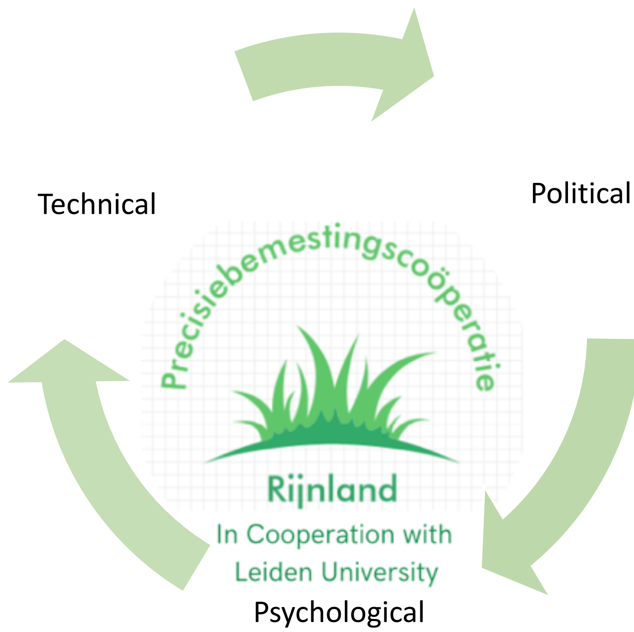
The Accountable Material Balance Report

2021

The Netherlands



The Accountable Material Balance Report 2021, The Netherlands				
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Abstract

The Dutch agricultural industry is responsible for a significant amount of nitrogen emissions, causing large environmental damage. An accountable material balance (AMB) has been proposed that stimulates farmers to reduce emissions and use their materials more effectively by using modern technology. This report analyses the political, technological, and psychological aspects connected to the AMB. Several recommendations are made based on the obtained results, including providing aid to the farmers and considering the industries surrounding farming during the transition; investing in both farm- and data-based infrastructure and technologies, and setting up pilot studies that test their efficacy; and seeking the early and active involvement from farmers throughout the implementation.

Acknowledgments

During the last three months, we were tasked with understanding and commenting on a very complex and multidisciplinary topic as part of a class on circular economy. We would like to thank a number of people for their help and involvement, without whom this report wouldn't have been possible. Firstly, we would like to thank our commissioner Herre Bartlema for his active involvement in the project, including organizing weekly meetings, informing us about the topic and connecting us with experts within the field. We would also like to thank Jan-Willem Erisman, Michel de Haan and Ad van Velde who shared their expertise with us during various stages of the project. Lastly, we would like to thank our professor René Kleijn for his support, as well as all the students from the Circular Economy class who attended our presentations and discussed the topic with us.

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Political Aspects

1.0 Introduction

1.2 The European Green Deal is a political initiative that sets out an ambitious goal: Europe as the 'first climate-neutral continent.' The European Commission has acknowledged that climate change is an existential threat and that "Europe needs a new growth strategy to transform the Union." Most relevant to our research is how the EU aims to decouple economic growth from resource use. This points at changing consumption and production patterns within all relevant sectors and industries. Without support from the public, an alteration in consumption and lifestyle won't be achievable. Guaranteeing changes from businesses and governments is dependent on the demands pressed by the public. In recent years, the discourse on agrarian development and methods of cultivation have taken priority. In this report, we broadly assess how political and social initiatives are transforming the Dutch farming sector. Notably, the transformation of the farming sector occurs incrementally and is different for each designation of work. In narrowing our research scope, we have paired up with the 'Smart Fertilisation Cooperative' in analyzing the discourse surrounding the reduction of Nitrogen Emissions.

2.0 European Green Deal & Nitrogen Emissions

"The European Green Deal is our new growth strategy – for a growth that gives back more than it takes away. It shows how to transform our way of living and working, of producing and consuming so that we live healthier and make our businesses innovative."

Ursula von der Leyen

2.1 The European Green Deal ('EGD') is a set of policy initiatives prepared by the European Commission ('commission'). The EGD aims at making Europe climate neutral by 2050. To do this, the European Commission proposes to reduce the EU's greenhouse gas emissions target between 50-55%. However, achieving an economic-environmental equilibrium that maximizes economic growth and significant environmental concessions is cumbersome. The commission has issued eight policies that require "intense coordination to exploit the available synergies across all policy areas" (Green Facts, 2020). Notably, the EU's policies and initiatives are not enshrined in law; thus, it is each European member states' onus to facilitate and roll out the EGB objectives.

The commission devised eight policy areas:

I. Increasing the EU's climate ambition for 2030 and 2050
II. Supplying clean, affordable, and secure energy
III. Mobilizing industry for a clean and circular economy
IV. Building and renovating in an energy and resource-efficient way
V. Accelerating the shift to sustainable and smart mobility
VI. From 'Farm to Fork': designing a fair, healthy and environmentally system.
VII. Preserving and restoring ecosystems and biodiversity
VIII. A zero-pollution ambition for a toxic-free

(UNIDO, 2020)

2.2 The commission acknowledges that a 'green mobilization' of European industries and businesses is only feasible if other countries push for a climate strategy. In order to persuade other countries to make a greener transition, the EU has implemented a "carbon border adjustment tax on imports for less ambitious countries." Furthermore, the commission has also advised for effective carbon pricing, "for selected sectors, to reduce the risk of carbon leakage and ensure that the price of imports reflects more accurately their carbon content" (UNIDO, 2020, p.5). The commission purports that such measures will drive competition and foster greater transparency on the carbon-net of products. Furthermore, it will encourage industries to modernize practices and innovate more sustainable and energy-efficient initiatives. These measures coincide with the established *EU's industrial strategy*, most pertinent to our study, the commission's new *Circular Economic Action Plan*, which "presents new initiatives along the entire life cycle of products to modernize and transform the European economy while protecting the environment. It aims to change the methods of consumption and the way of production" (UNIDO, 2020). Against the backdrop of reducing nitrogen emissions, the agricultural sectors aim to transform nitrogen waste into an opportunity. The ordinal practices have been to denitrify nitrogen; however, currently, researchers aim to recover nitrogen as an input feed for agriculture. The reduction of nitrogen emissions is not overtly identified in the EGD, however the notion of *Greening the EU's Common Agricultural Policy,* incorporates/ promotes sustainable practices that reduce output of any emissions (UNIDO, 2020). The EU does this in one of two ways, first, The EU's *Farm to Fork* initiative aims to reduce food loss and waste prevention, encourage sustainable food production and consumption, finally, sustainable food processing and distribution (UNIDO, 2020). Second, by establishing a common agricultural network for European farmers.

The commission purports that a *Farm Accountancy Data Network* will "enable the benchmarking of farm performance against regional, national or sectoral averages" (UNIDO, 2020, p. 12). The commission believes an agricultural *European Innovation Partnership* will provide farmers with the necessary direction to improve and modernize their agricultural practices. Moreover, the agro-innovation partnership will help capture the aforementioned EGD policy directive.

3.0 European Nitrogen Directive

3.1 The European Nitrogen Directive was conceived in 1991 to "protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices" (EU commission, 1991). The directive acknowledges the critical necessity of nitrogen for plant growth, however excessive concentrations are 'harmful to people and nature' (ibid., 1991). The directive proposes three measures to limit the concentration of nitrate through:

I. The monitoring of water bodies with regard to nature concentrations (ibid., 1991).
II. The designation of nitrate vulnerable zones (ibid. 1991).
III. Establishing codes of good agricultural practices and measures to prevent and reduce water pollution from nitrate (ibid.1991).

3.2 The implementation of the nitrate directive is overseen and assisted by appointed member states committees. The commission outsources expert groups to provide recommendations and insight on "technical aspects linked to implementation of the nitrates directive and nutrients policy" (EU commission, 2021; EU commission 1991). Notably, the efficacy of the nitrate directive is dependent on the willingness of European farmers to adopt codes of good agricultural practice.

4.0 Dutch National Context

4.1 The Dutch strategy of reducing excess nitrogen in vulnerable areas was ruled to be breaching EU law by the Council of State (highest administrative court in the Netherlands) in May 2019. Next to emissions from traffic and industry, a majority of nitrogen oxides ending up in the environment are a result of animal agriculture and the use of manure in farming (RIVM, 2020), as it is also illustrated in Figure 1. Therefore, the current focus on reducing nitrogen emissions in the farming sector is no surprise, as the Netherlands ranks second for agricultural exports worldwide after the United States. Being worth almost €100 billion annually, the Dutch agricultural export industry is a crucial economic sector (Erisman, 2021). Therefore, in the beginning of 2020, the Dutch government announced new measures and policies to reduce nitrogen pollution, encompassing all sectors including farming. The Ministry of Agriculture, Nature and Food Quality (2020) specified that

> *"for farmers who wish to continue farming, €172 million will be made available to help them innovate, and to make their livestock housing more sustainable. The government will also set up a transition fund to help farmers who want to make their operations circular. Funding will also be available to make livestock farms near Natura 2000 areas less intensive"*

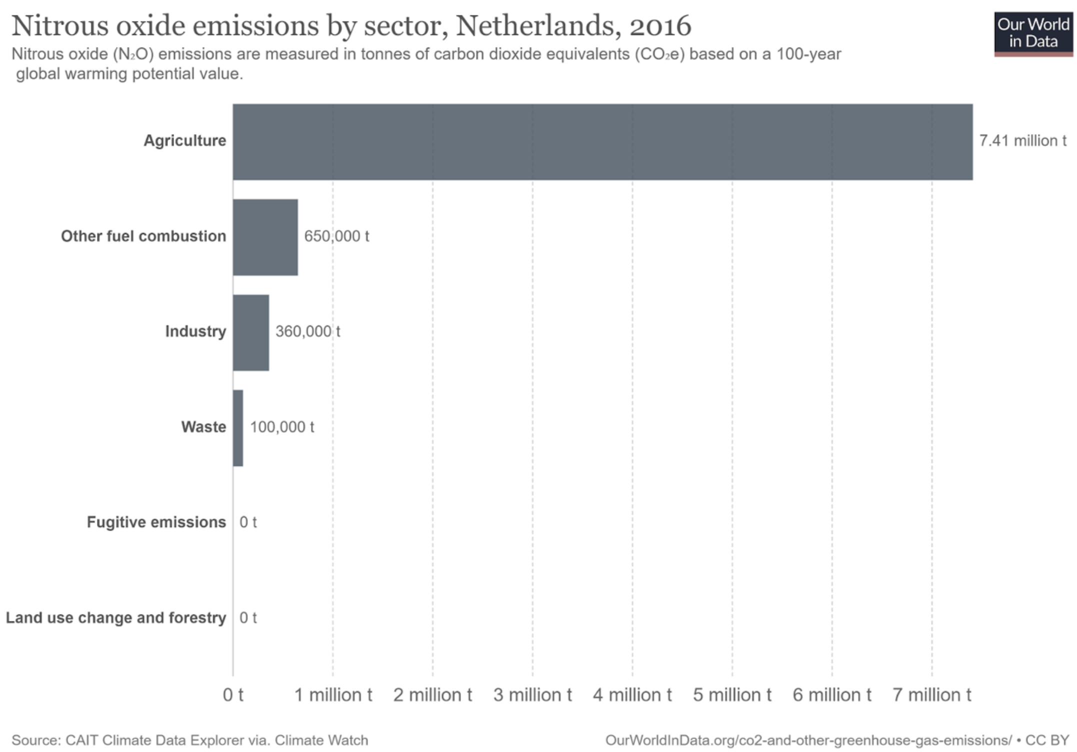


Figure 1 Nitrous Oxide emissions by Sector (World Data, 2021).

