory services, full coverage of annual
		8 – 14 kt	▪ Less-polluting spraying equipments and techniques
			▪ Subsidy costs
			▪ Control costs
				▪ Avoided Fertiliser costs,
				▪ Avoided WWT costs from reduced NO_3 content
				▪ Avoided health cost
				▪ Avoided environmental damage (biodiversity loss, direct climate change impact,
				▪ Reduced agricultural emissions and discharges

	fertilisation plans (64% UAA 2010) ▪ Tighter controls and sanctions for exceedance of Nsynth and Norg limits, ▪ Establish positive list, measure and control sanitised organic waste derivatives as fertiliser (Lioy interview 15.7.13) ▪ Revise Nitrates directive to promote primary use of local organic N sources and reduce N synthesis ▪ Use food waste as a protein source for animal feed ▪ Tighten water protection zones ▪ Institutional change: biomethanisation with sustainable development, not energy			
	▪ Increase N-fixing leguminous crops production (Dairyman 2010)	+ 0.3 kt	▪ Legumionous crops cultivation, harvesting, processing, trading costs	▪ Reduced feed imports ▪ Enhanced grassland biodiversity ▪ Reduced N pollution ▪ Reduced reliance on Nsynth ▪ Improved CO_2 sequestration
Consumer behaviour and lifestyle	▪ Dietary changes: o reduce individual animal protein intake by min 30% to meet WHO's health recommendation (less meat&milk, reintroduction of "Fridays without meat") o reduce food overconsumption o reduce food waste by 30% o favour local, seasonal, robust, field-grown food o increase food prices to reflect real economic price ▪ Mobility changes: o Disincentives to use car, to fly for fun o Compliance with speed limits, esp. during ozone exceedance levels o Shop on foot/by bike	1.75 kt	▪ Changes in farm income (meat/milk can be substituted by leguminous crops?) ▪ Changes in retailer income (milk producers, meat traders,...) ▪ Cost of a communication strategy ▪ Incentives costs ▪ Control costs	▪ Improved individual health, avoided national health cost (obesity, diabetes, cancer, cardiovascular diseases ▪ Reduced household food expenses ▪ Reduced food production costs if less is produced/wasted ▪ Reduced feed import costs ▪ Reduced overseas deforestation due to soybean production ▪ Increase in farm revenue from local food production ▪ reduced traffic due to food imports ▪ reduced emission from food processing, refrigeration, packaging
Settlements and Waste water	▪ Fix sewage leaks and losses ▪ Incentives to save drinking water and reduce effluents volumes ▪ Separate water collection system (household / industrial) ▪ Recover N from WW before denitrification (ENA (2011) p.	4.3 kt	▪ High Infrastructure and process costs ▪ Incentives costs ▪ Control costs	▪ Reduced emissions and discharges from WW ▪ Avoided fertiliser use and costs ▪ Reduced Water treatment costs

	548) • Recycle human urine (phosphorus and nitrogen recovery) • Increase WWTP price to industry and households • Tighter controls and sanctions for exceedance of Nitrate limits			• Higher fertilisation self-sufficiency • Co-benefit of recycling phosphorus
Total N savings and reduction potential 2010 (kt N/yr)		**24 – 30**		

Source: Synthesis based on the calculated Luxembourg NiNB 2010, Convis (2008), Dairyman report (2010), Water Administration (2012), on Interviews and Literature: Maurer et al (2003), DüV (2006), IPCC (2007), Garnett (2008), Liu et al (2010), Umweltbundesamt (2009), Sutton et al. (2011), Nyfeler D (2012)

Legend: the savings reduction potential has been evaluated as follows:

- Fuel combustion: 10 kt = 21 kt NO_x emissions validated for Luxembourg by the NECD minus the NECD ceiling to be achieved by Luxembourg of 11 kt
- Agriculure: est. Nleach/runoff savings of 8 to 14 kt NO_3 in 2010
- N-Fixing legumes: BNF was 0.13 kt N in 2010, and 0.3 kt N in 1960. The aim is to reach the same leguminous production levels as in the 1960, that is 0.3 kt N from BNF.
- Consumer behaviour: by reducing food waste and protein-rich diet, minimum 30% of 5.8 kt N in food could be saved, that is min 1.75 kt N.
- Waste Water: 4.3 kt N are recoverable in WW for fertilisation purposes (Table 7)

5.2. Significance of the Luxembourg NiNB 2010 results for designing mitigation measures

From Table 8 above, four abatement policy priorities with potential high N-impact are discussed. They concern first and foremost the transport, the agriculture and food production, as well as the wastewater sectors.

5.2.1. N-efficient Transport

Existing guide and limit values for the protection of human health from risks posed by NO_x and ozone in the air are being exceeded by 6 kt on a “fuel used” basis and 35 kt on a “fuel sold” basis. NECD directive and UNECE emission reduction objectives are not achieved in 2010. This is due to the substantial import and trade of fuel at attractive prices, compared to neighbouring country’s fuel prices. In 2010, Luxembourg imported and sold 2 840 kt of fuel, thereof 65 % diesel.

Along with other measures, such as a reduction of the Luxembourg dependency on imported fossil fuel sales, a tightening of fuel-combustion related emission regulations seems necessary to comply with international ceilings and standards. Another multi-beneficial measures would be to protect and extend the forest and grassland cover, since forests and grasslands are the highest removers of GHG (NIR 2013 p. 83).

5.2.2. N-efficient Agriculture

a. Substitution potential of imported artificial fertiliser by domestic organic N-sources

At the agricultural stage, technological and managerial approaches to N-mitigation could be taken. IPCC (2007) summarises the N related measures for GHG emissions reduction in the food chain as follows:

- Optimising nutrient use;
- Improving agricultural productivity;
- Managing and benefiting from the outputs: including manure and plant biomass: composting, and the use of anaerobic digestion.

When considering the option to benefit from Norg ouputs and substituting Nsynth with Norg, a critical question relates the legal limits imposed by the Nitrates directive and its national transposition texts. The EU Nitrates directive limit for Norg is currently 170 kg to be applied per hectare per year in the EU member states. This limit could is being reduced to 130 kg N/ha in the planed water protection zones, to be established by Luxembourg in compliance with the Nitrates Directive (Asta, Email MW, 11.3.2013)

Under given circumstances and considering the domestic availability of 12 kt N from animal excretions and of roughly 120 000 ha agricultural land used for spreading (Water Administration 2012, p. 35), a total of maximum 100 kg Nexcr was available per ha in 2010, leaving room for another 70 kg Norg/ha/year of non-farm organic sources. (For the water protection zones, this quantity would be about 30 kg Norg/ha/year). The total Nman available in Luxembourg is therewith not enough to systematically provide the legal potential of 170 kg Norg/ha (Marx S, interview 22.1.2013, Annex 5). There are also geographic differences in the availability of Nman: Livestock farms in the Centre and North of the country have more Nman/digestate available than crop farms in the South (Boonen S, interview, 14.4.2013).

In 2010, the following non-agricultural Norg sources existed in Luxembourg: composted kitchen/garden/forest waste (0.22 kt), composted sewage sludge (0.02 kt), “biodigested” organic waste (0.05 kt), waste water and sewage sludge and slurry (4.3 kt). The total domestic non-farm Norg capacity is estimated to reach up to 4.8 kt/yr (annex 4 Step 2.1.2) This would mean a theoretical availability of non-farm Norg of 38 kg/ha/yr. This technical potential for non-farm Norg is still far below the legal potential, yet available after having made use of the animal effluents. Beside the technical potential, Vaneeckhaute C, et al. (2013a) indicate that use of digestate might stimulate nutrient mobilisation from the soil, thereby increasing use efficiency of soil minerals, whereas the major part of N is lost during the composting process.

If the Nitrate directive limit of 170 kg Norg would be reconsidered (at the expense of Nsynth?), the organic non-farm substitution margin could be increased (Boonen S interview 14.4.2013, Annex 5).

b. Substitution of imported feed by locally grown protein carriers

Many claim that N-fixing legumes can partially substitute synthetic N-fertiliser (Crews et al (2004), Nemecek et al (2008), Dawson et al (2010), Pelletier et al (2011)). For Luxembourg, locally adapted legumes could partially displace imported soymeals. The use of local peas and beans as protein carriers has, with a national production of 0.97 kt in 2010 from an average of 1.7 kt in the 1960s, been on a steady decline since the 60 with the exception of the season 2009/10 (Fig. 11). The Ministry of Agriculture (2011) advances that this is due, among others, to the unattractive profits to earn for leguminous protein plants production, which face high labour cost, high crop fallouts rate for low market prices. For Marx S (interview 22.1.313, Annex 5), expansion of leguminous cultivation is also hindered by the fact that soy imports are comparatively cheaper and Luxembourg soils not adapted. Their substitution potential, acknowledged by Convis (not dated) to rape and soybean meal imports is not used.

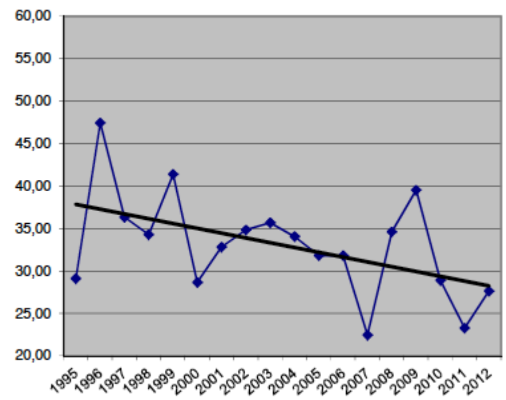

Fig. 11 - Total dried pulses production per ha, Luxembourg, 1995-2012 (100 kg/ha)
Source: SER (2012)

However this might change with the announced "greening" of the EU Common Agricultural Policy, promoting legume crops. This is currently already the case in Switzerland, where the N-input to agriculture is almost as high from BNF as from mineral fertiliser (Leip et al 2011).

5.2.3. N-efficient Food Consumption

Food is identified as one of the main systems that has an impact on the environment (EEA 2013). According to Garnett T (2011), food accounts for up to 31% of the EU-25's total GHG impacts, with a further 9% arising from the hotel and restaurants sector, without accounting for the food consumption-induced land use change emissions. Fig. 12 shows GHG mitigation options in the food chain: they are highest if animal products are reduced in the diet, and if the food chain's energy and fuel efficiencies are increased.

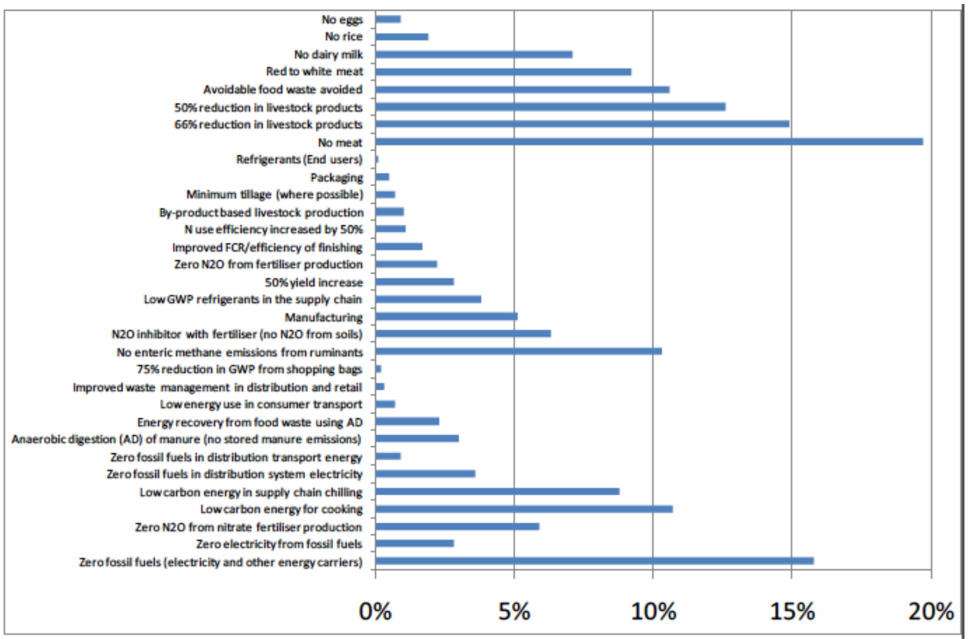

Fig. 12 – Food supply chain emission reduction potentials according to their importance
Source: Quoted in Audsley, Brander, Chatterton et al (2006)

The Luxembourg population (resident and commuting) is projected to continue its ascending curve. The demographic expansion will translate into an increase of food and protein demand as well as of the effluents volumes, and an intensification of traffic. A general intensification of N-emissions and escalation of pressures on all natural resources, including valuable farmland, water and atmospheric quality can be expected. This is particularly true for meat and dairy productions which are energy and N-inefficient. For a kg of beef protein about 15 times more N is needed compared to a kg of vegetable protein (Leip et al 2011). Luxembourg could make a weaning from its animal protein-rich diet and therewith try to meet the WHO's recommendation for maximum daily protein intake without negative health consequences.

The challenge consists in revising the overall approach to consumerism, in rethinking the consumers relationship with their food and waste, in reversing the "insular" conception of consequence-less consumption and unlimited abundance, in simplifying the food chain, in increasing the national food self-sufficiency.

5.2.4. N-efficient Waste water treatment

Existing guide and limit values for the protection of human health from risks posed by nitrate in drinking water are being exceeded. The EU Nitrate and the Water directives discharges objectives are not achieved in 2010.

The performance of the Luxembourg WWTP is thus not optimal. "Many WWTP receive too large quantities of WW, exceeding their treatment capacities. This excess WW load is a result of inadequate WWT capacities with respect to the demographic trends, as well as outdated and obsolete WW collection systems transporting too much rainwater." It is also difficult for the WWTP to cope with the non-residents surplus during daytime. As a consequence, sewage sludge is carried over into the receiving rivers. For complying with the EU Urban Waste Water Treatment Directive (91/271/EEC), "many WWTP would need to be equipped with a tertiary treatment phase" (Water Administration 2011). EEA (2010b) notes:

"A dual-channel system to separate rainwater (which can re-infiltrate the water table naturally) and sewage (which requires purification) is still not in place, with the exception of the cities of Luxembourg and Esch-sur-Alzette and in new housing developments".

The denitrification process in WWTPs improves the ground and surface water quality. However, the N contained in WW, instead of entering and polluting the surface waters, returns to the atmosphere, from which it was extracted to be fixed and become fertiliser in the first place. By denitrifying fixed N back into the atmosphere, the energy to produce fertiliser is lost. The synthesis of N through the Haber-Bosch process requires 1 ton oil equivalent (toe) for producing 1 ton of synthetic N-fertiliser. If Luxembourg recovered N from WW, containing in average 4.3 kt N/yr[1], to fertilise the fields, the country could save a minimum of 4.3 kt toe/yr, or 40 GWh/yr of energy (Delfosse, Kessler 2012). The potential of recovery of N in WW and organic waste (Vaneeckhaute 2013a,b) can be estimated to represent min 38 % of the national inorganic fertiliser imports (Table 9). If the total food N indigested (5.8 kt N in 2010, Fig. 7) were recovered, the substitution potential would rise to 48 %. One estimate sets the environmental value of removing N from waste water to 0.5 €/m3 (UNEP 2010).

Table 9 - Potential for substitution of Nsynth by non-farm Norg in agriculture, Luxembourg, 2010 (kt N/yr)

N-input from imported Nsynth	N amount in waste water (Residents only)	Non-farm N content in digestate	N amount in compost	Tot max domestic non-farm N org available	Substitution potential of Nsynth by local non-farm Norg (%)
12	4.3	0.05	0.22	4.57	38%

Source: own calculations based on SER, Water Administration 2012

If the plant nutrients found in wastewater can be returned to the soil, they can form part of a natural cycle, enabling money to be saved and the environment spared. New pilot WWT systems are being developed to capture N contained in WW and recycle it back into the food production chain. According to the Swedish Environmental protection agency (2013) "Alongside the continued improvement in sludge quality, there is scope for restoring nutrients by separating urine and toilet water from solid matter, and also for recovering the nutrients in and extracting contaminants from sludge. Since pathogens may occur in various fractions of sewage, there is a need for hygienisation to take place before sludge is used on land."

Biomethanisation of WW slurry is one technical possibility to recover N in a sanitised way from WW for fertilisation purposes, instead of denitrifying it back to the air (Rajagopal et al. (2013)). Composting sewage sludge together with other organic waste to create fertiliser, energy and fuel is successfully being implemented by the Luxembourg company *Soil-concept*.

5.3. Transposition of the Luxembourg NiNB 2010 findings into per capita values

5.3.1. Overall Luxembourg exceedance of international per capita N-use values

The per capita N-consumption values calculated in the NiNB process are found to be higher than the values given for Luxembourg by the SER (Table XI Annex 4) and replicated by international organisations, be it on a "residents" or on a "residents and commuters" (effective eaters) basis (Table 10 below). With around 11.5 kg N (residents) and 10 kg N (effective eaters) (Table IX, annex 4), the individual food N-intake is almost three times higher than the WHO recommended protein N-intake of approximately 3.4 kg N cap/yr (WHO 2007, quoted in ENA 2011, p. 17). The effective world average annual protein intake per person is 27 kg (FAOSTAT), that is 4.32 kg N per capita. In 2010, for an average Luxembourg resident it would be 72 kg proteins/yr or 11.5 kg N intake via food.

Table 10 below shows also that, as for N indigested with food, the national per capita N-use values lie above the known international reference averages for all documented N forms.

[1] WW containing 3.6 kt N (Water administration 2012) to 4.8 kt N (Conversion of WW into N, Annex 4, Step 2.1.2) n 2010

Table 10 – Transposition of the Luxembourg NiNB 2010 findings into per capita use/release values for different Nr forms, and comparison with international references (kg N/cap/yr)

N forms	International average annual per capita reference value	Luxembourg NiNB 2010	
		Per capita value on a "resident and commuter" basis	Per capita value on a "residents only" basis
N food	3.4 - 4.3 kg (WHO, FAO)	10	12
Nfert	5 kg planetary boundary	23	26
NOx	41 kg (EEA)	80	92
NH3	8 kg (EEA)	9	10
N2O	0.04 kg (German NIR)	3	4
NO3		25	29
N2		19	22
Total personal N-use		**169**	**194**

N container and flow	National totals as calculated with the NiNB (Fig. 7 and Table 4)	Luxembourg NiNB 2010	
		Per capita value on a "resident and commuter" basis	Per capita value on a "residents only" basis
N-input (national input)	135 kt N/yr	234	269
N in useful products (food, feed, fertilisers)	50 kt N/yr	86	100
N-loss ecosystems	46 kt N/yr	**80**	**92**

Source: own calculations, see Tables 4 and 5 above; Tables IX and XI in Annex 4

* NIR 2013 using a German default N2O use per capita figure (40g/cap/yr, from the German NIR

Two indicators are of particular interest here:

5.3.2. The personal N planetary boundary

The N planetary boundary was defined by the Swedish Environmental Protection Agency (2013) as the maximum removal of N_2 from the atmosphere for the production of synthetic fertiliser that can be operated within the carrying capacity of the planet, that is without provoking irreversible negative changes to the environment. It has been set at 25 % of the current level of the worldwide Haber-Bosch fertiliser production (121 Mt/yr), that is 35 Mt per year. When setting each country and each world citizen on an equal footing, this would mean in per capita terms that each world citizen would have 5 kg Nfert/year at his/her disposal for producing food. Luxembourg's absolute territorial Nfert use would be 2.5 kt instead of the current 13.3 kt Nfert.

A Luxembourg resident used 26 kg Nfert in 2010. This is 5 times what the planet can support and 5 times more than his/her fare per capita share of Nfert available in the world.

Luxembourg citizens, in line with other high consumptive nations, excrete on average 12 g Ntot per population equivalent (PE) per day, equivalent to 4.3 kg N/yr/cap (Water Administration 2011; Annex 4 Step 2, title 1.2 *Conversion of PE of WW into N*). This leads the Swedish Environmental Protection Agency to conclude that "the per capita planetary boundary of 5 kg Nfert a year corresponds well with the amount of N in urine and faeces that could be reused, closing the N cycle. Limiting the Nfert use to this level is arguably in the right order of magnitude."

5.3.3. The personal N-footprint

Whereas data is generally available to measure major N categories consumed per country, this is not so for the consumptive use of N, i. e. how much N embedded in goods and services is used worldwide within national borders and per capita.

Another integrated producers-consumers-policymakers model is in preparation under the auspices of the University of Virginia, the Energy Research Centre of the Netherlands, the University of Maryland, the University of California and INI – the International Nitrogen Initiative. For now only the consumer's tool is operational. It is called Nitrogen footprint calculator (N-calculator). This N-calculator aims at providing information on how individual and collective action can result in the loss of Nr to the environment. The calculator consists of an online questionnaire resulting in the measurement of the personal consumer's N footprint. N-footprints were calculated for the United States and the Netherlands, which were found to be 41 kg N/capita/yr and 24 kg N/capita/yr, respectively (Leach et al. 2012).