4.2 Compared to issues such as climate change and biodiversity loss, the nitrogen crisis has received surprisingly little attention despite the "consequent implications for the environment and human well-being" (Erisman, 2021, p. 15). An explanation can be that the effects of climate change may already be observed and felt, whereas it is more difficult to see the consequences of high nitrogen emissions. Moreover, the nitrogen problem is very complex in itself and might be dismissed as too technical to be understood. Nonetheless, nitrogen has been an important instance on the agenda of agricultural policy makers in the EU and the Dutch government since the 1980s (Baumann et al., 2012). As already outlined above, both on a national and supranational EU level efforts have been made for many years and new policies and ambitions are regularly developed to reduce nitrogen emissions.

5.0 The Abandonment. Dutch Government's Nitrogen Action Program' ('PAS')

5.1 On December 17th, 2020, the Dutch Administrative Court of the Council of State ruled in favour of the 'Nitrogen Law' supplanting the initial 'Dutch Government's Nitrogen Action Program' ('PAS'). The Dutch Ministry of Agriculture and other external agencies deemed PAS inadequate in addressing the exponential rise of nitrogen emissions. The difference between the PAS law and the Nitrogen law is the newly implemented legislation does not "steer economic activities based on calculated future nitrogen emissions but the actual nitrogen levels of the nature reserves" (Flach et al., 2021). This is more commonly understood as the *emissions offset scheme*, whereby the organization equilibrates its emissions into another project or sector. Such an approach is merely holding emissions in a state of abeyance. The aforementioned opposition groups deemed such an approach as inviable, given that "70 percent of the country's surface area exceeds critical limits for nitrogen" (Flach et al., 2021). The Nitrogen Law instilled provisions that urge municipal governments and relevant stakeholders to curb emissions in all areas possible. The Dutch government developed various pay-out schemes to drive out large emitters such as swine and cattle farmers. The approved pay-out schemes are a gamble, given the uncertainty on the number of farmers willing to forfeit their businesses. The pay-out measure is an effective method to eliminate intensive nitrogen emitters long-term, however the ramifications on the agro industry is significantly unaccounted for.

Approved Buy Out Schemes (Domestic)

I. The voluntary buy-out scheme for the swine sector amounting to €455 million. In addition to a new program of €350 million for livestock and poultry farmers' (ibid., 2021).

II. The €5 billion financial investment support is fixed to 'nature restoration' and buy out programs for enterprises that operate near nitrogen sensitive nature areas (ibid., 2021).

Alternative Endorsed Government Strategies (Domestic)

I. Between September 1st, 2020 - December 31st, 2020, the government issued an edict limiting protein in animal feed "in order to attain a reduction of 0.2 kilotons in nitrogen emissions' (ibid., et al. 2021). *This measure was employed as an emission offset scheme that would accommodate the 'construction of 75,000 new homes in the Netherlands' (ibid., et al. 2021).

II. Farmers that obtained permits before the enactment of the Nitrogen Law received assent to renovate or expand their farms [this clause applied to ± 3000 dutch farmers] (ibid., et al. 2021).

Alternative Strategies (Foreign)

I. The Nitrogen Law permits the Dutch Government to coordinate with European member states and the European Commission in curbing nitrogen emissions (ibid., et al. 2021).

6.0 Feasibility and Practicality of Nitrogen Reducing Policies

6.1 From the 1950s until 1989, the surplus of nitrogen and phosphorus in Dutch agriculture was steadily growing. However, between 1992 and 2010, this surplus decreased by almost 50 %, which is a result of implementing the EU Nitrates Directive and making changes in national policies (Figure 2). In 1998, the system of manure bookkeeping was replaced by a Mineral Accounting System (MINAS) (Baumann et al., 2012) which was designed to target mineral losses from agriculture, combining nutrient accounting with a tax system. However, the policy created challenges “which resulted in some farmers receiving very high unjustified taxes, and external socio-economic pressures, which in combination fuelled widespread resistance to the policy and hence escalating transaction costs due to the increasingly large administrative burden” (Wright, 2006, p. 107). It is crucial to examine how and why the MINAS created such issues, in order to avoid similar shortcomings for the Accountable Material Balance.

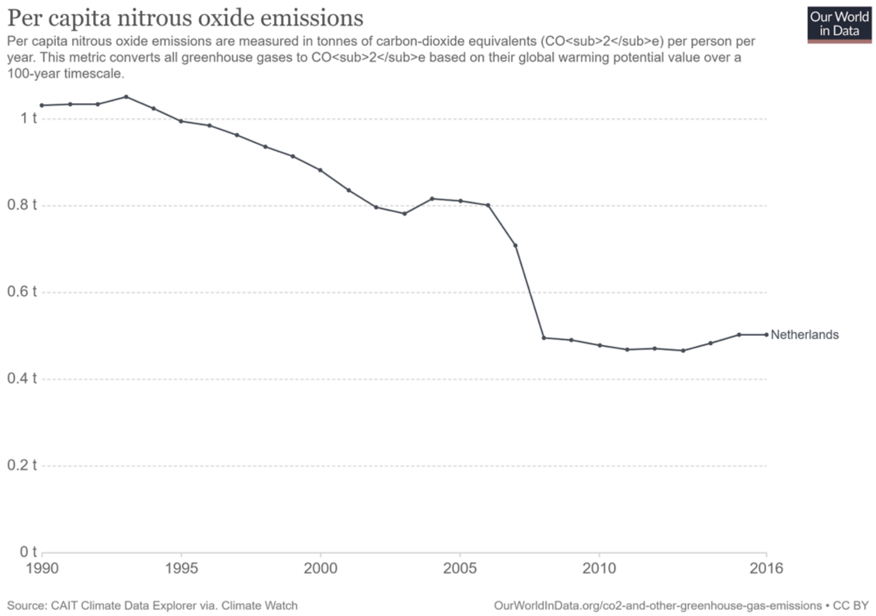


Figure 2, Per Capita Nitrous oxide emissions

6.2 MINAS was based on the mineral balance of nitrogen and phosphorus, setting limits on the permitted number of mineral surpluses on farms (Baumann et al., 2012, p. 11). It was an important step forward in environmental policy "because nutrient surpluses are better indicators of nutrient leaching than manure application standards, and because MINAS gave farmers the autonomy to determine how to reduce their surplus" (Klootwijk et al., 2016, p. 8385). Initially MINAS promised some advantages over the Nitrate Directive. It controlled the amount of minerals lost, rather than directly regulating the amount of manure applied to the land. This enabled farmers to even "apply significantly more nitrogen from manure" (Wright, 2006, p. 110). Consequently, the ambitious outset led to challenges and difficulties upon implementation. In a 2002 study on the management strategies of Dutch dairy farms to meet environmental regulations, Ondersteijn et al. (2002a) found that "the introduction of MINAS poses a serious threat to the financial viability and continuity of farms due to high levies and the large number of farms not yet meeting the standards" (Ondersteijn et al., 2002a, p. 48). The reason many farmers did not meet MINAS standard can be referred back to the fact that the new regulations were not mandatory in 1997, therefore farmers still built up their chemical fertiliser stocks shortly before the new policy was implemented. Moreover, MINAS was introduced stepwise and only in 2000 all farmers were subject to the policy (Ondersteijn et al., 2002b).

6.3 The MINAS tax system incentivised farmers to invest in new technologies, which allowed them to make changes for their specific circumstances. As already indicated above, MINAS focused on nutrient losses as the cause for environmental problems, compared to the Nitrate Directive which targeted the nutrient input through manure. The MINAS policy therefore taxed all nutrient sources such as artificial feed. This means that farmers had to be "careful with all sources of nutrients and the tax could not be avoided through the use of substitutes, as would have been the case if the levy were imposed upon fertilizer products" (Wright, 2006, p. 110). Despite the perceived advantages of MINAS, Wright (2006) identified multiple shortcomings of the system: "Financial compensation / refunds made to farmers; Exemptions made to farmers originally liable to taxation; Low percentage of tax revenues collected; Exploitation of loopholes within the system; Fraud; Litigation proceedings against the governing authorities; Refusal amongst target group to pay levies" (p. 110). This led to an increasing administrative burden and in October 2003, the European Court of Justice (Case C-322/00) found that the Netherlands did not fulfill its obligations according to the Nitrate Directive (ECJ, 2003). Nonetheless, the nitrogen surplus had further declined with the implementation of MINAS, after the level had remained stable between 1990 and 1998 (Baumann et al., 2012).

7.0 Stakeholders and Government Subsidies

7.1 Next to legislation on the EU and national level, there are various stakeholders in the agricultural sector which can influence policies and therefore need to be considered. These stakeholders include "growers, fishermen/women, research organisations, investors, traders, retailers, non-governmental organisations and landowners", and most importantly the farmers themselves (Ministry of Agriculture, Nature and Food Quality, 2019, p. 4). Furthermore, there is a strong agricultural lobby consisting of banks or suppliers of farming machinery, feed or fertilisers. They strive for a steady increase in production as their business model builds up on constant growth. This indicates that it is not just the technology which needs innovation in agriculture, but also the industry around the farmers needs to transform for the AMB to succeed. Currently there is a strong lobby to keep the system as it is, whilst the agricultural business model needs change (J. W. Erisman, personal communication, February 4, 2021).

The Dutch agricultural sector has a great significance for the economy. The worth of exported agricultural goods amounted to €94.5 billion in 2019. More than half of the exports went to only four countries, namely Germany, Belgium, The United Kingdom and France (Government of the Netherlands, 2020). The economic importance of the agricultural sector also makes the Dutch farming lobby very powerful and influential. The LTO, the Netherlands Agricultural and Horticultural Association, represents over 35,000 agricultural entrepreneurs and employers and aims to ameliorate the social and economic circumstances of their members (LTO, 2021). Especially the salience of farmers as a stakeholder was evident during the farmers protests in The Hague in 2019 and 2020. The protests first started because of the government's plans to reduce emissions of nitrogen oxide, where farmers feel disproportionately targeted by lawmakers. On the one hand, governmental measures include funds to buy out farmers who voluntarily want to close their farms, on the other hand modernisation of farms is encouraged and incentivised (Corder, 2020).