The N-footprint initiative also produced a new indicator describing the *potential loss of* N_r *to the environment* and expressed as the N_r loss per capita per year. This indicator is now on the list of potential new indicators to be adopted by the Convention on Biological Diversity (CBD), in relation to its Aichi Target 8: "By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity".

For the present research, an N-footprint questionnaire was administered in Luxembourg in April-May 2013. A press announcements (in German and English) invited people randomly to fill in the online questionnaire. Due time and word count constraints, the questionnaire results could unfortunately not be used to corroborate results. The press announcements as well as the results of the questionnaire are presented in Annex 7.

As a result, the 37 respondents had in average an annual N-footprint of 22 kg N in 2013. As for the USA and the NL, an overwhelming part of the Luxembourg footprint is taken up by the food portion (17 kg N per respondent for food production and consumption). This confirms the high-protein diet of Luxembourg consumers, but falls short of the total quantity of Nfood/cap/yr derived from the NiNB (up to 100 kg N/cap/yr used in the food supply chain). Transport is with an average of 4 kg N/cap/yr the second largest portion, but falls short of the 92 kg NO_x emissions per capita derived from the NiNB.

Further research efforts are needed to expand, analyse and evaluate N-footprint results in order to derive robust data. However, from a preliminary analysis it can be said that the Luxembourg N-footprint seems underestimated when compared to the findings of the Luxembourg NiNB 2010.

6. CONCLUSIONS

Despite of the measures taken by Luxembourg over the years to improve its Nitrogen performance, most of the N related environmental and health quality objectives and targets have not been met in 2010. Notwithstanding uncertainties, the N-surplus of 46 kt N in Luxembourg in 2010, calculated by the present NiNB work, must be assumed to be considerable. This would mean that at least 30 % of the N available for Luxembourg to prosper (135 kt N) is potentially lost to the environment. NUE is generally low in the Luxembourg milking nation, who will need to find how to feed more residents with less N.

The Luxembourg NiNB 2010 shows that transport and other combustion processes are the main source of anthropogenic N-emissions, followed by agriculture. Emissions to air exceed emissions to water, which in turn appear underestimated. Additional measures are needed to abate pollution of air, water and soil, to protect people's health (high atmospheric NO_x and NH_3) and to maintain biodiversity and forest vitality (ozone depletion pressure). A significant reduction of N_2O is required in order to diminish Luxembourg's contribution to climate change. While the conversion of Nr into harmless atmospheric N_2 in terrestrial and aquatic ecosystems is especially difficult to establish, it can be advanced that the potential to recover wastewater-N for fertilisation purposes represents around 38 % of the national synthetic fertiliser needs.

Technically 38 kg of the 100 kg Nsynth could be replaced by local non-farm organic N-sources. This technical potential is still far below the legal potential, yet available after having made use of the animal effluents. The potential of local Norg can grow further, by promoting BNF, organic waste recycling, sanitised WW sludge use in agriculture.

The research also highlights the individual consumer responsibility for the N-pollution deriving from food production, car driving or flying. There is a need for nitrogen-efficient behavioural changes in order to reduce individual N-losses to the environment.

Measures to address the N-pollution have been indicated but need to be further assessed as to their cost-efficiency and effectiveness in order to assist policy decision makers in the choice of the most cost-efficient N emission reduction measure. The German *Integrated strategy for the reduction of N emissions* (Umweltbundesamt 2009) is a good example on how to go about it.

Although beyond the scope of the present research, it is however pointed out that much can be expected from such a cost-benefit analysis:

> "The social cost of impacts of N in the EU27 in 2008 was estimated between €75-485 billion per year. A cost share of around 60% is related to emissions to air. The share of total impacts on human health is about 45%. The economic benefit of N in primary agricultural production ranges between €20-80 billion/yr and is lower than the annual cost of pollution by agricultural N which is in the range of €35-230 billion/yr. Internalizing these environmental costs would lower the optimum annual N-fertilisation rate in Northwestern Europe by about 50 kg/ha. Acknowledging the large uncertainties and conceptual issues of this cost-benefit estimates, the results support the priority for further reduction of NH_3 and NO_x emissions from transport and agriculture beyond commitments recently agreed in revision of the Gothenburg Protocol."
>
> Source: Van Grinsven H, Holland M, Jacobsen B, Klimont Z, Sutton M, and Willems W (2013)

If food production, mobility, dietary habits and waste handling are changed, it can cautiously be concluded that the quantitative potential exists for a "win-win scenario" (see Introduction, p. 11) to materialise. This requires however major changes towards a low-consumption, low-emissions, low-waste economy and society, and a "revised social contract between producers and consumers" (Dawson et al., 2010).

Then again these changes are deemed inevitable, since food security, human health and intact life-support ecosystems are invaluable assets. The high initial investment costs these changes imply, may be offset by the future financial savings from lowered costs for nutrients import, health care and environmental restoration.

A NiNB is a normative tool to help visualise the main elements of the N-cascade and guide policy prioritisation. However, like every normative approach to resource use, the full complexity of the question cannot be synthesised in one figure. By its integrative nature, the exercise limits risks to design mitigation measures, which ignore the cumulative effects, the potential synergies or the risks for pollution displacements between pools and Nr forms (Umweltbundesamt, 2009).

As to the methodology of the present research, the case study design does not allow to generalise or establish causation. The comparative information generated can only elicit an association between variables. The NiNB model in itself could be made more user-friendly and self-explaining in order to grow in popularity and use. This would foster its use as “a tool for monitoring the impact and environmental integrity of implemented policies” (Leip et al 2011a).

Specific Luxembourg priorities for further research could be :

- Reduce uncertainties and close the knowledge gaps,
- Study the effects of intensified trade and logistics fluxes considering that the national NO_x emissions exceeded their ceiling by 87 % in 2010;
- Forecast the development of N-fluxes and their effects;
- Improve N-monitoring and survey methods (Hoffmann 2013), monitor and update the present NiNB 2010 regularly, in order to inform which policies are effective in achieving set objectives and targets.
- Analyse costs and benefits of the mitigation measures, integrating societal and environmental parameters and focusing on “measures and instruments with synergistic and antagonistic (“pollution swapping”) effects” (Umweltbundesamt, 2009). The analysis should calculate different fertiliser taxation scenarios, allowing to derive a more sustainable taxation model than the current preferential Value added Tax advantage for the purchase of inorganic fertiliser;
- Investigate the potential for preferential sanitised digestate applications to fertilise the fields (as compared to compost applications since the majority of N is lost in the composting process, whereas it is preserved with the biomethanisation process) as a means to reduce N-emissions from fertilisation and to recover N in sewage sludge;
- Develop an N-footprint for Luxembourg, based on the survey methodology designed by the University of Virginia (Annex 7), in order to contribute to the establishment of the forward-looking indicator Total per capita N-loss to the environment.

The success of a Luxembourg N-mitigation strategy would reflect in an enhanced food and protein self-sufficiency, better human health and lesser pressures on the country’s limited natural resources.

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9. LIST OF APPENDICES

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7. N-print questionnaire

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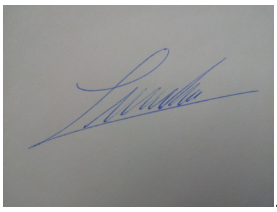
Signature: ………  … Date: September 15, 2013

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EB-30 Informal document no. 8 (revised)

Draft Guidance document on National Nitrogen Budgets

Submitted by the Co-chairs of the Task Force on Reactive Nitrogen

A. Pre-amble

Nitrogen budgeting at the national level has been proposed as a new provision in the Annex IX of the revised 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone. The Expert Panel on Nitrogen Budgets (EPNB) of the Task Force on Reactive Nitrogen has prepared a draft guidance document for establishing these nitrogen budgets at national scale, which is presented here.
The purpose of this "Guidance document on nitrogen budgets" is to provide clear recommendations which nitrogen pools and nitrogen flows should be considered for the construction of National Nitrogen Budgets (NNBs), and how these pools and flows should be combined. It is important to understand that "budgets" as defined here will not be limited to describe the flows across given system boundaries, but cover also stock changes and internal flows. All concepts are developed to allow guidance also for a broader range of Nitrogen Budgets (NBs) at different scales and also for economic entities.

B. Introduction

Nitrogen Budgets (NBs) respond to the needs of policy makers and national experts to coordinate activities assessing potentially adverse nitrogen flows in and to the environment. National and international regulations require the collection of relevant information about such flows or about the resulting environmental state. Often such information is specifically compiled for the agricultural sector, recognizing the importance of Nr as plant nutrient, while not fully reflecting the complete picture of the environmental nitrogen cascade. NBs overcome this problem (Leip et al., 2011):

(i) NBs are an efficient instrument for visualizing the N cascade and its potential impact and thus help to raise awareness;
(ii) NBs provide policy makers with information for identifying intervention points and developing efficient emission reduction measures;
(iii) NBs can provide a tool for monitoring the impact and environmental integrity of implemented policies;
(iv) NBs are useful for comparisons across countries; and
(v) NBs can help pinpoint knowledge gaps and thus contribute to improving our scientific understanding of the N cascade.

The present document provides guidance to build NBs with a focus to the national scale (national NBs or NNBs). The NNBs will support validation of environmental nitrogen flows (by way of identifying inconsistencies) and guide the identification of intervention points to regulate environmental nitrogen emissions or releases and to optimise N use. In order to fulfil these goals, a minimum number of pools and flows considered is needed, which also requires harmonization between countries.

To this purpose, this document (i) provides a clear terminology to be used when constructing NNBs and (ii) gives a description of the elements (pools) that must be included in any NNB taking into account the need to integrate existing structures and available documentation. Once NNBs becomes operative, additional descriptions and details for each of the pools will be developed.

C. Terminology

The following terms are described here in order to provide a better understanding of nitrogen budgets. They are therefore presented in a logical rather than alphabetical order.

A **Nitrogen budget** (NB) consists of the quantification of all major nitrogen flows across all sectors and media within given boundaries, and flows across these boundaries, in a given time frame (typically one year), as well as the changes of nitrogen stocks within the respective sectors and media. NBs can be constructed for any geographic entity, for example at supranational level (e.g., Europe), sub-national level (regions, districts), for watersheds or even individual households or for economic entities (such as farms). National NBs (NNBs) use the borders of a country including its coastal waters as system boundaries, such that the atmosphere above and the soil below this country are also included.

Pools: Nitrogen pools are elements in a nitrogen budget. They represent "containers" which serve to store quantities of nitrogen (these quantities may be referred to as nitrogen stocks). Exchange of nitrogen occurs between different pools via nitrogen flows. Nitrogen pools can be environmental media (e.g., atmosphere, water), economic sectors (e.g., industry, agriculture) or other societal elements (e.g., humans and settlements). Selection of pools may differ between budgets, e.g. for a NNB, all relevant pools to describe the nitrogen budget at a country-level shall be included.

Sub-pools: Pools can be further divided into sub-pools if sufficient data are available. For example, the pool "inland water" can be divided into groundwater, lakes, rivers, etc., with additional nitrogen flows across these sub-pools to be quantified.

Stocks represent real-world accumulations. Each pool can store a quantity of nitrogen, for example, as mineral or organic nitrogen in soils (for instance as in agriculture or semi-natural lands/pools). This quantity is the nitrogen stock. Nitrogen stocks may be very large with respect to nitrogen flows (e.g., for soil pools), and often N-stocks are difficult to quantify. However, the most relevant parameter for the NB is a potential stock change, i.e. a variation over time of the respective accumulation, rather than the nitrogen stock itself. Nitrogen stocks can be composed of N in any nitrogen form.

Flow: Nitrogen flows describe the transport of nitrogen over time between the various pools of an NB, or between the sub-pools within a pool. They also link any pool with the pools outside the system boundaries, the 'rest of the world' (RoW), in the form of imports or exports (e.g., trade, atmospheric transport, riverine export). Flows of nitrogen can occur as 'reactive nitrogen' (Nr) or N_2. In addition, flows during which the transformation of nitrogen from reactive nitrogen to molecular N_2 or vice versa need to be considered. These flows include fixation (biological nitrogen fixation by plants and technical fixation by combustion processes or ammonia synthesis) as well as conversion of Nr to N_2 (resulting from denitrification and the anammox processes in soil biology, or from recombination during combustion). Flows must be represented in the same unit, e.g. in tons of N per year, or in tons of N per km^2 per year (also termed "flux").

Nitrogen forms: Nitrogen can occur in various forms, some of which are irrelevant for NBs. An NB needs to cover reactive forms of nitrogen only.

> **Reactive nitrogen (Nr):** Reactive nitrogen (Nr) is any form of nitrogen that is available relatively easily to living organisms via biochemical processes. These compounds include NH_3, NO_x, N_2O, NO_3, organically-bound N in plants, animals, humans and soil – and many other chemical forms.
>
> **Inactive nitrogen:** Some forms of nitrogen may be considered inactive or inert as they are inaccessible to biosubstrates. This regards primarily molecular nitrogen (N_2), which is the dominant N species but can be excluded from an NB as separated by the considerable amount of energy to become bio-available. This activation process then constitutes a flow bringing Nr from this origin into a nitrogen budget. By way of analogy, other inactive natural forms of N are excluded from the nitrogen budget until being activated (e.g., N contained in mineral oil and its products).

Balance: Ideally, the balance of a pool, a sub-pool, or a full NB is closed, i.e. all nitrogen flows can be explained as input, output or stock changes. The balance equation $N_{output} + N_{stock\_change} - N_{input} = 0$ then. Such a closed N-balance is theoretically possible for each pool defined and for a full NB. In practice, a closed balance is not a requirement of an NB and the balance becomes a value different from 0, with the difference referring to unaccounted nitrogen flows, including any errors. Un-accounted nitrogen flows indicate that contradicting/inconsistent data sources are used or that some data are missing. Both cases point to a need of better integration of the scientific understanding.

Uncertainty: Provides a quantitative estimate on the influence of imperfect information on the quantity of a nitrogen flow or stock change. Uncertainty assessment helps to set the priority for improving nitrogen budgets and is an important element of quality assurance in NBs. According to standards set by the IPCC which should be used here, too, a quantitative description of an uncertainty range should cover 95% of the total sample space. Uncertainty quantification typically will not cover bias, as any bias will be corrected as soon as it gets discovered.

D. Pools in National Nitrogen Budgets

A NNB must include all relevant pools that store nitrogen in N-stocks and exchange nitrogen with other pools or the RoW. An example has been established by Leip et al. (2011) as a contribution to the European Nitrogen Assessment (ENA). It contains a set of national nitrogen budgets, as well as a European budget (Figure 1).

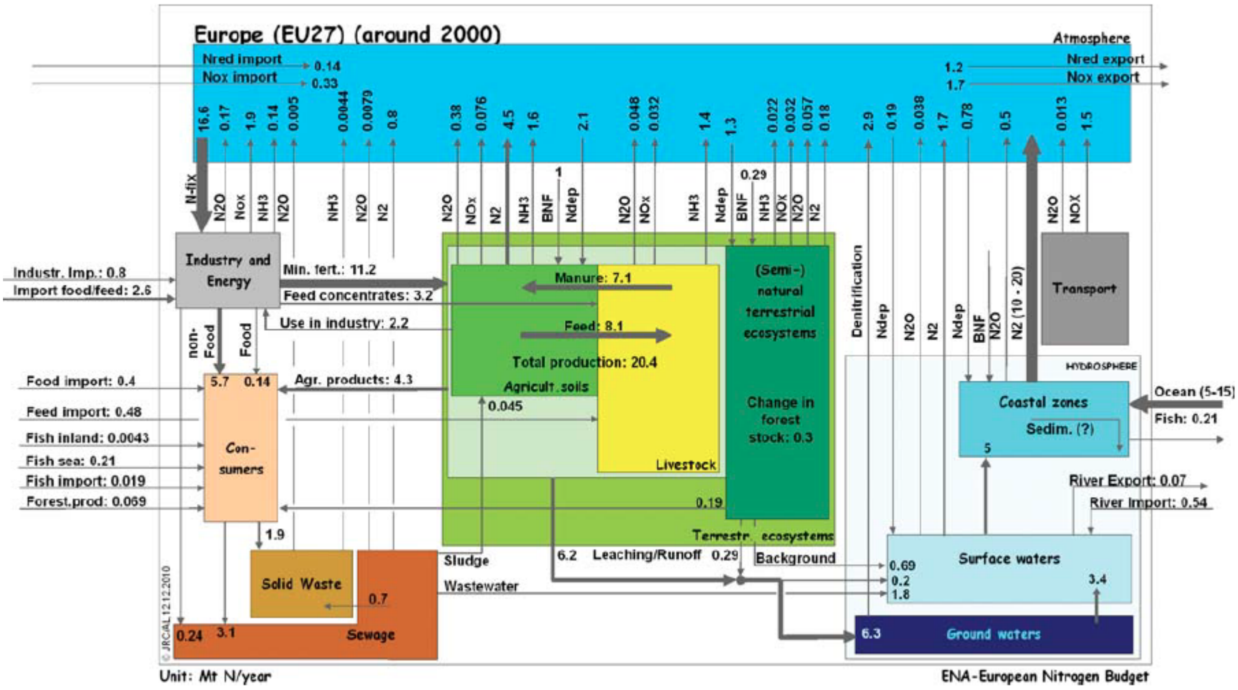

Figure 1: ENA Nitrogen budget (Leip et al., 2011)

The European NB provides a comprehensive picture of nitrogen flows in Europe and can thus serve a reference. However, the challenge of this guidance document consists in building upon existing and well-established schemes, which provide appropriate information on a range of scales. For NNBs it is important to take advantage of existing structures, and to remain fully compatible with each of these activities while minimizing resources to close the remaining gaps towards a NB. Specifically of interest in the context of NNBs are national balances, as well as reporting obligations for national emissions of Nr for which guidance has already been developed which are successfully applied in many countries:

The OECD, in cooperation with Eurostat, developed a handbook on gross nitrogen balances (OECD, 2007) and is estimating the agricultural gross nitrogen surplus at a regular basis for OECD countries

The EMEP/EEA air pollutant emission inventory guidebook (EEA, 2009) provides guidance on estimating emissions from both anthropogenic and natural emission sources of NO_x and NH_3.

The IPCC guidelines for National Greenhouse Gas Inventories (IPCC, 1997, 2006) provide guidance on the quantification of anthropogenic N_2O emissions.

In order to benefit, as much as possible, from the detailed data available from the air pollutant and greenhouse gas inventories submitted to EMEP (EEA, 2009) and the UNFCCC (see IPCC, 2006 and 1997), their structure is integrated closely. This also entails maintaining IPCC notation for reasons of consistency, except that classification focuses on pools in contrast to the economic sectors used in the IPCC guidelines.

A NNB must be composed of eight essential pools (Table 1). For some pools information on sub-pools must be provided. This concerns the Energy, Agriculture and the Waste pools, for which additional detail is required in order to include important flows occurring to- or from sub-pools and to provide a fully comparable national system. The definition of the subpools has been done according to IPCC definitions, thus data will be readily available.

The aim is for the list of pools to be comprehensive, i.e., any conceivable significant nitrogen flow between (sub-) pools can be accommodated into this scheme.

Table 1: Essential pools and sub-pools to be included in a NNB

Pool-ID	Sub-pool	(Sub)Pool-Name
1		**Energy and fuels**
1	A1 + B	Energy conversion (includes flaring and fugitive emissions from fuels)
1	A2	Manufacturing Industries and Construction
1	A3	Transport
1	A4	Other energy and fuels (e.g., residential)
2		**Material and products in industry (processes)**
3		**Humans and settlements**
4		**Agriculture**
4	A	Animals
4	B	Manure / manure management
4	C/D/E/F	Crops & agricultural soils
5		**Forest and semi-natural vegetation including soils**
6		**Waste**
6	A	Solid waste disposal
6	B	Wastewater handling
6	C	Waste incineration
6	D	Other waste
7		**Atmosphere**
8		**Hydrosphere**
8	A	Inland waters (including ground water)
8	B	Coastal and marine waters

E. Description of the pools

1 Energy and fuels

The 'Energy and fuels' pool encompasses the flows of nitrogen of energy conversion sites, industry, transport and other uses of energy and fuels. The flows of nitrogen to be quantified include input flows (N-fixation) and output flows (Nr emissions). Input of nitrogen occurs both by 'activating' nitrogen contained in the fuels and through thermal generation of Nr at high temperatures during the burning process. Distinction between these two flows is difficult, however, and not required.
Emissions of Nr are linked to fuel use the sub-pools, as reflected in national energy statistics and their implementation in UNFCCC/IPCC reporting. This is relevant to nitrogen pollution and emission flows are generally well covered in atmospheric / GHG inventories. Even the questions of international transport and allocation of emissions in cross-boundary transport have been addressed in such inventories.

2 Material and products in industry

Typically, statistical information (energy statistics) differentiates between fuel combustion and feedstock use of fuels. IPCC deals with the latter case under "industrial processes", a convention that is mimicked in NNBs.
Main input flows are nitrogen fixation processes, such as the Haber-Bosch ammonia synthesis. Industry processes use also nitrogen in agricultural products and imported products. Output flows that need to be quantified are fertilisers, compound feed products, food products, and non-food chemical products (nitric acid, melamine, caprolactam, etc. as used for example in explosives, plasticisers and nylon).

3 Humans and Settlements

A separate sector in the IPCC guidance covers the use of compounds that are subsequently released into the atmosphere. For NNBs, this concept needs to be extended, to subsume "humans" as a pool encompassing various sub-pools:

- the human body with intake of nitrogen in food from agriculture, fishery, industry, and output of nitrogen mainly to sewage systems;
- the 'material world' made of chemical products from industry which accumulate in the 'humans' pool or are disposed of, incinerated or otherwise managed in waste system;
- the 'organic world' with products from agriculture and forestry, including non-consumed food and

wood and paper products, but also flowers, package material etc. These products are entering various waste streams, i.e. sewage systems, landfills, waste incinerators, are composted or deposited in other ways.

non-agricultural animals (pets) that are fed on agricultural products.

The ‘humans’ pool is linked to the RoW through trade of products. Also the flows to and from the atmosphere (deposition, emissions) may need consideration. Output flows must be quantified to the different sub-pools of the ‘waste’ pool. Output flows to other pools are usually small, but should be quantified if significant.

4 Agriculture

Agriculture is a key pool for a NNB, and is a key driver for the global nitrogen cycle. Emissions of Nr from agricultural sources are important elements in environmental assessments. Agricultural flows are typically large and associated with high uncertainty. A NNB should differentiate the following sub-pools, defined in analogy to the IPCC source categories of the sector agriculture:

Animal husbandry (corresponding to category 4A). Input of nitrogen to livestock occurs through grazing, and feeding of crops/fodder and imported feed (concentrates). Output flows of nitrogen from livestock are in products (meat, milk, eggs, wool, etc.), non-carcass retained nitrogen in the animal body, and manure. Also emissions of Nr from animal housing systems might occur.

Manure management and manure storage systems (corresponding to category 4B). Input to manure management and storage systems is, first of all, from animal husbandry. The concept extends to N-input to biogas plants even when limiting to material from energy crops (consistent with approaches taken by EEA, 2009). Main output flows are emissions to the atmosphere and hydrosphere and application of manure on soils. If import/export of manure is a significant flow in a country, it should be quantified as well. Manure management and storage systems are important for emission mitigation measures.

Soil-based agricultural pools. This includes rice cultivation (category 4C), cultivation of upland crops (category 4D) including grazing by ruminants (category 4D2), and prescribed burning of savannas and field burning of agricultural residues (categories 4E and 4F). Input flows are the application of mineral fertilisers, nitrogen in manure that has been applied to fields (i.e., following spreading or from grazing livestock), nitrogen in other organic fertilisers (including crop residues), seeds, and N in atmospheric deposition and biological fixation. Output flows are harvested crop products, crop residues, and emissions of N to the atmosphere or hydrosphere.

In addition to IPCC’s definition of agriculture, NNBs consider not only soil processes, but also stock changes in animal husbandry, manure management and storage systems, and cropland and grassland soils.

In contrast to IPCC methodology, indirect emissions from agricultural sources are not included here, as they are no output flow from the agricultural pool. Instead, emissions of N following volatilisation and deposition of Nr are quantified for the pool where the atmospheric deposition happens (forests and other non-agricultural vegetation and soils, settlements, or inland or coastal/marine waters). Equally, emissions of agricultural N towards the hydrosphere are ‘followed’ along its path. This constitutes a deviation from IPCC’s approach but maintains consistency in the NNB.

The “Gross Nitrogen Balances” of the OECD (2007) have been used successfully to describe the nitrogen flows in the agriculture pool. More detailed information, supporting the development of some of the national coefficients used in the OECD approach, is being compiled by national authorities to fulfil the requirements of national GHG or air pollutant inventories. The DireDate project (Oenema et al., 2011) discusses the respective reporting requirements and data on agricultural nitrogen in detail and serves as an input to EUROSTAT’s activities to align the methodology for estimating Gross Nitrogen Balances with other international reporting obligations. Guidance provided here takes account of these existing activities and strives to harmonize, as much as possible, the different needs while taking advantage of existing activities. This will allow for a reassessment of data needs at all levels with respect to not only present nitrogen flows, but also potential flows under conditions of emission abatement. Integrating such options is important for the use of NBs to study intervention points.

5 Forest and semi-natural vegetation including soils

While the IPCC sector “Land use, land use change and forestry” focuses on carbon stock changes, the corresponding NNB pool assesses the related change in nitrogen stocks in biomass and non-agricultural soils. This comprises all natural and semi-natural terrestrial ecosystems, according to the CORINE land cover class 3

“Forests and semi-natural areas” (EEA, 2007). Input flows are atmospheric deposition, biological N-fixation, and application of mineral or organic fertiliser. Output flows are harvesting of products to industry, to the humans, or as a fuel to ‘energy’, as well as emissions to the atmosphere and the hydrosphere.

6 Waste

This sector is another major contributor of environmental nitrogen. By separation specifically between waste disposal, wastewater treatment, incineration of waste, and other waste streams, NNBs follow the same concept as IPCC. Due to coverage of multiple environmental media, several flows additional to the ones covered by IPCC need consideration. These include, specifically, waste and sewage produced by humans, application of sludge to fields and release of wastewater to surface waters.

7 Atmosphere

Atmosphere is used mainly as a transport medium, as the atmosphere serves to collect, to deposit and to transport reactive nitrogen under various chemical forms. Even though most of the available nitrogen is stored here in the form of inert molecular N_2, only the fraction present as Nr or being converted to or from Nr must be quantified. The quantification of conversions between compounds different possible atmospheric sub-pools (e.g., oxidised or reduces Nr-species) is not required, except for N_2 fixation to NO_x due to lightning, which is considered as an input flow. Other input flows are atmospheric import of Nr, as well as emissions from all other pools in a NNB. Also fluxes of N_2 from pools to the atmosphere are regarded as input flow. Output flows are biological and technical N-fixation, export of Nr by atmospheric transport and Nr-deposition to land-based pools.

8 Hydrosphere

The hydrosphere needs to be considered in addition to the existing IPCC categories. Water bodies not only provide a major environmental transport pathway but are also an important element in the nitrogen cascade. Some transformation processes, e.g. aqueous formation of the greenhouse gas N_2O actually take place here. Thus it is consistent to assign the “indirect” emissions due to leaching of agricultural nitrogen (in IPCC terminology) to the water pool, together with similar transformation of other water-available Nr. Again this difference to the IPCC approach is needed for consistency. Several other flows, most of which bear prime responsibility for water pollution, are specifically relevant for NNBs, as is the split into the individual pools describing inland waters (groundwater and surface water) and marine waters (such as coastal lagoons and estuaries). The quantification of imports and exports via surface and ground waters is of special importance for NNBs. These processes may play a dominant role for closing balance equations of the water pools.

F. Specific guidance on each nitrogen pools of a NNB

This guidance document contains the framework under which specific guidance to each of the 8 pools listed including the required sub-pools can be developed (to be added as Annexes to the document). For each pool, the following subsections should be considered:

1. Introduction, main known features of the pool (compared to other pools)
2. Definition: detailed description of activities/flows encompassed by the pool; clear definition of boundaries, separate description for all potential nitrogen species involved
3. Internal structure: possible reference to sub-pools and their structure.
4. Pool description: flows of Nr into and out of the pool; flows of N_2 formed or used when undergoing conversion (e.g., fixation or denitrification); stock changes within the pool; “unlocking” (of other relevant fixed nitrogen) into Nr, if relevant; conversion of Nr species, if needed. The pool definition requires keeping the balance of the pool conceptually closed.
5. Underlying data: suggestions of data sources to be used (e.g., reference to other guidelines).
6. Factors and models: detailed descriptions of calculation algorithms for quantitative flow (and stock change) information, labelling of flows that are determined as residual from closing balance equations
7. Uncertainties, data quality issues and other items critically affecting results; indication of potentially missing flows
8. References, bibliography, further reading
9. Document version, author contact information

G. References

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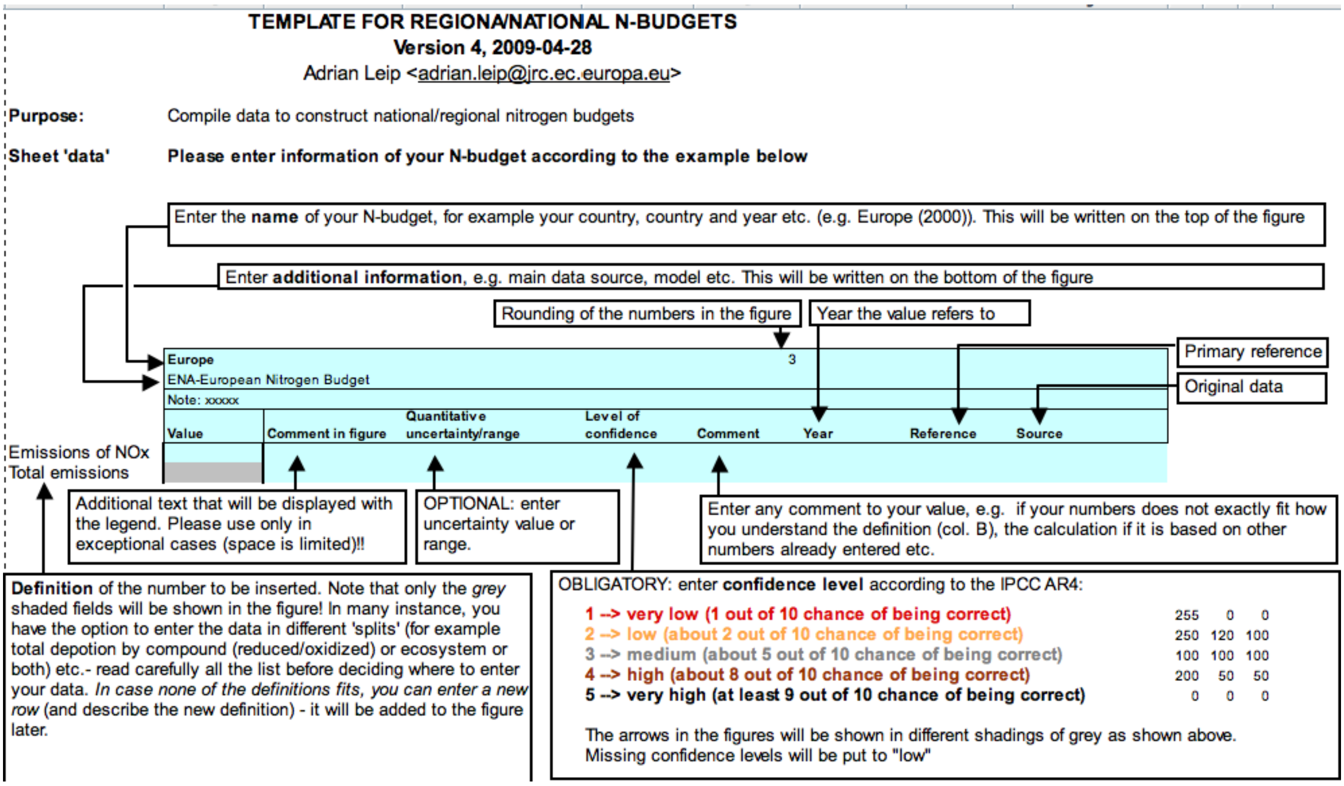
Oenema O., B. Amon, C. van Beek, N. Hutchings, M. Perez-Soba, C. Procter, S. Pietrzak, G.L. Velthof, F. Vinther, L. Wilson (2011). Farm data needed for Agri-environmental reporting. Technical document summarizing the findings of the DireDate project for the Final Seminar in Luxembourg on 28 March 2011. Eurostat Methodology and working papers 1977-0375, Luxembourg.

Example: how to fill in the N-budget excel and the confidence level information



1. Relevant National Context

The territory of Luxembourg has a surface of 258 600 ha, divided roughly, in 2010, in 94 000 ha forestland, 52 000 ha cropland, 86 000 ha grassland, 25 000 ha settlements, 1 300 ha wetland (Environment Administration 2013 p. 99).

The country is situated in an area with a temperate maritime climate, with an annual average temperature of 11.3°C, an annual average of 1 588 hours of sunshine and an annual average rainfall of 733.2 mm (STATEC 2012).

Meteorological conditions impact N-fluxes. The year 2010 had a dry and warm spring resulting in a late installation of the vegetation and a rainy late-summer. The long dry period had a direct effect on the agricultural N discharges to the groundwater (Water Adm. 2012 p. 46).

As can be verified on UNSTAT, OECD, Eurostat 2011, Statec, the Luxembourg economy and society are characterised by high energy, food, goods, services consumption and a high emission density. Due to high fuel sales to non-residents (transit, cross-border commuters, fuel “tourists” attracted by the lower Luxembourg fuel prices), the country has one of the highest per capita GHG emissions. With 74 733 US$ GNI/per capita in 2010, Luxembourg has also one of the highest per capita Gross national income (UNSTATS online 2013). Almost half of the working population are non-resident, non-national commuters.

Luxembourg could, in this sense, be compared to similar big administrative cities such as Brussels, Ile-de-France, Greater London. Eurostat considers the country also as a capital metropolitan region, an approach said to correct the distortions created by commuting and to render per inhabitant values meaningful (Eurostat 2013 a, b).

The three specificities of the Luxembourg population pattern consist in its considerable post War population increase, its high share of non-Luxembourgish inhabitants and the high numbers of commuters travelling daily to Luxembourg to work, but residing in the neighbouring countries (France, Belgium, Germany).

The population has passed from 314 889 inhabitants in 1960 to 502 100 inhabitants at the beginning of 2010.

2. Relevant national data used and their limits

The main data providers for the present research are the relevant national administrations and their registries (annual reports and shared excel datasets) and the National Official Statistical Office (Statec) for import/export data.

National GHG Emissions Data

Luxembourg's GHG emissions excel data, entitled *LU GHG Report 1990-2011,* as reported for the EC monitoring mechanism of Community CO_2 and other GHG, with purpose of reporting to the UNFCCC, is not restricted from public view. It can be accessed online on two internet sites:

The data used in this report is based on Luxembourg's GHG emission inventory submission version 2013v1.2 as submitted :

on March 15th, 2013 to the Eionet Central Data Repository (http://cdr.eionet.europa.eu/lu/eu/ghgmm/envuumpzw/index_html?&page=1 [Accessed 27.3.2013]

and

on April 15th, 2013 to the UNFCCC

(http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/7383.php).

The national inventory report 2013 (NIR 2013) (also available online at the UNFCCC website) was consulted for the methodological descriptions.

The NIR 2013 records N_2O emissions under the following IPCC source categories:

- 1A Energy: Fuel combustion activities, including road transportation
- 3D1 Solvents and other product use: emissions from anaesthesia
- 4D1 Agricultural soils – direct soil emissions
- 4D2 Agricultural soils – pasture, range and paddock manure
- 4D3 Agricultural soils – indirect emissions
- 6B Wastewater handling
- 6D Waste, other – compost production

Uncertainty analysis of this data, as included in the NIR 2013:

Luxembourg uses a Tier 1 and Tier 2 approach for the uncertainty assessment of its emission calculations. Tier 1 uses simple error propagation equations to estimate uncertainty and standard values found in the literature, often originating from the US and transposed to Europe and Luxembourg. Tier 2 is more detailed and situation – specific. Tier 2 uses a Monte Carlo analysis, which is suitable for detailed category-by-category assessments of uncertainty, where uncertainties are large and distributions non-normal … The Luxembourg Tier 2 approach relies a lot on “expert judgment”. Tier 3, which consists of country-specific data derived from on-site measurements, is only used in Luxembourg for a selection of heavy polluting industrial sites, and for N_2O emissions in road transportation.

The Luxembourg GHG emission estimates are based on quantities consumed/released and monitored by the administrations, aggregated and reported by national official statistics. On-site control or specific emissions measurements, surveys and questionnaires are only occasionally carried out. Declarations by emitting entities are trusted (NIR 2013 p49). Per capita values are a product of statistical analyzes and are rarely based on precise measurements. They aggregate residents and commuters data without distinction, which partly explains high per capita values. Uncertainties range from 0.5 % in the Energy and Transport sectors, over 20 % in the agriculture and waste sectors, to 25 % in the Land use Land use change and forestry (LULUCF) sectors. They are highest for soil emissions, f.i. manure application EFs follow a 50-200 % uncertainty for N_2O” (NIR 2013 p 82).

National discharges to water and air Data

Excel tables on the GHG inventory of the WWTPs of Luxembourg, entitled *Emission waste water handling_2012_120104.xls*, covering the years 1990 – 2011, communicated by the Water Administration (May 14, 2013), Administration de la Gestion de l’Eau, Ministère de l’Intérieur et à la Grande Région, Luxembourg.

National agricultural production data

Excel tables on the Food Supply balance 2000 – 2012. (Bilan d’approvisionnement 2000-2012) communicated by SER to the author, July 2013. Service Economie rurale, Ministry for

Agriculture, Luxembourg.

Relevant national publications referred to in the national literature review (chp 2.2)

- Final Report “Farm Nutrients and Energy Balances (NEB)” (CONVIS 2008). The report analyses, at farm level, the potential for feed self-sufficiency and N min savings, evaluates the contribution of agriculture to GHG emissions and proposes mitigation actions, assesses the impact of agriculture to biodiversity loss and gives recommendations for actions which are beneficial to the farmer (profitability), the environment (reduced pressure) and society;
- The Ecological Footprint of Luxembourg (CRTE 2010), which concluded that the country is among the world’s highest consumers of land (land as a proxy for consumption of resources and absorption of waste per capita), even without taking into account the important contribution of daily commuters into the country;
- The Dairyman report (2010) evaluating the sustainability of the Luxembourg agriculture;
- The Nitrates Report 2008 – 2011 (Water Administration 2012) on the transposition of the EU Nitrates Directive.

National sustainable development publications, referred to in the national literature review (chp 2.2)

- National Strategy for Reducing CO_2 Emissions in 2000,
- National CO_2 Emission Reduction Action Plans (first (2006) and second (2012)),
- Sustainable Development Plan (2011)

National trade statistics

Statec is the major source for food, feed and N-containing materials and substances imports and exports. Upon demand, Statec prepared customised .xls sheets with the major N items for the present research.

Statec gives the following reasons for the incompleteness or unreliability of the national import/export data:

- Trade flows and items below a trade value of 150 000€/year are exempt from reporting;
- Trade flows and items with a trade value comprised between 150 000 – 375 000 €/year are reported as monetary value only (no weight indication);
- From a trade value of 375 000€ onwards, trade data are reported in monetary and weight units;
- Statec depends on the good will of the private importing/exporting firms in declaring their data accurately. The declarations are rarely verified.

National Waste statistics

The Environment Administration is the major source. For the waste sector, sources do not indicate with clarity which part of the organic waste is “biodigested”, composted or co-composted and, for these processes, what is precisely the quantity of sewage sludge used. The domestic or extraterritorial origin and destination of these waste components is not clear. From a data management point of view, an overlap between biomethanisation, composted sewage sludge and compost ingredients is inevitable. The exported sewage sludge quantities diverge between sources. The values derived for N from organic waste are therefore uncertain in the NiNB.

Annex 4

Calculation of the Luxembourg NiNB 2010 –

data handling details, intermediary calculations, tables and references

Table of contents

Tables

Figures

STEP 1 – Calculation of NiNB data per pool and N form

For the industry, energy and transport sectors, data from national declarations to UNFCCC, EMEP, EEA, were crossed and findings were found to be consistent. The budget concerns here mainly NH_3, NO_X (related to fuel combustion) and N_2O gases.

1. Industry

N_2O emissions were 0.09kt for fuel combustion by manufacturing industries and construction and 0.02 kt for the solvent and other product use industries.

No NH_3 emissions were reported for the industry.

Industry emitted 4.57 kt NO_X due to combustion activities. Nitrous oxide was imported (0.038 kt in 2010), probably for industrial use as propellants to deliver foodstuffs (i.e. whipped cream and cooking spray) (Statec .xls 2013, Annex 3).