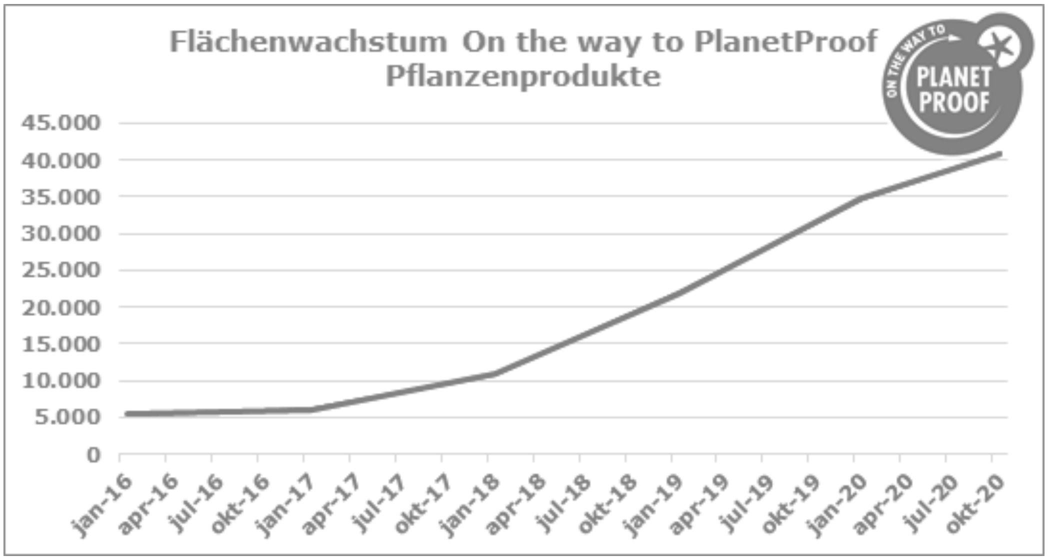
These incentives by the government include financial aid, for example subsidising corporations in the development of new machinery. Such an incentive structure was realised with the Rural Development Program (Plattelands Ontwikkelings Programma, POP3), which was approved in 2015 by the European Commission and is part of the Common Agricultural Policy. The focus lies on the following five themes, but each province decides which ones to empathise: strengthening innovation, sustainability and competitiveness; young farmers; nature and landscape; improvement of water quality; LEADER (strengthening rural areas) (RVO, n.d.). A challenge is providing help to everyone that requires it, whilst also ensuring that a reduction in nitrogen input is already shown. Such criteria need to be fulfilled in order to receive subsidies and financial help for material investments (A. den Hollander, personal communication, March 29, 2021). Here collaboration on a regional level and between various stakeholders is crucial and partnerships between the provinces, municipalities and water boards are already established in different regional deals (Ministry of Agriculture, Nature and Food Quality, 2019, p. 6). Next to governmental aid, labels and certifications can provide an incentive for farmers to adjust their means of production and effectively reduce nitrogen input.

8.0 Labels and Certifications

8.1 On the Way to PlanetProof is an independent environmental quality label which proves the sustainability of a product, bringing benefits for nature, the climate and animals. The label is managed by SMK (Stichting Milieukeur), a Dutch foundation that has worked with business organisations to improve the sustainability of products and business management for more than 25 years. Farmers work in compliance with the Sustainable Development Goals and aim to for “cultivation that is in balance with the earth’s capacity”. The label *On the Way to PlanetProof* can be requested for various products including the following: potatoes, vegetables, fruit, dairy, eggs, flowers, flower bulbs, trees and plants and processed products. The label also certifies that the farmer contributes to cleaner air, fertile soil, water quality, increased biodiversity on the farm, animal welfare and recycling.

8.2 Currently 1,660 companies on an area of 40,869 hectares grow and produce food with the *On the Way to PlanetProof* certificate (Figure 3). The cultivation of these products does not take place exclusively in the

Netherlands, but also farmers in Belgium, Germany, Poland, Portugal, Spain, Italy, France produces in compliance with On the Way to PlanetProof standards. Furthermore, there are 83 companies that are certified to trade these products.



8.3. Figure 3 Area growth of PlanetProof plant products (in hectares)

8.4 The label brings different advantages for both the producer and the buyer. First, the image and positioning of a company or farmer is ameliorated, as *On the Way to PlanetProof* promises insight into the production process and origin of materials. Second, reliability and transparency are ensured, and processes are supervised by experts and stakeholders including the producer organisations, retail, government, researchers, environmental experts and advocates of consumer interests. Furthermore, the auditing and certification of products or services is regulated according to European norms for product certification (ISO/ IEC 17065). Third, a guideline for sustainable purchasing is provided which helps consumers in their decision making. Lastly, and probably most important for this pilot study, is the advantage of cost reduction. This is relevant as companies and farmers complying to *On the Way to PlanetProof* standards often use less fertilisers, water and energy, which leads to long-term cost reduction by producing more sustainably with fewer inputs.

9.0 Farm to Fork

9.1 As discussed above, the European Green Deal is an initiative which aims at making Europe the first climate-neutral continent by 2050. An essential component of the deal is the Farm to Fork strategy (f2f). The intent is to address the "challenges of sustainable food systems and recognise the inextricable links between healthy people, healthy societies and a healthy planet" (European Union, 2020, p. 4). Again, the Sustainable Development Goals are a crucial element. Whilst the Farm to Fork initiative is an opportunity to improve lifestyles, health, and the environment, it is not legally binding.

9.2 To ensure sustainable food production, the importance of green and circular business models is highlighted. This also includes tackling the issue of excess nutrients in the environment, especially nitrogen and phosphorus. Some nutrients are used in excessive quantities and plants do not effectively absorb all those nutrients used in agriculture. Therefore, the "Commission will act to reduce nutrient losses by at least 50%" (European Union, 2020, p. 9), which is supposed to reduce fertiliser use by at least 20% by 2030. The Farm to Fork initiative also intends to develop an action plan for integrated nutrient management together with the Member States. This is important for the Accountable Material Balance, as "the Commission will also work with Member States to extend the application of precise fertilisation techniques and sustainable agricultural practices" (European Union, 2020, p. 9). A focus will be the recycling of organic waste into renewable fertiliser in areas of intensive livestock farming. In addition, carbon leakages resulting from animal feed imports should be avoided to minimise the environmental and climate impact of animal production. The placement of innovative and sustainable feed will be facilitated by the Commission as part of the Farm to Fork action plan.

10. Policy Implications

- Focus on the industry around the farmers and re-evaluate the agricultural business model. As the Dutch agriculture is a significant economic sector, lobbies, banks or suppliers are actors wanting to keep the system as it is and further increase growth.
- Provide incentives and facilitate the transition period for farmers if the means of production are adjusted. Aid and support can be received from the EU through initiatives like Farm to Fork, or on a national level through subsidies and increased regional collaboration. The Accountable Material Balance can be utilised to set criteria and identify who will receive financial aid.
- Next to political considerations, the Farm to Fork strategy as part of the European Green Deal outlines important components to enable the transition to a fairer, healthier and more

environmentally friendly food system. These include research, innovation, technology, advisory services, data and knowledge sharing, and skills (European Union, 2020, pp. 16-17). Investment into technological development and research is therefore crucial to enhance the prospects of nitrogen reduction in agriculture. The current technical possibilities and limitations for a successful implementation of the AMB will also be elaborated in the following part of this report.

11.0 Technical aspects on material balances

Extensive research has been performed into the nitrogen balances of farms, and several farms also perform active measurements on these balances within farms. (Oenema et al., 2015) The AMB intends to extend these measurements to a large proportion of Dutch farms and to improve these measurements, for example by using real-time measurements and by using measurements with high sensitivity and resolution. Furthermore, these automated measurements could be coupled to computational systems that can calculate a full nitrogen balance. This section discusses the material balances of interest, the currently applicable measurement techniques, and the implementation of data science techniques.

12.0 An existing material balance: the ANCA

12.1 Reactive nitrogen is emitted during farming activities in several forms. Ammonia (NH_3) is the most important form of nitrogen and is emitted from manure and fertilizer. Large ammonia emissions result in increased nitrogen amounts in natural habitats; certain plant species grow very well in these nitrogen-rich habitats and outcompete other plant species, resulting in disruption of natural processes and loss of biodiversity (Guthrie et al., 2018). The agricultural industry is the largest emitter of ammonia, producing 86% of ammonia emissions in 2016 (RIVM, 2016). Nitrates are a different form of nitrogen that is present in fertilizer and enters surrounding area via ground water; similarly, to ammonia, natural processes are disrupted, and the water quality is strongly diminished. (RIVM, 2020) Nitrous oxide (N_2O) is another pollutant that is frequently emitted in agricultural activities. (RIVM, 2016) Nitrogen flows also exist in other forms, most notably organic nitrogen, which is present in the form of proteins. (Boulos et al., 2020)

12.2 Several material balances have already been proposed and implemented in The Netherlands to measure and limit nitrogen emissions. Material balances present farmers with a tool to monitor their performance and locate instances where changes in practice could reduce emissions and improve outputs and profits. As a result, ammonia emissions have decreased by 66% between 1990 and 2017, although this reduction has since become stagnant and has even started increasing again, especially due to an increase in dairy cattle (CLO, 2019). These material balances are also concerned with the concentration of phosphates; those sections are outside the scope of this report and will not be evaluated here.

13.0 Background of the ANCA

13.1 The MINAS (Mineralen Aangiftesysteem) system was introduced in 1998 and was based on the mineral losses that farmers incurred, effectively limiting the amount of manure and fertiliser farmers were allowed to use. Loss norms were put into place that would result in fines if exceeded. These loss norms were calculated by the difference in input and output of farms and were based on the size of farms. (RIVM, 2002) Under MINAS, farmers reported significantly lower nitrogen and phosphate losses. Nevertheless, the system was scrapped in 2005; from 2006 onwards, new policies were focused on the application of manure and fertiliser rather than loss of nitrogen (RIVM, 2004).

13.2 Much more recently, the KringloopWijzer (Annual Nutrient Cycle Assessment, ANCA) was introduced. The ANCA is more comprehensive than the MINAS for two main reasons. Firstly, it takes more material flows into account. MINAS only accounted for inputs in the form of feed, fertilizer, and cattle, and outputs in the form of manure and produce (RIVM, 2004). The ANCA also takes deposition, biological fixation of legumes, mineralisation, and annual supply changes into account. Secondly, it distinguishes between ammonia, nitrous oxide and nitrates, while MINAS does not distinguish between nitrogen emissions. (Van Dijk et al., 2020) From 2017 onwards, use of the ANCA has become mandatory for all dairy farmers. (KringloopWijzer website, 2021) The calculations for ANCA are presented in a report that is updated yearly to reflect changes in legislature and acquisition of new knowledge, as well as to make improvements to parts of the model. (Van Dijk et al., 2020) An overview of the material flows considered in the ANCA is presented in figure 1.

13.3. In total, five indicators are calculated using the ANCA. The BEX (farm-specific excretion) indicates the amount of nitrogen and phosphates present in produced manure. This is calculated as the difference between N uptake (from feed) and fixation (in growing animals or in milk). It takes into account types and content of feed used and milk produced, cattle types, cattle ages, and other factors. Not all nitrogen is lost in the form of manure; for this reason, the BEA (farm-specific ammonia emissions) is also calculated. The BEA indicates the amount of ammonia emissions that occur during farming activities. This is done by evaluating the processing steps of manure and estimating the amount of nitrogen lost in each step through standardized emission factors. The BEN (farm-specific nitrogen flows) calculates the loss of nitrates and nitrous oxides, generally into groundwater and surface waters. This is based on the application of manure and fertilizer, as well as physical factors such as ground composition and precipitation. Once again, emissions factors are used for these calculations. The BEC focuses on carbon flows, but also provides information on organic nitrogen flows, as organic nitrogen-containing substances are often rich in carbon. The BEP focuses on phosphate and is of less relevance to this report. (Van Dijk et al., 2020)

14.0 Accuracy and applicability

14.1 The ANCA has proven to be relatively accurate. A 2017 evaluation on 16 dairy farms compared estimations from the ANCA with measurements on nitrogen and phosphate content, in a pilot project named 'koeien en kansen' (Cows and opportunities, C&O). The results showed correct estimations on nitrogen emissions in 75 percent of cases (estimations came within 5% of measurements) and an average underestimation of nitrogen excretions of 3 percent. This was also a more accurate estimation than the flat rates provided by the RVO, which were used previously to estimate nitrogen excretions. (Oenema et al., 2017)

14.2 The first iteration of the ANCA was initially applicable only to specialised dairy farms, accounting for 80% of relevant farms (Aarts et al., 2015). Since then, changes have broadened the scope of the ANCA to include farms that perform other ancillary activities or atypical farming methods. Nevertheless, the authors state that the ANCA is not suitable for several types of farms. Farms with low milk production or low numbers of dairy cows see less accurate results when the ANCA is applied, which is generally the case for smaller farms; similar problems arise for farms with large numbers of other ruminants. The ANCA also doesn't calculate the nitrogen content of non-ruminants, of which instead an estimation is used in the ANCA; integrating these calculations into the ANCA would serve as an improvement for dairy farms with large numbers of non-ruminants. (Van Dijk et al., 2020) Further inaccuracies to the ANCA, applicable to all farmers that make use of it, are also mentioned.