The *Air Liquid*'s N_2 use has not been integrated in the budget (3 mio m3 imported, 17 600 m3 exported in 2010 (Statec) since this concerns inert N_2 and since this firm's budget is supposed to be balanced.

2. Energy

In 2010, the energy sector emitted 1.84 kt NO_X and 0.05kt N_2O.

3. Transport

Road/rail transport

In 2010, the transport sector released 0.31 kt NH3 and 0.24kt N2O respectively.

Of all sectors and pools NOX emissions were, in absolute value and on a "fuel sold" basis, the highest for the transport sectors, with 37.8 kt NO_2 in 2010.

As for Austria, Belgium, Bulgaria, Ireland, the Netherlands and the United Kingdom, Luxembourg is allowed to report national totals for NO_X and NH_3on "fuel used in the geographic area of the Party" basis for compliance (UNECE, 2009). All other EU Member States report national totals for NO_X and NH_3 based on "fuel sold" (NEC Directive status report 2011).

Although Luxembourg is granted an exception, for the present work NO_X emissions from transport are considered on an extraterritorial "fuel sold" (higher than "fuel used") basis, since these emissions related to "fuel sold" are real and disperse into the atmosphere, independently from the accounting arrangement.

Indeed the categories "road fuel sales to non-residents" and "road fuel exports", are part of the national CO_{2e} emission total. A large quantity of fuel is sold to non-residents attracted by a lower taxation on Luxembourg fuel prices than their domestic taxation. According to EEA (online) 41% of the total national GHG emissions are generated by fuel sales to non-residents (confirmed by De Brabanter E, MDDI, mail communication 2.9.2013). This explains the high per capita GHG emissions in general, and especially for the road transport sector.

Aviation

The Luxembourg National GHG compiler confirms that international aircraft emissions beyond the landing and take off cycles are excluded from reporting under all NECD, CLRTAP, UNFCCC reporting obligations (M. Schuman, interview 19.4.2013). This is somewhat confusing since EEA considers international aviation (cruise) as included in national totals (EEA, NEC Directive Status report 2012). For the present NiNB only international landing and takeoff emissions and emissions linked to sports flying were reported. Together they accounted for 0.38kt NO_2 in 2010 in Luxembourg.

Excluding international cruise flying can be considered a serious national N-inventory leak for all countries, since NO_2 emissions from aviation are most significant during that cycle.

4. Agriculture

In 2010, Luxembourg disposed of 124 724 ha of utilised agricultural area (UAA), managed by 2 175 farms. To this add 6 382 ha used by Luxembourg farmers but situated outside the borders, mainly in Belgium (Weyland M, email 28.8.2013). This sums up to 131 106 ha UAA (Statec, 2012a,b). The agricultural area used to spread manure is estimated at 120 407 ha (Nitrate report 2011).

Table I – Evolution of agricultural land 2005 – 2011, Luxembourg, 2011 (ha)

	2005	2006	2007	2008	2009	2010	2011
SAU nationale	123.634	123.642	125.240	124.934	124.306	124.724	124.672
SAU exploitée à l'étranger	5.494	5.233	5.644	5.487	6.456	6.382	6.658
Total	129.128	128.875	130.884	130.421	130.762	131.106	131.330

Source: Water Adm. Nitrate report 2012

N-input to agriculture

The main N-inputs into agriculture derive from synthetic fertiliser application, manure, and atmospheric deposition. According to SER (2013), in 2010, 13.35 kt of manufactured N fertiliser were used in Luxembourg, with 102 kg Nfert/ha/yr applied by agriculture. It is thus difficult to make sense of figures reported by Statec (.xls 2013, Annex 3) of a trade balance of 23 kt chemical Nfert available in Luxembourg in 2010. NIR (2013) notes that "private" trade, cross border trade or home garden use of fertilisers escape the statistics. The present work follows the official SER data, according to the table II below:

Table II – Officially reported fertiliser use quantities Luxembourg 1999-2010 (t/yr and kg/ha/yr)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total consumption (in tons of nutritive substances)												
Nitrogenous fertilizer (N)	18 047	17 819	15 200	15 835	12 905	16 355	14 230	14 034	13 312	12 781	13 383	13 354
Phosphatic fertilizer (P2O5)	1 813	2 566	1 778	2 101	1 794	2 062	2 171	1 708	1 696	1 265	990	1 082
Potassic fertilizer (K2O)	3 019	2 898	2 009	2 204	1 884	2 267	2 388	1 876	1 853	1 290	735	973
Consumption per ha (in kg of nutritive substances per ha)												
Nitrogenous fertilizer (N)	141,7	139,6	118,8	123,6	100,7	127,7	110,2	108,9	101,7	98,0	102,4	101,9
Phosphatic fertilizer (P2O5)	14,2	20,1	13,9	16,4	14,0	16,1	16,8	13,3	13,0	9,7	7,6	8,3
Potassic fertilizer (K2O)	23,7	22,7	15,7	17,2	14,7	17,7	18,5	14,6	14,2	9,9	5,6	7,4

Source: SER Crop statistics (2013)

The quantities used in 2010 are a significant reduction from the 21.25 kt commercial N fertiliser use in 1992, the peak year for national inorganic N fertiliser use in agriculture, with approximately 160 kg Nfert/ha/yr (Water Adm., Nitrate report 2012).

According to the FAO, Luxembourg would belong, with 333 kg N/ha, to the top ten countries with the highest fertiliser nutrient use on arable and permanent crop area (see figure I below).

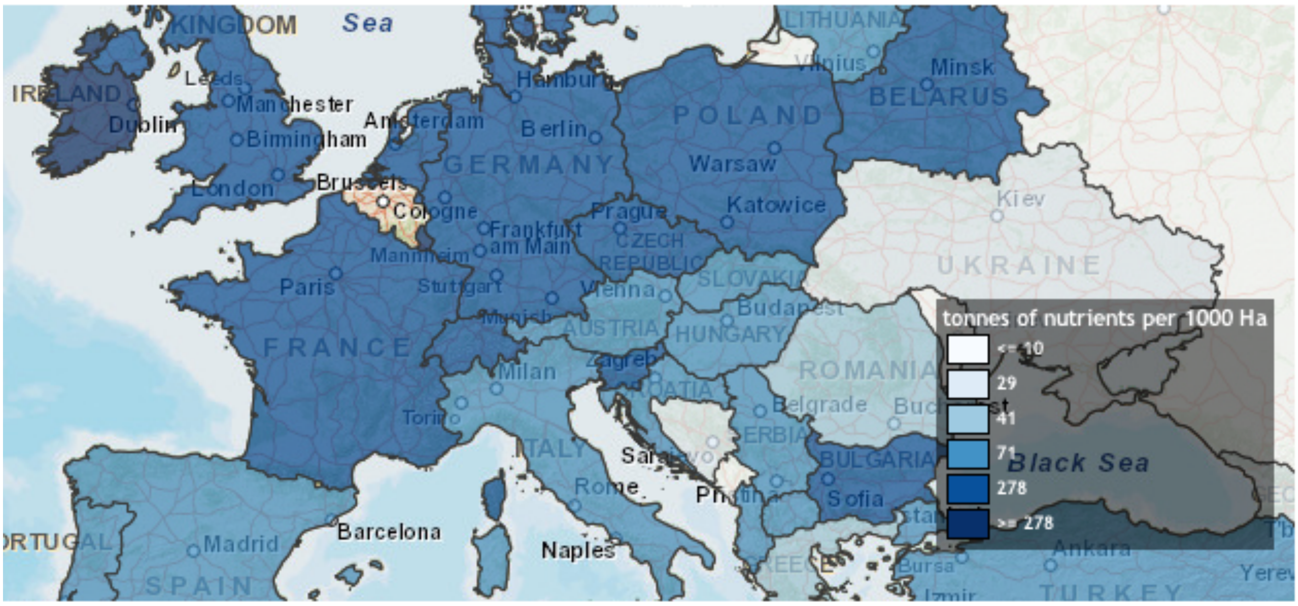


Figure I – Fertiliser nutrient use on arable and permanent crop area by country Average 2010 (t/ha)

Source: FAOSTAT 2013

(http://faostat3.fao.org/faostat-gateway/go/to/browse/E/EF/E)
(http://faostat.fao.org/Site/677/DesktopDefault.aspx?PageID=677#ancor)

It is likely that this conclusion is wrong since it seems the Luxembourg and the Belgian data have been cumulated to derive the Luxembourg N-use average. This misrepresentation on FAOSTAT would need clarification.

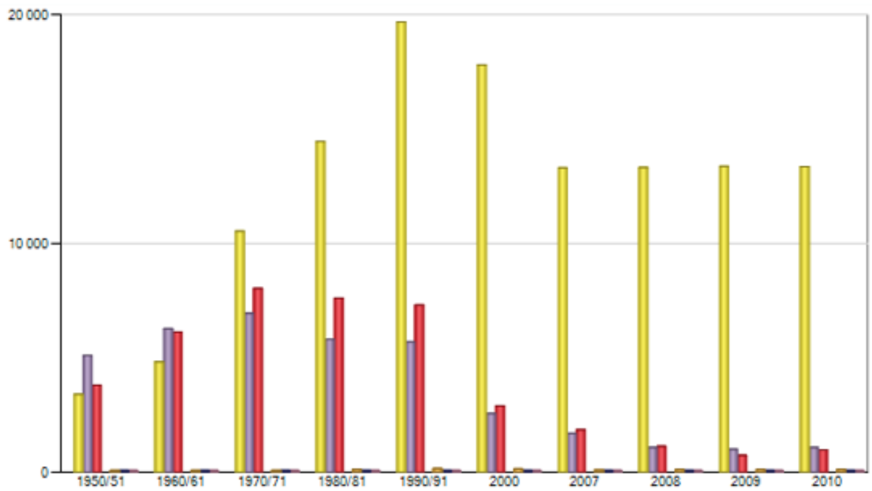


Figure II – Chemical fertiliser consumption, Luxembourg, 1950-2010 (t/yr)

Legend: In yellow nitrogenous fertiliser (N), in violet phosphate fertiliser (P_2O_5), in red, potassium oxide fertiliser (K_2O).

Source: Statec, 2012b

Different accounting methods exist for N-balances for agriculture, depending on the system boundaries (farm, land, soil budgets) (De Vries, ENA 2011 p. 318). For Luxembourg, Convis (2008) has undertaken an N-balance at farm level for 800 farms and SER also calculates NPK balances. Total agricultural area N-balances are derived from this work for reporting to the UNFCCC (NIR 2013 p 74) (Nitrate report p. 38).

According to the OECD Land system approach, the gross nitrogen balance calculates the difference between the N-inputs entering a farming system (i.e. mainly livestock manure and fertilisers) and the N-outputs leaving the system (i.e. the uptake of nutrients for crop and pasture production).

Table III below shows the N-balance (bilans azotés), expressed in kg N/ha of total agricultural land and the Nitrogen use efficiency (NUE) expressed in %.

Table III – N-surplus and NUE according to different sources and methods, Luxembourg, 2008-2010 (kg N/ha/yr)

	Water Adm. (2012) (quoting SER data) **For the year 2010** **a)**	**Dairyman (2010)** **For the year 2010** **b)**	**Convis (2008)** **Average for the years 2001-2005** **c)**	***Calculated possible Max*** ***from columns a), b), c) and NiNB 2010***
N-input	170	200	179	*285*
thereof Nmanure		98		*98*
thereof Nsynth	102	102	119	*119*
thereof Norg from compost, sludge, digestate from anaerobic digestion, other			1 (digestate)	*1*
thereof imported feed				*40*
thereof BNF				*1*
thereof Ndep				*26*
thereof crop residues				*?*
N-output (milk, meat, eggs, wool, cereals)	105		57 (animal products only)	*105*
Balance: N surplus (total N input-total N output)	**65**		**122**	***180***
Nitrogen use efficiency (NUE) 100 x N output/N input	*62 %*		*32 %*	*36 %*

Source: *Adapted* from Water administration Nitrate Report (2012) p. 39), SER, Dairyman report (2010), Convis NEB report (2008) (p. 22), ENA (2011 p. 319)

The significant differences in the SER and Convis results originate in the definitions applied for an N-balance. In 2009 SER gave up the Farmgate approach for a Farm-Land approach. From there, the SER NUE passed from an average of 30 % in 2004-2008 to 62 % in 2009-2010.

In 2010, according to the updated SER method of calculation, SER defines N-input as Nsynth, feed, seeds, life animals, and N-output as crop and animal sales, dead animals, reduction in livestock numbers. According to this method, in 2010, an N-surplus of 65 kg N/ha/yr is lost to the environment or reflects a variation in the stock of soil organic matter (Nitrate report p.39). This balance does not account for N-fixation, N-deposition, nitrification/dinitrification, crop residues returned to the soils, or soil N-stock changes, nor for Norg from compost, sludge or digestate from anaerobic digestion.

Table III shows that other national sources quote higher N-surplus values. Also SER reports an N-input of 13.26 kt N from manure in 2010, making in average 95 kg Norg/ha from manure available for application to agricultural soils (SER, Nitrate report 2012), and not 68 kg as assumed by SER in the Table III. In this respect the SER figure of 65 kg N-surplus/ha/yr has to be considered with caution, although it is in line with the European average of 67 kg N ha(-1)yr(-1) in farm budgets (Leip et al. 2011).

The last column of Table III incorporates all potential N-inputs (BNF, Ndep, imported feed, compost, sludge, …). Consequently the NUE decreases to 36 %. The Leip et al (2011) overall conclusion applies to Luxembourg: “total N-input, intensive farming, the share of imported feedstuff and the specialization to animal production are found to be the main drivers for a high N-surpluses and low NUE."

Is it assumed the N-leaching and runoff figure of 8 kt in 2010 reported by the NIR 2013, is the rounded result of this SER N-surplus of 62 kg/ha multiplied by 125 000 ha UAA = 8 kt. This shows the high sensitivity of the N-leaching figure to the methodology used for calculating the N-surplus and NUE. Depending on the definition of N-input and N-output and the quantities thereof, N-leach could actually be 105 kg N/ha N-surplus times UAA = 13 kt. This is a significant difference.

Independently from the accounting method, all sources agree that agricultural N-surpluses are on a downwards trend since the late 1990s, as a consequence of CAP subsidy modifications (Dairyman 2010), improved nitrogen and protein use efficiencies (NUE), extended fertilisation consultancy services, decrease in livestock numbers (Convis 2008), rising fertiliser prices (SER, CONVIS, Dairyman). The last reason is according to Dairyman 2010 (p. 91) the most relevant factor.

Emissions of N_2O from agriculture

Agriculture's contribution to N_2O emissions decreased also, by -20% from 1990 to 2010 (Water Adm., NIR 2013, p. 237):

- 4B – Manure Management, from 0.133 kt to 0.08 kt N_2O (-40%)
- 4D – Agricultural soils, from 1.17kt to 0.98 kt N_2O (-18%)
- 4 – Total Agriculture, from 1.3 kt in 1990 to 1.07 kt N_2O (-20%)

The NiNB model divides the category *Emissions of N_2O from agriculture* into 2:

- Emissions from animal sector (housing and manure) and
- Emissions from crop sector (soils).

N_2O emissions from the animal sector include N-input from manure applied to soils (0.12kt 2010) and N_2O emissions from N-excretion on pasture, range and paddock (0.19kt 2010).

N_2O emissions from crop sector (soils) regroup the remaining N_2O emissions related to fertiliser applications, N-fixing microbial processes, crop residues, direct emissions from agricultural soils, atmospheric deposition, leaching and runoff.

In 2010 N_2O emissions related to sewage sludge spread to agricultural soils were reported with 0.0025 kt in 2010.

Indirect emissions from agricultural soils (0.38kt in 2010) were not reported according to the EPNB guidance.

Total agricultural N_2O emission were reported with 0.68 kt in 2010 (0.75 kt according to Convis (2008).

Emissions of NH_3 from agriculture

The Nitrate Report (2012) indicates constant NH_3 emissions between 1990 - 2001 (5.27kt NH_3 from agriculture and forestry in 2001), but they have declined since.

Whereas the Nitrate report only considers discharge into the water, NIR 2013 considers their total impact on water, soil and air. For 2010, Luxembourg's agriculture reported 4.027 kt N as volatised N (mostly NH_3) into the atmosphere from fertilisers, animal manure and other sources. Convis (2008) estimated the agricultural NH_3 emission to 48 kg NH_3/ha, which would sum to 6 kt NH_3 for the total UAA.

Emissions of N_2 from agriculture

It is particularly difficult to measure soil dinitrification intensities and N_2 emissions from soils. Convis (2008) uses a literature-derived value of 40 kg N_2 loss per ha per year. ENA 2011 (p. 327) advances an estimated value of 34.6 kg N/ha/yr. With an average value of 37 kg N_2 emission per ha, this would sum to a total of 4.63 kt N_2 for the Luxembourg UAA of 125 000 ha.

Table IV – Total discharge of agricultural N to the air according to different sources and methods, Luxembourg, 2010 (kt N)

	ENA – Integrator Model (2000) a)	ENA – average all models (2000) b)	Convis (2008) c)	CLTRAP (2010) d)	NIR (2013) e)	*Calculated possible max from columns a) – e)*
N_2O	0.9	0.5	0.75		1.07	*1.07*
NH_3	2.7	3.45	6		4.027	*6*
N_2	4.5	4.3	4.63			*4.63*
NO_2	0	0.4		0.3		*0.4*

Source: adapted from references quoted in the head column

Discharges of NO_3 from agriculture

Discharges of Nitrates from agriculture into the soil and waters were reported to reach 8 kt in 2010 (NIR 2013, Convis 2008).

5. Land conversion

In 2010, according to NIR 2013 (p. 309), 5 380 ha of grassland and 870 ha of forested land have been converted to cropland, resulting in an emission of 0.01 kt of N_2O. The land area converted to settlements caused a CO_{2e} emission of 108 kt in 2010 (NIR 2013 p. 327). The related N_2O emissions are not estimated. According to Weyland M. (personal email communication 28.8.2013), the area of agricultural land converted to housing and infrastructures can be estimated to be 120 – 150 ha/year.

6. Forest and terrestrial ecosystems

The NiNB classifies non-agricultural land as (semi-) natural terrestrial ecosystems.

In 2010, Luxembourg had some 94 000 ha of forests. According to GHG inventory (NIR 2013) data, there is no N-fertilisation of forestland thus no direct N_2O emissions from N-fertilisation of forestland. For all N-fluxes in forestland, the data used is derived from INTEGRATOR (2000), as published by De Vries (ENA 2011, p. 335): N_2O, NO and N_2 emissions are derived with a statistical relationship with environmental factors (soil type, pH, precipitation, temperature etc.) based on results of a European wide application of the process oriented biogeochemical model Forest_DNDC (Li *et al.*, 2000) by Kesik *et al.* (2005). NH_3 emissions in forests are due to wild animals. The result is an N-accumulation in Luxembourg of 9.9 kg N $ha^{-1}yr^{-1}$ with an estimated total of 0.93 kt for 2010.

Forests are presented as net sinks in the NIR 2013, sequestering, in 2010, 470.16 Gg CO_{2eq}. NIR 2013 estimates that the forestland does not emit N_2O. However, De Vries (ENA 2011, p. 335) calculated the N_2O emissions from Luxembourg forests to be 0.39 kg N ha/yr for the year 2000, that is 0.037 kt N_2O emissions from forested land in 2010.

In 2010, Luxembourg imported 1 080 861 m3, and exported 364 744 m3 of wood (Statec, 2012a). It was not possible to quantify the N contained in the net wood trade. N in wood is however insignificant. N from wood combustion is normally included under *Energy*. If N is stored in lasting wooden furniture or used permanently in construction, the emissions are nil.

7. Fisheries

Fish production in Luxembourg is negligible. Seafood products are reported as food import/export data under Step 2 “N in Food” below.

8. Waste

As for the pools agriculture and consumers, waste and waste water generate three sorts of N-flows: N derived from the proteins contained in organic matter in the waste streams and effluents, N-discharges to the soil, surface and groundwaters as well as gaseous N-emissions to the air. Of interest here is the organic part of solid and liquid waste, the volume of N_2O leaching and runoff and of the gaseous emissions to the atmosphere.

Concerning GHG emissions, the waste sector (except waste incineration) is divided into 3 IPCC sector categories:

- 6A Solid waste disposal on land,
- 6B Liquid wastewater handling, with
  - 6B1 N_2O emissions from industrial WW
  - 6B2 N_2O from residential and commercial WW and septic tanks
- 6D Other – compost production

Sector category 6C – Waste incineration is allocated to the IPCC Sub category 1A1a *Fuel Combustion – Public Energy and Heat production*, on the assumption that the energy produced from burning waste is recovered and injected in the public electricity network.

According to the NIR 2013 (p. 337), the total waste related emissions have decreased significantly since 1990 due to the decrease in the quantity of waste being landfilled, as a consequence of the development of recycling schemes, the aerobic pre-treatment before land-filling, and the recent installation of methane recovery systems at waste dumping sites. Waste water treatment plants (WWTPs) capacity has steadily grown since 1990. This extra-capacity is however cancelled out by the significant resident and commuters population increases, which partly explains the increasing N_2O emissions from WWTPs.

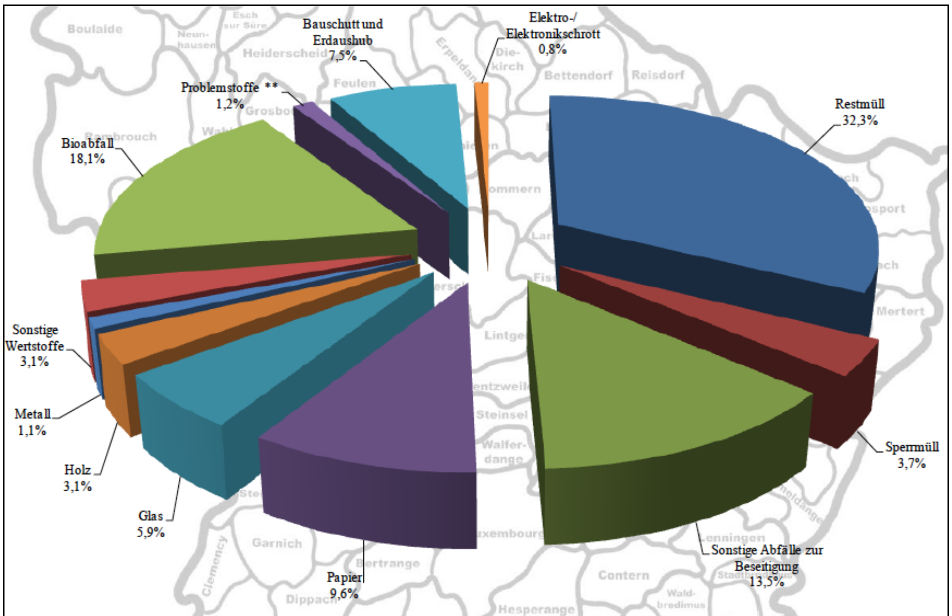


Figure III – Types and shares of each sub-component of the total amount of waste produced in Luxembourg in 2010 (%)

Legend: In 2010, the share of organic waste is 18% of the total waste generated in Luxembourg, that is 67 kt of organic waste.

Source: Env. Adm (2012c), Luxus Abfalldaten 2010, Gesamtabfallaufkommen p. 126

Solid Waste

In 2010, Luxembourg generated 372.35 kt of solid waste (Env. Adm. 2012c). The per capita waste quantity generated in 2010 is 742 kg, placing Luxembourg in the world top 10 per capita waste generators. The solid waste is either landfilled, incinerated, recycled/recovered, or exported (Env Adm. 2013 NIR p. 343). The emissions from the burning of approximately 130 kt/yr at the only national waste incinerator SIDOR are incorporated in the Energy budget.

NIR 2013 considers that no N_2O emissions occur for the category *6A Solid waste disposal on land*. No N2O emissions are given for landfilling.

According to a pilot study done by the Environment Administration (2004) on waste import and exports to Luxembourg, there is a heavy trade in waste, mostly for recycling and recovery needs. Eurostat reports for 2010 an export of 10 440 kt, thereof 8 731 kt from construction and demolition activities. This huge quantity of inert waste generated and exported by Luxembourg is not considered since it appears not relevant in terms of N content or emissions. Regarding waste trade, of relevance to the NiNB would be the import of poultry manure (feces from poultry) from The Netherlands and the export of agro-industrial waste, but no quantities are given by the Waste Division (2010, p 260).

Compost

From the end of the 90s, composting has developed into an industrial and generalised activity, which in turn has triggered an increase in N_2O emissions from compost.

According to the Environment Administration (2012a), almost the entire organic waste produced in the country (67.2 kt) is composted. In 2010, seven compost facilities exist in the country, plus one that co-composts sewage sludge (firm Soil concept) (Env. Adm 2013, NIR 2013 p. 76). That year they received 62 kt of organic compostable waste (of which 7 kt were exported) and produced 18 kt of compost (of which 6.6 kt were used in agriculture). The Environment Administration does not give the portion of solid organic waste which is "biodigested" domestically from domestic or traded ingredients. A quantity of 11kt of solid organic waste is "biodigested" as was estimated below in the section "anaerobic digestion".

N_2O emissions from composting represent, with 0.025 kt N_2O in 2010, 1,7% of the total N_2O emissions estimated for Luxembourg in 2010 (Env. Adm (2013), NIR p. 369). IPCC default EF have been applied (Env. Adm (2013), NIR p. 372).

From statistics compiled by the national Environment Administration (2012a p 81), it appears that NH_4-N emissions from produced compost are 0.003 kt in 2010, NO_3-N emissions are 0.001 kt. The total N-amount (est. at 1.9%) in the 18 kt end product "compost" would amount to 0.22 kt in 2010.

Anaeorobic digestion (biogas production)

According to the Environment Administration (2012b), in 2010, 211 kt of organic waste were "biodigested" in 26 biogas farms, to produce biogas and 195 kt of residual nutrient-rich digestate (biogas slurry) from the biomethanisation process. Roughly 20 mio m3 biogas, 39 mio kW/h, and minimum 19.5 mio kW/h heat were produced. The 211 kt of organic waste are composed of :

- 29,4 kt from non-farm origin (mostly organic waste related to feed, food, beverage, milk (*Molkereiwasser*) transformation industries, forest&garden&parc cuttings, public canteens, ...). The biggest portion consists in feed compound waste with 10.32 kt. It is noteworthy that the majority (18.5 kt) of the non-farm waste is imported (12 kt from Belgium, 6 kt from The Netherlands). From the figures, the quantity of domestic organic solid waste which has been "biodigested" can cautiously be estimated to be 11 kt in 2010;

- 138.7 kt of farm-origin (mostly manure and crop residues), and
- 42,85 kt are energy plants (above all maize and immature cereals).

Biogas production is according to the NIR 2013 not relevant for GHG production. However the 195 kt digestate contain 0.9 kt of N (mainly NH_4). This N-amount is a potential agricultural fertilisation source, if digestate were applied to the fields and pastures. The main ingredients being manure and slurry, 0.7 kt N are reported for under *Manure application (*and therefore not explicitly visible as an arrow in the resulting NiNB fig. 7, main text), 0.2 kt N under *Total crop production - other use of crop products*, 0.1 kt N under *Energy*.

Wastewater

In 2010, approx. 72,3 mio m^3 wastewater were treated (Env Adm 2011, p. 16), which represents an average population equivalent (PE) of 0,36 m^3/PE/day.

Data for N_2O emissions from industrial and municipal wastewater coincide between sources. Commuters are counted by the Water administration as 0.5 residents. In 2010, the gross (94%) N_2O emissions from WW originated from simple biological WWTP without denitrification facilities (covering 60% of the inhabitants). In 2010, 32% of the population were connected to WWTP with denitrification facilities where reactive N is converted into inert N_2 and the GHG N_2O (Table V).

Table V – Total emission of N_2O from waste water, Luxembourg, 2010 (t/yr and kt/yr)

Year	**2010**
N_2O for population not connected [t/year]	1.65
N_2O for WWTP without denitrification [t/year]	32.47
N_2O for WWTP with denitrification [t/year]	0.74
N_2O emission from industrial waste water treatment [t/year]	0.05
N_2O total [t/year]	34.91
N_2O total [kt/year]	0.035

Source: Water Administration .xls (2012) (Annex 3)

In 2010, N_2O emissions from WW represent 2.3% of the total N_2O emissions estimated for Luxembourg (NIR 2013 p 354). For the above evaluation of the N_2O emissions from WW, the IPCC default value of 3.2g N_2O per capita per year for biological WWTPs with denitrification processes, has been applied (Env. Adm. (2013), NIR p. 359). According to NIR 2013, the uncertainty is 50%.

Dinitrification

Dinitrification is the conversion of NO_3 to N_2 and constitutes a loss of Nr from the biosphere to the atmosphere (Galloway 2003). It can happen along the entire aquatic continuum. In the context of wastewater treatment, dinitrification is a microbially facilitated WW treatment process required under the EU directive 91/271/CEE concerning urban waste water treatment in view of reducing the risk of eutrophication of surface waters by removing nitrates. Untreated sewage and domestic wastewater contains ammonium and organic N.NO_2 and NO_3 are broken down into gaseous nitrogen N_2, which in turn is released into the atmosphere. WWTP in Luxembourg with an organic capacity larger than 10 000 population equivalents have to meet the minimum reduction rate of 75% of the total nitrogen load of their WW charge.

Sewage sludge

The total quantity of sludge produced by 36 WWTPs in 2010 is declared to amount to 7.43 kt (Env. Adm. 2011). Not all WWTP replied fully to the questionnaire sent by the Environment Administration. The later estimates this quantity to be rather 13.72 kt. Sludge is mostly returned to the national terrestrial ecosystems via direct spreading to agriculture (2.7 kt) or composting (3.3 kt), including the part which is composted by Soil concept (2.6 kt), except for the part which is incinerated (1.07 kt, 2010, reported in the NIR under Energy/industry Fuel combustion) or exported (212 t, 2010). The exported sewage sludge quantities (mainly to Germany) vary between sources, from approximately 200 to 2000 t in 2010 (212 t NIR 2013, 1 918 t Water administration, 1 371 t Environment Administration (2011)), as can be seen in Fig. III. This inconsistency concerns all years of the reporting series 2006 – 2012.

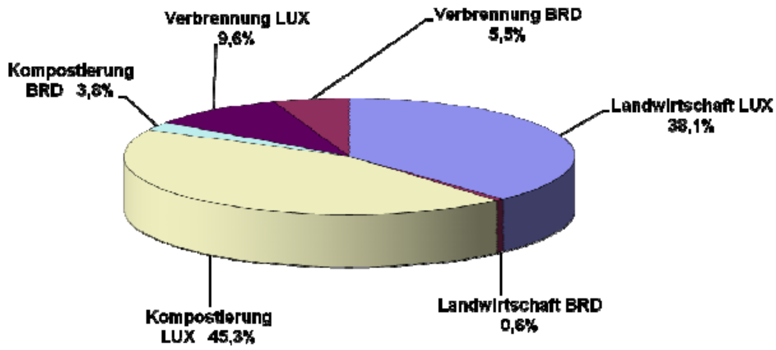


Figure IV – Destination of the sewage sludge, Luxembourg, 2010 (%)

Legend : According to this source, approximately 10% of the Luxembourg sludge, that is 1 370 t, are exported to Germany in 2010.

Source: Environment Administration (2011)

All major sewage treatment plants (> 10,000 PE) have a specific sludge treatment process. The larger systems have a sludge digestion and in most cases a stationary sludge dewatering. A conditioning and sanitation of the sludge is rarely performed. In smaller systems (<10,000 PE), the sludge is usually thickened statically in a thickener or in a stacking containers. A stationary sludge dewatering system with a centrifuge is rarely present. For an agricultural utilisation of sewage sludge, no nutrient load limits are specified in the national sewage sludge regulation (Env. Adm. (2011) p. 8, 63). Recovery of N from WW via WW biomethanisation is practised in some WWTPs.

Emissions related to the sludge residues of domestic and commercial wastewater handling are not estimated in NIR, except for the part spread in agriculture reported under Agriculture (NIR 2013 p 353). As for the N in sewage sludge, the NIR 2013 uses a proportion of 3.9% DM, the Environment Administration (2011) uses a scale of 2,8 – 4,5 % DM. When calculated with 4%, the potential N-input from sludge remaining in Luxembourg and returning to the national soils is approximately 0.5 kt N. Of this amount, 0.22 kt N was reported under “Sewage used in agriculture” and 0.28 kt N under “Sewage from communes”.

To avoid double counting, this N in sludge is not reported as a potential synthetic fertiliser substitution item since sludge is a derivative of WWT.

Table VI below summarizes, with an uncertainty of up to 50%, the N_2O emissions for the three considered waste categories.

Table VI – Annual N2O emissions per IPCC Waste category, Luxembourg, 2010 (kt/yr)

6A Solid waste disposal on land	6B Wastewater	6D Other – compost production	6 TOTAL Waste
NA	0.035	0.025	0.06

Source: Own calculations based on Water Administration .xls (annex 3) and Env Adm (2013)

9. Atmosphere

Atmospheric deposition of N through rainfall or dust particles is calculated with an estimated average value per ha (24 kg N ha) from the literature (ENA (2011) 16 kgN/ha/yr, Convis (2008) 30 kg N/ha, Water Adm. (2012) 25 kg N/ha) multiplied by the national land surface per pool (Env Adm (2013) NIR 2013 p 99), to arrive at the total N deposited on Luxembourgish soil. The counts are as follows:

Crop and grassland:	24kg N x 138 000 ha = 3.3 kt Ndep
Forests:	24kg N x 94 000 ha = 2.2 kt Ndep
Settlements :	24 kg N x 25 000 ha = 0.6 kt Ndep
Rivers and wetlands:	24 kg N x 1 300 ha = 0.03 kt Ndep

The total Ndep on Luxembourg would amount to 6.13 kt N in 2010. This is however uncertain, since land use surfaces are not coherent between sources.

EMEP (CLTRAP) generates data for atmospheric import and export of transboundary oxidised and reduced N to and from Luxembourg. In 2010, Luxembourg deposited approximately 14 kt of oxidized N in the EMEP domain, of which (without considering N river (Moselle-Rhine) export), 25% contributed to the acidification of the North Sea (NOS), the Atlantic (ATL) and the Mediterranean sea (MED) (Fig. IV).

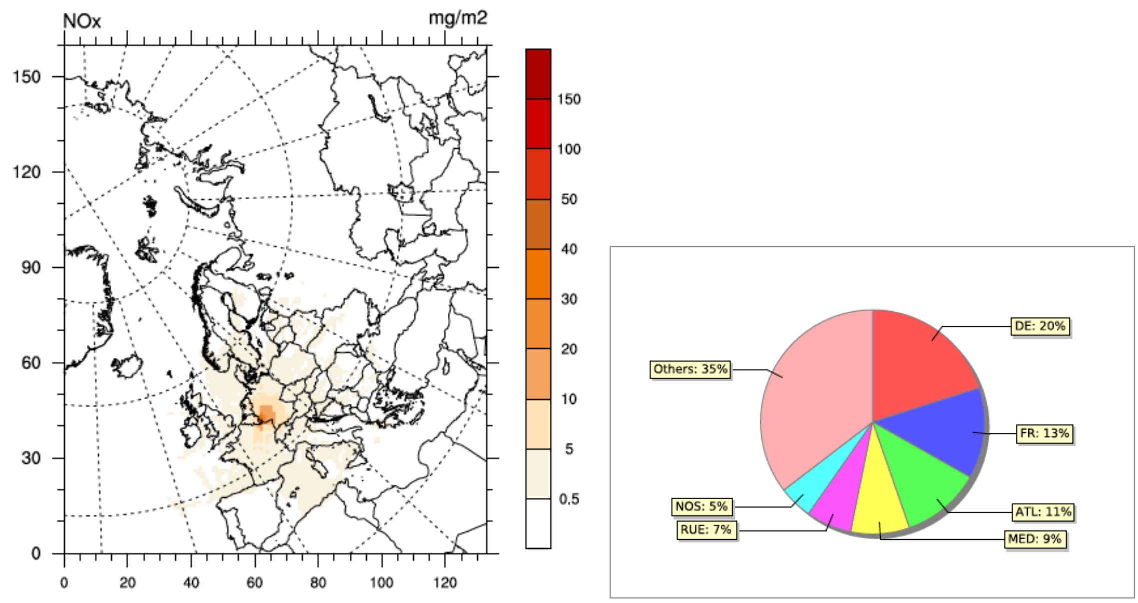


Figure V – Contribution of emissions from Luxembourg to deposition of oxidised nitrogen in the EMEP domain, 2010 (mg(N)/m2)

Legend: The pie chart shows the six main receptor areas where oxidised N from Luxembourg is deposited. Unit: %.
Source: EMEP 2012, http://www.emep.int/mscw/index_mscw.html)

Luxembourg received 2 kt of oxidized N mainly from its neighbouring countries. The country exported 5 kt reduced nitrogen (Nred) to the neighbouring countries, the Atlantic and the North sea, and imported in return 2 kt Nred from the neighbouring countries, through the air.

10. Hydrosphere

Rivers

Watercourses (175 km) and waterbodies occupy, with 1 300 ha surface, 0.4 % of the total country area. Luxembourg is situated in the Rhine river basin. It is classified as vulnerable zone in the context of the protection of the North sea (Water Adm 2012, Nitrates report p.

31). The emissions of the river Mosel, for the length bordering Germany, are credited to Luxembourg.

Discharges of agricultural Nitrate (NO_3) to the water

NIR 2013 estimates the quantity of N-leaching&runoff into the water to be 8.05 kt in 2010 (idem Convis 2008).

The outflow of N from groundwater to rivers, is, according to the Water Administration (2012), with an average of 5mg/l N for 258 000 ha national territory, 1,6 kt N for 2010.

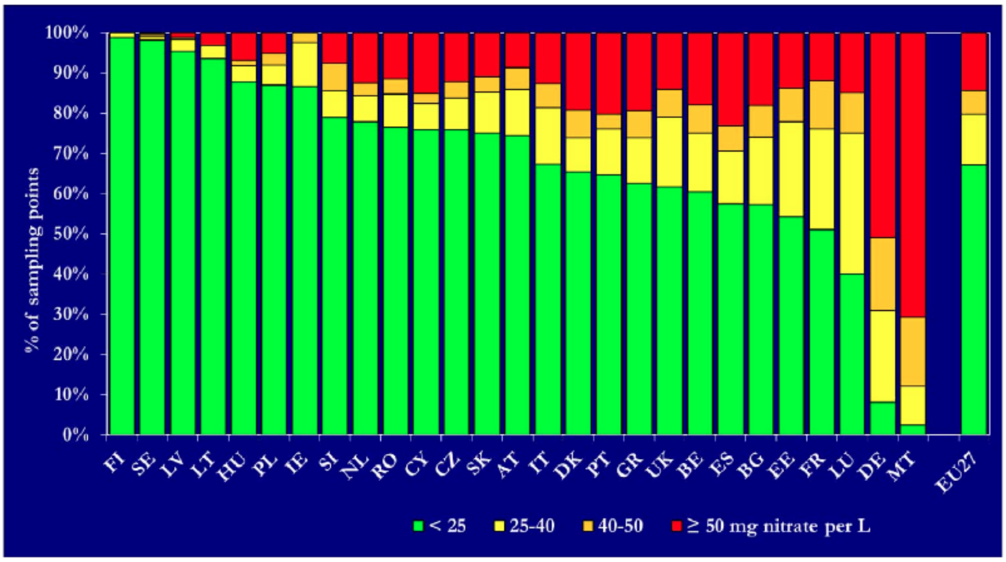
Table VII - Total agriculture and waste water related N-leaching and running off into waters, according to different sources and methods, Luxembourg, 2000 (Integrator) and 2010 (kt N)

	ENA (2011) **(Integrator Model for the year 2000)** **a)**	**Convis (2008)** **(for 2001-2005)** **b)**	**Water Adm. Nitrate Report (2012)** **for (2010)** **c)**	**Env. Adm. NIR (2013)** **(for 2010)** **d)**	***Calculated possible Max from columns a) - d)***
Agricultural fraction of Ninput (mainly manure) to the hydrosphere (2010) (without fertilisers as source, based on a surface of 218 164 ha (agri+forests))			2.75		*2.7*
N leaching&runoff from synthetic fertilisers (NO_3)	3.05	8.125		8.044	*8.1*
Domestic residual waste water fraction			1.571		*1.6*
Industrial waste water fraction			1.95		*2*
Total kt N/yr	**3.05**		**4.318**	**8.044**	***14.5***

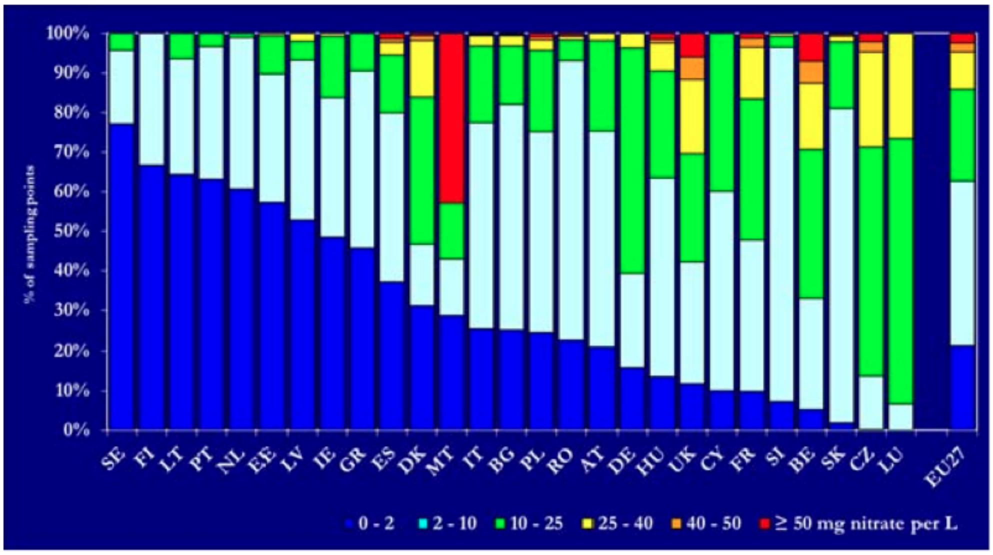
Source: adapted from the sources quoted in the head column

The Nitrate report 2012 estimates the agricultural fraction of NO_3 input to the surface and groundwater to be 2,75kt. However this estimate presents certain limits: commercial fertiliser is not considered, groundwater is treated as a source instead of a sink of N-input, the quantity of 1 000 kg of manure direct spreading (*Direkteintrag*) is not explained, agriculture and sylviculture seem mixed. The result can be considered an underestimation of agricultural N-input to waters, which is also confirmed by other observations, as shown in Table VII above and in the section discussing the agricultural fraction of N-leach (Table III for N-surplus estimates).