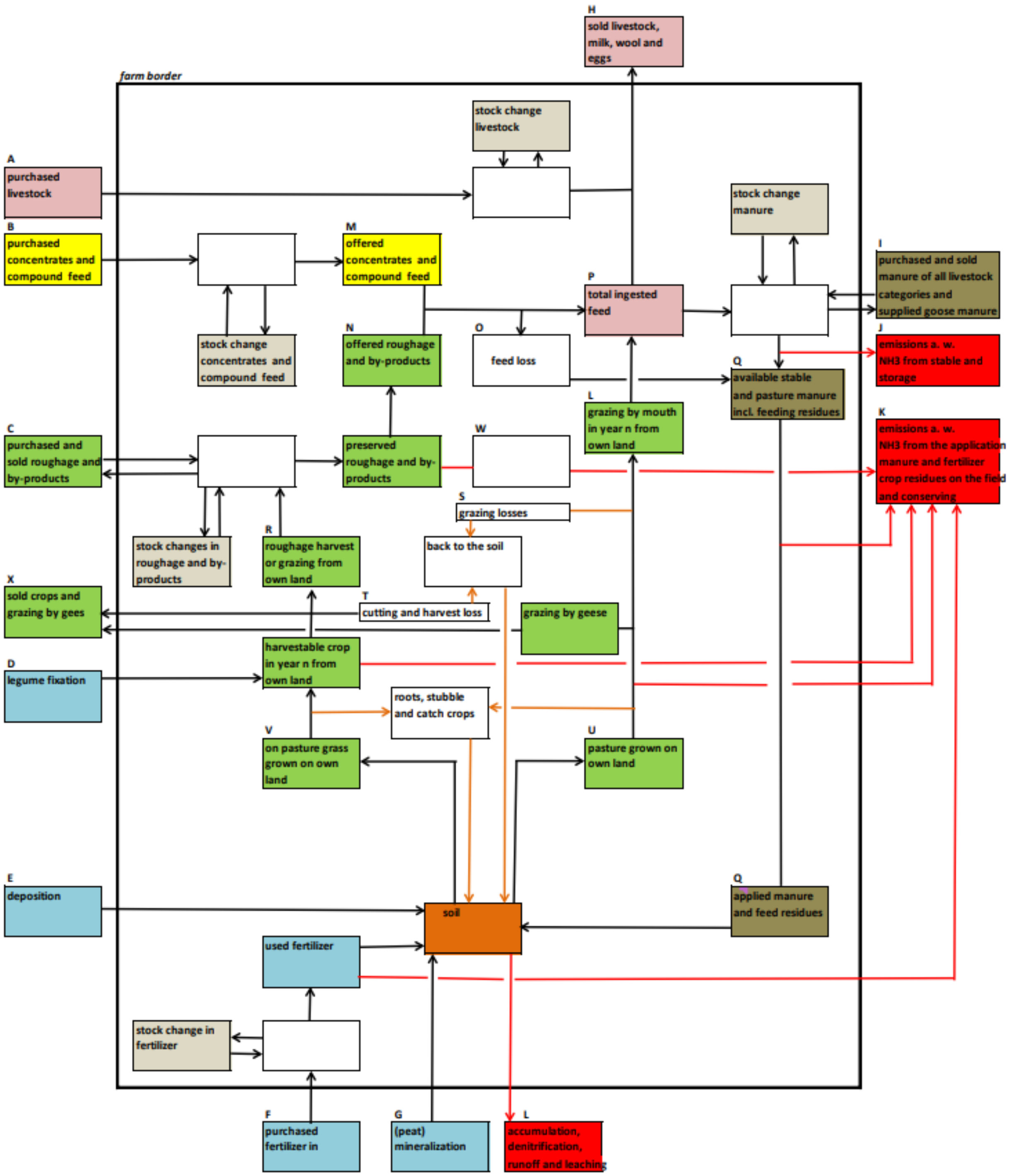


Figure 4. Comprehensive overview of material input and output flows, as well as internal flows, on a farm, with or without arable crop production and other (ruminant/non-ruminant) livestock. Adapted from Van Dijk et al., 2020.

14.3 The BEX, BEA and BEN together give a complete image of the nitrogen flows within a farm. However, in many cases the ANCA estimates specific nitrogen inputs, outputs and storage mutations with calculations or estimations using standardized values, rather than direct measurements. The ANCA only uses these estimations if they are deemed accurate enough (Van Dijk et al., 2020), and the aforementioned 2017 evaluation has indicated that the ANCA is sufficient in most cases. Nevertheless, using real-time measurements with modern technology could close the gap between the values calculated by the ANCA and actual values, as well as making the ANCA applicable for farms that currently see inaccurate results with it.

15.0 Methods of determining nitrogen flows in real time

15.1 As mentioned in the introduction, the AMB is based on real-time measurements and precision agriculture. Therefore, nitrogen inputs, outputs, supplies and waste should be measured where possible, rather than calculated using pre-existing models. Ideally, real-time measurements or frequent automated sampling are used to directly measure the nitrogen content of a material flow. However, if measurements are not feasible or accurate, other calculations or standardized estimations as used in the ANCA (Van Dijk et al., 2020) could still be used.

15.2 Nitrogen measurements are frequently used on farms participating in pilot and research projects. The aforementioned C&O program, used to validate the ANCA, used measurements in many places as a method of validation. Furthermore, data was used from De Marke, an experimental dairy farm with even more nutrient monitoring systems in place (Oenema et al., 2017). Data collection at De Marke is considered very intensive, while data collection at C&O is less intensive and is more often based on estimations (Oenema et al., 2015). The data collection regimes at these farms can form a basis for the real-time data used in the AMB.

15.3 The AMB is based on the transition towards zero-emission agriculture: losses of nitrogen into the surroundings, either by volatilization of ammonia, nitrate leaching or other methods, must be limited. Therefore, to monitor the performance of a farm, it is crucial to monitor the amount of nitrogen lost as harmful by-products during farming activities. In De Marke and the C&O farms, these losses were calculated using standardized values (Oenema et al., 2015). These values may not properly reflect losses that occur from farms that implement atypical farming methods focused on reducing emissions. For this reason, it is important the AMB uses data on nitrogen losses rather than estimates and assumptions. Methods and implementation of monitoring the two most important nitrogen losses, ammonia emissions and nitrate leaching, are described here.

16.0 Measuring ammonia and other airborne emissions

16.1 The mass of nitrogen emitted into the atmosphere in the form of ammonia, nitrous oxides or other nitrogen-containing compounds can be calculated based on data on the concentration of these compounds. Due to their low ambient concentration, even in the vicinity of agricultural activity, and their fluctuations in time (Pogány et al., 2015), it is important that these measurements are sensitive and have a high temporal resolution. The following section describes the monitoring of ammonia, but the systems and methods described can also be applied to other nitrogen emissions.

16.2 A report from the 17th International Congress of Meteorology gives an overview of current ammonia monitoring methods in two groups. Samplers collect airborne ammonia over time, the content of which is then analysed in the lab. Spectroscopic methods use light-based techniques to detect the concentration of ammonia in the air. Spectroscopy is generally preferred for being cheap and accurate compared to sampling (Pogány et al., 2015). Furthermore, sampling requires transport of samples to laboratories, which disables the ability to perform real-time analysis on farms.

16.3 So far, most real-time measurement systems for nitrogen are used primarily for experiments or pilots; this means they are generally bulky and are often mounted to vehicles to enable easier transport. For measurements in fields, this size is generally not an issue. A 2009 report by the RIVM reported on experimental results of two spectroscopic techniques to measure ammonia emissions after application of manure to fields, tunable diode lasers and lidar. Measurements of both techniques were in agreement with each other and with previous results. The techniques allowed measurements every 30 minutes or less, finding low concentrations and enabling a high temporal resolution. (Berkhout et al., 2009)

16.4 Taken together, the previous results show the possibility of measuring ammonia emissions from fields using spectroscopic techniques. In the aforementioned experiment by the RIVM, the temporal solution of 30 minutes was deemed sufficient to measure fluctuations in nitrogen. (Berkhout et al., 2009) A trade-off exists between machine size, lower detection limits and temporal resolution. Commercial sensors used in process technology are compact and can reach sampling rates as fast as 1 second, but their detection limits are generally above 0.5 ppm (parts per million) (Mettler Toledo, 2021; Teledyne, 2021), meaning they can’t detect agricultural ammonia emissions that generally lie around 0.1 ppm (Pogány et al., 2015). While higher temporal resolutions are unnecessary, large machine sizes may pose an issue in the ease of placement and use. Currently, no spectroscopic sensors are commercially available to measure ammonia emissions on farms, although there could be a market for them. The development of such a sensor that would be suitable for measuring ammonia emissions on farms should take into consideration its ease of placement and use, a reasonable temporal resolution and a high sensitivity.

16.5 For measurements of ammonia emitted from buildings, such as barns or manure storages, the question arises whether measurements should be performed indoors or outdoors. Emissions inside more accurately reflect the amount of ammonia that actually volatilizes as these occur closer to the emission source, and mass calculations from concentrations are easier to perform from indoor sensors (see below). Emissions measured outside, on the other hand, more accurately reflect the amount of nitrogen that actually leaves the enclosed system of a farm in the form of ammonia. Besides this, size constraints are generally a smaller issue outdoors compared to indoors. Furthermore, monitoring of air outside buildings can be integrated relatively easily with monitoring of fields. For these reasons, outdoor measurements are more accurate when determining ammonia emissions from buildings.

16.6 The measured concentration of ammonia should be compared to a baseline concentration; this is the ambient concentration of ammonia already present in the air, for example by natural biological processes or by emissions elsewhere. An extensive network of stations monitors the air quality in the Netherlands, including the ammonia concentration. (Luchtmeetnet, 2021). This data could be integrated to calculate the concentration of ammonia caused by farm activities.

17.0 Measuring nitrate contents in soil

17.1 Similarly, to ammonia the amount of nitrogen excreted to the environment as nitrates can be calculated based on the concentrations measured. Instruments that measure the nitrate concentration in soil have been extensively used for decades (Wetselaar et al., 1998) and commercial nitrate testing kits are available. These are mostly based on sampling of soil; this is inaccurate, as nitrate concentrations fluctuate significantly on a small-time scale (Yeshno et al., 2019). More recently, real-time soil monitoring equipment has also been developed.