According to the EU Commission and EEA (2013), Luxembourg's groundwater control stations network is of low density and the country fares very poorly in the EU-27 comparison of water quality, be it groundwater, freshwater or rivers, as can be seen in the graphics presented in Annex 4.



Frequency diagram of groundwater classes (Annual average nitrate concentrations). Results are presented for all groundwater stations at different depths. Source: European Commission 2013



Frequency diagram of average nitrate concentrations in fresh surface water classes (annual average nitrate concentrations). Source: European Commission 2013

11. Coastal zones

Luxembourg being landlocked country and in accordance with the designer of the NiNB, Dr A. Leip, coastal zones are not to be considered here (although Luxembourg has a responsibility in ocean acidification).

STEP 2 – Estimation of N-amount in Food and Feed

1. Estimation of N in Food (and waste water)

The pools “human food consumption” and “domestic waste water” are treated together on the assumption that N contained in food consumed is equal to N contained in human effluents, or in other words, that the quantity of proteins taken in equals the quantity of proteins excreted.

For estimating the N-amount in food consumed and in wastewater, three calculation methods were applied in order to corroborate results:

- Conversion of the average national **protein** intake via food consumption into N consumed and, by extension, into N contained in domestic wastewater (Protein-to-N method);
- Conversion of **population equivalents** of waste water effluents into N (Water-to-N method);
- Conversion of the total **quantity of food available for consumption** into N consumed and N flushed into domestic wastewater (Food-to-N method).

1.1 Conversion of food proteins into N (P-to-N method)

The protein-based conversion has been undertaken by the Water Administration in 2012. FAOSTAT estimates the annual protein intake by each Luxembourger to have reached 118 g per day per person for 2010 (from 102g/d/pers in 1990). This amounts to a protein consumption of 43,07 kg/person/yr in 2010. It is not specified whether the FAOSTAT methodology considers this protein-intake on a “residents and non-residents” or on a “residents only” basis.

a.1) Conversion of food proteins into N on a residents and non-residents basis.

The calculation is as follows:

N effluent = Pop * Protein * F NPR

Where

Pop = 578 050 persons

Protein = 43.07 kg protein/pers/yr

Jones' N-to-P default conversion factor (F NPR) = 0,16 kg N/kg Protein

N effluent 2010 = 3'983'458.16 kg N/pop/yr

or

N effluent 2010 = **4 kt N/pop res+nonres**/2010

a.2) Conversion of food proteins into N on a “residents only” basis.

The calculation is as follows:

N effluent = Pop * Protein * F NPR

Where

Pop = 502 100 persons

Protein = 43.07 kg protein/pers/yr

Jones' N-to-P default conversion factor (F NPR) = 0,16 kg N/kg Protein

N effluent 2010 = **3.5 kt N/pop res**/2010

According to the N-to-P conversion method, the N contained in food is 3.5 kt for residents only, and 4 kt on a residents plus commuters basis. For the resident population of Luxembourg, the food N consumption in 2010 would thus amount to 7 kg N/person/year.

1.2. Conversion of population equivalents of treated waste water effluents into N (WW PE-to-N method)

Following the Water administration's annual report 2011, a waste water (WW) volume corresponding to 1 086 000 PE was treated in Luxembourg's WWTP in 2010; an estimate 12 g Ntot per PE per day, that is 4.3 kg N/cap/yr, is contained in this wastewater. This estimate is in the range of the nitrogen factor (3-4 kg N/cap/yr) the IMAGE model uses for the N-influent to WWTPs, divided by the number of connected people (ENA p. 371).

On the basis of this WW PE method, a total of 4.8 kt Ntot would thus be contained in the wastewater entering the WWTPs. This quantity of 4.8 kt represents a second estimate of the N in food consumed/effluents produced by the total resident and non-resident population.

1.3. Conversion of total quantity of food consumed into N (Food-to-N method).

The total quantity of protein-rich food available for consumption in Luxembourg in 2010, by residents as well as non-resident persons, is calculated in three steps:

c.1) Identification of the major protein-rich food items in the local diet,

c.2) Calculation of the quantity of these protein-intense foodstuff effectively available for domestic human consumption

c.3) Conversion of the total quantity calculated under c.2) into N

add c.1) Identification of the major protein-rich food items in the local diet

Proteins are essential nutrients for the human body. They are found in animal sources, such as meat, milk, fish and eggs, and in plant sources, especially in whole grains, pulses, legumes, soy, fruits, nuts, coffee and seeds. Based on this general list of *protein-rich food items* and on the local dietary preferences, 14 different Statec food categories out of the Combined nomenclature (STATEC/EUROSTAT) have been selected. P/N poor food items such as sugar, honey, wine, beer, oils, fats have not been included.

add c.2) Calculation of the quantity of protein-intense foodstuff effectively available for inland human consumption

The import/export data communicated by Statec for these selected food groups was then combined with SER national food production data, to arrive at the estimated net quantity of protein/N available for human consumption in Luxembourg in 2010.

For the SER, crop production includes: cereals, dried pulses (peas, beans, others), potatoes, rapeseed, forage plants, forage legumes, grass seeds, temporary grass, permanent pasture and meadows. Thus the national crop production encompasses both human and animal consumption goods and excludes fruits, vegetables, nuts, wine, feed compound produced domestically.

For the needs of the NiNB this list had to be separated into human food and animal feed. The production information was then completed with the net trade data (balance between import-export of food) to arrive at the total amount of N available for consumption in-country. Food waste (estimated to amount to 30% of food, from pre-consumption to consumption stages, FAO 2011) is not accounted for, since it is considered that the food which is not eaten finishes in the organic waste flows and is not lost for the NiNB. Domestic transformation of primary products was not considered: f.i. the entire milk quantity produced is converted into N on the basis of the 2010 milk protein content, ignoring the fact that milk is transformed in cheese, butter etc. which each have different protein concentrations, due to the lower water content than milk.

add c.3) Conversion of the total quantity of protein-rich food into N

There are no country specific protein content references for the crops grown in Luxembourg, except for milk (SER, 2013). The protein content per food item is derived from FAOSTAT food composition tables. The content values used remain approximate due to the divergences in food item denominations between FAO, the national nomenclature and the NiNB.

Table VIII summarises the result for the estimation of the total quantity of food N available for human consumption in Luxembourg in 2010, for the resident and non-resident populations (“effective eaters”).

Table VIII – Total N-amount in protein-rich food available for human consumption, Luxembourg, 2010 (kt N/yr) est.

			PRODUCTION			TRADE							CONSUMPTION		
Chapter N° of the Combined nomenclature (STATEC) (EUROSTAT)	Major protein rich food group in the Luxembourg diet	Average Protein content of food items (% edible portion)	Food production (SER) (kt/yr)	Protein amount of food produced in-country (kt/yr)	N amount of food produced in-country (kt/yr)*	Food import (STATEC) (kt/yr)	Protein amount of food import (kt/yr)	N amount of food import (kt/yr)*	Food export (STATEC) (kt/yr)	Protein amount of food export (kt/yr)	N amount of food export (kt/yr)*	N amount of net food trade (kt/yr)*	Food available for domestic human consumption (Import+Production-Export) (kt/yr)	Protein amount in total food avaiable for dom. hum. consumption (kt/yr)	N amount in food avialable for domestic human consumption (kt/yr)*
2	Meat incl poultry and edible offal	20.0	31.7	6.34	1.01	38.9	7.8	1.24	25.2	5.04	0.81	0.44	45.4	9.08	1.45
3	Fish, crustaceans, molluscs and aquatic invertebrates	15.0				7.3	1.1	0.18	1.1	0.16	0.03	0.15	6.2	0.93	0.15
4	Milk, dairy products, butter	3.4	295.3	10.04	1.61	42.6	1.4	0.23	195.2	6.64	1.06	-0.83	142.8	4.85	0.78
4	Cheese	30.0				53.0	15.9	2.54	44.6	13.38	2.14	0.40	8.4	2.52	0.40
4	Eggs	12.0	1.4	0.17	0.03	4.2	0.5	0.08	0.4	0.04	0.01	0.07	5.2	0.62	0.10
7	Vegetables, plants, roots, tubers	1.4	1.3	0.02	0.00	49.8	0.7	0.11	4.8	0.07	0.01	0.10	46.2	0.65	0.10
7	Dried pulses (beans, peas, sweet lupins, chickpeas, ...)	22.0	0.4	0.10	0.02	1.2	0.3	0.04	0.9	0.20	0.03	0.01	0.7	0.15	0.02
8	Fruits, citrus fruits, melons, ...	0.5	2.8	0.01	0.00	38.3	0.2	0.03	2.0	0.01	0.00	0.03	39.1	0.20	0.03
8, 1202	Nuts, almonds, hazelnuts, pistachio, peanuts	16.0	0.0	0.00	0.00	31.2	5.0	0.80	14.3	2.29	0.37	0.43	16.9	2.71	0.43
9, 18	Coffee, Cocoa and cocoa preparations; tea, spices (marginal)	5.4				24.9	1.3	0.22	6.7	0.36	0.06	0.16	18.2	0.98	0.16
10	Cereals	13.4	49.2	6.59	1.05	83.7	11.2	1.79	69.7	9.34	1.49	0.30	63.2	8.46	1.35
SER	Potatoes	2.0	20.0	0.40	0.06	40.0	0.8	0.13	5.0	0.10	0.02	0.11	55.0	1.10	0.18
SER, 1205	Rapeseed for human consumption	20.9	16.0	3.09	0.49	1.5	0.3	0.05	13.8	2.89	0.46	-0.41	3.6	0.76	0.12
16	Prepared dishes (meat, fish, crustaceans, molluscs and aquatic invertebrates)	17.0				11.1	1.9	0.30	2.9	0.49	0.08	0.22	8.2	1.40	0.22
19	Prepared dishes (cereals, flour, starch, milk); pastries	10.0				39.3	3.9	0.63	26.2	2.62	0.42	0.21	13.0	1.30	0.21
20	Prepared dishes (vegetables, fruits, other plants parts)	1.4				45.3	0.6	0.10	16.0	0.22	0.04	0.07	29.4	0.41	0.07
21	Prepared dishes (other) incl yeast	2.0				17.1	0.3	0.05	6.1	0.12	0.02	0.04	11.0	0.22	0.04
	Total		418.1	26.8	4.3	529.3	53.3	8.5	434.9	44.0	7.0	1.5	512.5	36.4	5.8

Source: Own estimates and calculations, based on data from SER Supply balance tables (2013) and Statec (customised table, 2013)

Legend: Highlight green: the items considered under animal products

Highlight blue the protein value derived from FAOSTAT

Hightlight orang and yellow: the total N-quantities per production, trade and consumption categories.

Globally Table VIII shows a quantity of 512 kt of food available in 2010 in Luxembourg for human consumption, of which 418 were produced in Luxembourg and 94 kt remained in the country after trade. Food trade is very intense: the quantities of food imported (530 kt) and exported (435kt) are both higher than the quantity of food produced domestically.

Meat

According to SER, 31.7 kt of meat are produced in country (*production indigene brute*), 33.3 kt of meat is imported, 5.6 kt of live animals are imported, 16.4 kt of live animals are exported, 8.7 kt of meat is exported, leaving 45.4 kt in the country available for consumption, corresponding to an N-amount of 1.45 kt N. This does not coincide with Statec import/export data, which is respectively 16.35 kt and 5.06 kt for 2010, leaving 43 kt in-country for home consumption. The trade in meat is higher according to SER than what is reflected in STATEC trade data. Eventually SER data was used for the NiNB.

Milk

The national milk production was 295.3 tons in 2010, making it, in weight, the first agricultural product produced in Luxembourg. Over the last 50 years, the national milk production has doubled (STATEC, SER (2012)). In 2010 milk had a protein content of 3.4% (SER, 2013). Nitrogen in cheese is not reported under production but considered included in produced milk. It is however reported under trade and consumption. The quantity of milk exported (195 kt) makes it also the first national agricultural export product. It is impossible to say what part of the exported milk derives from the national production and what part from the imports (42.6 kt). However, the total quantity of milk available in Luxembourg for transformation in dairy products for home consumption is with 142 kt far higher than the quantity of dairy products actually consumed and reported in the SER supply balance tables (SER, 2013) (56 kt from 40kg milk, 9 kg cream, 60 kg yoghourt, 6 kg butter per capita consumption). According to SER, 295 kt of milk is produced, but only 43 kt are transformed in-country for the home market. According to the same source, 26 kt of dairy products processed in-country are exported, against 239.2 kt (195 kt of milk and 44.6 kt of cheese) in the official export data. It was not possible to explain these discrepancies. It is however evident that 2/3 of the milk produced is exported and transformed abroad (Dairyman 2010), mainly in the German branch of the Danish global dairy company Arla Foods (*Luxemburger Wort* 20.2.2014). From production and trade, 1.2 kt of N from dairy products were available for human consumption in Luxembourg in 2010.

Cereals

In 2010, 49 kt of cereals, 20 kt of potatoes, 16 kt of rapeseeds and 0.4 kt of legumes were produced in Luxembourg for human consumption, corresponding to an N-amount of approximately 1.62 kt of N, reported as national (human) N crop uptake. The categories “nuts, vegetables, fruits” are insignificantly small in terms of N content and are not considered. The national cereal production encompasses wheat (hard and soft), spelt, rye, barley, oats, maize, triticale. The national cereals humans consume are wheat, spelt and rye, barley for brewing. Soft wheat for breadmaking is the first nationally produced cereal consumed in 2010, with 44 kg/cap (SER, 2013). The cereals the country imports are mostly wheat, spelt, barley, maize. The cereals it exports are mainly spelt, barley, tricitale.

As for milk, data from Statec and SER do not no coincide for cereals: SER declares 133 kt of cereal imports and 125kt of cereal exports, versus 84 kt and 70 kt for Statec. The data from Statec and from SER are comparable only if the quantities imported/exported for the food groups “prepared dishes based on cereals, milling industry products and malt” (import 40 kt, export 26 kt) are added to the Statec import/export data for cereals.

Seeds

In 2010 10kt of seeds are produced locally. Many more are traded (f.i. Origin BayWa, Saaten Union, Germany, *Probstdorfer Saatzucht* Austria) but no data exists on quantities imported/exported. SER estimates the N-amount of seeds (cereals, potatoes, grass) to be 0.22kt in 2010 (NIR 2013). To avoid double counting, since it is assumed that the seeds avilable nationally are planted and become plants harvested the following season, seeds were not be accounted for.

Prepared dishes

For the food items "Prepared dishes", the average protein content of their main respective ingredients (either animal or vegetable) has been used. The result is a conservative estimate of 0.54 kt N available from consumption of prepared dishes in Luxembourg.

According to this third *Food-to-N method*, and as illustrated in Table VIII, the overall result of the conservative calculations of N contained in food available for human consumption in Luxembourg in 2010 is 5.8 kt. This is respectively 1.8 kt higher than the calculations under the *Protein-to-N method*, and 1 kt higher than the result of the *Water-to-N method*.

An N-amount of 5.8 kt in food is also 1.8 kt higher than the amount of N declared by the Water administration as N effluent contained in WW. The Water Administration's calculations are based on the FAO assumption of an annual individual protein intake of 43.07 kg. According to above calculations, this quantity seems underestimated, even when accounting for 30% food waste not ending up in WW (incinerated, exported, composted).

Table IX compares and summarises different calculations done by different sources following different methods and calculates the individual annual food N-consumption, on a residents only basis (502 100 persons in 2010) and on a residents plus commuters basis (578 050 persons in 2010). It illustrates that the maximum values are those derived from the detailed F-to-N method applied above. Since it is a fact that food available in Luxembourg is eaten by residents and commuters (counted, as stipulated, for 0.5 residents, total 578 050 persons) alike, there is no reason to restrict the analysis to "residents-only".

The meaningful per capita values are those calculated on an "effective eaters" basis. As a consequence, for the NiNB it was assumed that 5.8 kt food N are available in the country and that the annual per capita food N consumed in Luxembourg in 2010 can be estimated to be 10 kg N/cap/yr (Table IX).

Table IX - Total N in food according to different sources and methods, Luxembourg, 2010 (kt and kg N/yr)

	Unit	FAO/Water administration (2012) a. Protein-to-N method	Water administration (2012) b. Wastewater-to-N method	SER/STATEC (2013) (Table VIII) c. Food-to-N method	SER Supply balance tables (2013) d. given per capita data aggregated to national totals	*Calculation of possible maximum from columns a) - d) Idem column c)*
Total Food N available	kt N/yr	4	4.8	5.8	4.3	*5.8*
Food N available per capita (residents only)	kg N/cap/yr	8	10	11.5	8.5	*11.5*
Food N available per capita ("effective eaters basis" = residents and commuters)	kg N/cap/yr	7	8.3	10	7.4	*10*

Source: Adapted from sources quoted in the head column

2. Estimation of N contained in animal Feed

For the estimation of the N in fodder, forage, feed and feed compounds, the same procedure described for human food-to-N conversion was applied. Feedipedia nutritional tables are used as the reference for fodder and feed protein contents. Feed compound protein content is estimated at 30% based on Convis (2008).

Table X below shows the quantity of N available in 2010 for domestic animal feed, resulting from the sum of the feed production and of net feed trade data.

Table X – Total N in forage, feed and fodder in available in Luxembourg for animal consumption, 2010 (kt N) est.

				PRODUCTION			TRADE					CONSUMPTION		
Source	Feed item	Average dry matter content (%)	Average Protein content of feed/fodder item (%)	Feed/Fodder production (SER) (kt/yr)	Average Protein amount in feed/fodder produced in-country (kt/yr)	N amount in feed produced in-country (kt/yr)	Feed import (kt/yr)	Feed export (kt/yr)	Net trade of feed (kt/yr)	Average Protein amount in feed traded (kt/yr)	N amount in Net trade of feed (kt/yr)	Feed and Fodder available for animal consumption in-country (kt/yr)	Average Protein amount in feed and fodder available for animal consumption in-country (kt/yr)	N amount in feed and fodder available for animal consumption in-country (kt/yr)
SER	Cereals:													
SER	Winter fooder wheat, grain	87.0	12.6	35.9	3.9	0.6						35.9	4.5	0.7
SER	Fodder rye, grain	86.6	10.3	3.2	0.3	0.0						3.2	0.3	0.1
SER	Winter fodder barley, grain	87.0	11.8	28.2	2.9	0.5						28.2	3.3	0.5
SER	Spring fodder barley, grain	87.0	11.0	12.0	1.2	0.2						12.0	1.3	0.2
SER	Oats	88.0	13.0	4.8	0.5	0.1						4.8	0.6	0.1
SER	Mixed grains and others	87.0	11.7	1.2	0.1	0.0						1.2	0.1	0.0
SER	Grain maize	87.5	8.8	3.1	0.2	0.0						3.1		
SER	Triticale	87.0	11.5	25.5	2.6							25.5		
SER	Dried pulses (beans, peas, sweet lupins, ...)		22.0	0.5	0.1	0.4						0.5	0.1	0.0
SER	Forage plants (DM):													
SER	Green maize (DM) (sillage)		8.0	181.1	14.5	2.3						181.1	14.5	2.3
SER	Temporary grass (DM)		14.4	93.2	13.4	2.1						93.2	13.4	2.1
SER	Roots (DM)		15.0	0.2	0.0	0.0						0.2	0.0	0.0
SER	Forage legumes (DM)		25.0	3.6	0.9	0.1						3.6	0.9	0.1
SER	Permanent pasture and meadows (DM)		14.4	467.9	67.3	10.8						467.9	67.3	10.8
SER. STATEC	Animal feed products		30.0				135.4	52.9	82.5	24.7	4.0	82.5	24.7	4.0
SER. STATEC	Soybean meal	88.0	45.0	0.0	0.0	0.0	20.7	3.4	17.3	7.8	1.2	17.3	7.8	1.2
	Total			860	108	17	156	56	100	33	5	960	139	22.24

Source:: Own estimates and claculations, based on data from SER (2013) and Statec (customised table, 2013)

Legend: Highlight blue: protein and DM content from Feedipedia, FAO (online), Convis (2008).
Highlight yellow: total N feed N available for animal nutrition in Luxembourg in 2010

Table X above illustrates that 860 kt of animal feed are produced nationally, 156 kt are imported, 56 kt exported, leaving 960 kt in the country, which represent an N-input of 22.24 kt available as feed for animal consumption in Luxembourg in 2010. This result suffers however major limitations.