17.2 A recent review by Burton et al. summarises these developments and gives an overview of different measurement systems. (Burton et al., 2020) Sensors are divided into roughly two groups. Optical sensors make use of spectroscopic methods, similarly to those applied to measure ammonia emissions. Electrochemical sensors measure an electric current and calculate the nutrient concentration based on fluctuations in the current. These methods have been primarily tested in experimental settings but are slowly making their way towards commercial use. Real-time nitrate monitoring techniques are more feasible in the short term than those for ammonia and other nitrogen emissions due to their greater interest historically and longer history of development.

17.3 It is important to evaluate where nitrates end up after fertilizer application on fields: ideally, little as possible is lost and as much as possible is absorbed by plants. The main cause of loss is nitrate leaching, in which nitrates leave the system through ground water. Only measuring nitrate concentrations within the farm does not give an accurate representation of nitrate losses, as uptake of nitrates by plants occurs simultaneously; for this reason, sensors should also be placed around the farm. If these sensors show baseline or low nitrate concentrations, it indicates an efficient use of fertilizer and low level of nitrate leaching, while higher concentrations indicate nitrate losses and inefficient practices. Furthermore, nitrate concentrations should be compared to baseline concentrations, of which data is also available in The Netherlands. (RIVM, 2020)

18.0 Nitrogen inputs

18.1 Farm accounts can be used to determine the amount of imported feed and fertilizer (Oenema et al., 2015). In the case that the average composition of feed or fertilizer is known, for example through data provided by the manufacturer, this data can be used. Otherwise, the nitrogen content can be measured through sampling of the product, for which commercially available methods exist through the Kjedahl analysis (Boulos et al., 2020). Frequent samples would have to take place to ensure accurate data is obtained.

18.2 Harvested grass and maize can be weighed after each event as done at De Marke (Oenema et al., 2015), and nitrogen content can be reliably estimated from this using occasional sampling. Grass consumption through grazing can be estimated through the difference in biomass during a grazing event. As performed on De Marke (Oenema et al., 2015), spectroscopic techniques could be used to measure the nitrogen content in plants; this is useful to calculate nitrogen uptake by animals through grazing as well as nitrogen fixation by plants, which is another input stream.

18.3 To quantify nitrogen input from imported animals, category-specific nutrient contents for an extensive list of farm animals have been previously determined (Tamminga et al., 2000) and present a suitable tool to estimate nitrogen flows. Animals should be weighed prior to import; furthermore, they should be weighed several times per year to estimate nitrogen fixation in animals, especially young animals, to account for differences in nitrogen in- and output.

19.0 Nitrogen outputs

19.1 Nitrogen outputs can be calculated in a manner similar to nitrogen inputs. Nitrogen content of exported feed, fertilizer and animals can be calculated in the same manner as their imports. Outputs also takes place in the form of animal products, such as milk, eggs and wool. The nitrogen content of milk can be determined from its protein content, which can be done before leaving the farm. This is currently done mostly via sampling; real-time measurement methods have also been developed in the lab and would be easily applicable but are not yet commercially available. An overview of techniques is given in a recent review on the subject. (Kala et al., 2019) Nitrogen content of other animal products should be measured by sampling.

19.2 Excess manure that is not used as fertilizer also forms a nitrogen output flow. Although the total nitrogen content of manure is determined by the BEX in the ANCA (Van Dijk et al., 2020), manure content measurements could provide a more accurate image. It should be noted that the type and amount of nitrogen in manure changes constantly due to chemical processes and ammonia volatilization (Van Dijk et al., 2020); therefore, manure should be analysed as shortly before leaving the farm as possible. Several companies offer manure analysis methods, but these are mostly based on sampling and are generally performed in laboratories. Spectroscopic techniques could provide a solution as these can be integrated relatively simply into existing logistics and have the potential to measure nitrogen in real-time.

20.0 Nitrogen supplies and flows within a farm

20.1 Several nitrogen flows also exist that take place within the confines of a farm. Examples are the use of manure as fertilizer and harvested grass used as feed. These flows are already discussed in previous sections; it is important that the origin and destination of these flows is considered when forming an AMB to gain an accurate overview of all nitrogen flows. Supply changes within a farm also impact the amount of nitrogen flows; the amount of feed, fertilizer and animal product in storage at a farm should be measured to account for differences in input and output.

21.0 Integration of modern technology and data science infrastructure

21.2 State-of-the-art technologies form an integral part of the AMB. Real-time measurement techniques to monitor nitrogen flows are an important component of this system. However, these tools must be connected with other data sources to form an integral system to elucidate nitrogen material balances. Furthermore, this system requires the construction and maintenance of an extensive infrastructural system to collect and store data from various sources. This poses extra costs and logistical challenges for the AMB; however, modern data science can also offer new opportunities.

22.2 Connecting data sources

22.2The AMB appears under the backdrop of Big Data, a new trend to process and analyse large and various amounts of data as a new method of knowledge derivation. (McAfee & Brynjolfson, 2012) This has also generated significant interest in the agricultural sector due to its potential for solving sector-wide challenges. As such, various agricultural models have been successfully developed and implemented (Lokers et al., 2016).

22.3 Big Data offers a method to build models from data sources. One could envision such a model that collects sensor data and performs a large series of calculations to present a full material balance, which is the goal of the AMB. This has become feasible due to advances in computing power, data storage capabilities and the possibility to create an integrated network of sensors. Furthermore, Big Data allows for the use of external data, such as weather and soil data, landscape data and even economic data. (Antle et al., 2017) These external data sources could be integrated into the aforementioned calculations to increase accuracy of the model. However, several key factors should be considered to ensure reliable data use in the AMB.

22.4 Big Data was characterized by three V's by Laney: volume (the exceptionally large amounts of data), velocity (the high-speed acquisition of data) and variety (the collection of many different data types). (Laney, 2001) Data collected on nitrogen flows fits these categories: the use of multiple sensors results in a high data volume, real-time data acquisition yields a high velocity and the differences in input, output and emissions measurements indicate a large data variety. These issues can be overcome with increased computing power and data storage.

22.5 More recently, a fourth V has been introduced, namely veracity, which concerns the accuracy of data sources and which is very relevant in agriculture. (Lokers et al., 2016) This comes into play in two places. Firstly, sensors always have a certain level of uncertainty when measuring nitrogen flows. Secondly, more variances and biases are introduced when making calculations. Assumptions must be made on the size and effect of external processes on nitrogen flows. An example of this veracity is the calculation of total ammonia emissions. Calculating the mass of ammonia from its concentration is trivial in an enclosed system (i.e., a building) with no input or output. However, farms are open systems: new ammonia emissions occur constantly, and emitted ammonia is dispersed into the environment. Further complexities are added by variations in weather, such as temperature, precipitation and wind. (Berkhout et al., 2009) Similar issues exist for other nitrogen flows as well, most notably nitrogen losses as these are often ill-defined and less controlled. These complexities reflect the need for extensive calculations of raw data, generally using estimations or assumptions as important parameters and leading to a larger uncertainty in the obtained values for the addition of new calculations. Using multiple sensors could reduce this uncertainty to a certain degree at the cost of increased infrastructural and computational requirements.

22.6 A case of data reliability in practice can be seen in the evaluation of the ANCA. When analysing uncertainty of collected data on De Marke compared to C&O farms, Oenema et al. found that data collection on De Marke did not yield more reliable or certain results compared to the less rigorous data collection regimes on C&O farms. (Oenema et al., 2015) It should be noted that only one farm with extensive data collection was considered in this research. Nevertheless, more research should be done to evaluate if and how a reliable material balance can be made from collected data, and the possibility could exist that costly, extensive data collection regimes do not yield more accurate results.

22.7 Big Data has enabled the use of various agricultural models for academic research (Lokers et al., 2016), but there is also a growing need for agricultural models that are user-friendly and applicable to a wider range of stakeholders (Antle et al., 2017). Therefore, it is important that farmers understand the underlying models of the AMB and its results. Furthermore, farmers would ideally declare their own nitrogen flows. Nitrogen flows measured in real-time or by automated sampling can be registered automatically, but other data sources, such as feed and fertilizer purchases, cattle imports and exports and grass harvests, must be registered manually. These demands can be solved by the creation of user-friendly interfaces and apps (Antle et al., 2017). These programs could allow declaration of non-registered nitrogen flows, as well as presenting nitrogen flows within the farm in an understandable manner to enable farmers to make correct decisions regarding product yield and sustainability.

23.0 Data infrastructure

23.1 Besides creating a theoretically robust model, forming reliable connections between sensors and data management centres is important for a functioning AMB. Forming a connected system of data sources is an example of an Internet of Things (IoT), an infrastructure that allows advanced applications from physical objects by using modern IT solutions. (Wortmann & Flüchter, 2015) This requires devices that communicate among each other, preferably over internet, as well as data storage and processing units. The IoT has found its application in several places in agriculture and is notably of interest in precision agriculture. (Tzounis et al., 2017).

23.2 An IoT can not only measure nitrogen flows, but also relay feedback to farmers. For example, if consistently high nitrogen emissions are measured, farmers can be informed directly to enable a change of practice. Similarly, farmers can be warned if nitrogen flows don't add up and there is a significant discrepancy between input and output. In a much more basic fashion, IoT systems can also detect the presence of faulty equipment or tampering. These feedback loops enhance the primary physical function of devices used in the AMB. (Wortmann & Flüchter, 2015)

23.3 Setting up an IoT within a farm requires several practical considerations, mostly related to the monetary cost of constructing and maintaining such a system. Sensors should ideally be compact to allow for versatile placement. While this is a lesser problem for sensors placed outdoors, these can be subject to harsh environmental conditions or physical targeting, for example by animals, and therefore require a sturdy build. (Elijah et al., 2018) Measuring the same data with multiple sensors could not only increase accuracy, but also add resilience: if one sensor fails, the built-in redundancy allows for the continuation of data collection.

23.4 Similarly, sensor placement affects transfer of information from sensors to other places. A vast variety of wireless communication technologies exist, as summarised in recent reviews (Elijah et al., 2018; Tzounis et al., 2017). These systems generally have a trade-off between data transfer rates and transmission distance. Depending on the temporal resolution of sensors, transfer rates should be relatively limited, thus allowing for a larger range which is especially useful for sensors placed a larger distance from farms. Various data sources should use orthogonal signal types, as interference between data signals is a realistic problem that could cause data loss and reduced reliability (Elijah et al., 2018).

23.5 Storing and computing large amounts of data also poses a logistical challenge. As previously described, complex models are necessary to calculate an accurate material balance, while IoT systems generally only work on basic algorithms (Elijah et al., 2018). This means that, while an IoT system could transfer data, any data processing must likely occur at the output end of this system. Data processing could occur in a centralised or decentralised manner. Decentralised data processing would entail data processing on-site; on the other hand, a centralised data centre would receive raw data from all farms in a region and process these in a centralised location. Centralised data centres are cheaper for farmers, more energy-efficient and easier to maintain as all computational power is centred in one location; (Goiri et al., 2012) decentralised data processing can better protect the farmers' privacy as their data does not leave the farm, and it would allow for quicker feedback using processed data.

24.0 Certification: Blockchain technology

24.1 A major concern in 'Internet of things' ('IoT') technologies is the security and privacy of data. IoT systems prioritise data availability over confidentiality and safety measures are generally limited; there is still little agreement on how these risks should be perceived. (Asplund and Nadjm-Tehrani, 2016). Privacy is important here as data is an intellectual property that can give farmers competitive advantages (Elijah et al., 2018; Antle et al., 2017). At the same time, data must be made available to the public or to regulatory institutes to prove farmers are conforming to the AMB.

24.2 A potential solution to this dichotomy is to implement blockchain technology. Blockchain is essentially a public ledger system that tracks all transactions performed within a network. All transactions within that system are stored on all nodes within a system, each node being a separate computer or user. This method of storing and sharing information enables transparency and makes it difficult to cheat the system. (Yli-Huumo et al., 2016). Blockchain has found its way into agriculture as an emerging method to ensure the integrity of supply chains. (Ge et al., 2017) In this case, the aforementioned transactions are informational transactions, in which information is transferred from one user to another, for example the multiple parties in a supply chain. Each new party must then verify this information with all other parties to ensure its correctness. New parties can also verify that their actions are performed in a sustainable manner, such as the sustainable packaging or transport of animal products. Blockchain technology can be used as a form of certification: it can distinguish between farmers that fulfil the AMB and those who don't. Other forms of responsible supply chain management can also be tracked using blockchain, such as the origin of feed and fertilizer and standards related to animal welfare. In addition to preventing fraud, blockchain can still be used to protect the private data of the farmer. (Yli-Huumo et al., 2016)

24.3 Blockchain technology in agriculture is still in its infancy, and several challenges are identified as awareness and interest increases. A recent review lists a large number of applied studies on blockchain in the agriculture supply chain (Demestichas et al., 2020). They also identify four implementation challenges for blockchain: the limited technological knowledge of many stakeholders, the significant transformations of products throughout the supply chain, the large number and diversity of stakeholders and the global geographical scale of food supply chains. Solving these challenges is in the interest of the AMB.

25.0 Key considerations in the AMB

Overview

25.1 A schematic overview of the data streams within the AMB is given in figure 2. The AMB is divided into three relevant spaces: farm space, computational space and societal space. The farm space considers everything within the farm. Central here is an interface: here, the farmer can manually input data and receive recommendations for maintenance and good practices. Furthermore, sensors are also within the farm space; besides collecting data, they can inform farmers via the interface about maintenance requirements and other issues.

25.2 The computational space considers everything that takes place within computers; these could be placed either on the farm or in an external data centre. Data storage units collect all data streams and store them for a relevant timescale. This data can be sent to data processors, which can use computational models to determine the material balance created by a farm. If issues arise in data processing, such as discrepancies between material flows, emissions that exceed environmental

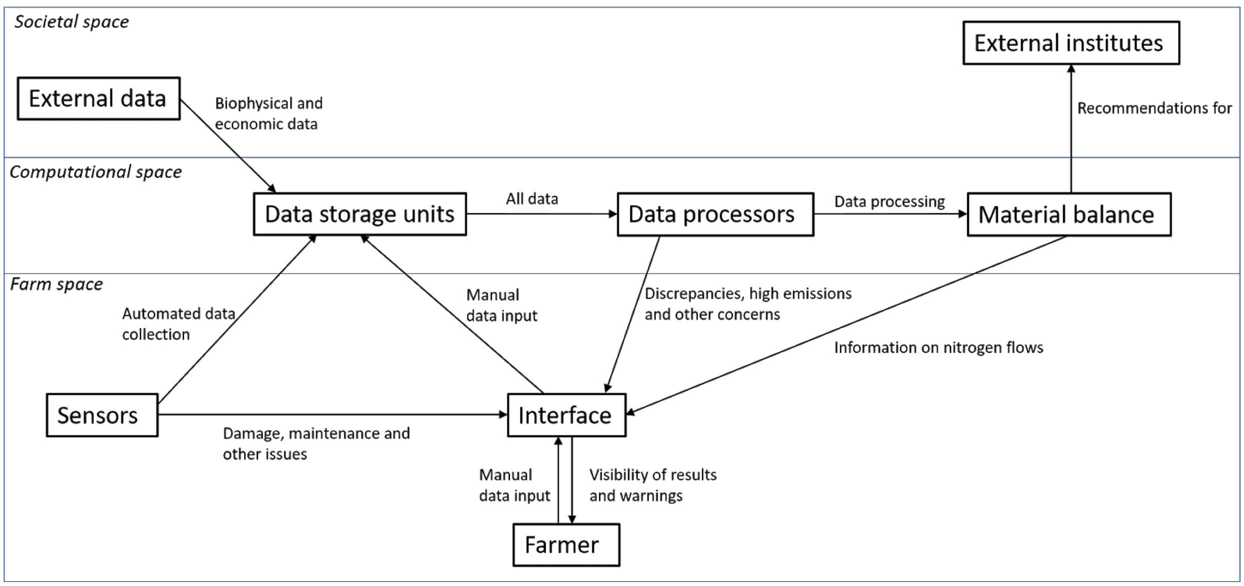


Figure 5. An overview of data streams and processes that occur in the AMB.

regulations or unusual input or output values, these can be returned to the interface and presented to the farmer. The final information on the material balance can also be relayed to the farmer.

The societal space contains all relevant external parties and dataflows. Information from the material balance could be sent to external institutes to validate that regulations are followed, and targets are met. Also in the societal space are external data sources, such as weather, landscape and economic data. These can also be incorporated to improve the accuracy of the model and provide better recommendations towards farmers.

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26.0 Limitations

26.1 Although promising, a variety of limitations may currently hamper the implementation of an effective AMB; five of these are expanded upon below. Although not unsolvable, they should be accounted for when considering whether the AMB can be realistically implemented and whether it offers a meaningful improvement over current material balances. These are issues that come into play when considering the AMB as a whole; individual components of the AMB also see their own issues, which have been discussed in the individual parts mentioned before.

26.2 Firstly, there is a lack of cheap and widely available real-time sensor equipment for farmers. Most equipment made for pilot studies is not produced in large quantities and this equipment is often bulky, unpractical and expensive. Furthermore, these sensors can only detect nitrogen flows they were designed to measure. For example, separate sensors would be needed for ammonia and nitrous oxides, and emissions of less prevalent compounds would be missed as these aren't detected. In many cases these emissions are small enough to be neglected or are easily corrected for, but they must be considered, nevertheless.

26.2 Secondly, discrepancies may occur between real-time, sensor-based measurements and data that requires manual input. As previously described, some nitrogen flows require manual input, such as purchased feed and sold amounts of animal products. Automated sensors will report measures constantly, while these numbers are only reported in selected intervals. The IoT-based system related to the AMB could provide direct feedback, but large manual reporting intervals may hamper the swiftness and efficacy of this feedback.

26.3 Thirdly, an important trade-off must be made between model accuracy and complexity. Simple computational models will not yield accurate results and show no advantages over existing material balances. Complex models, in turn, may offer a more accurate result, but they will require vast increases in computational power and may lack transparency and clarity, as is often seen in complex models. (Saltelli & Funtowicz, 2014) Besides accuracy issues, even complex models may have a large degree of uncertainty that can't be reduced with more measurements. (Oenema et al., 2015) Whether a model can be made that is simple, accurate and low in uncertainty remains to be seen in practice.

26.4 Fourthly, the presence of technology does not fully ensure an accurate material balance and proper certification procedure. Although there is much hype around blockchain being able to fully prevent fraud, this is not the case, as blockchain technology cannot prevent manipulation of data before it has entered the computational space. Farmers could tamper sensors or purposefully misreport feed and fertilizer purchases to perform better on the AMB, and this is often hard to detect by blockchain technology. The same issues can occur through damaged sensors or other human error (Demestichas et al., 2020). Blockchain may well be more robust than other certification procedures, but this should be evaluated in practice.

26.5 Finally, the electricity requirements of data processing and certification are a source of concern when scaling these up to a national level. Especially when using complex models, high computational requirements will lead to high combined energy needs. The monetary and environmental costs of energy usage may outweigh the benefits otherwise provided by the AMB. Energy requirements for blockchain techniques are also a source of concern. There is considerable debate on the climate impact of cryptocurrencies that use blockchain, as the decentralised nature of blockchain is intentionally designed to be inefficient. (Truby, 2018) If blockchain technology is implemented for certification purposes, its efficiency and energy usage should be critically evaluated. There is, however, a growing interest in using renewable energy sources to limit the environmental strain of computational activities (Goiri et al., 2012). Although promising, this is dictated largely by the availability of renewable energy; renewable sources only accounted for 18% of Dutch electricity usage in 2019, although this percentage is increasing over time (CBS, 2020).

27.0 Future prospects

27.1 The aforementioned section described the technical aspects of the AMB. This does not dictate how farmers should reduce their nitrogen emissions, but rather offers a framework by accurately measuring nitrogen flows in real-time and presenting metrics for the performance of a farm. The technical aspects should always be seen in conjunction with governmental rules and regulations and the preparedness of farmers to adopt new techniques (described in the other sections), as these are important for the successful implementation of the AMB.

27.2 To further analyse the costs and benefits of the AMB, a more quantitative analysis should be made of multiple components of the AMB. Firstly, the monetary costs of setting up and maintaining the system and the benefits resulting from increased productivity and from fulfilling certifications should be quantified and compared. Secondly, the accuracy and uncertainty of the resulting material balance should be estimated. Thirdly, the energy costs and related carbon emissions of all computational activities should be considered. In addition to quantitative analysis, small-scale pilot projects should be set up on multiple farms. These can be used to determine emergent benefits and issues concerning the practicality and implementation of the AMB. In addition, it could confirm whether the AMB is applicable to many types and scales of farming.

27.3 Furthermore, the framework of the AMB can be used for the evaluation of other material flows. Carbon and phosphate material flows are also of interest, as exemplified by their presence in the ANCA. Measurement equipment named in this report can also be used to measure carbon- and phosphate-containing compounds, and the use of computational models, data science infrastructure and blockchain technology will be very similar to those envisioned for the AMB. If the AMB proves to be successful for nitrogen, it can be adapted and implemented for other elements with relative ease. Conversely, if issues arise in the implementation of the AMB, these issues may also arise for material balances on other material flows.

Psychological Aspects

28.0 Psychological Background of Implementing Precision Fertilisation

28.1 We gained an understanding about the complexity of the farmers attitude towards implementing the Accountable Material Balance in an interview with Professor Jan Willem Erisman, a specialist in Environmental Sustainability. According to him, due to working with and around the risks of nature, farmers are more sensitive to risk-management and hence, there is a particular need to take short- and long-term risks into account when contemplating change. Some farmers experience a sense of anxiety around big changes and investments because they are suffering from nature's consequences to climate change like droughts and windstorms, milk price variations, low income, or unforeseeable expenses. Furthermore, there are various policies that are restricting their autonomy, and complicate agricultural processes and planning. This limitation of their freedom of choice, builds a defensive and sceptical attitude around new policies and their implementation.