The difficulty consists in separating cereals (locally produced and imported, 133 kt 2010, SER Supply balance tables 2013) into human and animal consumption, in identifying which part of the compound feed produced by the animal feed industry in Luxembourg is derived from the national grain production and which proportion are imported protein carriers. Triticale, oats, and barley (except for brewing barley) are almost exclusively reserved for animal feed.

Reliable and complete data for the import of protein plants or of maize for forage and silage is difficult to find. As a consequence, it is extremely difficult to avoid double counting.

When combining the national cereal production table (SER, 2013) and the supply balance tables (SER), it can be estimated that a max of 102 kt out of the 166 kt of cereals produced nationally are used to feed animals. Out of the 102 kt, 66 kt are directly fed to the animals at the farm. It can be estimated that the difference of 36 kt enters the national compound feed industry, which produced 78 kt of animal feed in 2010, with other imported ingredients. To avoid double counting, these 78 kt have not been entered in the Table X *N in feed* under *"Animal feed products"*, since they are part of the 102 kt of fodder grains already reported in Table X under "*Cereals*".

From the trade statistics, it appears that 135 kt of feed enter and 53 kt leave the country. Luxembourg almost exclusively imports two sorts of animal protein meals: Soybean meal (*Sojaextraktionsschrot* SES, 44-48 % proteins DM) followed by rape meal (*Rapsextraktionsschrot*, +/- 35% proteins DM). The export of feed consist mainly of commercial feed exports to Germany, where the Luxembourg feedstuff are competitive due to the lower Luxembourg VAT on feed than the German VAT.

The SER supply balance tables indicates a quantity of 8.2 kt of animal feed imported in 2010. The data retained for soybean cake (20.7 kt import, 3.4 kt export, 2010), correspond to the data used for calculating the Luxembourg Ecological footprint (CRTE (2010) (import of 22kt of cake of soybeans, export of 2kt, 2008). SER estimates further that the imported protein feed (*Eiweißfuttermittel*) could be of 45 - 50 kt/year (JP Hoffmann, email 2.7. 2013, Annex 5). This is still not anywhere near the import/export data of Statec which sums the animal feed and soybean meals imports to 156 kt and the exports to 56 kt, leaving a quantity of 100 kt in the country.

The reality seems to lie anywhere between 50 and 100 kt of annual animal feed increment to the national feed production. In case the conservative estimate of 50 kt protein-feed imports were retained, the N-quantity in feed consumed domestically would be 19.4 kt in 2010. In case the maximum estimate of 100 kt protein-feed imports were retained, the N quantity of feed consumed in-country would be 22.24 kt in 2010. For the present research, the higher value of 22.24 kt N available for feed in Luxembourg in 2010 has been used.

STEP 3 – Conversion of absolute N value into per capita N values

The human body requires ~ 2 kg N/yr of protein to survive (Smil (2000). The Dutch, a very N-intensive nation, consumed 6 kg N per capita via food on average for the period 1995-1999. The recommended protein N-intake is approximately 3.4 kg cap/yr (Leip A Bleeker A, 2011). Tables VIII and IX above indicate a maximum 10 kg N available for indigestion by residents and commuters ("effective eaters" = resident+commuting population, 578 050 persons) in Luxembourg in 2010.

Table XI below calculates the individual food nitrogen intake per year, on the basis of the reported (orange columns) and calculated (blue columns) food item per capita portions available for consumption in Luxembourg in 2010. The orange SER columns are not complete since seafood, coffee, fruits, nuts etc are not considered. Another divergence in Table XI between 8 and 11 kg N/cap/2010 derives from the divergences between SER (orange columns) and Table VIII calculations (blue columns) for per capita quantities of dairy products and cereals.

The results according to this per capita method vary between 8 and 11 kg N/cap/2010. This 11 kg N maximum, which would have been available per resident for consumption in Luxembourg in 2010, correspond to 10 kg N, which were actually available per "effective eater".

Table XI – Per capita quantities of food N available, according to different sources and methods, Luxembourg, 2010 (kg/cap/year and kt/yr)

Serial n°	Top protein rich food categories in the local diet	Amount of food available From SER Supply balance table (Nat. production and trade) (2013) Per resident (kg/cap/yr) a)	Equivalent N amount consumed Per resident (kg N/cap/yr) b)	Total protein-rich Food available for domestic human consumption (Nat. production and trade SER and STATEC) (from Table VIII) Residents+Commuters (kt/yr) c)	Equivalent amount of Food available per "effective eater" (From Table VIII, divided by number of "effective eaters") Residents+Commuters (kg/cap/year) d)	Equivalent N amount available per "effective eaters" Residents+commuters (kg N/cap/yr) e)
1	Meat incl poultry and edible offal + prepared meat dishes	90	2.9	50	86	2.8
2	Seafood + prepared sea food dishes			10	18	0.4
3	Dairy products	134		151	261	2.2
	thereof milk	40	0.2			
	thereof cream	9	0.0			
	thereof yoghourt	58	0.9			
	thereof butter	6	0.0			
	thereof cheese	21	1.0			
4	Eggs	10	0.2	5	9	0.2
5	Vegetables + prepared vegetable dishes			76	131	0.3
6	Legumes	1	0.0	1	1	0.0
7	Fruits			39	67	0.1
8	Nuts, almonds, hazelnuts, **pistachio**			17	29	0.8
9	Coffee			12	21	0.1
10	Cocoa and cocoa preparations			6	11	0.1
11	Cereals + prepared cereal-containing dishes	85	1.8	87	151	3.2
12	Potatoes	96	0.3	55	95	0.3
13	Rapeseed for human consumption	16	0.5	4	6	0.2
	Total per capita consumption	**432.2 kg food/cap/2010**	**8 kg N/cap/2010**	**512.5 kt/yr**	**887.3 kg food/cap/2010**	**10.7 kg N/cap/2010**

Source: Own estimates and calculations, based on data from SER Supply balance tables (2013) and Statec (customised tables, 2013)

Legend: Highlight orange: Calculations based on SER supply balance tables 2013; Highlight blue: Calculations based on Table VIII

On the basis of the individual food items quantities available, SER concludes that the rate of national food self-sufficiency (independently from their protein intensity) is, in 2010, 100% for cereals, 70% for meat and 106 % for milk. The SER rates of self-sufficiency for dairy products is shown in Fig. V below. Still, these rates are calculated on the basis of the sum of the national food production and the balance between food imports and exports. Self-sufficiency in this sense does not mean coverage of national food need by national food production, but includes food trade.

A more meaningful food N self-supply can be calculated from the results of Table VIII and FAO protein intake data: in 2010, Luxembourg's national food production was 418 kt equalling to 4.3 kt food N. Per capita ("effective eaters" = residents+commuters), this would represent an annual N-Food availability of 7.4 kg N/cap, covering roughly 63% of the 11 kg/cap yearly available to a Luxembourger through national food production and trade (512.5 kt food).

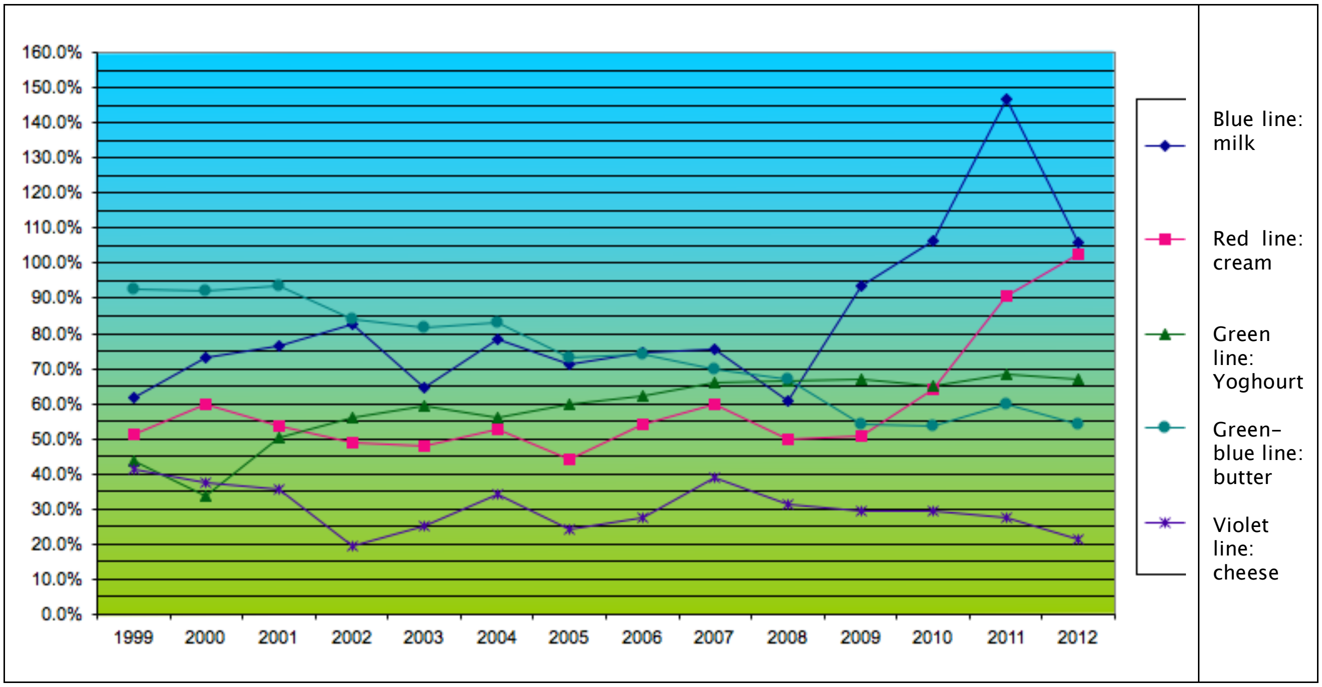


Figure VI – Rates for national dairy products self-sufficiency, Luxembourg 1999 – 2012 (%)

Souce: SER Supply balance tables (2013) (Annex 3) and Table VIII above

List of persons interviewed, work sessions, visits, email exchanges

Name of institution	Name and Contact of persons met	Date and Type of exchange
Ministry of Agriculture	Mr Marc WEYLAND Chef de Service de la Production Végétale Ministère de l'Agriculture Administration des Services Techniques de l'Agriculture BP 1904, L-1019 LUXEMBOURG Tel: +352-457172-234 Fax: +352-457172-341 Email: marc.weyland@asta.etat.lu Web: www.asta.etat.lu	10.7.2012: Pilot interview by phone to test feasibility and method of proposed research, followed email exchanges
Minett compost (Municipal Composting and Biogas facility)	Um Monkeler, Schifflange, LUXEMBOURG Tel : 55 70 09 - 1 Fax : 55 70 09 - 52 Web: http://www.minett-kompost.lu	26.9.2012, visit
Soil Concept	Mr Marc Demoulling (administrateur délégué) Friidhaff - B.P. 139 L-9202 DIEKIRCH Tél. : (352) 26.800.381 Fax : (352) 26.800.385 Email: mdem@soil-concept.lu Web: http://www.soil-concept.lu/	4.1.2013: Face to face interview and visit of sewage sludge composting unit
Ministry of Agriculture	Ms Simone MARX Ing.- chef de service Administration des services techniques de l'agriculture Division des laboratoires de contrôle et d'essais Service de pédologie 72, Avenue Salentiny L-9080 ETTELBRUCK Tel.: ++ 352 81 00 81 - 235 Fax: ++ 352 81 00 81 - 333 Email: simone.marx@asta.etat.lu Web: http://www.asta.etat.lu/Laboratoires/Boden/Boden.htl	22.1.2013: Face to face interview
Ministry Sustainable Development and Infrastructure (MSDI)	Mr Eric de Brabanter Climate Change Indicators & Statistics EEA/EIONET MB member & NFPOECD/EPOC delegate & WPEI Chair Département de l'Environnement Ministère du Développement durable et des Infrastructures (MDDI) 4, Place de l'Europe, L-2918 LUXEMBOURG Tel: (+352)2478-6842 Fax: (+352)2478-6835 Email: eric.debrabanter@mev.etat.lu Web: www.emwelt.lu & www.mddi.lu	5.2.2013, email and telephone exchanges 14.3.2013 23.3.2013
Ministry of Agriculture	Mr Jean-Paul Hoffmann, Ms Christine Herzeele Service d'Economie Rurale (SER) Division des statistiques agricoles, des marchés agricoles et des relations extérieures 115, rue de Hollerich, L-1741 LUXEMBOURG Tel +352 24782551 Fax +352 491619 Email jean-paul.hoffmann@ser.etat.lu	12.2.2013: Face to Face interview, followed by email exchanges

	Web: www.ser.public.lu	
Biogasvereenegung Luxemburg **(Luxembourg Association of Biogas Producers)**	Mr Severin Boonen President Biogasvereenegung Luxemburg 8, Gruefwee L-8533 ELVANGE Tel: 00352 691 568743 Email: boonenseverin@hotmail.com Web: http://www.biogasvereenegung.lu	14.4.2013: Biogas plant and farm visit, interview
Lëtzebuerger Landjugend – Jongbaueren a Jongwënzer a.s.b.l. (Luxembourg Association of young Farmers and young Wine-growers)	Mr Jeff Boonen, President 5, avenue Marie-Thérèse, L-2132 LUXEMBOURG Tel.: +352 44743 - 252 Fax: +352 44743 - 563 Email: landju@pt.lu Web: http://jongbaueren.lu	14.4.2013: Interview
Ministry Sustainable Development and Infrastructure	Mr Marc Schuman D. Phil. National Greenhouse gases compiler Air Emissions & Inventories Air & Noise Division, Environment Agency Administration de l'Environnement 1 Avenue du Rock'n'Roll, L-4361 ESCH-SUR-ALZETTE Tel: +352 405656 553 Fax: +352 405656 699 Email: marc.schuman@aev.etat.lu Web: http://www.environnement.public.lu/functions/apropos_du_site/aev/aev_division_air_bruit/index.html	19.4.2013: Face to face interview and working session
CONVIS Herdbuch	Jean Stoll (retired) Rocco Lioy and Romain Reding Nationale und internationale Projekte, Düngepläne, Energie- und Nährstoffbilanzen, Humus- und Flächenbilanzen, Lebenszyklusanalysen CONVIS 4 Zone artisanale et Commerciale, L-9085 ETTELBRUCK Tel: 26 81 20 0, dir: 26 81 20-57 Fax: 26 81 20 12 Email: Rocco.Lioy@convis.lu Web: http://www.convis.lu	23.11.2012, interview 15.7.2013, interview and working session

Email and telephone exchanges		
European Commission **Joint Research Centre, IT**	Dr Adrian Leip Integrated Nitrogen Budget Institute for Environment and Sustainability Monitoring Agricultural Resources Unit - H04 Joint Research Centre European Commission ISPRA (VA), ITALY Email: adrian.leip@ec.europa.eu Web: http://mars.jrc.ec.europa.eu/mars	

Wageningen University and Research centre, NL	Mr Wim de Vries Special Professor on Integrated Nitrogen Impact Modelling Alterra, Wageningen University and Research Centre Wageningen, The NETHERLANDS Email: wim.devries@wur.nl Web: http://www.esa.wur.nl/UK/Staff/Vries/	
University of Virginia, USA **Department of Environmental Sciences** **N Footprint calculator**	Dr James Galloway Ms Alley Leach University of Virginia, USA Email: "James Galloway" jng@eservices.virginia.edu Allison Leach aml4x@virginia.edu	
Ministry of the Interior **Water administration, Luxembourg**	Dr André Weidenhaupt, Director Mr Dominique Manetta Administration de la Gestion de l'Eau 1, avenue du Rock'n'Roll L-4361 Esch/Alzette Luxembourg Email: Andre.Weidenhaupt@eau.etat.lu, Dominique.Manetta@eau.etat.lu Web: www.waasser.lu, www.eau.public.lu/	
Statec Luxembourg **(National Statistical Office)**	Ms Nadine Urhausen ENT1, Commerce Extérieur de biens Centre Administratif Pierre Werner 13, rue Erasme L-1468 LUXEMBOURG Email: demande-comext@statec.etat.lu Web: www.statec.lu	
FAO Rome	Mr Olaf Thieme Ph.D. Livestock Development Officer FAO Animal Production and Health Division Viale delle Terme di Caracalla - 00153 Rome, Italy Email: olaf.thieme@fao.org Web FAO Dairy Gateway: http://www.fao.org/agriculture/dairy-gateway/en/	

Annex 6
Nitrogen entry into surface water in the Rhine catchment area of Luxembourg

Stickstoffeintrag in die Fließgewässer über diffuse Quellen im Rheineinzugsgebiet von Luxemburg											
	Methode:	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Niederschläge		675	887	619	820	985	888	816	705	593	mm
			Moyenne Clemency (sauf 2008 et 2010), Asselborn (Ettelbruck sur 2008/2011), Grevenmacher (sauf 2010)								
Wasserbilanz:											
Abfluss	27%	182,25	239,49	167,13	221,4	265,95	239,76	220,32	190,35	160,11	mm
Verdunstung	55%	371,25	487,85	340,45	451	541,75	488,4	448,8	387,75	326,15	mm
Einsickerung	18%	121,5	159,66	111,42	147,6	177,3	159,84	146,88	126,9	106,74	mm
N aus Wirtschafts-düngern (2):		13 534 671	12 084 071	12 081 483	11 913 098	12 300 923	12 396 593	12 557 351	12 726 990	12 379 131	kg
Düngerausbringung	Direkteintrag (1) (3)	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	kg
Weidewirtschaft	N*0,4*0,01 (1) (4)	54 139	48 336	48 326	47 652	49 204	49 586	50 229	50 908	49 517	kg
Direkteinleitung	N*0,01 (1) (5)	135 347	120 841	120 815	119 131	123 009	123 966	125 574	127 270	123 791	kg
Kunstdünger											
Atmosphäre	2900 ha (Gewässer-oberfläche)x25kg/ha (1) (6)	73	73	73	73	73	73	73	73	73	Tonnen
Dränwasser:	(Grunland+Acker-land)/2	31	31	31	31	31	31	31	31	31	Tonnen
Grünland	4000 ha*1/3*5kg (1)	6,6	6,6	6,6	6,6	6,6	6,6	6,6	6,6	6,6	Tonnen
Ackerland	4000 ha*2/3*21kg (1) (7)	56	56	56	56	56	56	56	56	56	Tonnen
Grundwasser:											
Pro ha:	Einsickerung*5 mg/l*0.01 (1) (8)	6,075	7,983	5,571	7,38	8,865	7,992	7,344	6,345	5,337	kg/ha
Land:	Pro ha * (Acker +Grünland+Wald)	1 308 026	1 718 149	1 202 679	1 591 955	1 930 496	1 737 868	1 599 178	1 384 251	1 164 704	kg
Erosion:											
Abtransport (partikulär)	(Acker+Grünland+Wald)x1,5kg/ha (1)	322 970	322 839	323 823	323 568	326 649	326 177	326 630	327 246	327 348	kg
Abfluss (gelöst)	Wald (A):Abfluss*0.3*0.01	0,54675	0,71847	0,50139	0,6642	0,79785	0,71928	0,66096	0,57105	0,48033	
	LN (B): Abfluss*2*0.01	3,645	4,7898	3,3426	4,428	5,319	4,7952	4,4064	3,807	3,2022	
	Total: (A)*Wald + (B)*LN	510 249	670 088	469 819	621 625	757 633	681 513	627 586	543 780	457 610	kg
Niederschlägen	27%*2552km2*25.4kg/ha	1750	1750	1750	1750	1750	1750	1750	1750	1750	Tonne
Oberflächen-abfluss:											
*Wegenetz	(Abflus+Einsickerung)*0.0036*(5500ha+2%Wald+LN)	146 492	192 376	134 909	178 490	217 684	195 794	180 318	156 259	131 500	kg
*Gülleabschwemmungen	Direkteinleitung*75%*(Grünland/Grün+Acker)	51 942	46 579	47 879	47 403	48 665	48 477	49 133	49 805	48 280	kg
Acker	(Statec)	61 865	61 538	60 017	59 665	61 022	61 659	61 766	61 951	62 212	ha
Grünland	(Statec)	64 828	65 068	67 245	67 427	68 124	67 172	67 367	67 593	67 400	ha
Wald		88 620	88 620	88 620	88 620	88 620	88 620	88 620	88 620	88 620	ha
	Summe	215 313	215 226	215 882	215 712	217 766	217 451	217 753	218 164	218 232	ha