28.2 In 2019 and 2020 there have been numerous protests around the EU of hundreds of farmers criticizing the policies created to lower nitrate in the soils and ground water (Geil, 2019). To them, the guidelines are overly bureaucratic, non-practical and are jeopardising their family businesses. Through the current trend of "farmer bashing", many farmers feel unfairly patronised and made to society's scapegoat for animal cruelty and environmental sins. While the farmers emphasise that they care about making agricultural practices more environmentally friendly, they nevertheless do not want to be deprived of their right of decision. The agriculturalists hence demand to be actively involved in developing policies that are suitable for daily use, and not precipitously set-in place by nature conservation organisations.

28.3 The necessity of attending to the farmers concerns becomes even more apparent when talking to Ad van Velde, the president of Global Dairy Farmers. Global Dairy Farmers is an international network of progressive dairy farmers and experts of different fields around the dairy industry. Their team is working together to expand their knowledge and use the latest developments towards action and results, while focusing on the benefits for people, planet and profit. According to van Velde, farmers are often presented with a fait accompli, not being able to raise concerns or opinions beforehand. There have been issues with implementing the MINAS, the system the Accountable Material Balance is trying to replace, since it was difficult and time consuming to understand the instructions. This led to some frustration and annoyance within the farming sector and strengthens the scepticism towards ideas such as the Accountable Material Balance. Often, new policies often go a hand with increased paperwork and having to reorganising the agricultural processes. Van Velde hence emphasises how important it is to actively involve dairy farmers in a new project right from the beginning. This provides them with a platform to voice their opinions or concerns and to contribute original ideas and wishes. Moreover, they have the expertise of how an idea can be made suitable for daily use. By doing this with the Accountable Material Balance, one might reach a broader audience, increase its acceptance and the willingness of dairy farmers to experiment with it, while decreasing the farmers frustration and scepticism around the new idea.

28.4 Ad van Velde is one of a small number of pioneers, working towards a more circular fertilisation, however, there still is no wide acceptance around the matter. How can we get farmers interested in wanting to be involved in the Accountable Material Balance?

29.0 Which Psychological Theories could help with the transition?

29.1 The theoretical framework of behavioural change

Before diving into the topic of motivation, it is important to understand the theoretical basis of behavioural change. The most popular framework concerning change and its adaption, is the transtheoretical model of change by James Prochaska and Carlo DiClimente (1984), which divides the process of behavioural change into six stages.

Precontemplation

People in this stage do not have the interest, nor the intention of changing their behaviours. While they may be aware of the costs of their behaviours, however they do not outweigh the benefits significantly.

The primary task for leaving this stage is raising awareness.

Contemplation

People in this stage are aware of the problems associated to their behaviours but are ambivalent whether it is worthwhile to change. They may be exploring the possibility to change at an unspecified time in the future, are willing to change but lack the confidence and commitment to do so, and do not have a concrete plan.

The primary task for leaving this stage is to resolve their ambivalence and support them in choosing to change.

Between the second and the third state, the client will arrive at the decision that the benefits of changing their behaviours outweigh the costs and hence, make the commitment to change.

Determination/Preparation

People in this stage are willing to change and accept their responsibility towards changing their behaviours. They are developing a plan for action, have the intention to change and slowly increase their confidence and commitment towards it. This stage will take around 4 weeks.

The primary task for leaving this stage is to help identify appropriate change strategies.

Action

People in this stage are enthusiastically incorporating change by reaching fresh insights, and developing new skills. They will consciously embrace their new behaviours, practise to overcome tendencies towards their unwanted behaviours, and engage in action towards change. This stage lasts approximately six months.

The primary task for leaving this stage is to implement change strategies and help avoid relapses.

Maintenance

People in this stage are strengthening and safeguarding their change strategies. They will have mastered a level of self-control and can put their new behaviours in action with minimal effort. They will focus on relapse prevention and stay alert to high-risk situations.

The primary task for staying in this stage is to establish a skill set aimed at maintaining the new behaviours.

Termination

People in this stage are tempted to relapse into old behavioural patterns.

The primary task for leaving this stage is to raise awareness and re-enter the stages of the transtheoretical model of change.

While relapse into a prior stage is always possible, it is less likely to happen once one has reached the last stage of the change model.

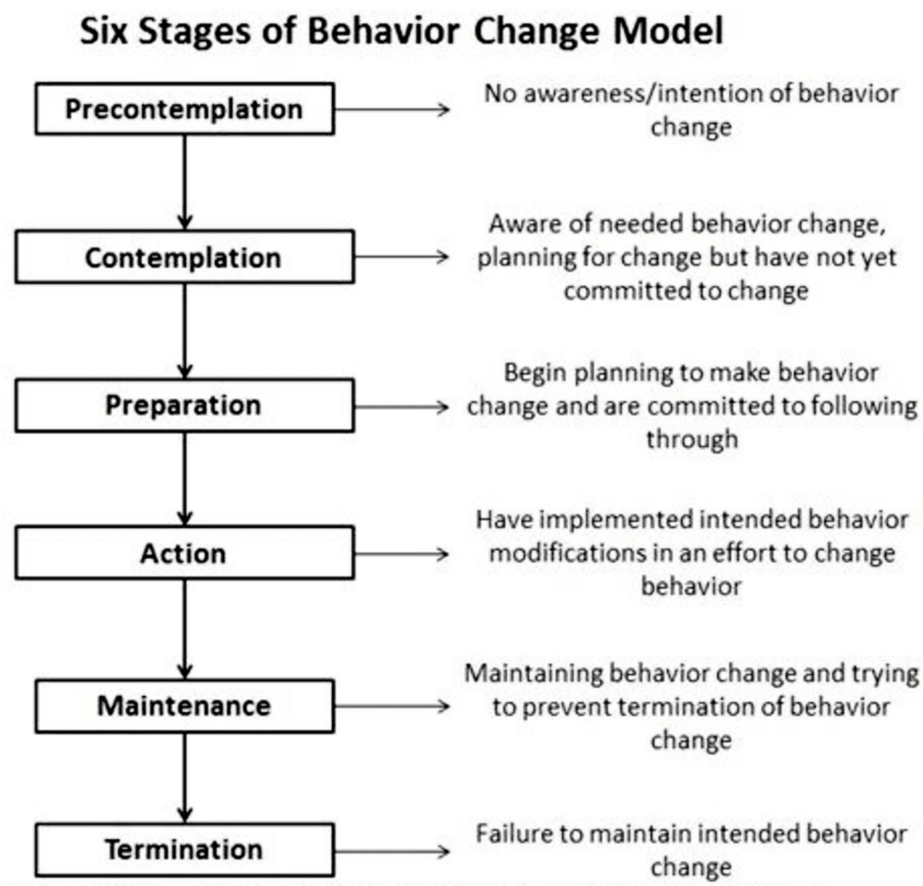

Figure 6 transtheoretical Model stages of behavior change 1983;51(3):390-5.

29.2 Based on our research and interviews with multiple experts of the field, we would categorise the majority of Dutch dairy farmers into the precontemplation and contemplation stage of the transtheoretical model of change. This means that according to the model, it is of importance to raise awareness around precision fertilisation and the Accountable Material Balance by providing multiple opportunities for education around this topic. This can be done by holding webinars, speaking in front of farmer's associations, or distributing information on agricultural news channels. In the next step, one would focus on resolving the farmer's ambivalence towards this transition and support them in choosing to change. One way to achieve this could be outlying the cost-benefit ratio associated with the change or putting in an effort to increase the farmer's personal motivation in participating in the transition. But how can this be done?

30.0 Motivation to Change- The history of motivation

30.1 Elton Mayo's Hawthorne studies (1924) are responsible for our shift in perception around employee management. He was the first to discover that workers are not solemnly motivated by monetary reward, but that their behaviours are linked to their attitudes and beliefs. Hence it is necessary to consider their needs and motivation when making management decisions.

30.2 Based on Frederik Herzberg's Two Factor Theory (1964) job satisfaction and performance are dependent on two factors: the contextual factors, which are the conditions necessary to execute the work, as well as motivational factors. These motivational factors include achievement, recognition, responsibility, advancement, and the work itself, while unfair pay, working conditions, or policies decrease the worker's motivation.

30.3 Seeing this in context, dairy farmers face multiple demotivating factors in today's society. These include their fluctuating and comparably low wages, their difficult working conditions with long hours and a shortage of skilled labour, as well as multiple strict policies. Moreover, they experience a lack of recognition. All factors together contribute to a lower job satisfaction and motivation to pursue their occupation, yet alone eagerly adapt new policies that may negatively impact their workload, or salary.

30.4 Considering that motivation is beneficial in adapting new regulations, there are multiple ways it can be increased. Following the self-determination theory by Ryan and Deci (2000), one differentiates between internal and external sources that can motivate an individual's behaviour. Extrinsic motivation refers to partaking in an activity due to an external motivator such as, monetary rewards, approval of others, congruence, or self-endorsement of goals. Intrinsic motivation on the other hand is driven by internal factors such as a personal interest or enjoyment in the matter. While both intrinsic and extrinsic factors have been shown effective in motivating change, previous studies found intrinsic motivation to encourage cohesive interaction, higher effort and increased long-term performance (Pinder, 2011), and has also shown to change behaviours more effectively in the long-term (Buckworth, Lee, Regan, Schneider, & DiClemente, 2007).

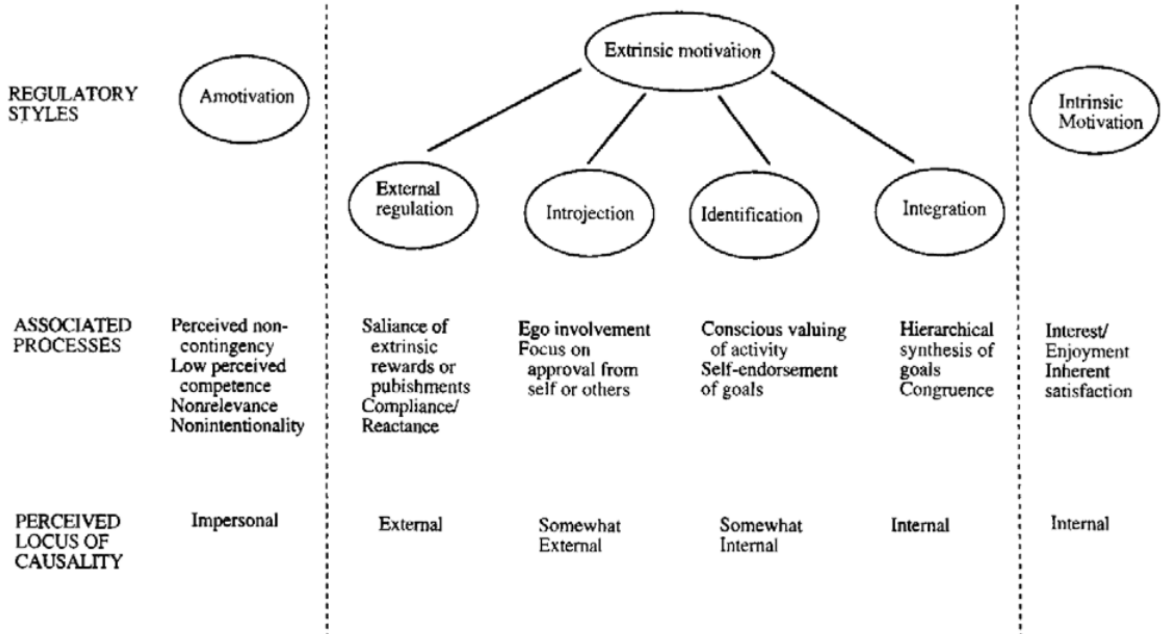

Figure 7. A taxonomy of human motivation. (Ryan and Deci, 2000)

30.5 In the context of dairy farming, the internal motivation could be raised through increasing the farmer's personal interest in the matter. Of course, it is important to emphasise that there are no hard and fast rules in increasing the internal motivation of a group of people. Every dairy farmer will have individual thoughts and beliefs around the Accountable Material Balance, and it will simply not be possible to gain every single farmer's personal interest in the topic. However, there are certain actions that could be favourable. One possibility to increase intrinsic motivation is providing thorough education around the nitrate crisis and the advantages of precision fertilisation or the usage of the Accountable Material Balance in the farming sectors concerning environmental and personal benefits. Another way of increasing intrinsic motivation can be, as mentioned earlier, to actively involve farmers in the development, adaption or decision making around new policies or regulations. The active interest in the matter does not strictly need to be related to saving the environment or minimising the nitrogen footprint, it could also be a personal interest in developing the dairy farm to produce less with increased profit.