ENDBILANZ (kg pro Jahr)											
		2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	
Atmosphäre		73 000	73 000	73 000	73 000	73 000	73 000	73 000	73 000	73 000	
Dränage		31 000	31 000	31 000	31 000	31 000	31 000	31 000	31 000	31 000	
Grundwasser		1 308 026	1 718 149	1 202 679	1 591 955	1 930 496	1 737 868	1 599 178	1 384 251	1 164 704	
Direkteintrag:											
Dünger		1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	
Weide		54 139	48 336	48 326	47 652	49 204	49 586	50 229	50 908	49 517	
Gülle Direkteinleitung		135 347	120 841	120 815	119 131	123 009	123 966	125 574	127 270	123 791	
Erosion:											
partikulär		322 970	322 839	323 823	323 568	326 649	326 177	326 630	327 246	327 348	
gelöst		510 249	670 088	469 819	621 625	757 633	681 513	627 586	543 780	457 610	
Oberflächenabfluss:											
Wegennetz		146 492	192 376	134 909	178 490	217 684	195 794	180 318	156 259	131 500	
Gülleabschwemmung		51 942	46 579	47 879	47 403	48 665	48 477	49 133	49 805	48 280	
TOTAL N Diffuser Eintrag		**2 634 164**	**3 224 208**	**2 453 250**	**3 034 824**	**3 558 340**	**3 268 381**	**3 063 648**	**2 744 519**	**2 407 750**	**kg**
(1) Auerswald K., Isermann K., Olfs H.-W., Werner W. Stickstoff- und Phosphateintrag in Fließgewässer über "diffuse Quellen". Agrikulturchemisches Institut											
der rheinischen Friedrich-Wilhelms-Universität Bonn.											
(2) Le calcul est basé sur les UGB entre 1999 et 2003 et sur les UF entre 2004 et 2011.											
(3) Nach Direkteintrag für Bundesrepublik Deutschland: 600 t N.											
(4) 40% der Exkremente fallen ausserhalb der Stallungen an; 1% gelangen in die Gewässer.											
(5) 1% der insgesamt anfallenden Nährstoffmengen in Tierexkrementen werden in die Gewässer eingeleitet.											
(6) Eintrag von 8,4 kg NO3-N und 16,8 kg NH4-N/ha.											
(7) Schätzung: 4000 ha Dränfläche, davon 1/3 unter Grünlandnutzung und 2/3 unter Ackernutzung.											
(8) Mittlere Stickstoffkonzentration: 5 mg/l N.											

Source: Water administration (2012), Nitrates Report

Press Announcement for the
Scientific data-collection carried out in Luxembourg
in April-May 2013:
“Calculate your Personal Nitrogen Footprint online”

A nitrogen footprint is a measure of the amount of reactive nitrogen released to the environment as a result of human activities.

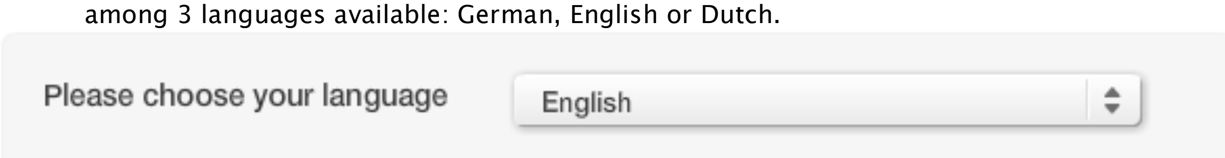
The human use of nitrogen through agriculture, energy use, transportation, resource consumption has profound beneficial and detrimental impacts on all people and the environment. When used excessively, nitrogen can lead to smog, acid rain, forest dieback, costal „dead zones“, biodiversity loss, ozone depletion and an enhanced greenhouse effect. This expansive impact makes it important to understand one’s nitrogen footprint.

A team of international scientists has developed a calculator, which allows to calculate each person’s Nitrogen-Footprint online:

www.n-print.org/sites/n-print.org/files/footprint_java/index.html#/home

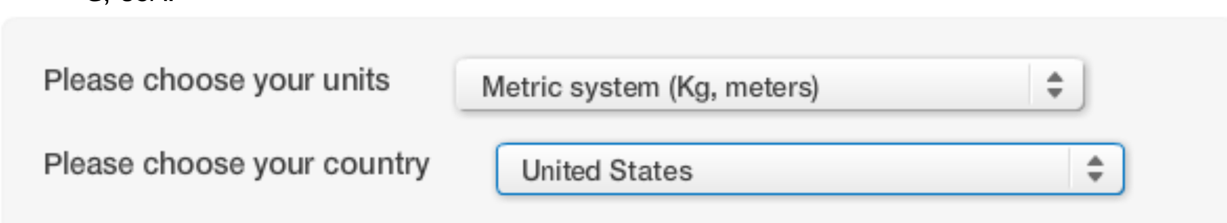
The calculation is voluntary, free and anonymous. It requires 10 – 15 minutes time. The calculator website contains the necessary background information and guidance for filling in the questionnaire:

1. The respondent first chooses the language in which he/she wants to fill the questionnaire among 3 languages available: German, English or Dutch.



2. The respondent then chooses the units of calculation: Metric system.

3. The respondent then chooses any virtual country among the 3 virtual countries listed: NL, G, USA.



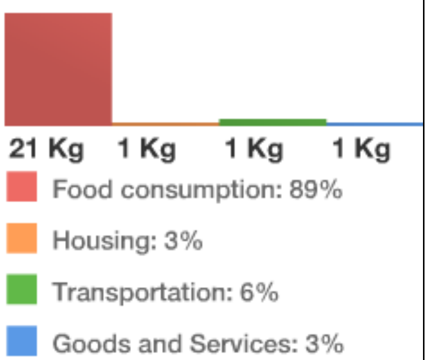
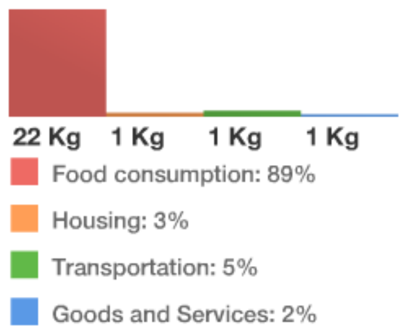
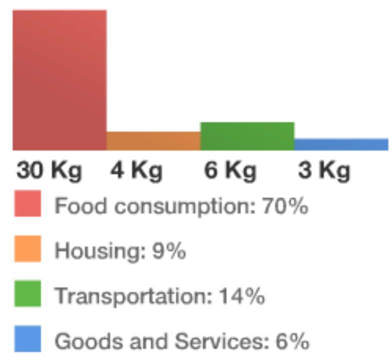
4. The respondent continues answering to the subsequent questions on his/her individual behaviour with respect to food consumption, housing, transportation, goods and services;

5. At the end, by answering the final question “Where do you live?”, the respondent will indicate his/her real country of residence, generating a new country category and saving

new country information. The personal annual Nitrogen-consumption (N-footprint) of the respondent will then show.

The overall data collected for Luxembourg during April – May 2013 will be used for scientific analysis and international comparison.

By way of illustration, the table below shows the average Nitrogen footprint per person per year for 3 countries for which results are available:

<table>
<tr><th>Germany</th><th>The Netherlands</th><th>USA</th></tr>
<tr>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
<tr><td>24 kg</td><td>25 kg</td><td>43 kg</td></tr>
</table>

How will Luxemburg fare?

Your participation can help find out.

Good luck and thank you for your participation in this scientific experience!

Scientific data-collection carried out in Luxembourg

in April-May 2013

“Calculate your Personal Nitrogen Footprint online”

Results of the N-Footprint questionnaire filled in by 37 voluntary respondents

N-Calculator Selections					Food Answers																Housing Answers			Transit Answers			Goods & Services Ar	Results				
Home country	Date taken	Email	Language	N-Calculator selected	Coffee/tea	Wheat and grains	Rice	Fruit	Legumes	Potatoes	Vegetables	Nuts	Alcohol drinks	Milk	Poultry	Beef	Cheese	Pork	Seafood	Eggs	Electricity	Gas	Household size	Flights	Public transit	Personal car	Goods & Services answer	Total: Food	Total: Housing	Total: Transport	Total: Goods & services	Total Footprint
	Date				Number of cups / week	Number of portions / week														Number of eggs/week	kwh/household/month	m3/household/month	Number	hours/cap/yr	km/cap/week	km/cap/week	Answer	kg N/cap/yr	kg N/cap/yr	kg N/cap/yr	kg N/cap/yr	kg N/cap/yr
LU	5.4.2013 8.03	pwolff@vdl.lu	de	DE	0	0	1	10	1	4	9.7	1.5	12	12	2.8	2.5	6.8	2.2	2.3	3	500	99.9	2.7	3.7	99.9	639.9	BELOW_AVERAGE	24.6	0.9	9.0	1.0	35.5
LU	5.4.2013 12.51	null	de	DE	0	0	0.8	8	3	3	15.2	0.8	1.5	12.5	2	1.7	6.5	0	3.3	2.3	130	93.3	1.3	9.3	19	19	BELOW_AVERAGE	20.8	0.6	2.0	0.3	23.7
LU	5.4.2013 12.52	null	de	DE	0	0	0.8	8	3	3	15.2	0.8	1.5	12.5	2	1.7	6.5	0	3.3	2.3	130	93.3	1.3	9.3	19	19	BELOW_AVERAGE	20.8	0.6	2.0	0.3	23.7
LU	5.4.2013 14.53	pacro1@pt.lu	en	DE	0	0	1.2	10	0.1	10.3	18.2	0.8	0.5	11.8	0.5	1.3	12	0.3	0.5	0.3	150	0	1.4	0	3	97	BELOW_AVERAGE	19.2	0.4	0.7	0.7	21.0
LU	5.4.2013 14.59	fernand.sauer@gmail.cc	de	DE	0	0	0	1.8	2.5	3.2	7	0	16.7	0	0.7	0	7.2	0	1.3	1.3	130	51.7	2	0	55	243	BELOW_AVERAGE	10.4	0.4	3.1	0.3	14.3
LU	8.4.2013 11.17	null	en	DE	0	0	0	8	1.7	4.7	6.3	2.7	10.8	4.2	3	2	17	3	2	2.3	288	0	3.8	10.3	56	197	BELOW_AVERAGE	22.6	0.4	2.8	0.7	26.4
LU	9.4.2013 18.07	null	en	NL	0	0	3.3	13.2	2	1.8	10.5	2.3	3.8	0	1.8	0.3	2.3	0.3	1.8	1.8	647	99.9	3.7	10	26.1	171	BELOW_AVERAGE	13.2	0.5	2.5	0.3	16.4
LU	10.4.2013 7.14	null	en	DE	0	0	2	11.8	1.5	3.5	8.3	0	0	8	1.2	1.1	3.8	1	1.8	1.3	460	0	2.6	0	99.9	0	BELOW_AVERAGE	15.6	0.5	3.5	0.7	20.3
LU	10.4.2013 17.02	null	en	US	0	0	0	8	3	1	11	1	2	4	6	1	4	0	2.3	1	500	70	2.3	18	99.9	0	BELOW_AVERAGE	20.0	1.7	5.2	1.3	28.2
LU	11.4.2013 7.26	null	de	DE	0	0	1.3	7.5	6.8	2	7.5	1	0	11.8	1.3	1.1	14.5	1.3	1.3	2.3	90	99.9	2.5	8.3	99.9	0	BELOW_AVERAGE	21.4	0.4	5.0	0.7	27.5
LU	13.4.2013 18.01	null	en	DE	0	0	1.2	10.5	2.5	3.7	9.7	0	14.3	11.8	0	0	8	1.2	0	2.3	260	99.9	2	22.3	19	37	BELOW_AVERAGE	15.2	0.6	3.9	0.3	20.0
LU	13.4.2013 19.41	null	en	NL	0	0	3.8	7.2	1.8	0	6.9	0.8	0	0	1.3	0.8	0.8	0.2	3.3	1	200	53.3	1.2	40	99.9	0	BELOW_AVERAGE	9.9	0.5	6.0	0.3	16.6
LU	13.4.2013 20.41	null	de	DE	0	0	1.8	7.7	0.8	7	14	2.2	3.3	12	0.8	2.7	8.2	2.3	1.7	3.2	140	0	3.7	3	0	275	BELOW_AVERAGE	23.7	0.3	3.5	1.0	28.5
LU	13.4.2013 22.32	null	de	DE	0	0	2	1	2	2	7	1.5	14	3	1.3	1.1	7.3	0	1.3	2.3	350	99.9	2	4	10	49	BELOW_AVERAGE	13.5	0.8	1.6	0.7	16.5
LU	15.4.2013 7.27	null	de	DE	0	0	2.3	7	0.1	0	7	12.2	0	5.5	0	1.1	6.7	0	1.5	0.8	288	99.9	2	7.7	0	101	BELOW_AVERAGE	11.9	0.7	1.8	0.7	15.1
LU	15.4.2013 8.17	null	en	DE	0	0	0.3	4.5	0.1	4.9	9.7	1.5	8.9	4.7	1.3	2.3	5.3	0	0	0	288	0	2	0.8	37.1	500.9	BELOW_AVERAGE	13.1	0.5	5.6	0.7	19.8
LU	15.4.2013 8.43	null	de	DE	0	0	1.3	7.3	1.5	2.5	7.5	1.3	15.3	7.2	0.2	1.1	1	0.5	0.8	2.3	500	99.9	3.6	12.3	7	101	BELOW_AVERAGE	13.4	0.6	3.2	1.0	18.3
LU	18.4.2013 16.54	defosse@pt.lu	en	DE	0	0	1	10	1.7	3.5	14.5	1.2	6.7	7.2	1.3	2	3.3	1	1.3	2.3	110	99.9	3.6	3	0	37	BELOW_AVERAGE	17.6	0.4	1.3	0.3	19.6
LU	24.4.2013 21.22	vschmit7@gmail.com	de	DE	0	0	0	12.8	2.8	3.2	13.2	0	0	18.7	0	0	5.2	0	2	2.3	320	99.9	4.5	3.7	0	281	BELOW_AVERAGE	16.1	0.4	3.7	0.7	20.9
LU	29.4.2013 8.32	null	en	DE	0	0	3.2	7.8	0.1	4.9	8.5	5	12	5.7	1.3	1.5	8	1.5	2.3	2.3	250	99.9	2.3	15	91	207	BELOW_AVERAGE	18.3	0.6	3.7	0.7	23.3
LU	3.5.2013 12.46	null	de	DE	0	0	1.8	10	3	5.2	9.7	4	1.8	4.5	2	2.2	9	3	3.3	4.7	288	99.9	2	14.3	0	207	BELOW_AVERAGE	22.7	0.7	4.5	0.7	28.6
LU	12.5.2013 21.11	ajamamer@pt.lu	de	DE	0	0	1.8	19.7	2.5	3.8	7	0	4.3	3.8	0	0	9.8	0	2.2	3	450	99.9	2.7	0.3	0	61	BELOW_AVERAGE	12.8	0.8	0.7	0.7	14.9
LU	12.5.2013 21.22	null	de	DE	0	0	2	5.3	1.2	5.5	6.7	5.3	10.7	6.3	0	0	8	0	1.8	3.8	450	99.9	2.5	0	0	161	BELOW_AVERAGE	10.3	0.8	2.0	0.7	13.8
LU	21.5.2013 12.12	null	de	DE	0	0	10.3	25	17.2	14.8	14.8	4.5	0.8	10.3	2.3	0	8.2	1.5	1.5	5	100	51.7	1.3	3	99.9	5	BELOW_AVERAGE	20.8	0.5	1.9	0.3	23.5
LU	27.5.2013 15.38	null	en	UK	0	0	1.8	13.2	1.2	2	9.3	0	3	28.5	0.8	2	1.8	0.8	2.3	3.4	200	98	3.8	25.3	0	53	BELOW_AVERAGE	17.0	1.5	3.1	0.6	22.1
LU	28.5.2013 16.23	satam99@hotmail.con	en	DE	0	0	2.2	12.3	5.3	1.7	14.3	1	0	15	1.3	4.8	6.5	2	2	2.5	550	0	3.8	25.3	0	253	BELOW_AVERAGE	24.2	0.5	6.4	0.7	31.8
LU	28.5.2013 16.27		en	DE	0	0	3.7	7	1.2	2.5	17.3	1.7	7.7	21.8	0	1.3	9.3	0	1	0.7	180	99.9	1.5	39.7	99.9	0	BELOW_AVERAGE	16.9	0.6	8.0	0.7	26.3
LU	28.5.2013 17.40	ponn@loomann.lu	en	DE	0	0	2.2	7	4.8	2.8	7	4.5	9.6	20.5	2.3	1	7	3.3	2.2	1	288	99.9	2.5	21	23	404.9	BELOW_AVERAGE	19.2	0.6	7.4	0.7	27.9
LU	28.5.2013 17.50	null	en	DE	0	0	1	8	0.1	3	7	1	7	7	1.2	1.1	2	0	2	0	250	0	2	40	0	300	BELOW_AVERAGE	10.4	0.5	9.0	0.3	20.2
LU	29.5.2013 10.10	geogant@loomann.lu	en	NL	0	0	0.2	10.2	5.2	0	19.7	5	7.1	10	0	1.3	10.5	0	1.5	0	200	41.7	1.4	28	99.9	0	BELOW_AVERAGE	17.3	0.4	4.3	0.5	22.6
LU	29.5.2013 10.45	areboqea@hotmail.cc	en	DE	0	0	2.8	7.7	1	3	8.2	1.7	6	3	3.2	0	7	0.7	1.4	3.9	100	0	1	49.7	27	0	BELOW_AVERAGE	13.4	0.4	7.7	0.7	22.2
LU	29.5.2013 11.43	null	en	NL	0	0	1.8	7.5	2	4	13	1.8	5.3	9.8	1.7	1.3	9.7	0	1	5	400	83.3	3.6	10	9	202	BELOW_AVERAGE	15.9	0.4	3.3	0.5	20.1
LU	29.5.2013 11.44	null	en	NL	0	0	1.8	7.5	2	4	13	1.8	5.3	9.8	1.7	1.3	9.7	0	1	5	400	83.3	3.6	10	9	202	BELOW_AVERAGE	15.9	0.4	3.3	0.5	20.1
LU	29.5.2013 11.46	null	en	NL	0	0	1.8	7.5	2	4	13	1.8	5.3	9.8	1.7	1.3	9.7	0	1	5	420	88.3	3.6	10	9	185	BELOW_AVERAGE	15.9	0.4	3.1	0.5	20.0
LU	29.5.2013 13.10	dmolton@loomann.lu	de	DE	0	0	1.5	6	0	2.2	5	1.7	19	20.3	1.2	0	6.7	3.3	1.4	5.7	110	99.9	1	29.7	0	500.9	BELOW_AVERAGE	16.2	0.8	9.4	0.3	26.8
LU	31.5.2013 14.39		en	DE	0	0	2	5	1	3	7	0	0	4	4.8	3	7	0	4	2	120	50	1	16	99.9	0	BELOW_AVERAGE	18.1	0.6	5.5	0.7	24.7
LU	3.6.2013 15.19	ferrone@loomann.lu	en	DE	0	0	3	7.7	3.8	6.4	9.5	0	0	6.7	1.8	1.8	3.2	0.3	1.8	2	500	0	2.7	5.7	0	41	BELOW_AVERAGE	15.3	0.6	1.7	0.7	18.2
					0.00	0.00	1.86	8.88	2.47	3.68	10.50	1.96	5.84	9.29	1.48	1.29	7.01	0.80	1.77	2.42	290.19	66.39	2.45	13.75	35.63	150.02		16.87	0.60	4.09	0.59	22.14