30.6 The overall motivation of the dairy sector could be reinforced through involving extrinsic factors additionally. Prior experience has shown that farmers are more likely to adapt a more sustainable approach when farmers in their immediate surroundings have pioneered in modifying their business models successfully (Erisman, personal communication, 2021). While this is not only a positive example that could have the power to decrease their worries around the short and long-term risks of investing in a greener future, but it can also act as external motivation. It provides the farmers an opportunity for identification and integration, acting in congruence with the lucrative neighbours. Another way of external motivation could be introjection, in which the farmers would find a sense of ego involvement in the matter of change. This might comprise getting approval from others for switching towards a more sustainable way of fertilisation, or the approval from themselves. Whether this results from the feeling of helping the environment, accomplishing to set a plan into action, or investing in their future is of secondary importance. The last and most effective way of extrinsic motivation is external regulation which describes the reaction to rewards and punishments and compliance to rules. While external regulation does not correlate positively to contentment or high wellbeing (Schmuck, Kasser, & Ryan, 1999), it can be a good start to get people actively involved.

31.0 Societal Challenges of Transitioning towards Precision Fertilisation

31.1 It must be considered, that even if support and education are provided perfectly, in combination with monetary rewards, there still will be farmers not willing to adopt this approach. As explained in the adoption cycle by Rogers (2010) which is still eagerly utilised in marketing approaches, there are certain persistent personality traits connected to how easily one adapts to an innovative idea.

31.2 Roughly 2.5 percent of the population could be described as innovators that act as pioneers in adapting new innovations. They will be willing to experiment with innovative ideas and show increased risk-taking behaviour. The pioneers are followed by the early adopters which make up 13.5 percent of people. This group shows a high degree of opinion leadership, realising this choice as an option of maintaining a central communication position.

31.3 The next group opting for change makes up 34 percent of the community. They are usually characterised by an above average social status and have shown to be in direct contact with early developers. While they are comparably slow to adapt to change, they are considered the “early majority”.

31.4 The “late majority” (34%) is made up of a highly sceptical community, that usually have less financial resources available, are considered to have a below average social status and will only contemplate change when more than half of the population has already successfully adjusted to it. They tend to not have contact outside of the early and late majority sections.

31.5 The last group to opt for change are called “Laggards” (16%). This group consists of an older population, which values tradition, and members of this group will typically have the lowest social status and financial lucidity. Moreover, they show to have minimal contact points with society outside their close family and friends.

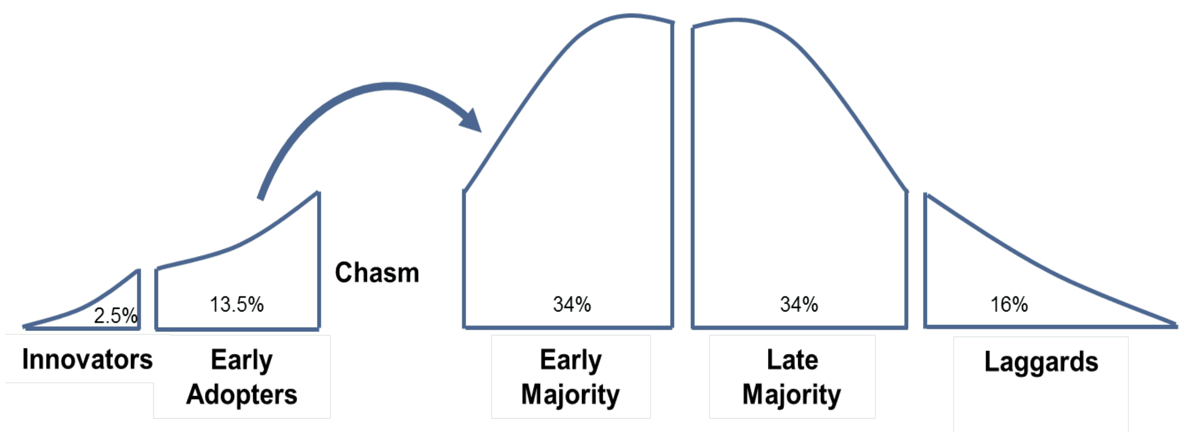

Figure 8 Psychological Diffusion Curve

31.6 Considering all subgroups of the adoption cycle, this theory clarifies how long societal adaption to new policies and ideas can take. While there is a small percentage of people that are willing to experiment with change, it must be considered that convincing the majority of implementing a non-compulsory policy will take years, if not decades.

32.0 Overcoming Future Challenges of Transitioning towards Precision Fertilisation

32.1 In context, one might conclude that to obtain a fast change in a broad audience, transitioning towards using the Accountable Material Balance should not be strictly optional. However, it has been shown in the past, that enforcing new policies often led to counterproductive frustration within the farming sector (Grefe, 2021). As mentioned before, it would be advised to increase the communication between the dairy farmers and the developers of the Accountable Material Balance, the policy makers, and the government. This way, farmers will have the reassurance of feeling included in the transition which can increase both intrinsic and extrinsic motivation (Bidee et al., 2017). Moreover, the government could work with monetary rewards when using the Accountable Material Balance properly, or monetary punishments when the policy is violated.

32.2 Another promising option could be political nudging, which is an economic tactic that manipulates behavioural change through positive reinforcement or indirect suggestions (Wilkinson, 2012). Nudges are simple and inexpensive changes in someone's environment aimed at triggering automatic cognitive processes that influence people to choose a desired outcome. This can be achieved through setting the desired option as default, improving its salience, or through social proof heuristics, in which people replicate the behaviour of their immediate social environment. Nudging has been a successful tool in marketing, health care or in establishing governmental decisions, by altering the frame in which a choice is presented while preserving the individual's freedom of choice (Thaler & Sunstein, 2008).

32.3 As previously implied, there are multiple factors influencing a person's choice. External factors including social norms, traditions, rules, as well as different facets of an individual's personality, belief systems and fears. Moreover, public opinions, politics, education and the consumed media have a large impact (Steiger & Lippmann, 2013). Since people tend to prefer immediate rather than long-term rewards or prospects (Thaler & Sunstein, 2008), it is important to emphasise instant benefits connected to this change. One study trying to encourage people to reduce their energy output through social proof heuristics, calculated the participants monetary losses in comparison to similar sized energy saving households in their neighbourhoods. Through providing a bill showing the amount of immediate savings, as well as a pamphlet on how to save energy, they were able to cut down their energy output by 2 percent (Alcott, 2011). This has also been tried within the farming sector. By sending messages containing information about the farmers own water usage in comparison to that of their neighbour farms, a study by Chabé-Ferret and colleagues (2019) found a decrease in water usage. They explain how social comparison nudging towards pro-environmental behaviour builds upon two psychological phenomena. Firstly, changing out of a fear of social sanctions (Sunstein, 1996) or out of a longing to adapt a behaviour that seems to be effective in other people (Thøgersen,2014). And secondly, designing other people's behaviour more saliently in order to change one's individual conduct through automatic heuristics (Cialdini, Reno and Kallgren,1990). This idea ties back to what Professor Erisman explained, about farmers being more likely to adapt new policies when their immediate surroundings have successfully implemented them. Hence, it is imaginable that nudging could be beneficial in establishing precision fertilisation or the Accountable Material Balance.

32.4 While this is a good starting point, there are other factors that need to be taken into account when holistically approaching the transition towards precision fertilisation. As previously stated, many efforts to reform environmental policies have been systematically averted or adjusted by stakeholders (Nischwitz, Chojnowski & Eller, 2019). Hence, it is necessary to involve large corporate enterprises within the milk industry into adapting this approach as well. Moreover, while there is a trend gravitating towards more sustainable options, in and outside of the food sector, there still is not a big enough demand for fair sourced dairy. In order to support labels such as planet proof or farm to fork, it is essential to support, or even nudge sustainable consumer behaviour to boost the demand and supply chain.

32.5 In conclusion, in order to increase motivation while limiting counterproductive frustration, it is psychologically necessary to involve dairy farmers in the development, improvement, and implementation of new policies right from the beginning. This will ensure that the policy is suitable for daily use, time saving and easy to understand, which will be beneficial for meeting the needs of a broader audience of farmers. Furthermore, through involving interested farmers in the development of the project, these farmers will be more likely to adapt the policy early on, and act as pioneers in their neighbourhoods. Through contact with innovators, other farmers will automatically be nudged towards experimenting with the policy themselves through social proof heuristics.

Conclusion

In conclusion, this report analysed the political, technological, and psychological aspects connected to the AMB. The nitrogen crisis has been listed on the political agenda since the 1980s, and substantial efforts have been made to reduce emissions. However, pushback by agricultural unions and other relevant stakeholders has made curbing emissions cumbersome. The rise of new technologies and innovation suggest promising *long-term solutions* that accommodate the preferences of farmers and environmental needs. It is technologically feasible to use farm-based measurements to calculate the nitrogen material balance in real-time, but difficulties lie mainly in envisioning the infrastructure required for this. Most technologies necessary for the AMB have already been developed; now, the focus must shift towards integrating these technologies and making them suitable for use on a farm. Several challenges in particular, such as the lack of widely available and appropriate sensors, the high complexity of calculations and the high energy usage of the required computing power, currently limit the application of the AMB in practice. Pilot studies would test how these technologies are best brought into practice; in addition, these studies would test whether the AMB is a meaningful improvement over the current methods to estimate nitrogen flows on a farm. The psychological purports that using monetary rewards and punishments in implementing the AMB would likely be beneficial in the short term. However, when pursuing long-term goals, increased performance, and contentment within the dairy farming sector, other options seem more suitable. A voluntary transition towards using the AMB in dairy farming may take a long time, it seems psychologically possible. However, to limit frustrations and risks on behalf of the farmers themselves, it is necessary to include them in every step of the progress and implementation. This will not only ensure that the AMB is easy to utilize and suitable for daily use, but it will also provide it with a platform to reach a broad audience of farmers. As early research shows, most people are more likely to adopt a new behaviour if it has been proven successful in pioneers in their immediate surroundings. Furthermore, this contact may be beneficial in terms of political nudging since these innovators will activate social proof heuristics that can motivate late bloomers towards experimenting with the AMB.

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